CHARACTERIZATION OF THE DISSIMILAR METAL WELDING - AUSTENITIC STAINLESS STEEL -AISI 304 WITH NICKEL ALLOY FILLER METAL INCONEL 625[1]

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Abstract

In elevated temperature environments, austenitic stainless steel and nickel alloy has a superior corrosion resistance due to its high Cr content. Consequently, this alloys is widely used in nuclear reactors components and others plants of energy generation that burn fossil fuel or gas, chemical and petrochemical industries. The object of the present work was to research the welding of AISI 304 austenitic stainless steel using the nickel alloy filler metals, Inconel 625. Gas tungsten arc welding, post weld heat treatment, mechanical and metallographical tests, and compositional analysis of the joint were used. A fundamental investigation was undertaken to characterize fusion boundary microstructure and to better understand the nature and character of boundaries that are associated with cracking in dissimilar welds. The results indicate that the microstructure of the fusion zone has a dendritic structure, inclusions, and precipitated phases containing Ti and Nb are present in the inter-dendritic region. In some parts near to the fusion line it can be seen a band in the weld, probably a eutectic phase with lower melting point than the AISI 304, were the cracking may be beginning by stress corrosion.

Key word: Dissimilar metal weld; Nickel alloy; Liquation.

CARACTERIZAÇÃO DE SOLDA DE METAIS DISSIMILARES - AÇO INOXIDÁVEL AUSTENÍTICO AISI-304 COM ADIÇÃO DE LIGAS DE NÍQUEL INCONEL 625

Resumo

Em ambientes com elevadas temperaturas o aço inoxidável austenítico e as ligas de níquel tem uma resistência à corrosão superior, devido ao seu alto teor Cr. Consequentemente, esta ligas são amplamente utilizada em componentes de reatores nucleares e de outras plantas de geração de energia que queimam combustíveis fósseis ou gás, indústrias químicas e petroquímicas. O objetivo deste trabalho foi investigar uma solda de aço inoxidável austenítico AISI 304 utilizando como metal de adição a liga de níquel, Inconel 625. Foram utilizados, soldagem GTAW, tratamento térmico pós-soldagem, ensaios mecânicos e metalográficos, e análise composicional da junta. Foi realizada uma investigação para caracterizar a microestrutura próxima do contorno da linha de fusão e compreender melhor a natureza e o caráter dos contornos de grão, que estão associados a fissuração em soldas dissimilares. Os resultados indicaram que a microestrutura da zona de fusão tem uma estrutura dendríticas, na região interdendrítica estão presentes inclusões e fases contendo precipitados de Ti e Nb. Algumas regiões junto à linha de fusão, podem ser consideradas como uma banda na solda, são provavelmente uma fase eutética com ponto de fusão menor do que o AISI 304, zona de liqüação, e podem ser o início de trincas por corrosão sob tensão.

Palavras-chave: Solda de metal dissimilar; Ligas de níquel; Liqüação.

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1 INTRODUCTION

Welds between different metals are called Dissimilar Metal Weld (DMW). Nickel-based filler metal has superior corrosion resistance, thus are used frequently in applications requiring dissimilar welding. They are used in a variety of joint involving carbon steel, stainless steel, nickel base alloy, and overlaying welding. These welds are commonly employed in plants of energy generation, chemical and petrochemical industries. In nuclear power plants DMWs are used in safety class systems of all Pressurized Water Reactors (PWR) and "Water Water Energy Reactor" WWER plants. DMWs are generally designed and fabricated to high quality standards. However some instances of flaws and/or leakages in operation with nickel alloys have been reported. It is difficult to detect the potential damage with in-service inspection systems because of the dendritic nature of the weld, geometric factors, component form and accessibility. Investigations of potential degradation mechanisms, integrity assessment methods have been performed in many developments nuclear center.(1-4)

In DMW the fusion line (FL) is the result of melting which fuses the base metal (BM) and filler metal to produce a region with a composition that is most often different from that of the BM. In this region also has a thin region adjacent to the FL, known as the unmixed region, where the BM is melted and then quickly solidified to produce a composition similar to the BM. The partially melted region is usually one or two grains into the heat-affected zone (HAZ). It is characterized by grain boundary liquation, which may result in cracking. HAZ liquation cracking is the root cause of this difficulty, which occurs in the partially melted region of the HAZ. During welding, the components are often subjected to numerous cycles consisting of welding followed by post-weld heat treating (PWHT)applied to reduce residual stresses. Nickel-based alloys are sensitive to liquation cracking in the HAZ upon (PWHT).(5-8)

