MECHANICAL PROPERTIES OF STAINLESS STEEL WELD JOINTS USING PULSED ARC TUBULAR WIRE

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Abstract.

It was developed a welding condition for AISI304 stainless steel sheets with an AWS E316LT1-4 tubular wire using constant voltage source (CV) and pulsed arc. It was analyzed the influence of the welding parameters on the mechanical properties, such as tensile strength and Vickers microhardness.
Based on the optimized condition, the influence of the heat input (H) in the tensile strength and microhardness profiles of the molten zone and heat affected zone was evaluated.
Due to the results obtained, the best welding parameters adjustment condition was established, and the optimized condition provided the highest tensile strength. Microhardness analyzes profiles did not show considerable variations, when submitted to different levels of heat input.
However, there were gains related to the ease of deposition through the control of the heat input, especially if these parameters are resized for the welding out of position; as well as to the increase of deposition rate, because for the same heat input, is necessary higher speeds wire.

Keywords: flux cored arc welding, pulsed arc, stainless steel, mechanical proprieties.

1. INTRODUCTION

Due to the increasing use of the tubular wire (FCAW) welding process, associated to its characteristics of high deposition rate, high efficiency and adequate mechanical properties of the welded joint, this process has been widely studied (Arun et al., 2019; Oliveira et al., 2005), because of the ease of application in the field (Oliveira, 2005).

Industries are concerned in obtaining welding procedures combining versatility, productivity and quality, related to reduced costs in their operations, in order to guarantee the greater competitiveness in a fierce competition sector.

Among the options for welding, the tubular wire process (FCAW) has been growing in use due some peculiarities, such as ease field application (Oliveira, 2005; Starling and Modenesi, 2006; Dias, 2009; Marques, 2005).

This process allows high quality weld bead and good visual appearance. It can be used in all welding positions through adjusting the operating parameters. It also presents a high productivity, due to its high deposition rate and low spatter index, providing high deposit yield (Lima and Ferraresi, 2006).

Problems with materials concerning to welding are many and difficult to solve. This applies particularly to the welding of stainless steels and high temperature resistant alloys, for example, high nickel alloys. This weldment should not only have adequate physical and mechanical properties, but must be compatible to base metals concerning corrosion resistance and high temperature properties.

By using a curve for the GMAW-P process, the current oscillates between two levels, a low (base current) and a high (peak current); so the resulting average current is less than the transition current (current where there is a change in globular / spray transfer).

The operational difficulty using this curve type is setting the pulsed parameters leading to a higher quality level of welding, normally this is done by trial and error. Therefore, despite the evident advantages, it is still a little-known process and consequently accepted in Brazil, its operational limits not well defined yet.

Some studies have been published in the literature regarding the adjustment of the parameters regarding to a greater stability of the process.

Flux Cored Arc Weldments can experience inferior notch toughness, both room temperature and sub-zero temperature owing to the prominent amount of secondary austenite and precipitation of intermetallic phases compared to the other process (Arun et al., 2019).

2. EXPERIMENTAL METODOLOGY

In order to optimize the parameters it was used statistical technique of projects and analysis of experiments (DOE) (Walpole et al., 2013; Montgomery and Runger, 2003); using in the first phase the fractional factorial design and in a second phase these parameters were optimized by analyzing their influences, as a function of the heat input (H) in the tensile strength and microhardness. Therefore, the mechanical resistance of selected specimens was determined.

The welds were made in butt joints (Fig. 1) with a V groove (chamfer = 30°), using heat input (H) of 450.4; 549.7 and 650.7 J/mm (some values of H are not integers due to the difficulty of adjusting values with a decimal point of welding speed in cutting machine). Table 1 shows the chemical composition of Addition Metal and Base Metal. The welds were performed with protection by argon at the root (backing), in order to avoid contamination of the weld and minimize discontinuities and defects. The mechanism was composed of a box and copper tube and an aluminum plate (Fig. 2), these materials were chosen due to high thermal diffusivity, not fusing them in the region near the electric arc, which has been proven by tests.

The specimens were punched through the TIG process by ER316L rods and clamped through 4 fastening devices ("clamps").

