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EFFECTS OF POST WELD HEAT TREATMENT AND WELD OVERLAY ON THE RESIDUAL STRESS AND MECHANICAL PROPERTIES IN DISSIMILAR METAL WELD

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ABSTRACT

The object of this work is a dissimilar metal weld (DMW) pipe joint between carbon steel (A-106 Gr B) and stainless steel (A-312 TP316L) pipes and filler metals of Nickel alloy (82/182), which find wide application in the field of chemical, oil, petroleum industries, fossil fuel and nuclear power plant. A lot of the failures that have occurred in dissimilar metal welded are affected greatly by residual stresses. Residual stress is often a cause of premature failure of critical components under normal operation of welded components. Several methods have been tested and developed for removing the tensile residual stresses. The aim of the methods is to reduce the tensile stress state or to create compressive stresses at a predefined area, such as the inner surface of a welded pipe joint. Post weld heat treatment (PWHT) and weld overlay (WOL) are two of the residual stress mitigation methods which reduce the tensile residual stress, create compressive stresses and arrest crack initiation and crack growth. The technique used to substantially minimized or eliminated this failure development in the root weld is the post weld heat treatments (stress relief heat treatment) or the weld overlay. In this work was studied the effectiveness in reducing internal residual stress in dissimilar metal welded pipe joints subjected to post weld heat treatment and weld overlay, measurement by hole-drilling strain-gage method of stress relaxation. Also held was mechanical characterization of the welded pipe joint itself.

1. INTRODUCTION

Many of the degradation mechanisms to welded components can be increased by residual stresses that reside within the material. Residual stresses occur through a variety of mechanisms including temperature gradients in welding process or heat treatments, plastic deformations in forming process, or phase transformation. In welding processes are very common the appearance of structural distortions and residual stresses due to the located heating of the materials to be joined and non uniform temperature distribution during the welding thermal cycle. Many cases of stress corrosion cracking (SCC) have been found in the DMWs of the many plants, from the chemical plants up to nuclear power plants, and the residual stress is considered as one of the critical contributing factors. In order to estimate the possibility of SCC is essential the understanding and knowledge the magnitude and distribution of weld residual stresses [1-7].

Welds between different metals are called dissimilar metal weld (DMW) and are of special importance for constructions of pipe work connections in chemical, oil, petroleum industries, and plants of energy generation that burn fossil fuel and nuclear. In the nuclear power industry the DMW are used for joining low-alloy ferritic steel components to Nickel alloy and/or austenite stainless steel pipelines with Nickel-base filler metals. Nickel alloys 82/182 are commonly used as a filler metal in these types of welded joints because its thermal expansion coefficient lies between those of ferritic steel and austenitic stainless steel [7-10].

During welding process high level residual stresses may occur due to the restriction of the metals during solidification. These stresses may be as high as the yield strength of the parent materials, which when combined with normal workload stresses these may exceed the design stresses. The heat affected zone and the weld metal dilution in the vicinity of welded joints are aided considerably by post welding heat treatments (PWHT). The properties of those zones are improved by the reduction of residual stresses together with the metallurgical changes brought about by the PWHT [3-5, 12].

PWHT to relieve stress may be required in welded joints. Since PWHT of DMWs typically is performed at temperatures exceeding 600°C. For DMW between ferritic carbon steels and austenitic stainless steels, the PWHT between 600-650°C is usually adequate to minimize partially stresses relief. The PWHT promote a relief in the residual stress, but can also lead to degradation of the materials microstructures. These degradations are dependent on the temperature and holding time of heat treatment. For these reasons, the welding overlay (WOL) methods were developed as alternatives to PWHT. The WOL have been used successfully on many applications in petrochemical and nuclear plants [2, 7, 11-13].

The term weld overlay (WOL) is used to define applications of welding processes deposit one or more layers application on the welded pipe joints to relieve the residual tensile stresses and to increase the thickness of the wall in cases of internal cracking. The purpose of a WOL is to change the residual stress of the inner pipe wall of dissimilar metal welded joints due to the shrinkage of the weld overlay material during the cooling. Sometimes the weld overlay changes the residual stress of the inner pipe wall of welds from tensile to compressive stress. A key aspect of the weld overlay design process is to demonstrate that favorable residual stress reversal occurs such that SCC initiation and growth is mitigated [14-17].

