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ANALYSIS OF HEAT INPUT INFLUENCE IN AUSTENITIC STAINLESS STEEL PLATES WELDED BY SMAW PROCESS

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Abstract. *The joining of metals by welding is a manufacturing method widely used because it produces a resistant and versatile bond as it can be applied in various materials and conditions. Stainless steel is used in several projects, where many of these involves welding, because it shows excellent resistance to corrosion, excellent mechanical strength and good weldability compared to carbon steels. The SMAW process is mainly employed in repair operations in the field. So that, in this work the influence of the heat input on the quality of the similar joint of stainless steel AISI 316 plate with 309-L covered electrode weld by SMAW process is studied. The weld joints are examined by the tests of macrography, micrography and microhardness. The joint of the AISI 316 steel is welded with three different heat inputs. There was no significant change in the microhardness along the base metal, the heat affected zone and the weld metal. The heat input had influence in the macrostructures of the test specimens, being proportional to the size of the heat affected zone. In the microstructure, the volumetric fraction of delta ferrite was apparently affected by the thermal cycle, being greater with the increase of the heat input.*

Keywords: *Austenitic stainless steel, Welding SMAW, Heat Input, Microhardness, Microstructure.*

1. INTRODUCTION

AISI 316 austenitic stainless steel plates are widely used in many of components for chemical and process industries which demand good formability in addition to high corrosion resistance. Stainless steels can be welded by several processes, but the Shielded Metal Arc Welding (SMAW) are mainly employed in field applications. The stainless steel welds exhibit a series of phenomena that can influence the behaviour of welded joints. Thus, for example, the following situations have been commonly observed during the weld cycle: (a) segregation during solidification; (b) distribution of elements during phase changes; and (c) precipitation of secondary phase particles (Meshram et al., 2014; Srinivasan and Balasubramanian, 2011)

In this sense the present work studies the influence of three different heat input in similar joint of stainless steel AISI 316 plate with 309-L covered electrode weld by SMAW process. The quality of the weld is analyzed by the tests of macrography, micrography and microhardness, in order to evaluate the changes provoked by the thermal cycle due to the difference in heat input applied.

2. MATERIALS AND EXPERIMENTAL METHODS

The material of the base metal (BM) used in this study was AISI 316 stainless steel donated by Aperam South America. Six specimens were cut in the form of sheets with 56 mm by 20 mm and thickness of 5.6 mm. The filler metal (FM) used in the SMAW welding was a 309L stainless steel electrode in the form of a rod of the ESAB trade mark, corresponding to the classification AWS A 5.4 E 309L-16, with a 3.25 mm diameter. The Table 1 presents the chemical composition and some mechanical properties of the BM and FM.

Table 1. Chemical composition and mechanical properties of base and filler metals.

Material	Chemical Composition (% weight). Fe in balance							Hardness (HV)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
	Cr	Ni	Mo	Mn	Si	C	S				
BM	17.25	11.50	2.25	2.00	0.75	0.07	0,015	160	340	650	51
FM	23.66	12.26	0.19	1.03	0.85	0.03	-	-	-	700 - 750	32

The welding was carried out by the SMAW process, using direct current with direct polarity (CC^-). The consumable used was the 3.25 mm diameter stainless electrode E309L-17, according to ASME SFA 5.4 The workpieces were positioned with their axes at 0º in relation to the horizontal plane, characterizing the flat welding position (1G), with top joint and chamfer in X, as showed in Fig. 1. With the purpose of investigating the heat input in the SMAW process, it was conducted an experiment using three different heat inputs that was an arithmetic average of heat input of the two pass. The Table 2 exhibits the welding parameters. The thermal efficiency applied was 0.85.

