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COMPARATIVE STUDY OF PROPERTIES IN WELDING OF A HIGH STRENGTH STEEL AND LOW ALLOY WELDED BY PROCESSES HELICAL AND CIRCUMFERENTIAL SUBMERGED ARC

JOÃO ROBERTO SARTORI MORENO[1*]; BRUNA BERBEL SELOTO[1]; JULIO CESAR DE SOUZA FRANCISCO[1]; ERENILTON PEREIRA DA SILVA[2]; HAROLDO CAVALCANTI PINTO[2]; JULIAN A. ÁVILA[3]
1 - UNIVERSIDADE TECNOLÓGICA FEDERAL DO PARANÁ; 2 - UNIVERSIDADE DE SÃO PAULO – ESCOLA DE ENGENHARIA DE SÃO CARLOS – USP; 3 - UNIVERSIDADE ESTADUAL PAULISTA – S.J. BOA VISTA, SP
joaosartori@utfpr.edu.br; brunex_bs@hotmail.com; jcesar@utfpr.edu.br; erenilton.silva@sc.usp.br; haroldo@sc.usp.br; julian.avila@sjbv.unesp.br

**Corresponding author: Joao Roberto Sartori Moreno, Universidade Tecnologica Federal Parana, Mechanical Departament; Materials Laboratory-Cornelio Procopio-PR 86300-000, Brazil. Email: joaosartori@utfpr.edu.br*

Abstract** - The high strength and low alloy steels API 5L X70 appropriately used in piping lines of the petroleum industry, was studied in this work. For this purpose, we welded tubes using arc welding submerged by the helical process and the circumferential process, where macrostructures, microstructures and hardness of the base metal (BM), heat affected zones (HAZ) and fusion metal (FM) were compared. The results showed that the process of helical welding by having multiple sequential pass causes the region of the weld root to be strongly influenced by the energy of the previous passes, causing changes that causes the acicular ferrite in the base metal with smaller grains to grow as the primary ferrite grains, changing the average microhardness in the fusion metal (FM) and heat-affected zone (HAZ) for 214 Vickers, especially in the circumferential welding process (CW) due to the formation of bainite islands in pro-eutotoid ferritic matrix , which in the helical process did not occur, because they formed austenite dendritic and martensite that imposed medium microhardness of 237 HV in the fusion metal (FM) and heat affected zone (HAZ) for the helical process (HSAW).

***Keywords:** HSAW. Circumferential Welding. Acicular Ferrite. Helical Welding. Bainite Islands.*

I. INTRODUCTION

The growing demand for pipes used in pipeline construction and major interconnections has led research to focus on lowering production costs, improving operational efficiency and improving construction materials to reduce technical risks in the pipeline and oil pipelines sector. To meet these market requirements, steel must be designed with high strength and good weldability for the best performance of the pipe, and the high strength and low alloy steel (HSLA) is meeting these specifications, mainly due to its microstructure (ROSADO *et al.* 2013).

The processing used and the manufacturing technique of these micro-alloyed steels improve the weight and the costs compared to the thermally treated materials. Therefore, its strength characteristics are linked to its chemical composition, lamination process with different thermomechanical treatments and suitable welding procedures (BILLINGHAM, *et al.* 2003).

HSLA tubes are made by seam pipe process, due to the benefit of being able to make repairs on the material without interfering with the flow of fluid inside the tube. These welds represent critical regions in relation to the rest of the material, so it is important to ensure their quality, especially for pipe line safety (NAFISI, *el al*. 2011).

After welding, due to high temperatures caused by the joining process, which is substantially affects more heat affected zone (HAZ), the fusion metal (FM), since they have different microstructures of the base metal (BM). A welding implies a discontinuity in the pipe, so these areas are considered critical parts where more detailed studies should be conducted. API 5L X70 steels have an X70 rating which translates to a minimum flow limit of 70,000 psi and a minimum tensile strength limit of 82,000 psi, which also confers the same characteristics after welding (SOHN, *et al*. 2013).