Table 1 – Base metal and filler metal chemical compositions

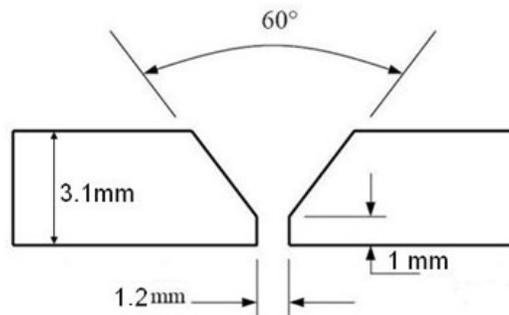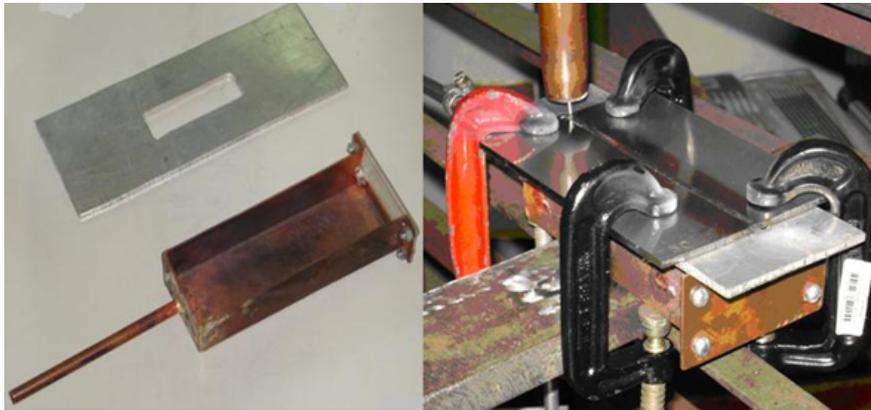|	C %	Si %	Mn %	Cr %	Ni %	Mo%	S %	P %	Ti %	Cr_{eq}	Ni_{eq}
AWS316LT1	0.03	1.00	1.58	18.50	12.4	2.46	-	-	1.00	22.46	14.09
AISI 304	0.08	1.00	0.045	18.0-20.0	8.0-10.5	-	0.03	0.045	-	20.50	11.67

Figure 1 – Joint dimensions.

Figure 2 – Backing gases.

2.1 Tensile Testing

The specimens were cut, machined and underwent tensile testing according to ASTM E8 / E 8M-08 (Standard Test Methods for Tension Testing of Metallic Materials). An Emic DL 3000 Machine was used in the Destructive and Non Destructive Testing Laboratory of the Mechanical Engineering Department of UNIFEI. Discarded the start and end of weld, the metallographic analysis was performed in part M of Fig. 3 (a).
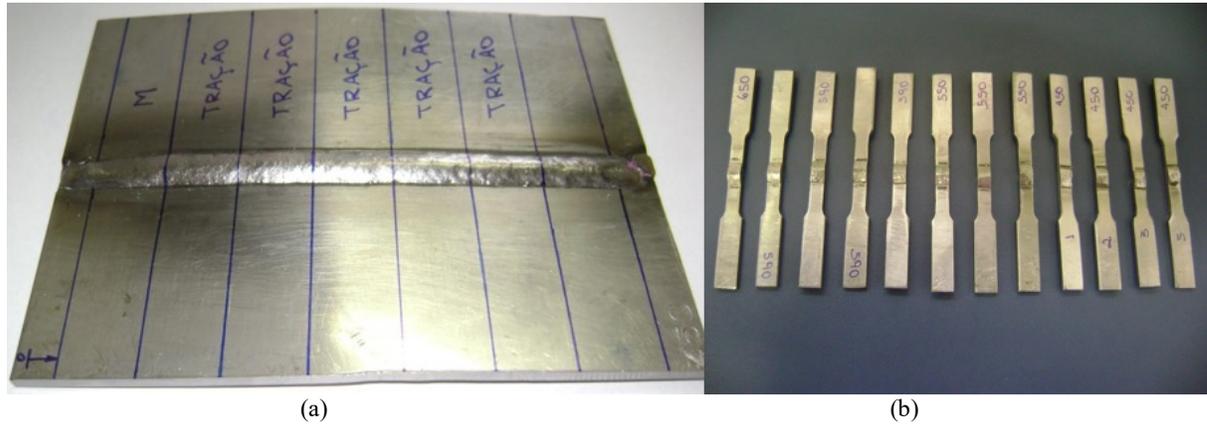

(a)   (b)

Figure 3 – Tensile test specimens. (a) Before cutting, (b) After cutting.