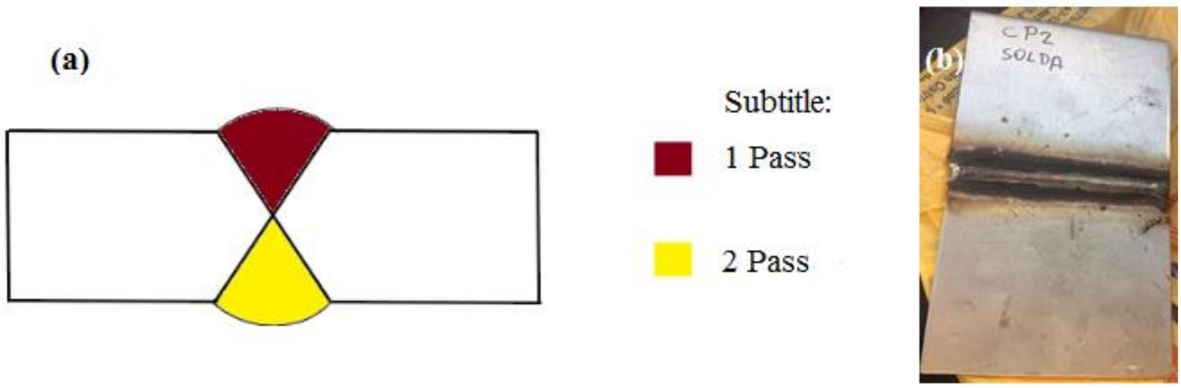

Figure 1. Schematic showing welding passes (a) and the plate welded (b).

Table 2. Welding parameters.

Specimens	Pass	Amperage (A)	Voltage (V)	Length (mm)	Time (s)	Velocity (mm/s)	Heat Input (J/mm)	Average Heat Input (kJ/mm)
1	1	197	23	115	33	3.485	1073	1.105
	2	197	23	115	35	3.286	1138	
2	1	173	23	115	40	2.875	1142	1.346
	2	188	23	115	50	2.300	1551	
3	1	156	23	115	60	1.917	1544	1.555
	2	153	23	115	62	1.855	1565	

After welding the specimens (40 mm x 8 mm x 5.6 mm) were machined on a CNC Romi Discovery 4040 milling machine, the milling cutter was 8mm made by cemented carbide.

In order to perform the macroscopic and microscopic characterizations of the welded joint, the samples were carried out using the conventional metallographic procedure, later electrolytic etched with oxalic acid (6 g of oxalic acid in 80 ml of distilled water). After that, the samples were observed in a stereoscope and optical microscope from the Laboratory of Metallography and Thermal Treatments (LABMETT) of UFF (Universidade Federal Fluminense).

The Figure 2 (a) exhibits the measurement scheme of microhardness profile, where the first line was carried out a 1 mm from de surface and the second one a 2,5 mm. All measurements were conducted with the samples etched with oxalic acid reagent, like Fig. 2 (b) presents as well as the guide line.

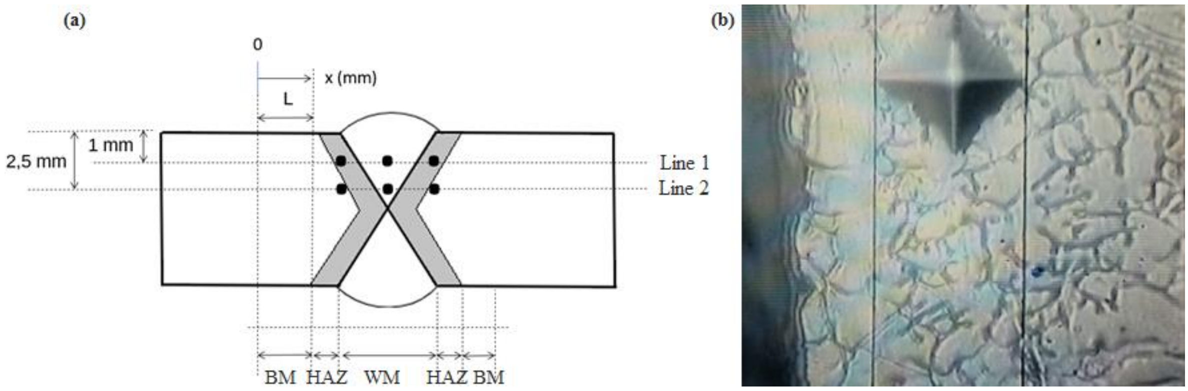

Figure 2. Microhardness profile measurements scheme, where: BM is base metal, HAZ is heat affected zone and WM is weld metal (a) and a Microdurometer´s image showing an indentation close to line 1 in the welding metal (WM) (b).

3. RESULTS AND DISCUSSION

Figure 3 shows a BM characteristic microstructure etched by oxalic acid. The dark lines are represented by precipitated ferrite-delta (Fe-δ). The matrix is the austenitic phase (γ). The grains are polycrystalline with heterogeneous size like also reported by Meshram et al. (2014).

