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MICROSTRUCTURAL CHARACTERIZATION OF THE INTERFACE OF THE WELDED JOINT API 5L X52 STEEL COATED WITH INCONEL 625

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Abstract: This work aims to microstructurally characterize the interface region formed between API 5LX52 microalloyed steel internally coated with a Nickel Inconel 625 superalloy through the multipass GTAW welding process. The motivation of this study is due to the microstructural difference that can weaken the interface region. This work consists of analyzing metallographically and through Vickers microhardness profile a sample containing 50% of both materials. The microstructures were revealed using two chemical reagents: Nital 2% to attack API X52 steel and an oxalic solution. ($C_2H_2O_4.2H_2O$) at 10% to react with Inconel 625 and subsequently recorded through optical and electron microscopy. The chemical attacks used made it possible to identify in the thermally affected zone, with essentially baianitic microstructure, presence of polygonal ferrite, granular bainite and Widmanstätten ferrite. The microhardness profile had minimum values of 150 HV and maximum values of 320 HV.
Keywords: API steels, welded joint microstructure, inconel 625 coating.

INTRODUCTION

The steels with properties necessary for the manufacture of pipelines currently used are the steels called ARBL (high strength and low alloy). These materials are used in applications that require quality linked to a low cost. Its manufacture begins with care in liquid steel, which must meet the chemical composition ranges stipulated by the API Standard 5L [1] and meet the specified resistance limits of each steel [2]. These pipelines are used in the oil and gas industry in exploration, drilling, production and transfer [3], so they deserve special attention. Offshore pipelines, in addition to the high external pressure to which they are subjected, are subject to variations in internal loads that, linked to material degradation, generated by corrosive processes, can cause premature collapse. Linked to material degradation, pipeline joining processes are responsible for presenting catastrophic ruptures. Jambo [4] highlighted in his studies that aggressive media can generate cracks transverse to the weld seams and thus weaken the steel. This type of cracking is normally associated with the HAZ regions (thermally affected zone), however, the cracks are not restricted to this area.

Faced with these facts, studying the quality of welds in pipes becomes essential. In order to avoid the corrosive action of the inner wall in the ducts, bimetallic tubes appear as a viable alternative, from an economic point of view [5,6]. One of the manufacturing processes of these ducts is through the welding of coatings (welding overlay) of clad plates [5,6]. Thus, in this work, a coating of Inconel 625 was used, a nickel-based superalloy commonly used as a metal clad, as reported by [7,8]. This is because Inconel 625 has a favorable chemical composition against aggressive environments, due to the high levels of Cr and Ni. According to Telles [9] and Telles [10] in addition to high corrosion resistance, coatings clad with superalloys, based on nickel, also have high mechanical resistance for work at high temperatures. However, the high content of alloying elements has presented problems after the welding process, as mentioned by El-Reedy et al. [11] and Silva et al. [12]. Furthermore, nickel alloys are susceptible to the appearance of solidification cracks [13]. Such facts have caused great concern due to the formation of microstructures that can weaken the interface region. Previous studies on the weldability of API 5L X52 steels were favorable regarding the behavior of this material, according to the works of Gray and Pontemoli [14] and Dhua [15] who related through graphs the equivalent carbon content with the of carbon found in steels.

Thus, this work aims to microstructurally characterize through metallographic analysis and microhardness profile the substrate/coating interface region formed between API 5LX52 microalloyed steel (substrate) internally coated with a superalloy of Nickel Inconel 625 (coating) through the process GTAW multipass welding.

MATERIALS AND METHODS

MATERIALS THAT WERE USED

The material used in this study was a tubular steel sample API 5L X52, 150 mm long, 168 mm in external diameter and 22.5 mm thick. The metallic coating used was an Inconel 625 wire electrode (AWS ER-NiCrMo-3) with a diameter of 1.2 mm. The same was deposited in layers through the automated orbital TIG welding process until reaching a thickness of 15 mm. The nominal chemical compositions of the two materials are shown in Tab. 1 and are provided by API 5L and Inconel 625 (AWS ER-NiCrMo-3) by the ESAB catalog (ESAB material) and compared in the literature [16].

MICROSTRUCTURAL CHARACTERIZATION

The metallographic sample was analyzed in three distinct regions: base metal, coating and interface. A bimetallic sample used for microstructural characterization was a 30 mm wide, 12.5 mm long and 4 mm thick plate. After being properly sanded and polished, the sample was attacked using two different reagents. The coating, composed of nickel alloy, was chemically attacked by an electrolytic process with oxalic solution (C2H2O4.2H2O) at 10% in water, applying a voltage of 3 V for 30 seconds. Soon after, the material was entirely submerged in Nital (2%) for 30 seconds to attack the other regions of the sample. The revealed microstructures were analyzed using optical and scanning electron microscopy, using the OLYMPUS BX60M and JEOL JSM 6460LV microscope, respectively. EDS NORAN SYSTEM SIX 200 was also used to profile the chemical composition across the interface.