The residual stress measurement technologies have many limitations. Accurate analysis for residual stress in DMWs is very difficult due to its different characteristics. Several studies have been conducted to analyze residual stresses welding, and the objects of studies varied significantly from the detailed process physics to economic procedures for capturing the important features in a residual stress distribution [4, 5, 7, 18, 19].

The hole-drilling strain gage method of stress relaxation is known as the most reliable technology among the currently available methods to measure the residual stress. This is a mechanical technique that can determine residual stresses as a function of depth. The hole-drilling involves introducing a small hole at the center of a specially designed strain gage (rosette), and measuring the resulting strain relaxation. Residual stress is determined from the relaxed strain and calibration coefficients, hole size, and materials. This method has been standardized at a world level by the ASTM E 837-13 “Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method” [19-22].

In this study, an attempt is made to measure residual stresses inner the surface of a dissimilar metal welded pipe by hole-drilling strain gage method. The residual stresses measurements are made in three dissimilar metal welded pipe joints conditions, as welded, after PWHT and after WOL. In addition, the mechanical characterization of the welded joint pipes are examined.

To measure the residual stresses inner the surface of the welded joints by hole-drilling method was used equipment developed in Centro de Desenvolvimento da Tecnologia Nuclear (CDTN). This equipment to measure strains inner surface the pipes could be positioned concentrically inside the pipe diameter. The equipment has mechanisms that allow positioning the drill exactly in the rosette centre. A web-cam connected to the equipment is used to align the drill with the rosette centre and to measure the hole diameter. The equipment is shown in Figure 1. The hole diameter is measured calibrating the webcam pictures with the diameter of the gage circle [23].

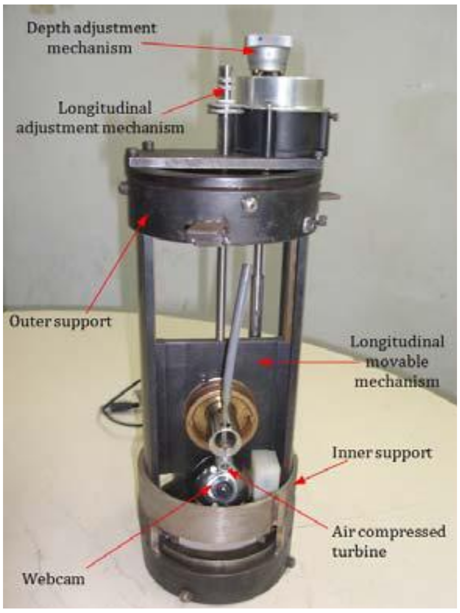


Figure 1: Developed equipment to assist measuring residual stresses inner wall pipes by hole-drilling method [23].

2. MATERIALS AND METHODS

2.1. Materials

DMW pipe joints were composed of a carbon steel pipes (ASTM A-106 Gr B) and a austenitic stainless steel pipes (ASTM A-312 TP316L), schedule 160 with diameter of 168.2mm and wall thickness of 18.3mm, with length of 150mm, and two different filler metals, the Nickel alloy 82 (AWS A5.14 ER NiCr-3) with 2.0mm diameter, buttering and root layer weld, and Nickel alloy 182 (AWS A5.11 E NiCrFe-3) with diameter of 3.25mm to complete the welding. The chemical compositions of the base metals and weld metals are summarized in Table 1.

Table 1: The nominal chemical composition (wt. %) of the pipes and the filler metals.

Material	C	Mn	Si	Cr	Mo	Nb	Ti	Ni	Fe
A-106 Gr B	0.30	0.29-1.06	0.10	0.40	0.15	-	-	0.40	Bal
TP316L	0.035	2.00	1.00	16.0-18.0	2.00-3.00	-	-	10.00-14.00	Bal
Alloy 82	<0.10	2.50-3.50	<0.015	18.0-22.0	-	2.00-3.00	<0.75	>67.0	<3.00
Alloy 182	<0.10	5.00-9.50	<0.015	13.0-17.0	-	1.00-2.50	<1.00	>59.0	<10.00

2.2. Dissimilar Welding of Pipes

Three dissimilar welding pipes were made for this study. The pipes of austenitic stainless steel (A-312 TP316L) and carbon steel (A-106 Gr B) were prepared for the welding with a single V groove of 30°. Before groove welding, the face groove of the A-106 was buttered with three layers of Alloy 82 filler metal with about a 5mm thick by Gas Tungsten Arc Welding (GTAW). To make the joints, the pipes were welded to the top with narrow gap of 2.0 mm, with pre-heating at 150°C and interpass temperature at between 130-170°C. The first 2 beads (root weld) were welded by manual GTAW using Alloy 82, and additional 7 beads were completed by Shielded Metal Arc Welding (SMAW) using Alloy 182. Table 2 shows the welding parameters, and in Figure 2 a complete dissimilar metal welded pipe.