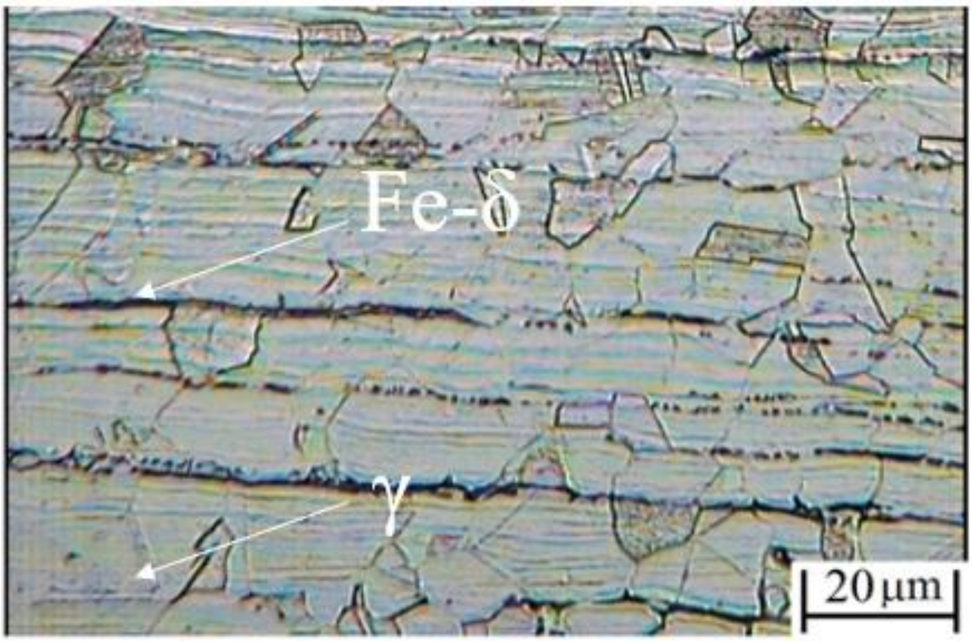

Figure 3. Micrograph of the MB microstructure as received.

The larger HAZ was obtained in the specimen that received the highest heat input, and the shorter one, in the specimen that received the lowest heat input. Thus, the direct relationship between the heat input and the HAZ extension can be verified. Figure 4 presents this result, with ascending order of heat input.