VICKERS MICROHARDNESS PROFILE

Two microhardness profiles were performed transversely to the interface, including substrate and coating. The scans were spaced 4 mm apart, totaling 19 measurements in each profile. Vickers microhardness tests were performed using a load of 50g and a relaxation time of 30 seconds at room temperature. This test was carried out in the mechanical properties laboratory (PROPMEC) of the PEMM, according to the recommendations of the ASTM E18 [17] standard, using the Leitz Wetzlar microhardness tester.

Material	C	Mn	Si	Cr	Ni	Mo	S	Cu	Ti	Al	Fe
API X52	0,24	1,4	0,45	0,3	0,3	0,15	0,009	0,5	-	0,032	-
Inconel 625	<0,1	3,0	<0,5	20,0	>67,0	--	--	--	<0,7	--	<3,0

Table 1. Nominal chemical composition (wt%) of API 5L X52 steel and Inconel 625.

RESULTS AND DISCUSSION

BASE METAL

Figure 1 shows a microstructure composed of refined polygonal ferrite (FP) grains and a second phase with pearlitic grains. The banding present is typical of the lamination process, which produces a microstructure aligned in the longitudinal direction of the sheet.

THERMALLY AFFECTED ZONE (ZTA)

The characterization of the heat affected zone (ZTA) was analyzed by scanning electron microscopy (SEM). Figure 2 revealed two distinct regions. Region 1 corresponds to the base metal, where it is possible to identify the lamination banding already identified in figure 1. The banded structures of the base metal are no longer visible as we approach the second region. In region 2, the lamellar pearlites that make up the banded structures of the base metal were no longer observed due to the proximity of this region to the interface that underwent successive heating and cooling caused by the thermal cycles of the eight weld passes. The thermal variations generated during the welding process are responsible for microstructural changes and, linked to this fact, changes in metallurgical and mechanical properties can occur [18]. Thus, a change in the morphology of the banded pearlite was observed, which presented itself as a very fine equiaxed microstructure, composed of an essentially baianitic microstructure, with the presence of polygonal ferrite (FP), granular bainite (BG) and Widmanstätten ferrite (FW), as can be seen in figure 3, also obtained by SEM.

CLADDING METAL

The coating metal presented a microstructure basically composed of an austenitic phase, with dendritic morphology, with growth oriented parallel to the direction of greater heat extraction. The revealed microstructures are composed of a hypoeutectic structure with Nickel γ dendrites (Ni-CFC) and another non-lamellar interdendritic structure, containing carbides, as shown in Figure 4 and according to studies by Gould [13].

INTERFACE

The dissimilar weld interface is formed by a fusion line adjacent to a diffuse gap constituted by an intermediate chemical composition between the base metal (API 5L X52 steel) and the weld metal (nickel alloy), which will be called in this work of ZPD (partially diluted zone). Figures 5 (a,b,c) show the interface and its surroundings. Figure 5a shows the interface region after polishing. Figures 5 (b,c) identify the interface after a double etching, which reveal the microstructures of the base metal (MB) and the coating, as previously shown in Figures 3 and 4. The dimension of the coating is in the order of tens of micrometers and its chemical composition varies across the interface, as can be seen with the aid of in-line EDS shown in figure 6 (a,b). In this test, the electron beam passed through the sample, initially focusing on point 2, crossing the interface and ending at point 1 (Figure 6 a).

The EDS presented shows the variations of the alloying elements along the interface and confirmed the presence of the main chemical elements present in the chemical composition of the base metal, such as Fe, C and Mn. Through the chemical composition profile, it is possible to observe that in the partial dilution zone (PDZ), a region delimited by dashed lines in figure 6b, there is a reduction in the iron content along its extension, which remains stabilized in the region of the iron metal. coating. The nickel content, as well as Cr, Mo and Nb, present in the coating metal, increased significantly