Table 2: Welding parameters for dissimilar weld pipe joints fabrication.

Process	Localization	Weld rod [mm]	Current [A]	Voltage [V]
GTAW	Butt and Root	2.00	140	11
SMAW	Dissimilar Welding	3.25	120	20

Figure 2: Dissimilar welded pipes, austenitic stainless steel (ASTM A-312 TP316L) carbon steel (ASTM A-106 Gr B) and filler metals (Alloy 82 and 182).

2.3. Post Weld Heat Treatment - PWHT

After residual stresses measurements inner the dissimilar welded pipes, one of the welded pipes was conducted at 620ºC for 2.5 hours to a localized PWHT, in order to reduce the microhardness and the weld residual stresses.

2.4. Weld Overlay – WOL

After the measurement of the residual stresses in the welded joints, a coating welder was made in other dissimilar welded pipe joint, which was composed of 5 layers with Nickel alloy 82 (AWS A5.14 ER NiCr-3), by GTAW process, using the same conditions of those butt and root welding. This coating had a length of 115mm and 7mm of thickness. Figure 5 shows the weld overlay on the dissimilar metal welded pipe joint.

Figure 5. The weld overlay on the dissimilar welded pipe.

2.5. Vickers Microhardness Profiles

Microhardness Vickers profiles in the cross section of the welded joints, near the weld root, at 2mm of the internal surface, were evaluated for the three different conditions, as welded, after PWHT and after WOL. The profiles extended from the austenitic stainless steel TP316L through the HAZ, fusion zone alloy 82 and HAZ again until the carbon steel A-106 Gr B. The microhardness measurements were carried at 1mm the internal surface and the load applied was 0.01kg for 15s.

2.6. Measurement of Residual Stress as Welded Condition

After welding, the internal surface of the welded joints was prepared to hoop and axial stresses measurements. The residual stress in one line inside surface was measured using strain gage type rosette. Strain gages rosette TML manufacturing, FRS-2-11 for carbon steel and FRS-2-17 for stainless steel were bounded. The rosettes were distributed along the longitudinal direction of the pipes, one close to the weld, one at the end of the pipe and one at intermediate position inside the pipes surface of each side of the welds, see Figure 3.

Figure 4 shows the drilling equipment to measure strains inner surface the pipes positioned for drilling a rosette installed on the inside of welded pipe.

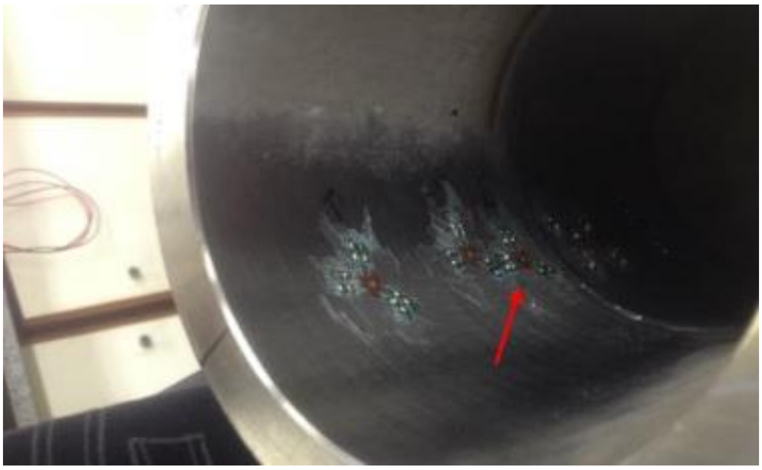


Figure 3: Positioning of the strain gages rosette type used in internal residual stress measurements.