The tensile test of the specimens welded with H = 450.4 J/mm is shown in Tab. 2 and Fig. 5. It was observed that the best condition was obtained for CP1, with maximum rupture strength of 1236.02 kgf and maximum tension of 651.68 MPa. The specimens 2 and 3 had little deformation due to the lack of fusion in nose chamfer, and the specimens 4 and 5 had little deformation due to lack of penetration (Fig. 4), reducing the limit of tensile strength.

This behavior was created by the base metal thermal expansion, causing a chamfer closure and blocking weld penetration, even after applying tack welds and fastening devices (Fig. 2 and Fig. 4).
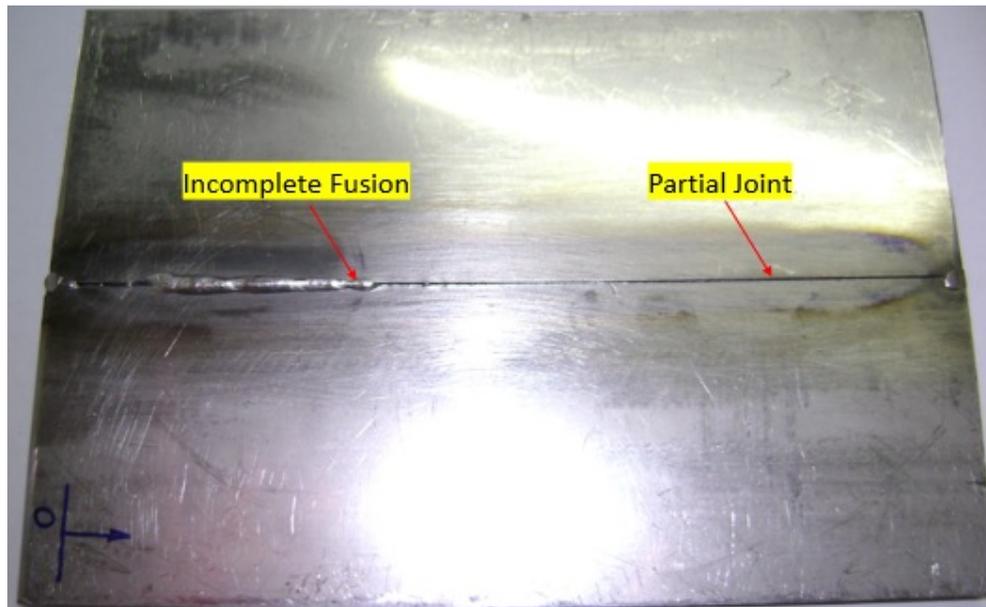

Figure 4 – Defects and discontinuity in specimen welded in H = 450,4 J/mm condition.

Consequently, the specimens 4 and 5 (Fig. 5), 5 (Fig. 6) and 2, 3, 4 and 5 (Fig. 7) have their destructive testing data omitted, because the same issue had occurred for this heat input conditions.

Table 2 – Tensile test results for H = 450,4 J/mm condition.

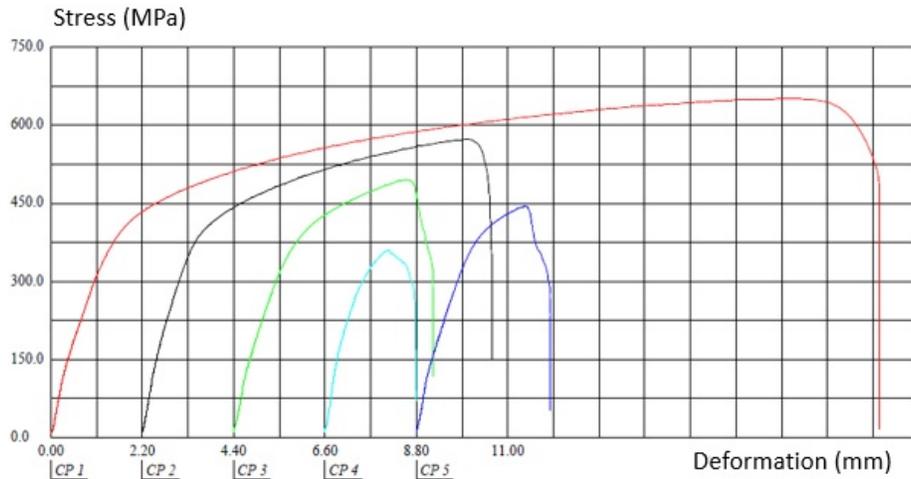| CP	Width	Full Force	Breaking Force	Maximun Tension	Tensile Strenght	Tension Leakage	Tensile Module
	mm	kgf	kgf	MPa	MPa	MPa	MPa
1	6	1236.02	937.68	651.68	494.38	10.16	9837.44
2	6	1088.53	688.50	573.91	363.00	39.31	11641.59
3	6	941.03	582.77	496.14	307.26	42.41	10615.54
4	6	683.3	491.48	360.31	259.13	39.19	13283.47
5	6	842.70	540.83	444.30	285.14	44.46	11231.89

