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PERFORMANCE OF THE MIG / MAG - CCC (CONTROLLED SHORT CIRCUITING) VERSION IN THE ROOT WELDING IN PIPES WITH MECHANIZED SYSTEM

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Abstract

Welding plays a key role in the energy sector for the construction of pipelines used in the transport of oil, natural gas and biofuels. Most welding applications destined to Brazilian constructions bring little technological intervention, which would in fact add more productive value and better quality indices. Given this scenario and as an attempt to change this paradigm, the present work presents an approach that aims at the implementation of a technology developed nationally and envisaged for pipe root welding, entitled Controlled Short Circuiting (CCC). The performance of the CCC version was verified in the root welding of different pipes with varied diameters and wall thicknesses. All the trials for validation of procedures were performed with orbital mechanized system in API 5L X 70 and API 5L grade B pipes, with "U" groove profile, without the use of weld pool backing. These tests were simulated in situations similar to those found in the field in the construction of pipelines. The results obtained showed the reliability of the system as a whole, which performed root pass welds with great robustness, quality and repeatability, meeting specific standards requirements for this segment.

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1. Introduction

Whether for Onshore or Offshore applications, welding is the main manufacturing process used in the construction of pipelines. Among the challenges is the welding of the root pass, which is considered to be the most difficult due to operational requirements during the preparation of the joints and the execution of the weld, in addition to the conditions that will be submitted in service.

The MIG / MAG process, in its short-circuiting versions with current control, has been increasingly gaining application and relevance in global terms for the root welding operation. These versions, due to the metallic transfer control characteristic, are more suitable for the application when compared with other welding processes or even with the conventional short-circuit MIG/MAG version. The conventional MIG/MAG welding process does not act directly on the current, which is the determining variable in welding. The indirect actuation restricts certain objectives, making it difficult to control the root pass at the bottom of the groove, due to the variation of the average current that occurs when the torch moves itself weaving into the joint or also when there is variation of the contact tip to work distance (CTWD) [1].

Another challenge in root welding is the use of mechanized systems, which requires a higher degree of precision in the machining and assembly of the joints due to the dimensional and geometric imperfections caused during the manufacture of the pipes. On the other hand, the use of mechanized systems tends to generate procedures with higher quality and repeatability in the application compared to manual welding, combined with the fact of generating higher productivity. Several reports in magazines, however, point mechanized welding as the main means applied to this welding process, with surprising results and emphasizing productivity with the reduction of welding time [2] [3] [4]. The shortage of skilled welding professionals on the market today [5] makes global branch companies to invest in these systems.

Envisioning the potential of the competitiveness improvement of the Brazilian energy sector, especially regarding to the exploration, production and transportation of oil, natural gas and biofuels, and the lack of modernization of welding processes in this sector, LABSOLDA, the Welding and Mechatronics Institute of the Federal University of Santa Catarina, has been acting over the years in the research and development of systems for mechanized orbital welding in pipes. The institute has sought the constant improvement of the robotic manipulators developed for this application, as well as acting in the development of arc welding technologies, such as CCC (Short Circuiting Control), and its procedures. The CCC technology, in this work, aimed at the realization of its application to root passes in tubes, without the use of backing to support the metallic pool.

2. Welding Technology with Current Control - CCC - for Root in Pipes

In the mechanized operations for the root welding in pipes with MIG/MAG processes, there is the possibility of the procedure being performed with or without backing to support the weld pool. The most common, when using the backing, is that it is made by copper adapted in internal line-up clamp. However, the use of backings manufactured with copper can generate contamination in the weld metal **[6]**, which would lead to cause embrittlement of the base metal and also loss of mechanical properties **[7]**.

Not opting for the use of the backing, welding becomes more difficult to be carried out due to being in a situation of balance between the lack of penetration and the perforation in the joint. Therefore, all the variations of current originated along the welding path in the pipe cause changes in temperature and, consequently, in the fluidity of the material [8], which negatively influence the equilibrium situation of the weld pool.