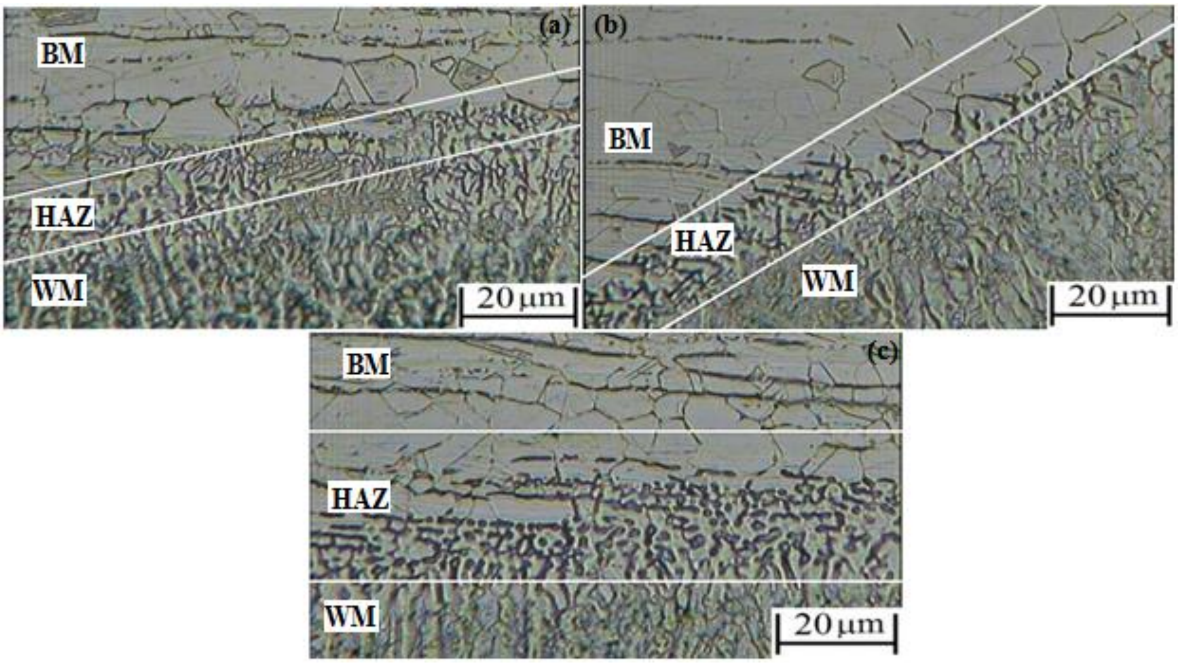

Figure 4. Microstructure micrograph showing MB (base metal), HAZ (heat affected zone) and WM (weld metal) for heat inputs: 1.105 kJ/mm (a), 1.346 kJ/mm (b) and 1.55 kJ/mm (c).

Figure 5 shows the weld metal in increasing order of heat input. The metal base (MB) has a lower percentage of ferrite stabilizing elements than filler metal (FM), wherefore the equivalent chromium of MB is smaller than that of MA. The weld metal (WM) is formed by FM and MB, so WM also has an equivalent chromium larger than MB. The MB equivalent Cr is 20.63%, while for FM it is 25.13, while the equivalent Ni has closer values: 14.6% and 13.68% for MB and FM, respectively.

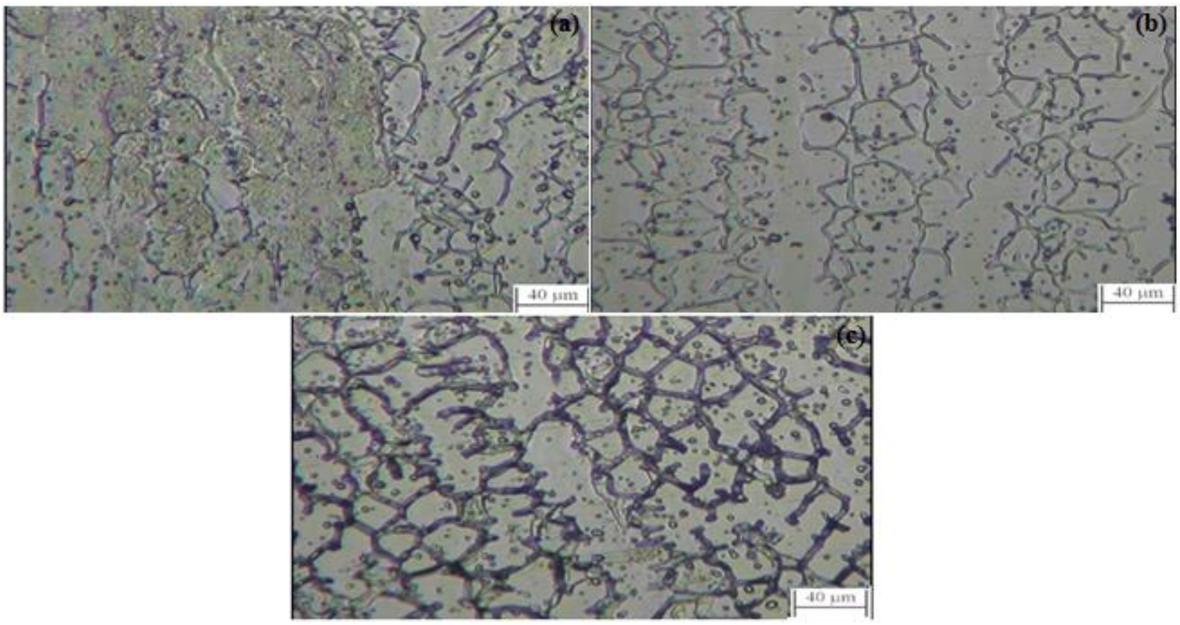

Figure 5. Microstructure micrograph showing WM (weld metal) for heat inputs: 1.105 kJ/mm (a), 1.346 kJ/mm (b) and 1.55 kJ/mm (c).