Figure 5 – Stress-strain curves of welded specimens for H = 450.4 J/mm condition.

Then, it is essential ensuring a strong clamping to avoid specimen warpage and rotation, possible cause of the lack of penetration in H = 450.4; 590 and 650.7 J/mm conditions (Fig. 5, 6 and 7).

The tensile test data for specimens welded with H = 590 J/mm is presented in Table 3 and in Figure 6. Considering mechanical resistance, it is clear that the prime condition is achieved for CP4 (full force of 1276.73 kgf and a maximum tension of 673.14 MPa);
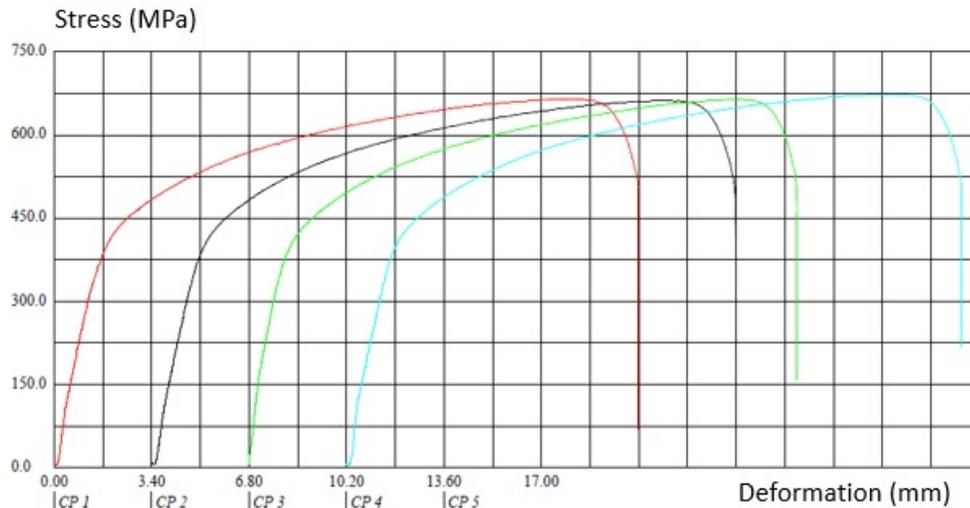

Figure 6 – Stress-strain curves of welded specimens for H = 590 J/mm condition.

Table 3 – Tensile test results for H = 590 J/mm condition.

CP	Width	Full Force	Breaking Force	Maximun Tension	Tensile Strenght	Tension Leakage	Tensile Module
	mm	kgf	kgf	MPa	MPa	MPa	MPa
1	6	1261.93	968.17	665.34	510.45	5.48	5283.58
2	6	1257.35	951.42	662.92	501.63	7.66	4777.08
3	6	1260.69	950.01	664.69	500.88	35.24	12524.11
4	6	1276.73	973.80	673.14	513.43	5.85	5215.15
Average	6	1264	960.9	666.5	506.6	13.56	6950

Tensile test data for H = 650.7 J/mm condition is presented in Table 4 and in Fig. 7, showing a full force of 1262.28 kgf and a 665.52 MPa maximum tension.

Table 4 – Tensile test results for H = 650.7 J/mm condition.