Some authors praise the advantages in field applications with the use of MIG/MAG short-circuiting versions with current control **[9] [3] [10] [11]**. To understand the reason or why these versions with current control offer great advantages, it is necessary to understand the basis of its operation. From the formation of the droplet to its transfer by short circuit, several physical phenomena happen. For this type of metallic transfer, current waveforms are modulated so as to obtain an adequate dimensioning of the transferred drops **[12]**, in addition to the fact of the minimization of their repulsive effects and the excess of spatters, commonly observed in operations with conventional MIG/MAG.

The force called the surface tension is the most pronounced when it comes to short-circuit metallic transfer with current control. This force acts in order to reduce to the minimum free surface energy **[13]**. In the case of MIG/MAG welding, the force of the surface tension acts primarily to retain the metallic drop to the electrode, tending to form a spherical shape. However, when the short circuit occurs, the surface tension acts in the opposite direction, pulling the drop towards the weld pool **[14]**.

CCC is a technology developed in LABSOLDA and has been researched and improved a few years ago in several works, by different researchers **[15] [16] [8] [17]**. The technology has the form of fully electronic current control, with high dynamics in order to carry out the detachment of the drop smoothly, with low spatters rate and minimum variations of the average current throughout the process. **Erro! Fonte de referência não encontrada.** shows the detailed sequence of the CCC version, from the fully formed drop, the initial contact of the drop with the weld pool, the formation of the metal bridge to its rupture, the reopening of the arc and, finally, the formation of a new drop giving continuity to the cycle.

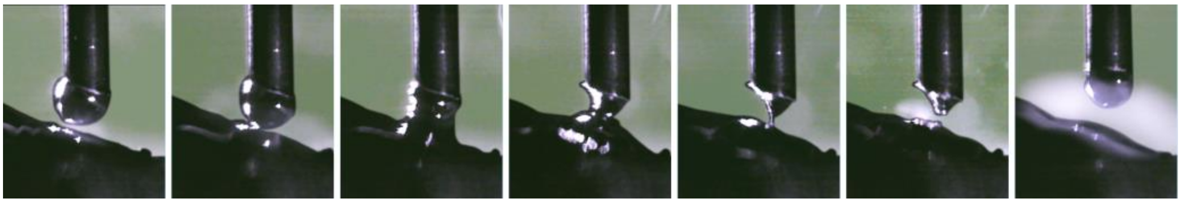


Figure 1. Sequence of the CCC cycle with real images of the metallic transfer

3. Materials, Equipment and Methodology

For the trials carried out in order to evaluate the performance of the CCC version in situations similar to those found in the field, API 5L grade B and API 5L X 70 carbon steel pipes, with different diameters and wall thickness, were welded. The "U" groove was adopted as the best solution in terms of the mechanization of the root procedure, considering that the author of this work had already done research in which he used the "V" groove and found numerous difficulties for the procedure **[18]**. The electrode wire assigned was the ER 70S-6 with 1.2 mm diameter and the binary mixture C25 (75% Argon, 25% CO_2) as protection gas.

The mechanized system that was applied to the research is also a development of LABSOLDA called Tartílope V4. It is a cartesian robotic manipulator that moves itself on a rail attached to the pipe. The welding torch is adapted to the manipulator, which produces continuous and repetitive movements according to the regulated variable settings. The welding source, Digiplus A7 from the manufacturer IMC Welding, which holds the CCC technology, was used in all the trials that will be presented in this work.

For mechanized orbital welding, due to the difficulties of the development of the whole procedure, several welding variables must be adjusted in order to find the equilibrium point between the metallic transfer and the consequent formation of the weld pool with the movement of the system. This balance is achieved by parameterizing the welding source electrical variables with the mechanized system moving variables. For this stage of the research, the values used in previous work with "V" groove were adopted as initial values **[18]**. Nevertheless, it was seen the need for minor adjustments, especially regarding to the movement variables of the mechanized system.