The Nickel alloy type Inconel 625 exhibits a complex precipitation behavior at elevated temperatures, during welding, due to the high alloying constituents of Ti, Nb and Mo. Furthermore, the precipitation behavior will depend upon the carbon content and the final annealing temperature.(9,10)

The object of the present work was to research the welding of the AISI-304 using Inconel 625 filler metals. Mechanical tests, metallographical and compositional analysis of the joint were used to study. A fundamental investigation was to undertaken to characterize fusion boundary and to better understand the nature and character of boundaries that are associated with cracking in dissimilar metal welds.

2 EXPERIMENTAL DETAILS

An austenitic stainless steel, AISI 304 plate (300x100x5mm) and a Nickel alloy filler metal wire, Inconel 625 with 0.8mm diameter were used. The Table 1 shown the typical composition of the AISI 304 and Inconel 625 in weight percent.

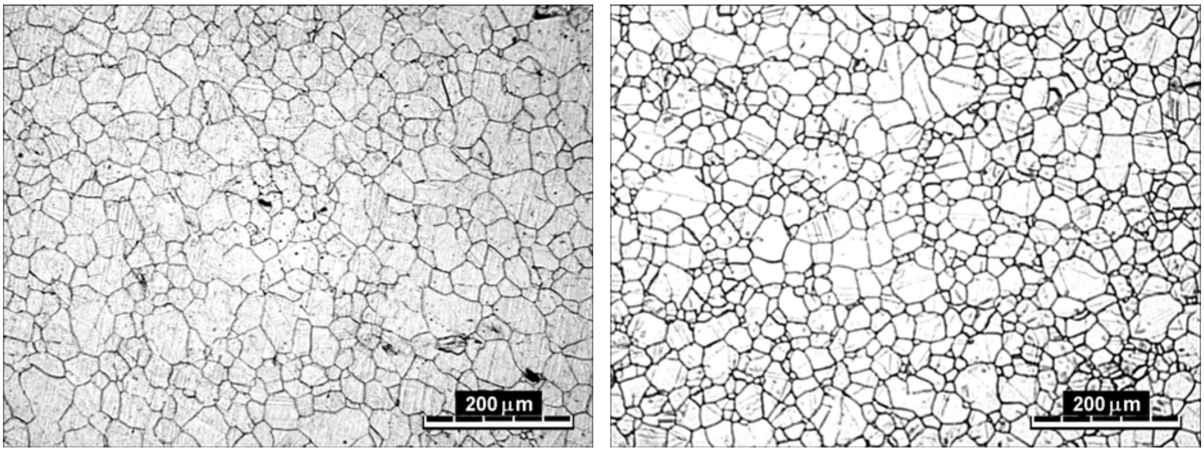
Table 1. Typical Chemical Composition of the AISI 304 and Inconel 625 (% W).

		Co	Cr	Mo	Fe	Si	Mn	C	Al	Ti	S	P	Cb+Ta	Ni
AISI 304	**min**	-	18.0	-	Bal	-	-	-	-	-	-	-	-	8.0
	max	-	20.0	2.00	Bal	0.75	-	0.08	-	-	0.030	0.450	-	10.5
Inconel 625	**min**	-	20.0	8.00	-	-	-	-	-	-	-	-	3.15	58.0
	max	1.00	23.0	10.00	5.00	0.50	0.50	0.10	0.40	0.40	0.015	0.015	4.15	-

Two welds joint were made using the GTAW process in four passes butt welds will be were used to produce the weld bead layers. A V-groove joint weld with 1300 J/mm for the root weld and 900 J/mm for other beads were performed.
One joint was then subjected to a post-weld heat treatment (PWHT) at 800°C for 3 h in order to release the residual stress in weld joint.
The metallographic specimens were prepared across the root weld surface for microhardness testing and estimate of the amount of damage on the joint weld microstructure. These specimens were submitted to electrolytic attach in oxalic acid 10%.
Optical and Scanning Electronic Microscope, and Energy Depressive Spectroscopy (EDS) examined the sample exposed and no exposed to PWHT.
The three-point bend test in the root weld, until 180°, was often used to evaluate the soundness and ductility of the dissimilar welding in sample exposed and no exposed to PWHT.