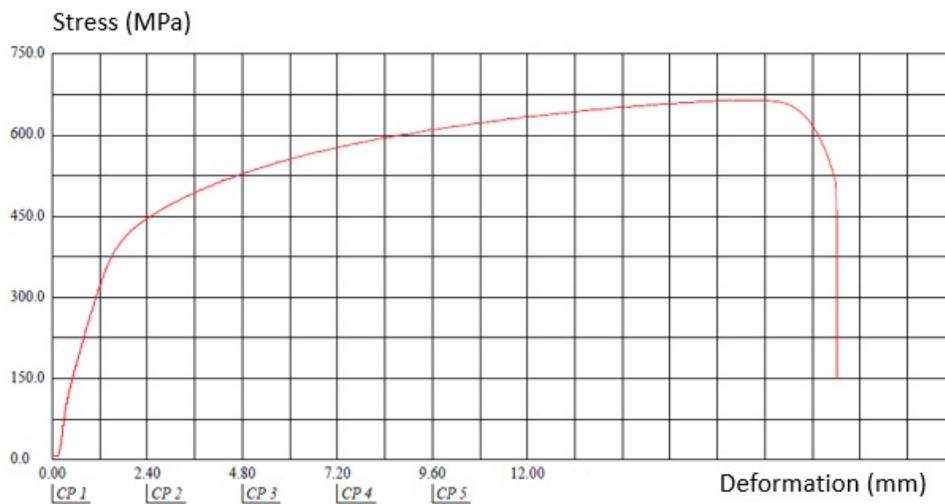| CP	Width	Full Force	Breaking Force	Maximun Tension	Tensile Strenght	Tension Leakage	Tensile Module
	mm	kgf	kgf	MPa	MPa	MPa	MPa
1	6	1262.28	968.69	665.52	510.73	7.71	4937.61

Figure 7 – Stress-strain curve of welded specimen for H = 650.7 J/mm condition

Increasing alloying element contents makes tensile strength more susceptible to heat input fluctuations (Vercesi & Surian, 1996), proved by increased tensile strength between 549.7 J/mm a 590 J/mm. In such manner, cooling must proceed carefully at the time of welding, following very strict parameters.

Regardless of the applied energy, necking and further rupture do not occurred in the fusion zone, HAZ or base metal – exceptions include 2, 3, 4, and 5 specimens in Fig. 5, in which lack of fusion and penetration caused ductile and brittle fractures in tensile tests as shown in Fig. 8.
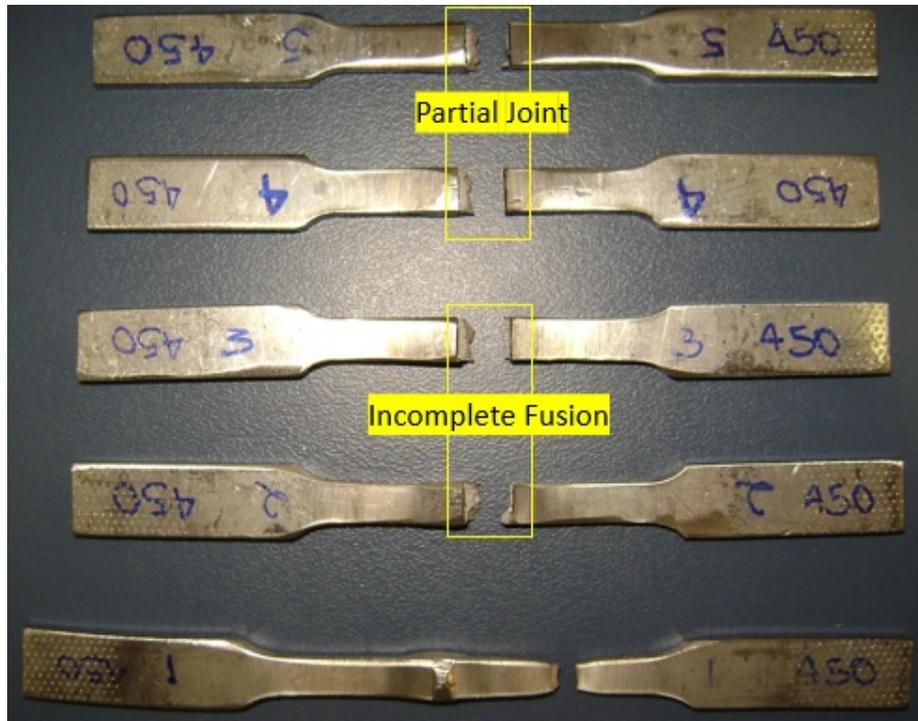
Figure 8 – Fractures in specimens 2, 3, 4, and 5 for H = 450.4 J/mm condition.