In order to simulate the conditions found in the field with the highest possible realism, including with regard to the relief conditions, there were variations of pipe positioning. Welded pipes of smaller diameter, 16 inch and ½ inch wall thickness; 18 inch and 7/16 inch thickness were welded at position 5G 0°, position in which the pipe is horizontal in relation to the ground. However, the pipe of greater diameter, 22 inch and 1 ¼ inch wall thickness, was welded in position 5G with a slope of 20° relative to the ground. An important and very common issue found in field welding applications is the misalignment between the tubes in the joint assembly, known as high-low. In some of the trials carried out, misalignments are purposely attributed in order to verify the robustness of the welding procedure. One of the most common standards in this area is API 1104 **[19]**, which indicates a limit value for the high-low condition of 3 mm.

Figure 2 shows all the apparatus used in the trials, such as pipe welding clamping workbench, welding source, robotic manipulator and the detail of the "U" groove in a 22 inch pipe.

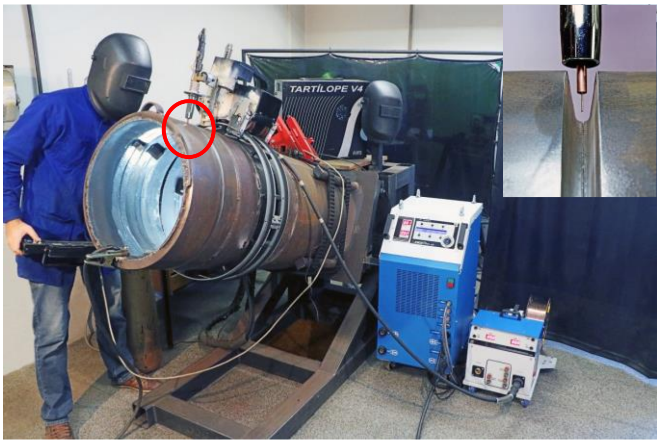


Figure 2. Test bench for orbital welding

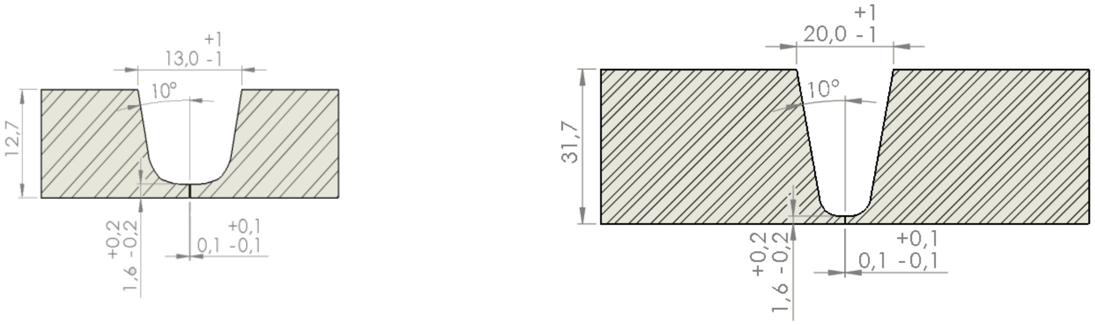
4. Results and Discussions

Welding of mechanized orbital root brings numerous challenges, especially when one chooses not to use the backing to support the weld pool. In the initial trials, it was verified the need to adjust the welding variables and also the dimensions of the groove, in order to avoid defects such as lack of fusion in the root or its perforation, as shown in Figure 3.

a) b)

Figure 3. a) Lack of fusion at the root, overhead position-5h; b) Root perforation, overhead position-5h

The groove adopted as standard is shown in Figure 4 with the admissible values and tolerances. One of the facilities found in the use of this type of groove is in the joint assembly, so that the two pipes can be abutted without the need to leave any root opening. In other types of groove, such as the "V" groove, these root opening variations are extremely critical to the mechanized system because of the need for adjustments that the welder must perform to compensate them.



a) b)

Figure 4. Adopted "U" groove - a) ½ inch pipes; b) 1 ¼ inch pipes

The values of the welding variables used in all the validated trials are presented in Table 1. A welding procedure to be used in mechanized systems must be very well defined, so that it is robust enough to meet the assigned application.