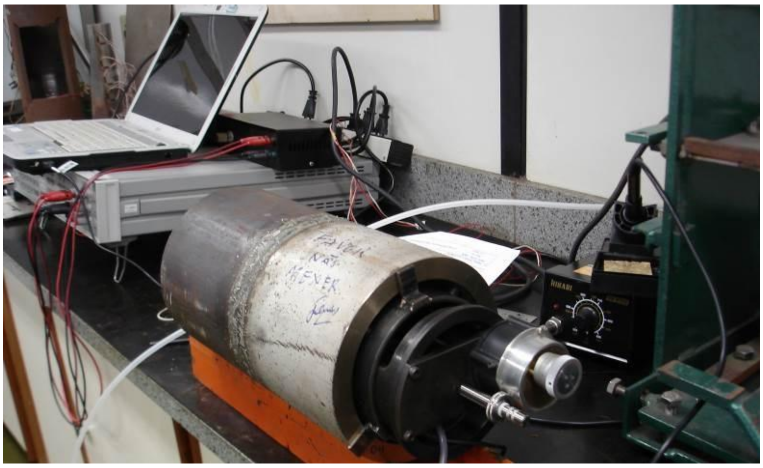


Figure 4: The equipment to measure strains inner surface the pipes installed inside the welded pipe.

2.7. Measurement of Residual Stress After PWHT and WOL

After the PWHT and the WOL, the residual stresses were once again measurements on the inner surface of the welded pipes to evaluate the effect of the PWHT and the WOL on the residual stresses in the welded joints.

3. RESULTS

3.1. Mechanical Properties

3.1.1. Tensile test

Table 3 shown the results on the tensile tests in ambient temperature 22ºC and 350ºC operate temperature of nuclear power plant, in three conditions as welded, after PWHT and WOL.

Table 3: Results of tensile tests on the dissimilar welded pipe joints.

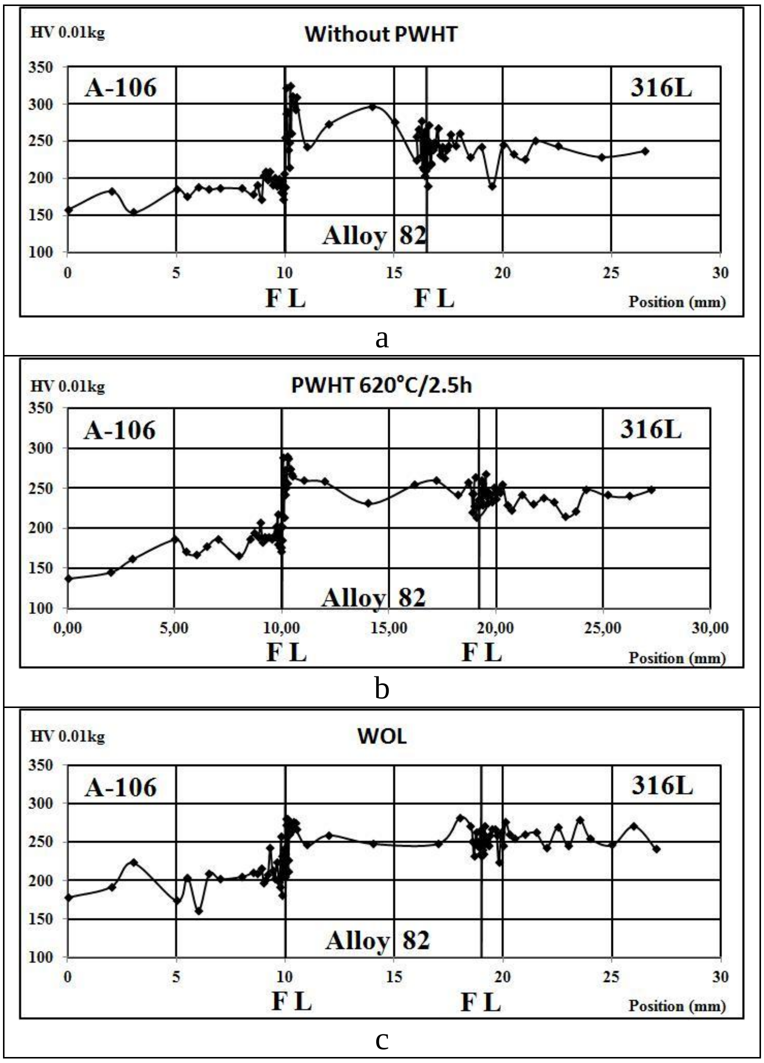
CP	Temperature	Yield	SD	Rupture	SD	Elongation	SD	Area Reduction	SD
	(°C)	(Mpa)	(Mpa)	(Mpa)	(Mpa)	(%)	(%)	(%)	(%)
As welded	22	333.25	6.55	483.21	0.19	13.26	2.46	58.89	24.20
	350	242.42	1.58	418.03	4.92	20.52	2.27	82.70	0.81
PHWT	22	313.79	0,06	473.21	6.54	14.18	1.48	71.92	0.75
	350	261.37	12.61	422.86	2.17	17.86	1.45	81.50	0.93
WOL	22	375.26	17.27	500.62	12.08	15.52	0.60	74.89	5.19
	350	324.77	8.27	440.88	5.03	15.34	3.79	80.75	2.00