Through Figure 5 it is possible to observe the dendritic structure in WM of all of the specimens. The specimen that received the largest heat input has the largest volumetric fraction of ferrite (Figure 5 (c)), represented by the black regions. The morphology of the WM presented in Figure 5 suggests that solidification of the filler metal and base metal are of the austenite-ferrite (AF) solidification type, that is, the ferrite formed by eutectic reaction in the boundaries of the austenite that solidified primarily. The percentage of ferrite depends on the solidification conditions resulting from the thermal welding cycle and the Creq / Nieq ratio (Kou, 2003). Therefore, the precipitation of ferrite from the austenite boundaries is diffusional, thus, the higher heat input used, longer time at the critical transformation temperature will be and more ferrite will be formed. Thus, it is extremely consistent with the qualitative observation: higher heat input resulted in the highest percentage of ferrite in the WM. Hammar & Svensson (1979) demonstrated that the transition from primary austenite to primary ferrite in solidification occurs to a Creq / Nieq ratio from 1.55. The values found in the present study are: 1.41 and 1.83, for MB and FM, respectively. Using this criterion, it is possible to infer that the FM contribution was not sufficient for the Creq / Nieq ratio in WM to exceed 1.55. However, a chemical analysis of WM for quantify the chemical elements percentage and calculation of Creq and Nieq is required for this confirmation. In addition, Senior (1987) studied the phase transformations in solidification during welding for different types of stainless steels, noting that the transition from AISI 316 was of type AF solidification, as in the present work, besides suggesting an equation to estimate the percentage of ferrite from the Creq and Nieq.

Figure 6 presents the macrograph of the cross section of the joints for all specimens made with the different heat inputs. The Specimen 1 (heat input: 1.105 kJ/mm), represented by Figure 6 (a), showed the defects of lack of penetration and lack of fusion. Specimen 2, Figure 6 (b), (heat input: 1.346 kJ/mm) exhibited slag inclusion and lack of penetration defects. The specimen 3, showed in Figure 6 (c), with heat input: 1.55 kJ/mm (highest current used) did not present defect and obtained full penetration. The joints were cleaned before each welding and counter welding operation. The welder was qualified and experienced, so it is believed that the possible reason for slag inclusion was the use of low current (Specimen 2). The lack of penetration and lack of fusion are possibly caused by usage of low current. Another possible cause for low penetration was the choice of direct polarity (CC^-), which has a high deposition rate and low penetration.

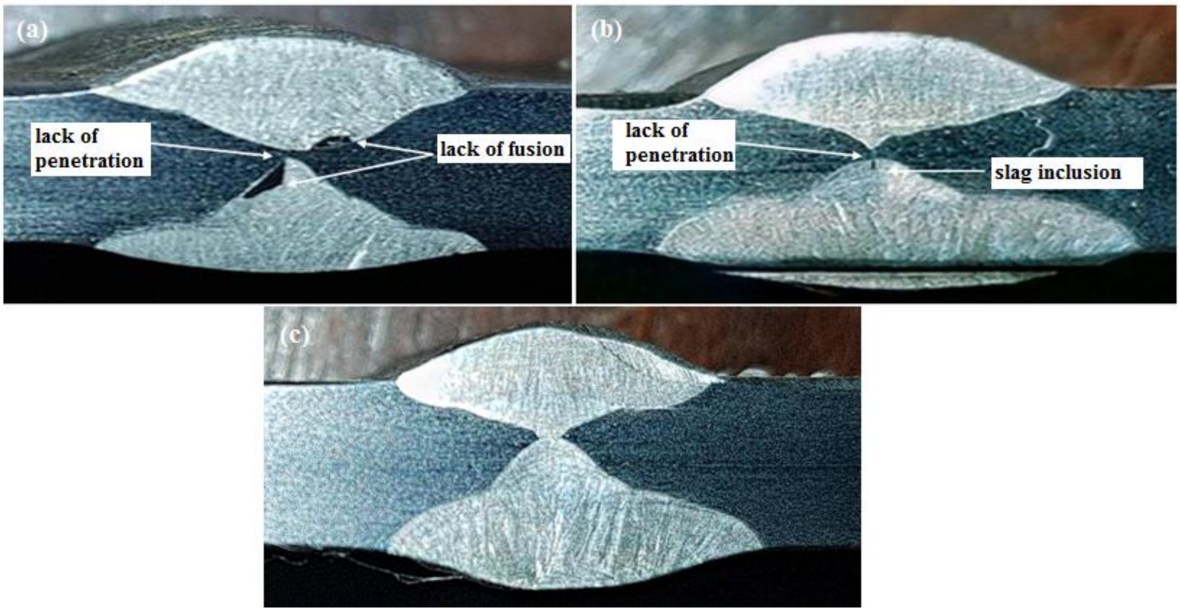

Figure 6. Macrography of the welded joints for heat inputs: 1.105 kJ/mm (a), 1.346 kJ/mm (b) and 1.55 kJ/mm (c).