Table 1. Welding Variables

Synergistic Version of the MIG/MAG Process	IMC - CCC – "Carbon Steel C25 1,2 mm"
Wire Feed Speed (wfs)	3,0 a 3,3 m/min
Variable "a"	30
Cta	1,0
Ckr	0,0
Welding Speed (ws)	28 a 31 cm/min
Width of weaving (ww)	3,0 a 4,0 mm
Frequency of weaving (f)	1,0 Hz
Torch Stop Time on the Groove Laterals (st)	150 ms
Torch Slope Angle	10° a 12° Pushing
CTWD	15 a 17 mm
Profile of weaving	Triangular
Welding Progression	Downward

During the welding, the CCC version showed good results, regarding the stability of the metallic transfer, which were verified in oscillograms analyses. Figure 5 shows part of this stability that was repeated throughout the welding. In a qualitative analysis made during the trials, the amount of spatter was minimal − one of the characteristics of the good functioning of this version.

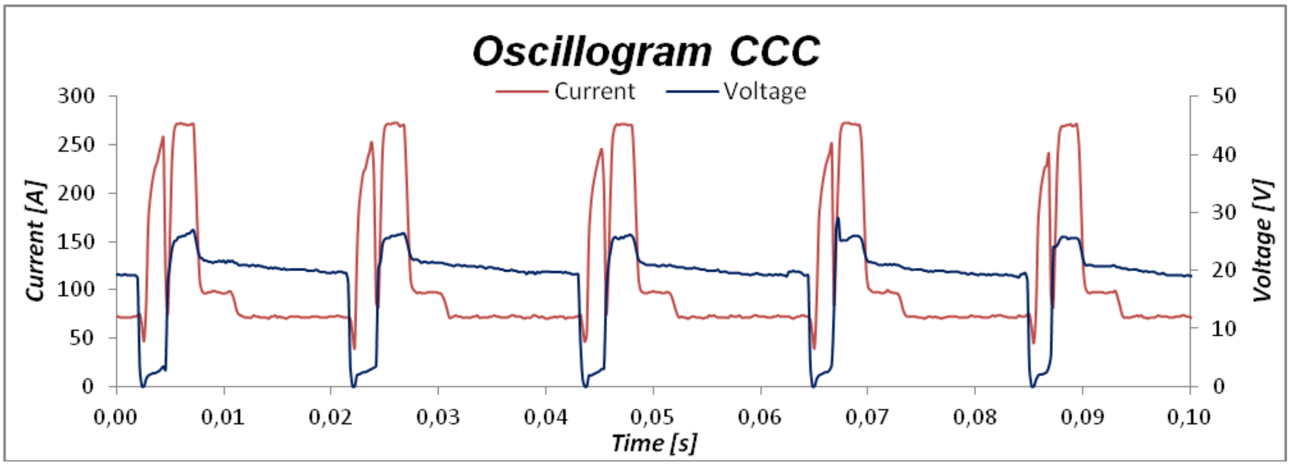


Figure 5. Oscillogram of the Short Circuiting Controlled version (CCC)

A varied range of tests was performed to verify and validate the operation of the entire root welding procedure, and thus verify the performance of the CCC version. Some operational details must be carefully observed by the mechanized system operator during the execution of the welding, so that it can interfere with the necessary corrections, and thus result in weld beads with good quality. During the displacement of the torch in the perimeter of the pipe, the weld pool receives the effects of gravity. In the flat position, gravity acts favoring the detachment of the droplet and the accommodation of the weld pool in the bottom of the groove. In the downward vertical position, gravity acts in order to aid in the draining of the metallic pool, which makes necessary the correction of the robotic manipulator movement, so that the electric arc and the drops which are being highlighted follow this tendency of drainage. And finally, gravity acts in the opposite direction to the detachment of the drops when it is in the overhead position, which makes it difficult to drop in the weld pool, and, after the solidification of the metallic pool, often causes slight convexity in the weld bead profile.