3.1.2. Microhardness test

The microhardness profiles of the dissimilar welded pipe joints, as welded, with PWHT and WOL, are shown in Figure 6. In the as welded condition, Figure 6 (a), the weld metal (alloy 82) has higher microhardness than both of the base metals (316L and A-106). The weld metal near the interface with A-106 exhibits the highest microhardness value. In both HAZ closed to the fusion line show higher microhardness than the base metals farther from fusion line.

After PWHT, Figure 6 (b), the microhardness values in weld metal (alloy 82) has lower than as welded condition, theses values were similar to the austenitic stainless steel (TP316L), and highest than carbon steel (A-106). The PWHT did not significantly change the microhardness values in bolt base metals. Both HAZ closed to the fusion line showed a slightly lower microhardness value than as welded condition.

After WOL, Figure 6 (c), the microhardness values in weld metal (alloy 82) has lower than as welded condition, theses values were similar to the austenitic stainless steel (TP316L), and highest than carbon steel (A-106). The interface weld metal and HAZ of A-106, after WOL, exhibits the lower microhardness value than as welded and PWHT condition. The TP316L show slightly higher microhardness than as welded and PWHT condition.



a

b

c

Figure 6: Microhardness Vickers profile along cross-section in root in for dissimilar welded joint as welded (a) after PWHT (b) and after WOL (c).

3.2. Residual Stress Measurements

3.2.1. Residual stress measurements, as welded condition

Figure 7 shows the average maximum axial stress profile and average maximum hoop stress profile, respectively, inner the three welded pipes, as welded condition. The behavior of the curves for both axial and circumferential residual stresses is the similar. In the region of the stainless steel (TP316L) near the weld, the maximum hoop stress is a tensile stress and it is 220MPa, as it moves away from this region, the tensile stresses become compressive stresses, -180MPa, and stabilizing near zero at end of the pipe. On the other side, in the carbon steel (A-106), near the weld there are compressive stresses, -220MPa, and stabilizing near zero at end of the pipe.

The maximum axial stress in the stainless steel (TP316L) near the weld root, there is a tensile stress and it is 220MPa, as it moves away from this region, the tensile stresses become compressive stresses, -250MPa, and stabilizing zero at end of the pipe. On the other side in the carbon steel (A-106), near the weld there is compressive stresses, -220MPa, and stabilizing near zero at end of the pipe.