3 RESULTS AND DISCUSSION

The microstructure of the AISI 304 as-received condition and after heat-treated (800°C for 3 h) is shown in Figure 1, it is a fully austenitic microstructure. The grain boundary in sample with heat treatment was more attached because of the Cr precipitated. The grain size of the AISI 304 did not change appreciably after the heat treatment.



a b

Figure 1. Micrography of the AISI 304, austenitic grain (a) as supplied and (b) after heat treatment (800°C for 3 h), with some coarse grain boundary. The grain size of the AISI 304 did not change appreciably after the heat treatment.

The HAZ microstructure of as welded and PWHT (800°C for 3 h) is shown in Figure 2. In both HAZ microstructures were found a sensitization, Cr carbides localized in grain boundaries. In the sample as welded the sensitization was higher near the fusion line (FL) only, Figure 2 (a). In the sample with PWHT the sensitization was lower near the FL and more evidence develops for carbon diffusion towards the base metal, this becomes clearer, when a thicker dark-etching carbide layer forms at the grain boundary, as seen in Figure 2 (b).

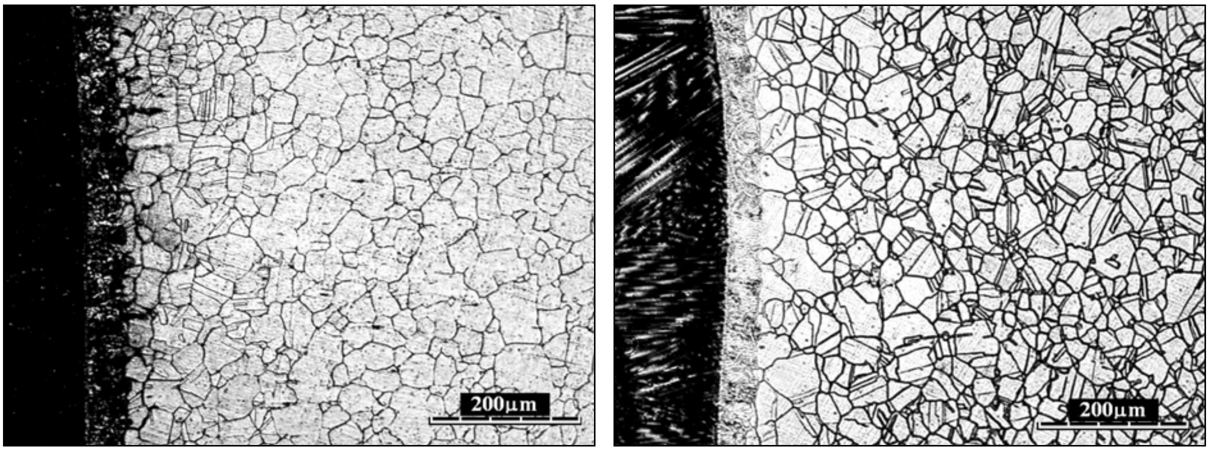


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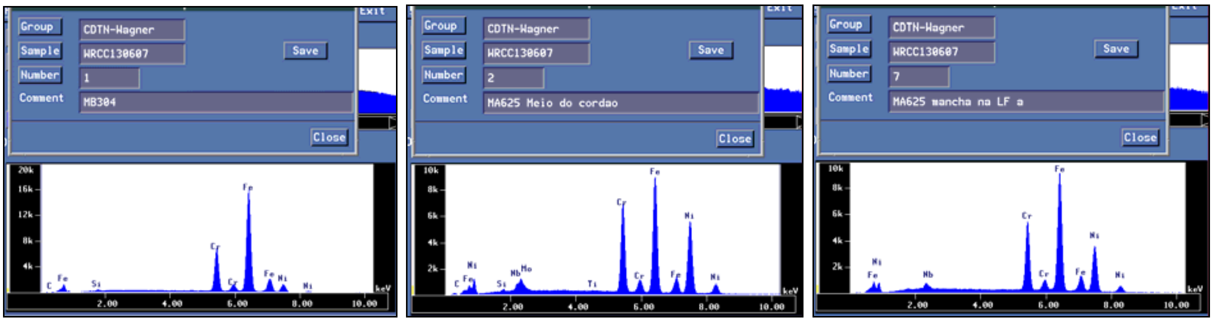
Figure 2. HAZ micrography. The sensitization in grain boundary near the fusion line, as welded (a) was lower with PWHT (800°C for 3 h) (b).