The pipes of the 18 inch diameter and 7/16 inch wall thickness were used to begin the development of the welding procedure. In the initial trials, it was found some difficulties to reach an acceptable result. However, from slight corrections, mainly in the movement variables of the mechanized equipment, a procedure was obtained in which total penetration was achieved in the entire path of the weld, with good surface appearance, excellent wettability and minimal face convexity. Figure 6 shows a portion of the welding result that was repeated over the entire length of the tube. Figure 7 shows the macrographs at specific points of each welding position with the resulting fusion profile.

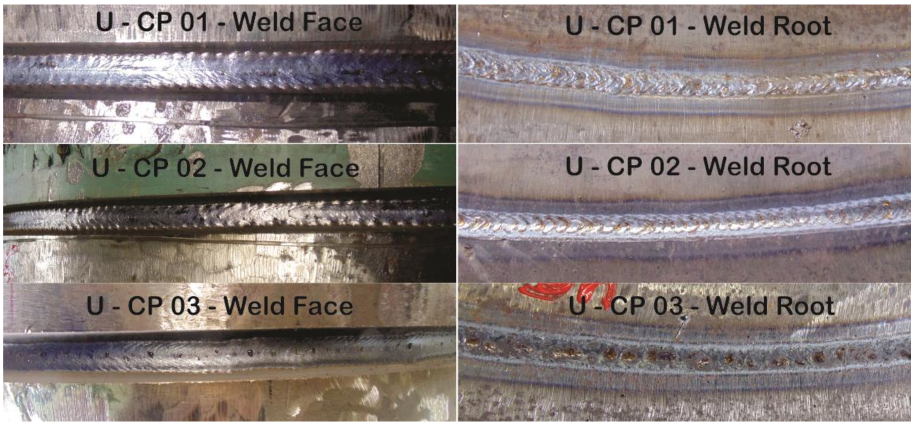


Figure 6. Welds in pipes 18 inch diameter and 7/16 inch wall thickness.