Tables 3 to 5 present the Vickers microhardness results for welded joints produced with the three different heat inputs. As can be seen from the analysis of the tables, the microhardness of the weld metal (WM) showed a slight reduction with the increase of heat input, this may be due to the increase of the amount of ferrite, as showed in Figure 5. The AISI 316 has a low thermal conductivity, which facilitates heat retention in the material, thereby decreasing the cooling rate and facilitating diffusional reactions of austenite to ferrite. The same tendency was also reported by Srinivasan and Balasubramanian (2011). The hardness profile showed that the microhardness in the HAZ has a slight reduction tendency in relation to the base metal as Fonseca et al. (2017) identified in their study about the influence of the heat input on the microstructure in welded stainless steel joints of AISI 304. The hardness of the MB as received was around 210 HV for AISI 304 steel, while the hardness for AISI 316 is around 200 HV. In contrast, Srinivasan and Balasubramanian (2011), who also studied AISI 316 joints, however by the GMAW process, found a tendency for HAZ hardness to increase in relation to WM and BM. While Meshram, et al. (2014) did not find any significant difference in hardness values for BM, HAZ and WM and the hardness value found for BM as received was 190 HV. In addition, Fonseca et al. (2017), in agreement with the results obtained in the present work, also verified that the extension of the HAZ has a direct relation with the thermal input. The results showed that the HAZ in both cases is small due to little microstructure change in this region (when it is compared to plain carbon steel). However, for the percentage of ferrite, these authors found an inversely proportional relationship with the heat input for AISI 304, unlike the results found here for AISI 316 steel and other studies mentioned before.

Table 3 - Microhardness by location, Specimen 1 (heat input: 1.105 kJ/mm).

Specimen 1					
Location	BM	HAZ	WM	HAZ	BM
Microhardness	193±9	177.7±1.9	199.4±6.9	189.1±3.2	197.4±8.6

Table 4 - Microhardness by location, Specimen 2 (1.346 kJ/mm).

Specimen 2					
Location	BM	HAZ	WM	HAZ	BM
Microhardness	170±3.8	185.3±5.3	193.6±8.5	194.7±4.5	191.4±3.6

Table 5 - Microhardness by location, Specimen 3 (1.55 kJ/mm).

Specimen 3					
Location	BM	HAZ	WM	HAZ	BM
Microhardness	208.4±8.2	186.2±0	183.1±12.3	172.7±12.3	199.9±3

Zumelzu et al. (1998) studied the influence of microstructure on the mechanical properties of welded joints of 316L steel with 3 different types of filler metal by SMAW and GMAW processes. They found that for the AWS E 308 L-16 and AWS E 316 L-16 electrodes the hardness tended to increase with increasing ferrite percentage, while for the AWS ER 316 L electrode the ferrite percentage was approximately constant. In addition, the percentage of ferrite and the tensile strength were directly proportional to the heat input for the AWS E 308 L-16 electrode, while for the AWS E 316 L-16 electrode this ratio was inversely proportional. The present work also verified a tendency of hardness increase when the ferrite percentage is higher with the use of increasing heat inputs, as previously explained. Srinivasan and Balasubramanian (2011) also verified the tendency of hardness increase with the increase of heat input.

4. CONCLUSIONS

The main objective of this work was to evaluate the influence of welding energy on the microhardness and metallographic characterization of a similar joint of AISI 316 stainless steel, using different welding current levels by the SMAW process, allowing the following conclusions:

- There was no significant influence of the different levels of heat input on microhardness measurements in any of the three specimens, thus concluding that the microhardness of AISI 316 steel is little changed by this welding parameter.
- The different heat input values greatly influenced the macroscopic profile of the joint. The specimen that had a low current, and thus a low heat input, presented lack of penetration and lack of fusion mainly. The specimen with the highest welding energy showed no welding defects, and had its zones perfectly identified.
- Grain size did not seem to be affected by the applied heat inputs. The size of the HAZ was directly influenced by the heat input, being the one with the largest extension that received the largest one. However, the HAZ was small in all cases, if compared to plain carbon steels.
- The phase transformation that occurs in the WM is type AF (austenite-ferrite) solidification, the higher heat input resulted in a higher percentage of ferrite in the WM, due to its permanence at temperatures above the critical transformation temperature.

5. ACKNOWLEDGEMENTS

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