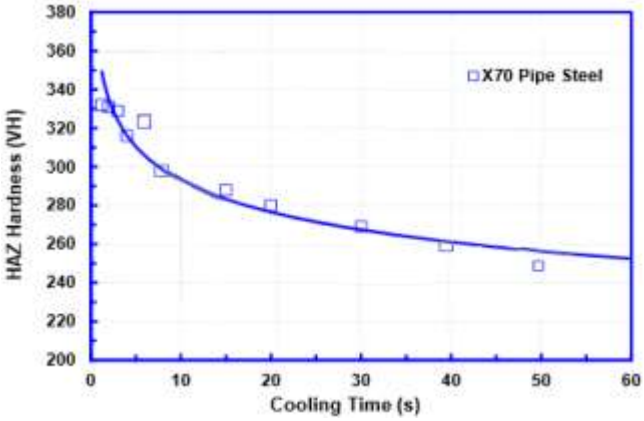
Although steel tubes HSLA be welded using the circumferential welding process (CW) with half notch V, the helical welding submerged arc (HSAW) currently requires a double notch V and the steel pipes are produced by automated machines able The production of helically welded tubes using the submerged arc process is based on the technique of joint welding of inner and outer coil edges that have been cut and adjusted by milling to a high quality weld structure. Hot rolled steel coils take a spiral shape after passing through rollers to achieve excellent outer solder quality at high welding speeds and double submerged arc.

Despite the attempt to seek the same characteristics, the base material (BM), the fusion metal (FM) and the heat affected zone (HAZ) invariably present microstructural changes due to high temperatures imposed by the welding process fusion and the cooling as shown in Figure 1.

Studies have demonstrated the importance of helical welding steels of this type, which leads to better results for yield strength and hardness. Helical submerged arc welding is generally the preferred method of joining the edges of seam large diameter pipes but can cause residual stresses in the welding process (FOROUZAN, *et al*. 2012).

Thus, the present study aims to examine the different metallurgical characteristics such as microstructure and hardness profile for CW and HSAW welding processes.

Figure 1 - Micro hardness of the HAZ in time cooling function



Source: MURANSKY, 2012.

II. PROCEDURES

In this work we use API X 70 steels, and Table 1 shows the chemical composition according to the ANSI/API, 2009 standard of the steel used for the production of tubes welded by the submerged arc helical process (HSAW) and the circumferential process (CW).

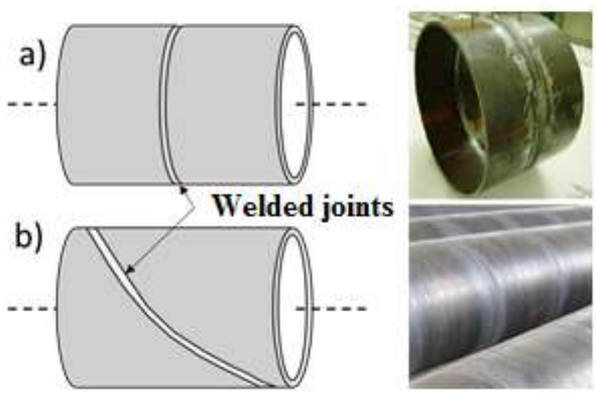
Table 1 - Chemical composition and thickness of API 5L X70 steels used in helical (HSAW) and circumferential (CW) to submerged arc welding

Procedure Welding	Plate Thicknes (mm)	C_{max}	Mn_{max}	P_{max}	S_{max}
HSAW	12	0.26	1.65	0.03	0.03
CW	14	0.22	1.85	0.025	0.01

In the circumferential welding (CW), specimens with a single V-groove were used, and double notched V for helical welding (HSAW) with welding made by ESAB consumable electrodes, both ASME SFA 5.5 E8010-G (0 ,07% C, 0.13% Si, 0.60% Mn, 0.70% Ni and 0.30% Mo).

Some schematic views of the performed welds are shown in Figure 2.