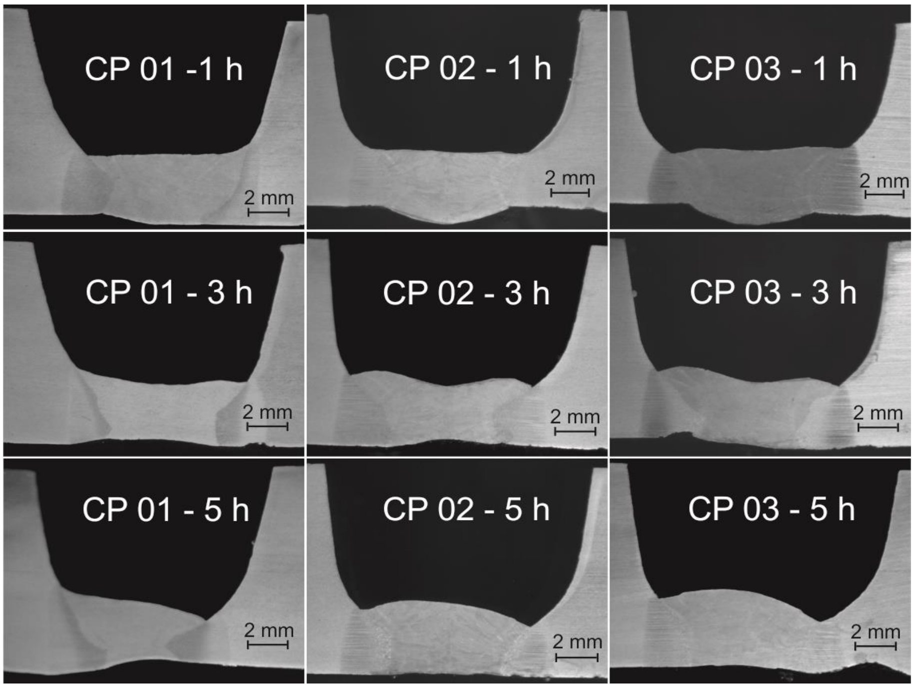


Figure 7. Macrographs U-CP 01, U-CP 02 and U CP-03

The samples of Figure 8 show the geometric profile of the molten metal in tests with purposely misaligned tubes. The misalignment was provoked in different positions in order to verify, even in the positions of greater complexity, the behavior of the procedure in relation to the weld compensation. This type of assembly with high-low is common to be found in pipelines construction in the field, due to the geometric imperfections of the pipes.

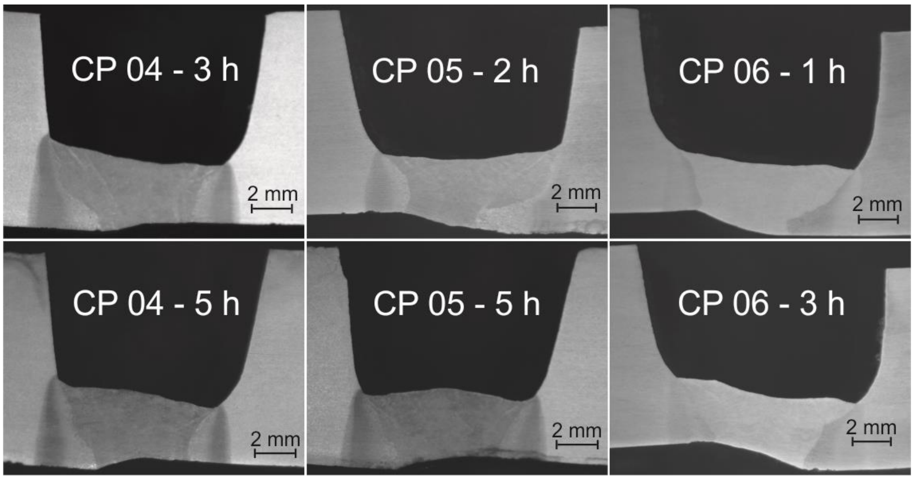


Figure 8. Macrographs U-CP 04, U-CP 05 and U-CP 06

It was possible to verify that the procedure was robust and compensated for the misalignment in several points of the joint. The values of the misalignments were gradually increased with each test. In the case of U-CP 04, the maximum misalignment was 1.0 mm, the U-CP 05 with 1.5 mm and the U-CP 06 reaching 2.0 mm. It was important to note that in the case of U-CP 06, the compensation occurred in a position considered of greater complexity, due to the greater fluidity of the weld pool: PV position - 3h.

With the exploitation of oil and natural gas in distinct and inhospitable locations, the companies in the welding area should have a structure of welding procedures that meets this diversity of pipes diameters and wall thicknesses. It is common for companies to present Welding Process Specifications (WPS) with a wide range of values for welding variables This may induce the operator to choose a set of nonfunctional welding variables, which ultimately can lead to welds with discontinuities and defects that have to be reworked. In this context, the tests for validation of the root procedure with the CCC version were applied in pipes of different diameters and wall thicknesses.

Then, the welded pipes were the API 5L X70 MS, 22 inch in diameter and 1¼ inch wall thickness, shown in Figure 9, and the API 5L Grade B tube 16 inch in diameter and ½ inch wall thickness, shown in Figure 10. The same values of the variables presented in Table 1 and used for the 18 inch pipe were reapplied for this procedure. It was observed that the performed procedure reached good results and proved to be robust and with good repeatability for the situations tested.