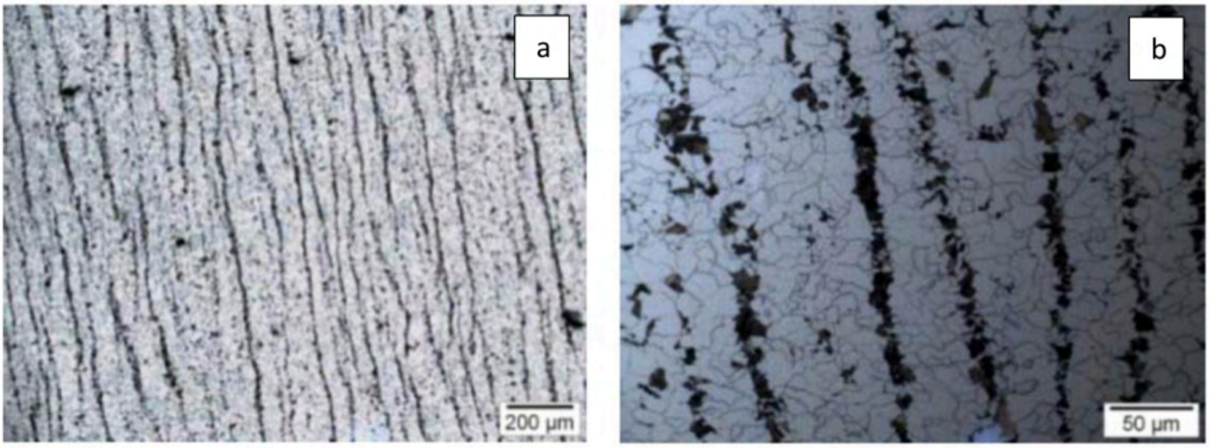

Figure 1: Characteristic microstructure of the base metal obtained by optical microscopy with lower(a) and higher(b) magnification.

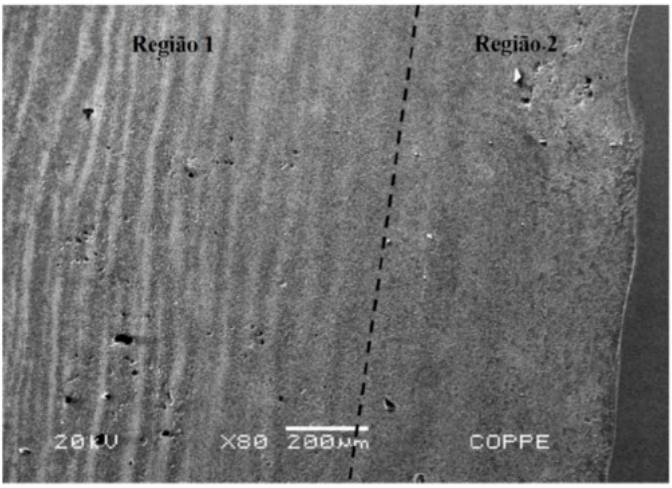

Figure 2: Base metal microstructure and HAZ, obtained by SEM, lower magnification.

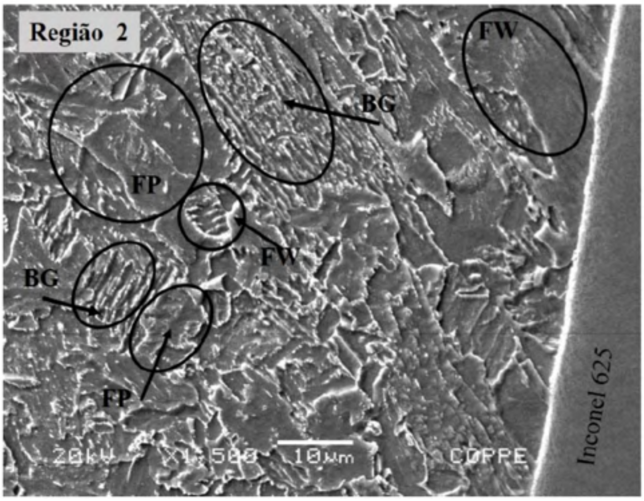

Figure 3: Typical HAZ microstructure, obtained by SEM, higher magnification.