Figure 3 shows EDS spectra in weld joint. The BM AISI 304 presented Fe, Cr and Ni, Figure 3 (a), the middle of the welding Inconel 625 presented Ni, Cr, Fe, Nb, Mo and Ti, Figure (b), and near the fusion line in the Inconel 625 occur the dilution region, it presented a composition between the AISI 304 and Inconel 625, Figure (c).



a b c

Figure 3. EDS spectra of the base metal AISI 304 (a), the center of the weld metal Inconel 625 (b), and dilution of the AISI 304 in Inconel 625 (c).

The weld metal presented inclusion and precipitates were qualitatively analyzed using EDS. Some Nb inclusion, and Nb and Ti precipitate were localized in weld metal and dendrite boundary, the precipitated was increase with PWHT, see Figure 4 (a). The tendency for Inconel 625 to liquate at the weld dendrite boundaries is greater apparently due to the presence of Nb and Ti precipitated which is known to cause liquation cracking in nickel alloy. The interface of the weld with the base metal reveals the presence of an unmixed zone in which the BM has melted and resolidified without mixing with the filler material, Figure 4 (b). On the HAZ, as welded, there is evidence of grain boundary thickening and liquation, especially where inclusion-rich stringers intersect the fusion boundary, Figure 4 (c). On the HAZ, with PWHT (800°C for 3 h), there is more evidence of grain boundary thickening and liquation, and appear a fusion boundary Type II,[3] Fig.ure4 (d).