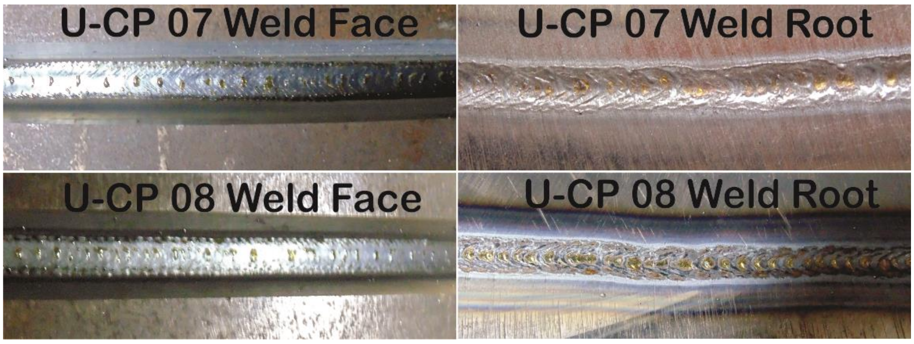


Figure 9. Welds in 22 inch diameter and 1 ¼ inch wall thickness pipe

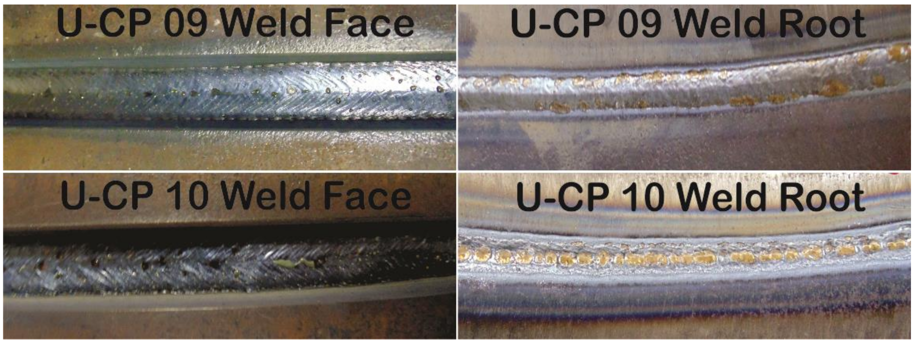
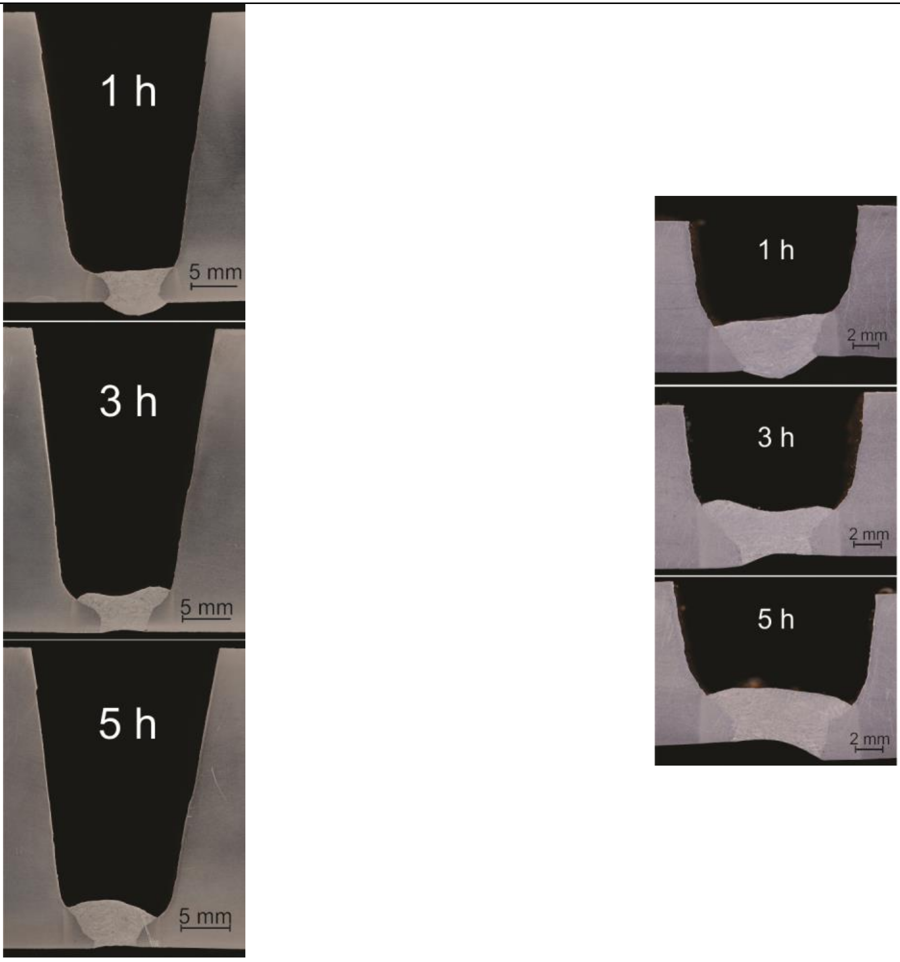