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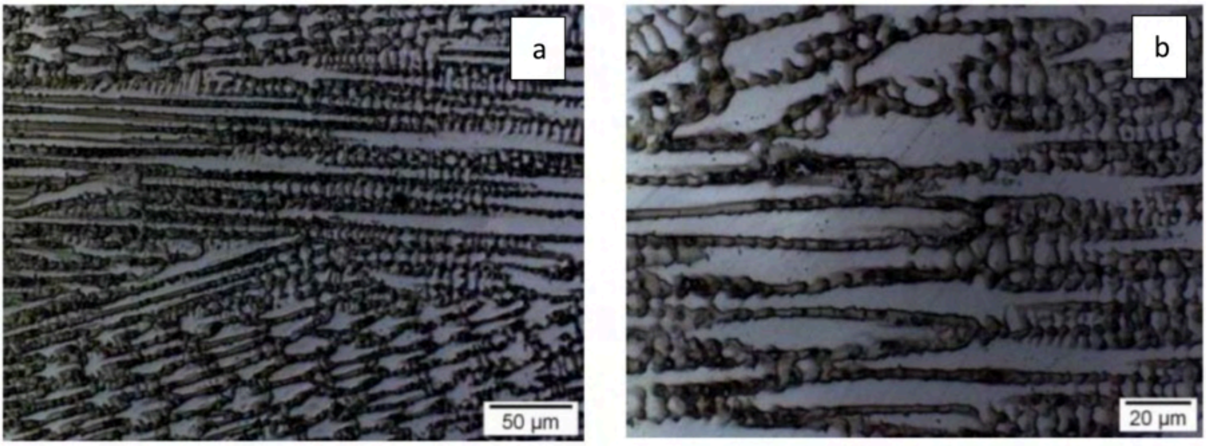

Figure 4: Micrographs obtained from the Inconel 625 coating, with lower (a) and higher (b) magnification.

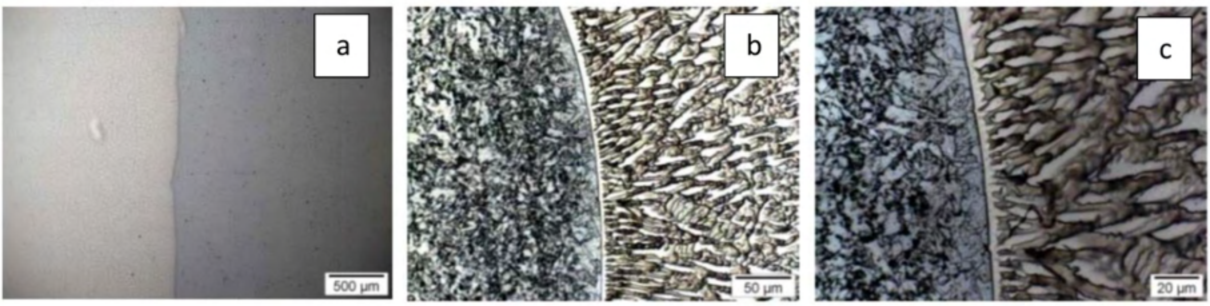

Figure 5: Characteristic microstructure of the interface region Obtained by MO with different magnifications.

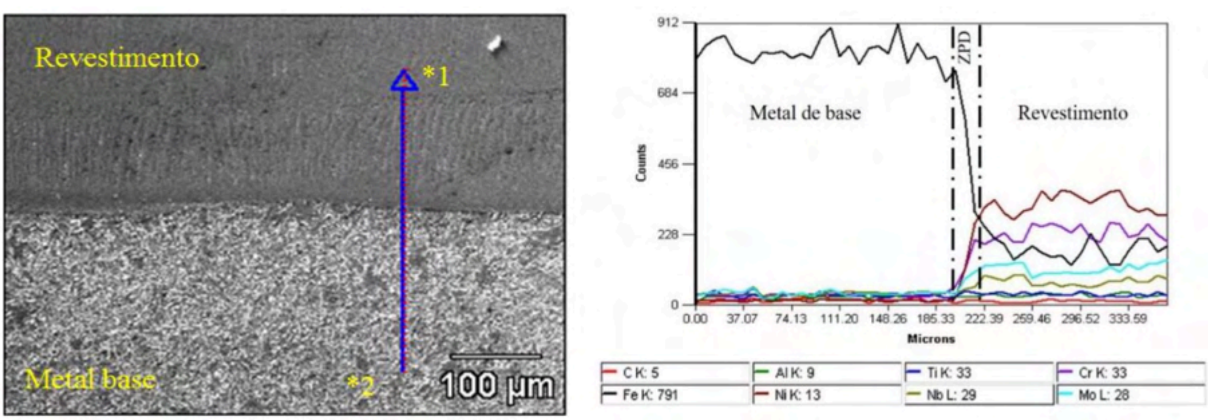

Figure 6: In-line EDS evidencing the chemical composition along the dissimilar interface between API 5L X52 steel and Inconel 625 nickel alloy.