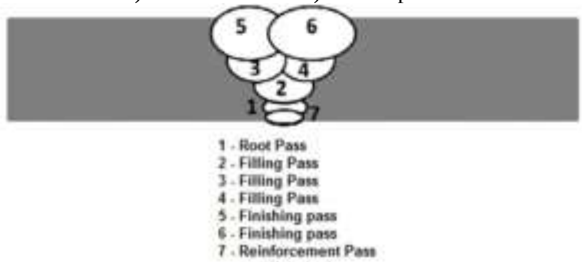
Figure 2 - Schematic and illustrative photos of welded joints: a) circumferentially (CW); b) helically (HSAW).



Source: author.

On the other hand, in Figure 3, we show all welding parameters and procedures to perform the helical and circumferential weld passes, as well as notch, electrode, position and gas shield dimensions (NARAYANAN, *et al*. 2007).

Figure 3 - Schematic passes distribution and welding parameters: a) circumferential b) helical process



Parameters					
	Diameter (mm)	Current (A)	Voltage (V)	Welding Speed (mm/s)	Thermal Input (kJ/ m)
Root (1)	2.00	77	29	1.45	1.23
Filling (2)(3) (4)	3.25	90	40	1.50	1.92
Finishing (5) (6)	3.25	90	40	1.50	1.92
Reinforcement (7)	3.25	90	40	1.50	1.92

Source: Author.

The cross-sectional samples of these welded tubes were removed, machined and polished for the metallographic study, whose attack was done in Nital 4% to obtain the macrographs of the cross sections and 2% to reveal the microstructures of the base metal (MB), heat affected zone (HAZ) and fusion metal (MF).

The metallographic analyzes were performed in a digital optical microscope, model DINO-LITE-AM-413TPRO, for each sample the grain structure formed in the regions of interest and their micro constituents were observed.

The microhardness measurements were performed with a Vickers scale, with load of 500 g, distance of 0.25 mm between the indentations.

The profiles of these data were established to compare their behavior along the cross section, specifically in the heat affected zone (HAZ) and fusion metal (FM) (ASTM E 384-73).

III. RESULTS AND DISCUSSION

3.1 - Macrographs

Figure 4 shows the cross-sections of the macrographs of the circumferential-welded (CW) and spiral-welded pipes macrographs.

Three different microstructural regions were identified, base metal (BM), heat affected zone (HAZ) and the fusion metal (FM) with the boundaries shown with dashed blue lines.

However, in both cross-sections, we can observed the relief of the applied pass, with the horizontal dashed red lines show the positions of the hardness profile.

However, the Helical Submerged Arc Welding (HSAW) presented a more uniform HAZ than the circumferential-welded (CW), due to the less number of passes and therefore less heat affectation.

On the other hand, the columnar dendritic zone produced in the cast region, is also observed over HSAW that usually appears in castings process.

The HAZ of circumferential welding was larger at the root section than the cap region, because the heat accumulation by following passes (upper layers).

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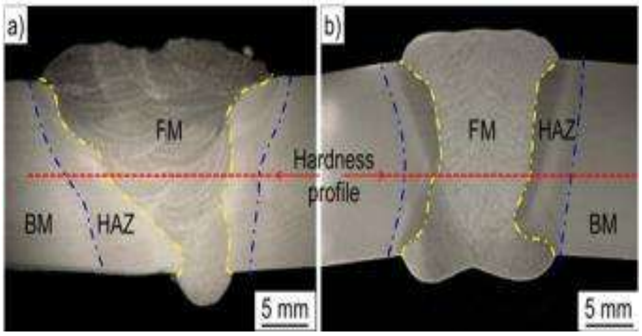
Figure 4 - Cross-sections of the macrographs of the a) circumferential-welded (CW); b) spiral-welded pipes (HSAW)