Figure 10. Welds in 16 inch in diameter and ½ inch wall thickness pipe

Some of these tests were submitted to the preparation of macrographs, presented in Figure 11, to evaluate the fusion profile in the joint. In general, as it can be seen, the characteristic fusion profile is intrinsically related to the position of the weld in the pipe. There is a clear trend to a more pronounced root reinforcement in the flat position, the leftover material in the areas adjacent to the groove flank, due to the draining of the weld pool in the downward vertical position and a slight convexity in the overhead position. All these effects are typical of the gravitational force acting on the weld pool, as already commented in the text.

For all the tests, the acquisition of electrical data and wire feed speed (wfs) was performed. The values shown in Table 2 are the instantaneous average values.

In general, the tests showed a procedure that meets the conditions of the standards applied for the construction of pipelines and, mainly, compensating for the minor variations of the machining and misalignment of the groove. However, minimal changes in some welding variables were, in fact, necessarily altered for the arising compensations. Nevertheless, any of these values is very broad, compared to what is currently seen in the field of WPS for manual welding.



a) b)

Figure 11. Macrographs – a) U - CP 07 22 inch Pipe - b) U - CP 09 16 inch Pipe

Table 2. Instantaneous average results

Weld Piece	Voltage [V]	Current [A]	Power [W]	Wire Feed Speed [wfs]
U – CP 01	17,6	123	2101	2,9
U – CP 02	17,4	121	2091	2,9
U – CP 03	17,7	122	2157	3,0
U – CP 04	17,4	120	2074	2,8
U – CP 05	17,4	118	2080	2,9
U – CP 06	17,4	121	2094	2,8
U – CP 07	18,0	127	2329	3,4
U – CP 08	18,2	130	2393	3,3
U – CP 09	18,1	119	2137	2,9
U – CP 10	17,6	135	2449	3,4

5. Conclusion

The present work represented an important contribution to the development of the orbital welding technology towards root passes in pipes The practical realism of the applications created propitious environments for the entire development of this work, whose information gathering was of total representativeness for the scope and evolution of the LABSOLDA Institution.

Regarding the CCC, whose version is an internal technological development of the laboratory, the good results in pipes with different diameters and wall thicknesses prove their robustness and reliability, making the version applicable in the industrial environment and of easy operation as to its regulation. The welding procedures developed with the CCC version serve a wide variety of pipes, such as the ones with 16 inch, 18 inch and 22 inch diameters and

7/16 inch, ½ inch and 1¼ inch wall thicknesses. For these pipes, adjustments with minimum interference of operation are required, in which the welding operator would act more as a lecturer of the initial setup of the procedure, with minimal action in corrections during the welding.

The tests carried out demonstrate the application of the CCC to the root pass without the use of backing − an application that was envisioned for many years within the laboratory and has been incessantly researched throughout the history of LABSOLDA, reaching its completion on the current days.

6. Acknowledgements

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