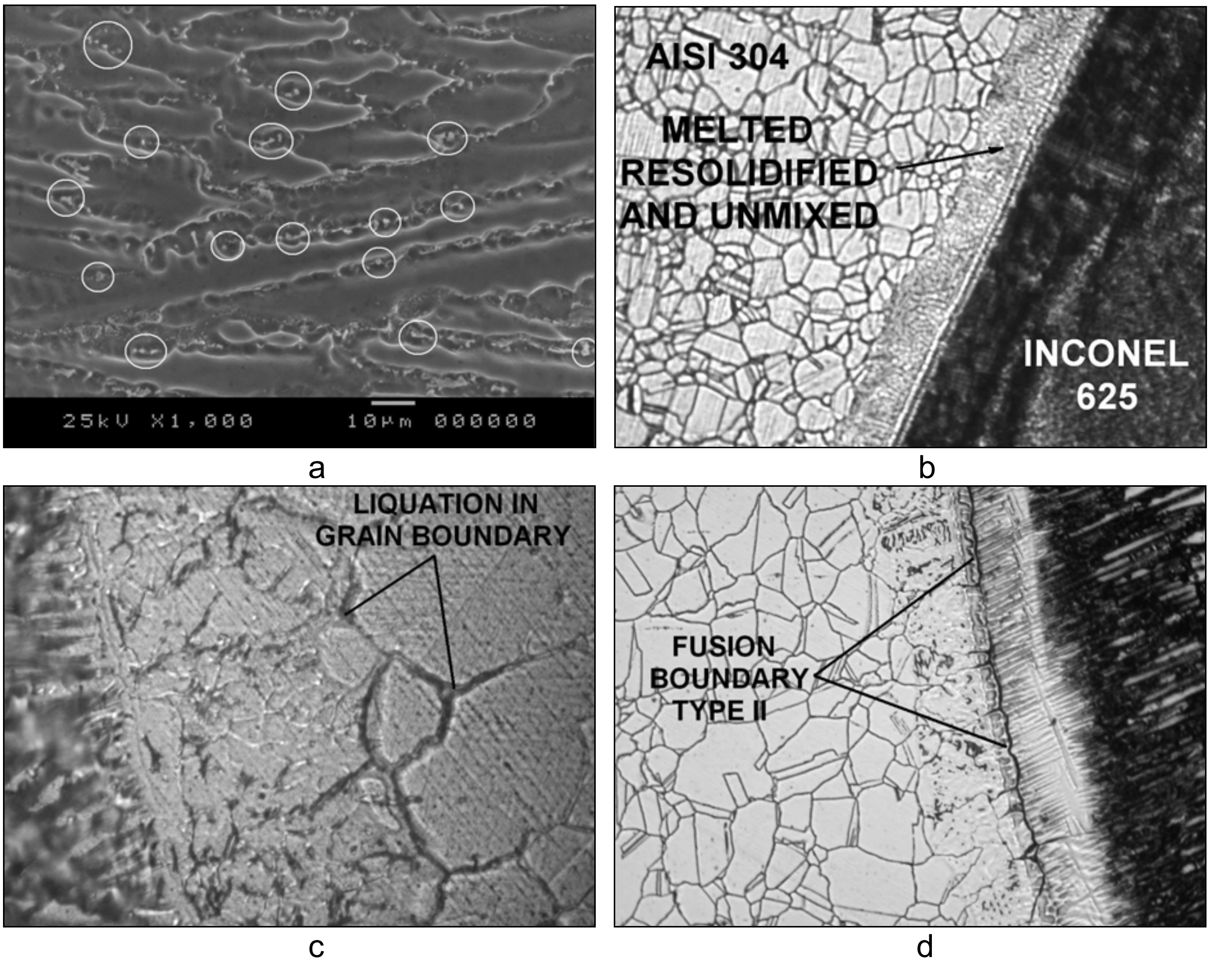


Figure 4. Micrography of the weld joint. Precipitation in dendrite boundary, circle in weld metal (a), melted and unmixed zone in HAZ (b), HAZ liquation in grain boundary near the fusion line as welded (c), fusion boundary Type II sample after PWHT (800°C for 3 h) in fusion line (d).

Figure 5 shows EDS spectra in the weld metal Inconel 625, Niobium precipitate (a) in sample without PWHT, the Niobium, Titanium and Chromium precipitate in dendrite boundary (b) in sample with PWHT, and Chromium carbide precipitate in grain boundary in the HAZ AISI 304 without PWHT.

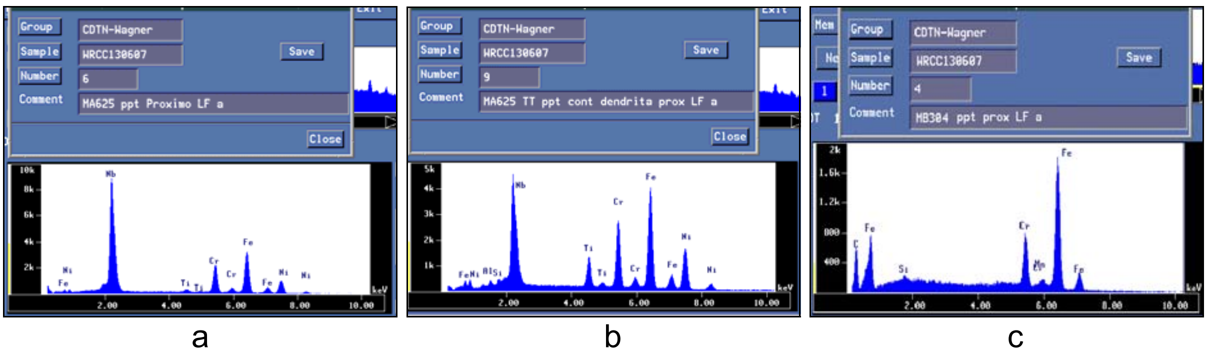


Figure 5. EDS spectra in the weld metal Inconel 625 Niobium precipitate (a) in sample without PWHT and the Niobium, Titanium and Chromium precipitate in dendrite boundary (b) in sample with PWHT

Figure 6 shows composition profile by EDS analysis of the dilution, AISI 304 in weld metal Inconel 625, in sample without PWHT, the extent of this region was approximately 4 mm. After the fusion line, the base metal AISI 304 toward the weld metal Inconel 625, occur a decrease of the Fe content, increase of the Ni and Nb contents. In this region Nb precipitation occurs more than in the middle of the welding.