Source: Author

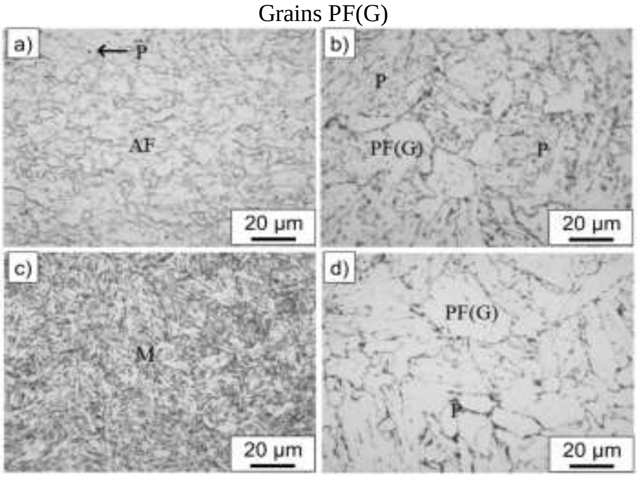
3.2 - Micrographs

The microstructures of samples welded by HSAW (Helical Submerged Arc Welding) and CW (Circumferential Welding) were characterized by the presence of perlite (P), martensite (M), dendritic austenite (AD), acicular ferrite (FA), primary ferrite with coarse grain boundaries (PF(G)) and intergranular polygonal ferrite (PF(I)), as reported for similar steels (WEI et. al. 2011).

In view of this, the Figure 5 and 6 shows the microstructures of these two HSAW and CW processes, respectively, observing that both microstructures constitute base metal composed basically of acicular ferrite (AF) and some small, scattered content of perlite (P) (STONE et al. 2008).

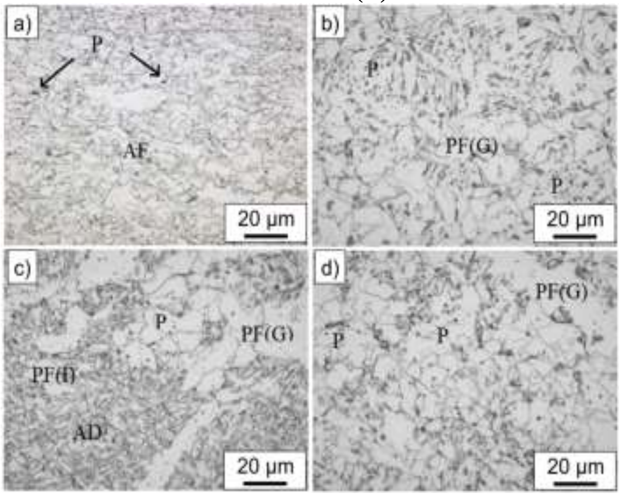
Therefore in this studied microstructure, was possible to observe that in the pearlite matrix has been dominated by the ferrite transformation throughout the HAZ, which has primary ferrite coarse grain boundaries. In the filler metal where found martensitic islands with higher bainite, solubilized perlite, and in the weld root were observed predominantly ferrite in a perlite matrix with coarse grain boundaries [11]. The weld filler microstructure consist of refined upper bainite randomly embedded in the polygonal fine-grained ferrite matrix.

Figure 5 - Microstructure of Helical Submerged Arc Welding: a) Base Metal b) Heat Affected Zone; c) Filling Welding with Martensite; d) Root Welding with Primary Ferrite with Coarse Grains PF(G)



Source: Author

Figura 7 - Microstructure of Circumferential Submerged Arc Welding: a) Base Metal b) Heat Affected Zone c) Filling Welding with Austenite Dendritic d) Welding by Root with Primary Ferrite Coarse PF(G)



Source: Author

It is known that microstructural changes in welding are mainly affected by the welding parameters, for example: welding current of 230 amps, welding speed of 32 cm/min and arc voltage of 26 volts and subsequent cooling (HASHEMI et al. 2012). However, in the Figure 6 that refers to the Circumferential Submerged Arc Welding process, we did not verify the presence of martensite, but was detected austenite dendritic in the weld metal zone.