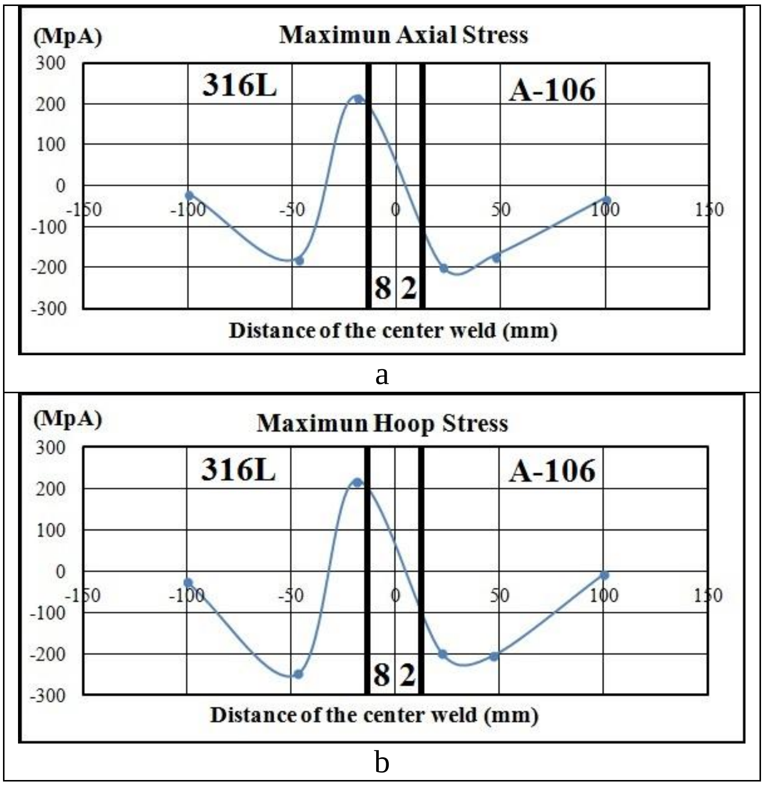


Figure 7: The average maximum axial stress (a) and average maximum hoop stress (b) profile inner the three welded pipes, as welded condition.

3.2.2. Residual stress measurement of the welded pipe joint before and after PWHT

Figure 8 shows the maximum axial stress profile and maximum hoop stress profile, respectively, inner the welded pipe, after PWHT. The PWHT reduced the level of residual stresses in both tensile and compressive stresses. There was no generation of compression stresses on the inner surface of the welded pipe joint.

The maximum axial stress in the stainless steel TP316L near the weld, there is a tensile stress and it is 50MPa, as it moves away from this region, the tensile stresses stabilized near zero at end of the pipe. On the other side, in the carbon steel A-106, did not occur significant variations in the residual stresses, near the weld there is compressive stresses, -200MPa, and stabilizing near zero at end of the pipe. The maximum hoop stress in the stainless steel TP316L near the weld, there is a tensile stress close zero, and in carbon steel A-106, near the weld there is compressive stresses, -120MPa, and stabilizing near zero at end of the pipe.

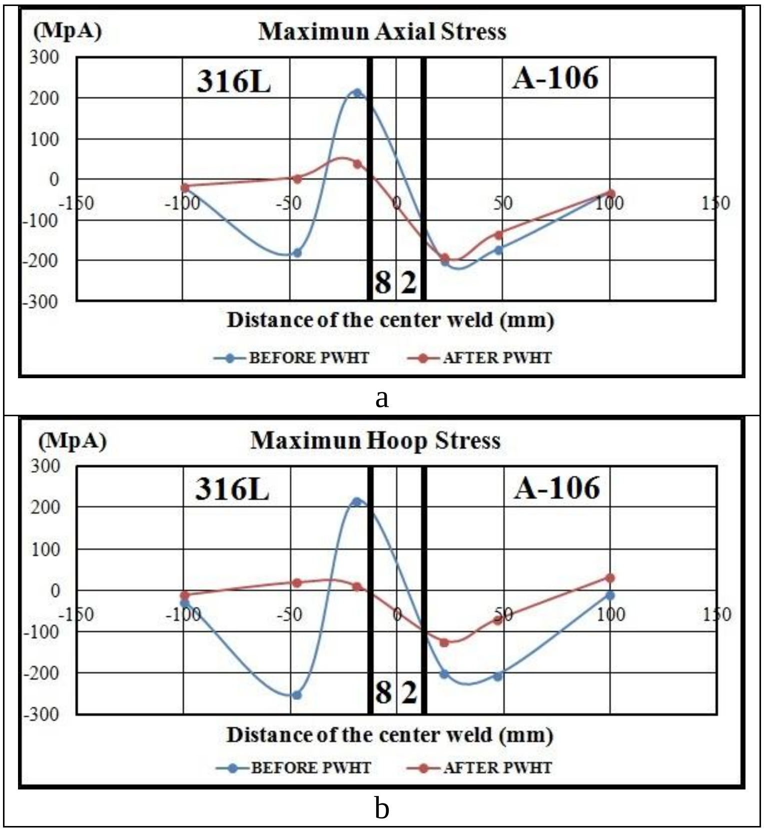


Figure 8: The maximum axial stress and maximum hoop stress profile inner the welded pipes, after PWHT.

3.2.3. Residual stress measurement of the welded pipe joint before and after WOL

Figure 9 shows the maximum axial stress profile and maximum hoop stress profile inner the welded pipes, after WOL. The WOL change significantly the level of tensile residual stresses. There was generation of compression stresses on the inner surface of the welded pipe joint.