2.2 Hardness Vickers Tester

For welding deposition its micro-hardness profile was defined for 450.4 J/mm (Fig. 9) and 650.7 J/mm (Fig. 10) welding energies and 39.3 e 27.2 cm/min welding speeds, respectively. Brittle phases were not created at these temperatures, condition which is commonly found in austenitic steels.

The average Vickers micro-hardness for the lowest energy condition was HVx = 204.1 HV (varying from a minimum 174.1 HV to a maximum 218.0 HV). In addition, another 5 measures were taken in the fusion zone, indicating an average 196.9 HV. Although micro-hardness does not vary significantly, a tendency for a higher hardness in the HAZ is revealed when compared to the fusion zone, a common feature of welded materials, particularly considering harsher metallographic modification in the HAZ, between (-11) and (-5), and (3) and (5) in Figure 9.
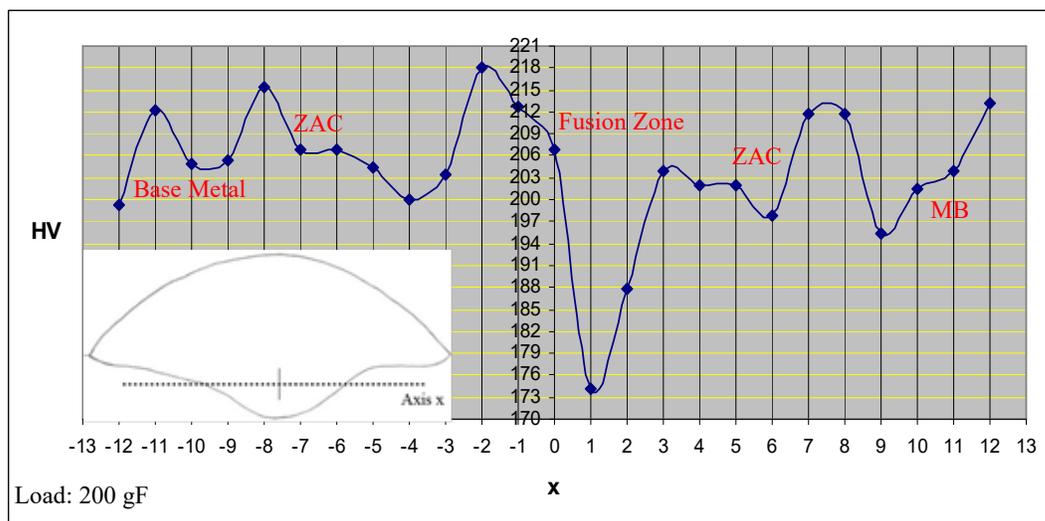

Figure 9 – Vickers micro-hardness profile for H = 450.4 J/mm condition

The average Vickers micro-hardness for the highest energy condition was HVx = 207.2 HV (varying from a minimum 192 HV to a maximum 237.7 HV). A higher micro-hardness value is found nearby the fusion zone, close to y axis; the lower values occur in the HAZ. This scenario differs from those aforementioned, apparently as a high heat input promotes higher activation in the fusion zone, which probably underwent more severe metallurgical modification due to the metal elements added to flow, leading to a micro-hardness increase. A wire richer in Mo and containing sparse amounts of Ni would explain this micro-hardness increase, as also described by Heisterkamp et al. (1993).
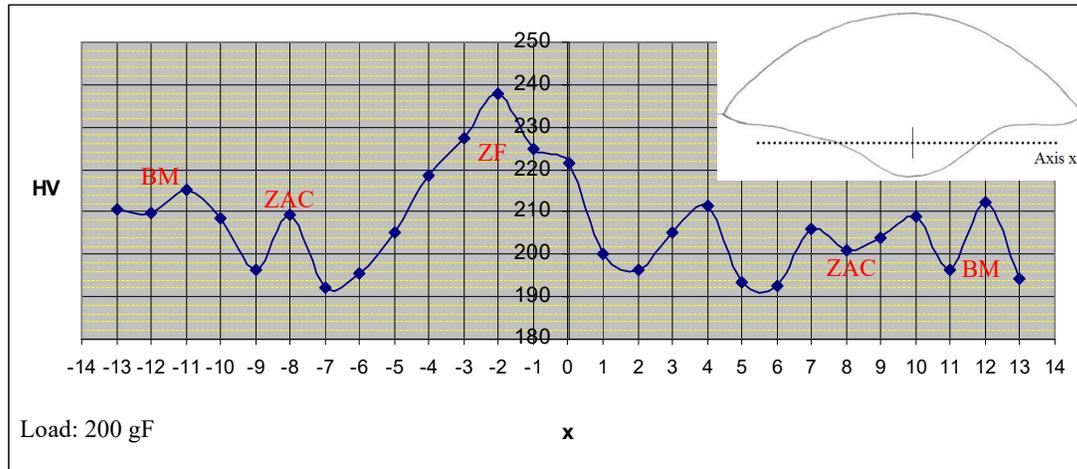