3.3 – Microhardness

With the delimitation of the BM, HAZ and FM regions, a Vickers microhardness profile was determined applying 500 g of load in each parallel region and for each CW and HSAW welding process. Hardness profiles measured from 0.25/0.50 at 0.25/0.50 are also shown for both cases. The average values of microhardness found in both the melt metal (FM) and the thermally affected zone (HAZ) are high due to the presence of upper bainite island in the fusion metal and martensite (NANNINGA, *et al*. 2010; LEE, *et al*. 2011).

Figure 7 shows that in the Circumferential Welding (CW), the microhardness distribution was different, because in the ZTA the values isolated were high due to the interpass heating, which affects the local near the base metal, which generates a quenching effect, resulting in larger grain sizes and hardness higher than the average of 215 HV [15-16].

On the other hand in the fusion metal, the microhardness fell and showed up to below the average of 215 HV.

However, in Figure 8 we observed the data for the helical submerged arc welding (HSAW) process, and we have that in the HAZ the microhardness was higher, 237 HV, than the base metal in most of the profile, since points of lower hardness, which are assigned to the type of process and the amount and type of micro-alloying elements.

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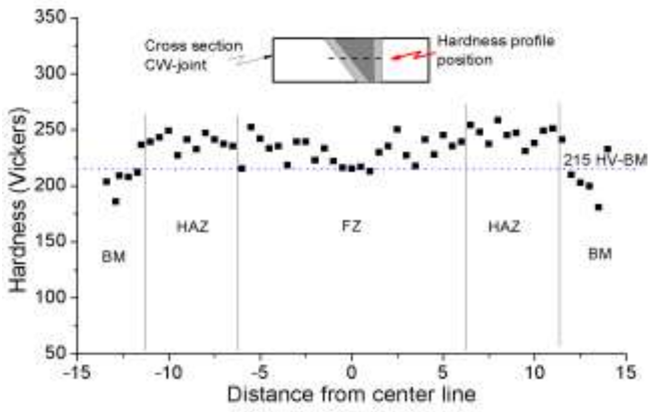
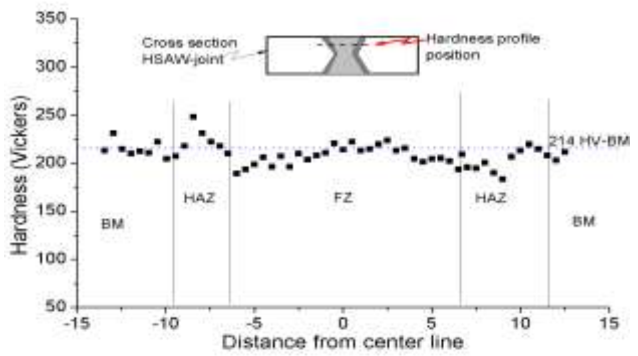
Figure 7 - Profile of microhardness in the regions: BM, HAZ and FM for the Circumferential Welding Process



Source: Author.

Figure 8 - Profile of microhardness in the regions: BMB, HAZ and FM for the Helical Process



Source: Author.

IV. CONCLUSION

The micro-hardness and texture profile differences between the two welding processes, Helical Submerged arc welding (HSAW) and circumferential welding (CW)

were evaluated and it was verified that the average microhardness of the welded cords in the HSAW process presented 9 % greater than the average of micro hardness of strands welded by the CW process mainly due to the formation of bainite and martensite.

However, these variations are performed not only by changing welding parameters for each process, but by the composition of common metals that have differences in carbon and manganese content. This can be explained by the presence of martensite and upper bainite islands in perlite matrix in the presence of coarse ones, responsible for the greater hardness recorded in the HSAW process.

Therefore, the variation of microstructure and hardness in several sub-zones of helical submerged arc welding (HSAW) showed a high level of hardness 279 HV in the melt (MF), but decreasing to 245HV in the thermally affected zone (ZTA) due to the transformation of the acicular ferrite present in the base metal. Finally, the predominant microstructure in the filler metal of the HSAW process was Widmanstatten pro-eutectoid ferrite, which led to a slight increase in hardness from an average value of 215 HV to 310 HV observed in the melt metal for the HSAW process, which can be attributed to high temperature processing.

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