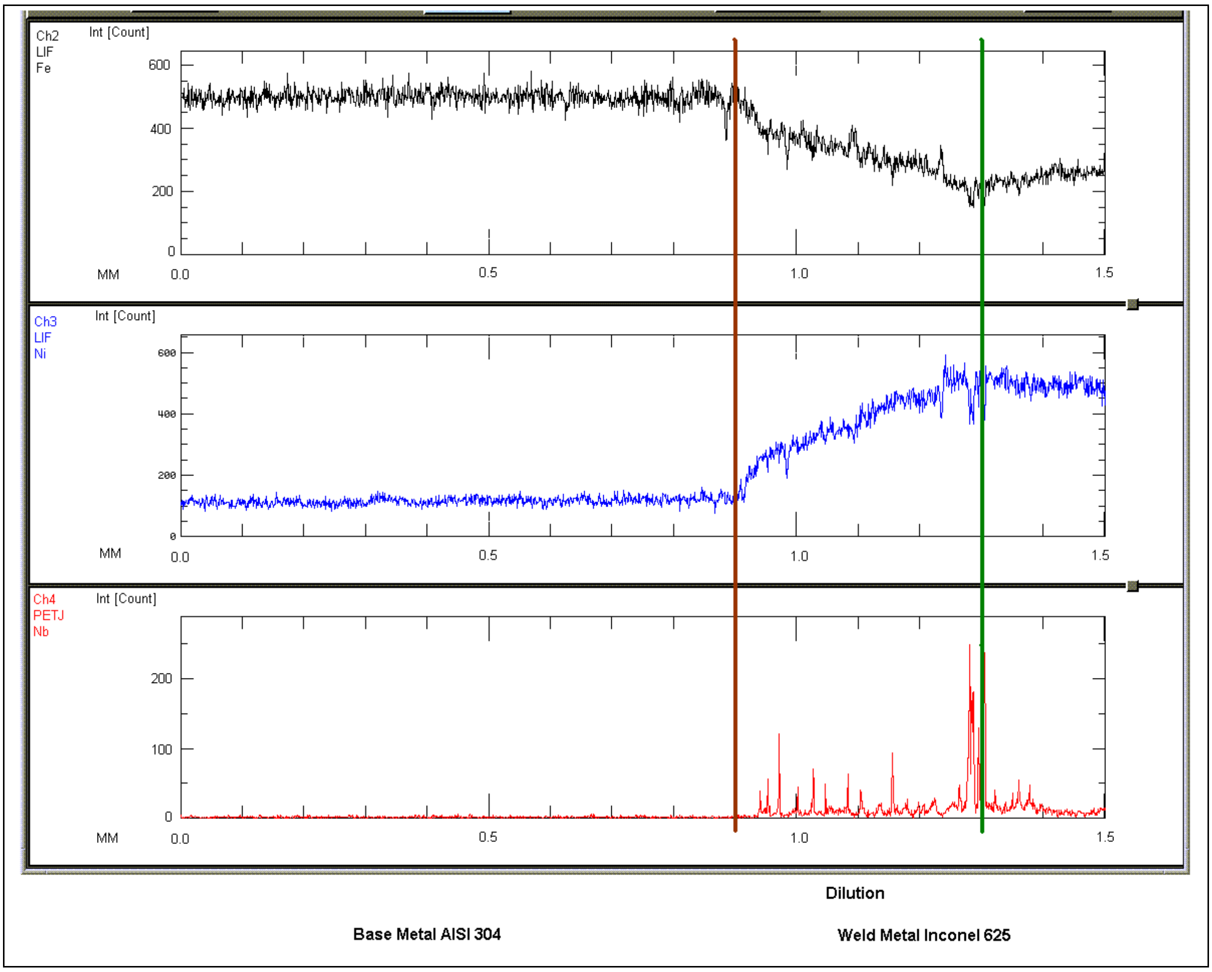


Figure 6. Composition profile of the Fe, Ni and Nb in dilution region of the BM AISI 304 in weld metal Inconel 625, without PWHT.

Figures 7 are shown cross-weld microhardness surveys of the samples. In sample as welded, the HAZ and near the FL, approximated by 4 mm, in weld metal, the microhardness was higher probably due to residual stress, the Nb precipitation and the dilution of the AISI 304 in Inconel 625. In sample with PWHT, the HAZ and near the FL, in metal weld, the microhardness value was decreasing due to release the residual stress. In weld metal with PWHT, the microhardness increase due Nb and Ti carbide precipitation, and the HAZ microhardness decrease due to Chromium deplete for the grain boundary and release the residual stress.