Figure 10 – Vickers micro-hardness profile for H = 650.7 J/mm and deposition welding conditions

3. CONCLUSIONS

Butt joint welding (for 3,1 mm thick) in a single pass performed in a 60° chamfer, 1.2 mm root opening and a 1.5 mm nose produced a satisfactory 30% penetration over the specimens.

However, samples larger than 70 mm in length must be held by fastening devices, which prevent them from rotating although damaging the joint penetration. Tensile strength analyzes suggest that the best weld conditions occurred in energy levels around 590 kJ/mm.

Profile microhardness analyzes performed do not revealed, in general, considerable changes in specimens over the welding heat input range. Despite that, changes emerge probably from microstructure heterogeneity created by different cooling conditions.

4. ACKNOWLEDGEMENTS

5. REFERENCES

Arun, D., Ramkumar, K. D., Vimala, R., 2019. "Multi-pass arc welding techniques of 12 mm thick Super-duplex stainless steel". *Journal of Material Process*. Accepted Manuscript.https://doi.org/10.1016/j.jmatprotec.2019.03.031

Dias, A.O., 2009. *Análise da Influência dos Parâmetros de Pulsação na Soldagem do Aço Inoxidável AISI 304 Através do Arame Tubular AWS E316LT1-4*. 116p. Dissertação (Mestrado) - Departamento de Mecânica, Universidade Federal de Itajubá, Itajubá, Brazil.

Heisterkamp, F., Hulka, K., Gray, J. M., 1993 "*Metallurgical Concept And Full-Scale Testing of High Toughness, H2S Resistant 0,03%C-0,10%Nb Steel",* Niobium Technical Report, CBMM, February, São Paulo.

Jia, C., Zhang, Y., Wu, J., Xing, C., Zhao, B., Wu, C., 2019. "Comprehensive analysis of spatter loss in wet FCAW considering interactions of bubbles, droplets and arc – Part 1: Measurement and improvement". *Journal of Material Process*. Vol. 40, pp. 122–127.

Lima, A.C., Ferraresi, V.A., 2006. "Estudo dos Modos de Transferência Metálica de um Arame Tubular Autoprotegido com Variação na Distância Bico de Contato-Peça" , *In: Congresso Nacional de Soldagem - CONSOLDA* 2006. São Paulo, Brazil, pp.164-172.

Marques, P.V. et al., 2005. *Soldagem: Fundamentos e Tecnologia*, Editora UFMG, Belo Horizonte, 2nd Edition, pp.233-231.

Montgomery, D. C., Runger, G. C., 2003. Estatística Aplicada e Probabilidade para Engenheiros. LTC Editora, Rio de Janeiro. 2nd edition.

Oliveira, L.M. Uma Investigação da Influência dos Parâmetros de Pulso em Soldagem com Eletrodo Tubular com Proteção Gasosa: 2005. 103p. Dissertação (Mestrado) - Departamento de Mecânica, Universidade Federal de Itajubá, Itajubá.

Scotti, A. "A Portrait of the Welding Research in Brazil". Soldagem & Inspeção, Vol.13, No.2, pp.160-164, 2008.

Starling, D.M.C., Modenesi, P. J. "Avaliação da Transferência de Metal de Arames Tubulares", Soldagem & Inspeção, Vol.11, No.3, pp.147-155, 2006.

Vercesi, J., Surian, E. (1996), "The Effect of Welding Parameters on High-Strength SMAW All-Weld-Metal – Part 1: AWS E11018M", *Welding Journal,* Miami, n 5, pp 191-196.

Walpole, R. E., Myers, R. H., Myers, S. L., Ye, K., 2013. Probabilidade & Estatística para engenharia e ciências. Pearson, São Paulo, 8nd edition.

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