The maximum axial stress in the stainless steel TP316L near the weld, there is a compressive stress close zero, as it moves away from this region, the stresses is near zero at end of the pipe. On the other side, in the carbon steel A-106, did not occur significant variations in the residual stresses, at end of the pipe the compressive stress is stabilized in 50MPa.

The maximum hoop stress in the stainless steel TP316L near the weld, there is a compressive stress close -100MPa, as it moves away from this region, the compressive stresses stabilized near zero at end of the pipe. In the carbon steel A-106, near the weld there is compressive stresses increased of the -220MPa to -300MPa, and stabilizing near zero at end of the pipe.

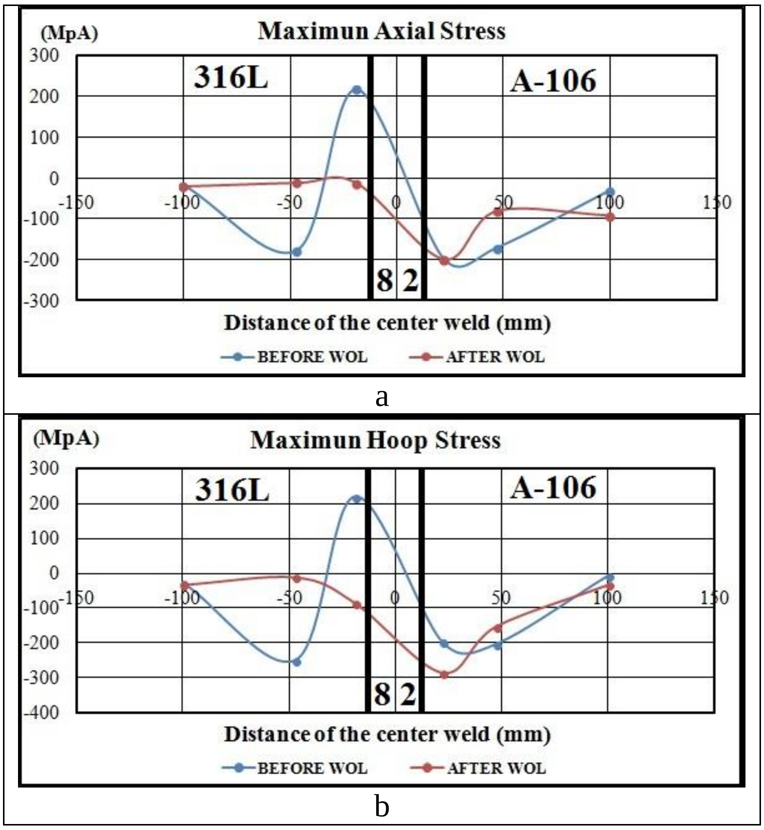


Figure 9: The maximum axial stress and maximum hoop stress profile inner the welded pipes, after WOL.

4. CONCLUSIONS

The dissimilar metal welded pipe joints, analyzed in this study, in the as welded condition, presented higher microhardness values in the dilution region at interface A-106 and alloy 182, higher than 300 Vickers. It also has higher values of residual stresses in the HAZ of 316L stainless steel, higher 200MPa.

The effect of applying PWHT and WOL on the dissimilar metal welded pipe joints between carbon steel (A-106 Gr B) and stainless steel (A-312 TP316L) pipes and filler metals of Nickel alloy (82/182) has been evaluated.

Both PWHT and WOL were efficient in the reduction the microhardness in the weld metal and near the fusion line in the dilution region at interface A-106 and alloy 82; however the WOL was more efficient at reduction the microhardness near the fusion line in the dilution region at interface A-106 and alloy 82, region higher hardness value.

With the PWHT occurred a small reduction in the microhardness values in the HAZ in the base metals, while with the WOL the microhardness in relation to the sample in the as welded condition was slight higher.

The PWHT and WOL were efficient to reduce the level of residual stresses in both tensile and compressive stresses in stainless steel TP316L. In the carbon steel A-106 the compressive residual stress reduced with the PWHT, but with WOL compressive stress was higher.

Thus, it can be concluded that the WOL was slightly superior in reducing the hardness and residual stresses in the dissimilar metal welded pipe joints studied, but since it is not always possible to perform the WOL, the PWHT can be more practical in many cases.

Additional studies must be made in relation to the PWHT and WOL effect on the corrosion resistance by electrochemical and the slow strain rate test.

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