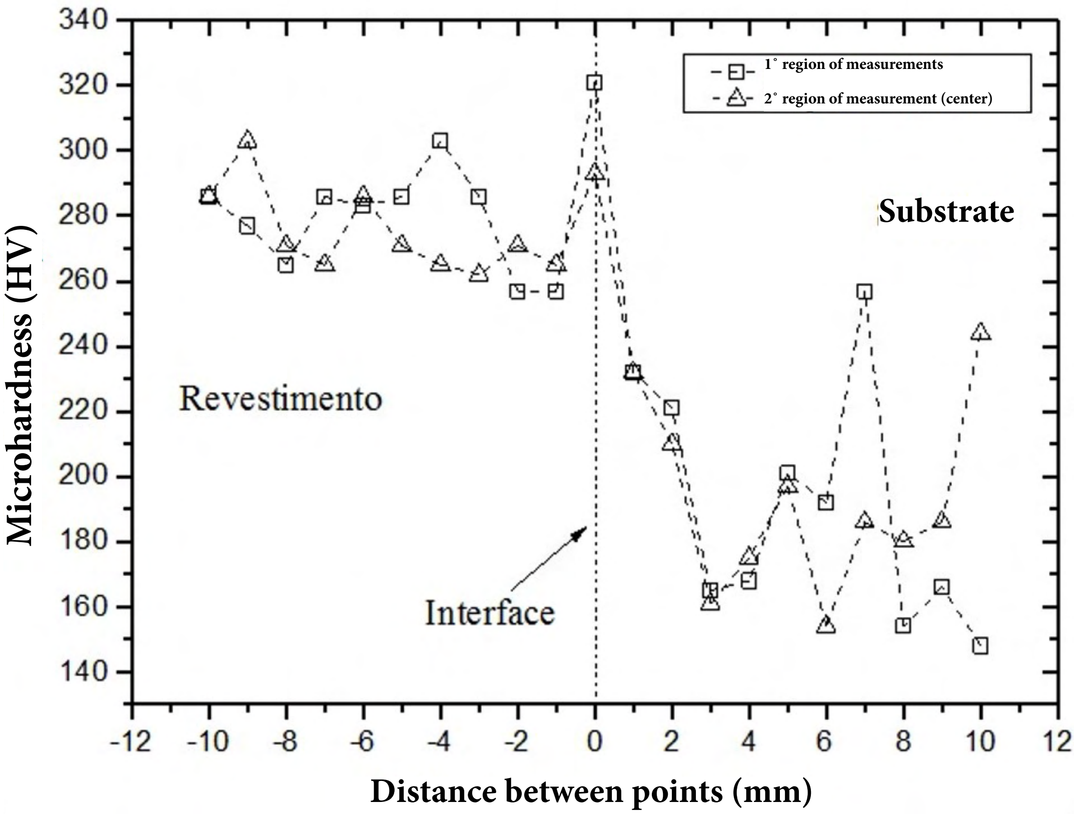

Figure 7: Vickers microhardness profile.

at the end of the transition after having exceeded the ZDP, remaining constant until the end of the analysis performed.

Near region 1, an austenitic structure (cfc) rich in Fe is found, which stabilizes at room temperature by the partial incorporation of Ni from the filler metal. KUO et al. [19] and SILVA et al. [20]. Subsequently, there are regions of planar growth and columnar growth of the cladding metal.

But the presence of Fe, C and Si in the dilute nickel alloy region favors the formation of the Laves phase, rich in Fe, and NbC [21] which can decrease the tenacity of this region, which makes it, therefore, a zone important to analyze with regard to the integrity of the component.

VICKERS MICROHARDNESS PROFILE

The results of two microhardness scans are shown in figure 7. The Inconel 625 coating showed microhardness between approximately 270 and 310 $HV_{0.5}$, higher than that of API 5L X52 steel. The values for the coating obtained in this work are close to those obtained by SONG et al. [22], from the same material (approximately between 245 and 270 $HV_{0.5}$). The API 5L X52 steel substrate presented microhardness between 150 and 260$HV_{0.5}$. However, at the interface, Vickers microhardness values reached values of approximately 320 $HV_{0.5}$. These values, higher than those of the Inconel 625 coating, indicate the presence of harder regions close to the interface.

CONCLUSION

Through this work it is possible to conclude through the microstructural characterization that the base metal underwent changes in the surroundings of the interface due to the thermal cycles generated in the TIG welding with Inconel 625 wire electrode. polygonal ferrite, granular bainite and Widmanstätten ferrite, with hardness between 150 and 260 $HV_{0.5}$. The interface region showed a chemical composition composed of nickel, chromium and iron and a hardness of approximately 320 HV0.5, followed by the coating metal composed of a dendritic structure of Inconel 625 with microhardness values between 270 and 310 $HV_{0.5.}$

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