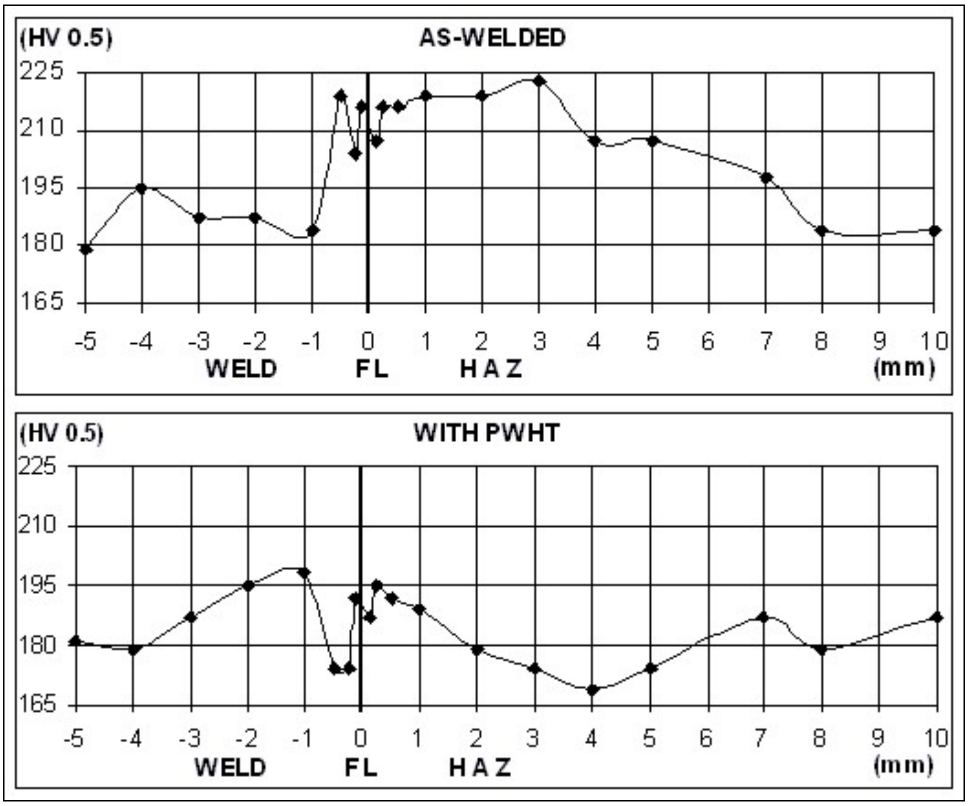


Figure 7. Cross-weld Vickers microhardness surveys of the samples. (a) as welded and (b) with PWHT (800°C for 3 h).

The three-point bending tests on root weld in bolt samples, as welded and with PWHT (800°C for 3 h), show good sound and ductility and no cracking after bend-test in 180°.

4 CONCLUSIONS

From the results and discussion presented, the following conclusions can be made:

- The welding increased the microhardness near the fusion line, probably due the residual stress and the dilution of the AISI 304 in Inconel 625. Near the fusion line, in the AISI 304, occurs grain boundary precipitation (Cr carbide). In HAZ near the fusion line and the weld metal was occurred liquation due the formation of eutectic constituents of the low fusing point in grain and the dendrite boundaries.
- After PWHT was occurred precipitation (Cr carbide) in the grain boundary in base metal (AISI 304), and increase the Nb and Ti precipitation in the boundary dendrite, (Inconel 625). The liquation in grain boundary near the fusion line (AISI 304) increased with PWHT. Grain size of the AISI 304 did not change appreciably during the PWHT.
- The PWHT was an effective way to reduce in microhardness near the fusion line. This reduce in microhardness may be accomplished through a reduction in residual stress. But after PWHT occurs an increase in the microhardness in weld metal probably due the increase of the Nb and Ti precipitation in the dendrite boundary.
- Bending test did not present crack in two conditions, as welded and after PWHT, indicating that the welding conditions had presented a good mechanics properties.
- The residual stress in fusion line and HAZ can be a problem how much to the stress corrosion crack, then it becomes necessary a PWHT. However, the PWHT increase the HAZ liquation and the precipitation in the dendrite boundary that can diminish the resistance to the stress corrosion.

Acknowledgments

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