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TECHNOLOGICAL INSIGHTS INTO THE TIG MULTICATHODE WELDING

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Abstract. *This study is within the context of searching for innovations in processes and increased productivity, especially in the TIG welding process. Two new welding process technologies will be investigated, the Multi-Cathode TIG (TIG-MC) with three electrodes, with wire feeding and simultaneous actuation between three TIG electrodes and the hybrid TIG-MIG MC process, with a MIG/MAG wire between the TIG electrodes. Previous research has allowed the creation of basic technology for the application of TIG MC with two electrodes (TIG DE - Double Electrode), and to conclude a potential increase in productivity and weld quality, by better controllability of arc geometry and pressure exerted on the weld pool. The main object is the basic characterization (new process-specific parameters and interaction between the arcs). Related to this object, it is then intended to establish a mapping of parameterization ranges and formulation of welding procedures dedicated to prospective applications. The effects of the combined arc of three tungsten electrodes acting simultaneously on the same welding torch with and without an arc on the central wire, varying the possible distances and angulations of electrode placement, and the wire parameters, will be characterized by means of various monitoring and evaluation technologies. Preliminary results have already proven the torch's adequate functionality, and it is possible to apply this technology with a total of four simultaneous arcs. Depending on the distance between electrodes, it is possible to obtain the formation of a single arc with morphological characteristics very similar to the conventional TIG process, but with the ability to act with three times the current value in the same process. Another relevant aspect was the proper operation of the MIG/MAG process in spray mode, simultaneously with the three TIG electrodes already at this early stage of the work. This shows the potential of this technology to obtain a welding process where deposition rates can be significantly increased compared to TIG and MIG/MAG processes operating separately. In addition, it has also been possible to identify, measure and document the flow of electric current between electrodes.*

Keywords: *Multicathode; Hybrid welding; TIG-MIG; Coupled Arc*

1. INTRODUCTION

The demand for increased productivity and quality has driven the development of numerous variants and techniques in arc welding processes, thus having a potential economic impact of hundreds of thousands of dollars annually in several world economies. In conjunction with the MIG/MAG process, and among the current variants, welding with tungsten electrode and inert gas, the TIG, is considered one of the most widespread welding techniques using an electric arc as a heat source to generate fusion. Continuous improvement strategies in the most distinct welding technologies are employed to increase productivity. For this, the domain of techniques to evaluate the interactions and control of the electric arc are fundamental. This applies to the case of multi-electrode welding and hybrid welding, where more than one heat source or welding process is operating simultaneously.

Kumar and Debroy (2006) showed welding results where the manipulation of the arc by means of magnetic fields was used to change its morphology, making it possible to increase the speed of displacement of the arc on the workpiece to be welded. When the arc is manipulated and used in the shape of an ellipse (deformed by the magnetic fields), aligned in the welding direction, it is possible to increase the torch displacement speed. In this context, by using the TIG process with two parallel aligned electrodes it would be possible to obtain a morphological profile of the arc analogous to the ellipse and, with this, obtain similar fusion to the arc deformed by magnetic fields, thus making it possible to increase welding speed. It is important to note that the use and development of the multi-electrode TIG process is not recent, and it is possible to find industrial applications of up to three TIG electrodes operating simultaneously. However, in these cases, the distance between the electrodes is relatively large and the mutual influence between arcs is negligible (LEDICA, 2020).

Okada et al. (1980) applied the variant of the TIG process with three cathodes and compared different positions of the electrodes, and found that the triangular arrangement in the welding direction (two electrodes behind parallel and one in forward), generated a wider weld bead compared to the series arrangement (three tandem electrodes). However, the interaction between the electric arcs, caused by the triangular arrangement between the electrodes, resulted in severe instability and also promoted bite formation on one side of the bead. Xiao et al. (2013), developed a welding torch with three electrodes in order to significantly improve the quality of the process. According to the authors, the proximity between the arcs and the pulsation of the electric current at frequencies close to 100 Hz increases the efficiency of the energy density in the ionization region of the arc due to the pinch effect produced by the fields of the three arcs, especially during the current pulses. Wu et al. (2019) presented a study with several innovative technologies of the TIG process, among them C-TIG (Condensing TIG). This variant is cited as a new arc welding method and was originally proposed by a group of researchers from Beijing University of Technology, led by researcher Yonglun Song. The tungsten electrodes are properly positioned such that they enable the three parallel arcs to converge into a single arc. Wu et al. (2019) cites that the major differentiator of this technology is based on gas shielding, where the arc is protected by two layers of gas termed as inner gas and outer gas. In this torch, the three tungsten electrodes have parallel arrangement (no angulation) and are fed by three independent welding sources.

The main benefits of this technique of using the TIG process is related to the gain in productivity in the sense of obtaining high welding speeds, besides significantly reducing the occurrence of defects such as undercuts. Previous studies, such as Yasuda et al. (1989), have applied the TIG welding process with two tungsten electrodes, 22 mm apart, to the welding of thin plates to mitigate the occurrence of undercuts in the weld. Kobayashi et al. (2004) applied the same process with smaller cathode spacings, close to 1 mm, for joining welds of thick sheets. Thus, the welding speed can be significantly higher compared to the welding speeds obtained with conventional TIG. This process variant has mainly been used for specialized applications for speed welding above 2m/min, of longitudinal pipe seams (LEDICA, 2020). Okada et al. (1980) explains that the development of the TIG process with three electrodes, especially, operating in tandem mode, produces high toughness welds, because in this way it was possible to take advantage of the thermal effects generated when more than one electrode passes through the same weld bead on the work piece. The microstructure formed in the solidification of the first bead, formed with the passage of the first electrode, can present a coarse grain structure. However, it can be transformed into a refined structure in subsequent weld beads, when reheated by the second and third electrode. For this purpose, it is essential that the layers are built up in a controlled manner so as to transfer the heat from the top bead to the bottom bead.

To achieve high productivity, some companies around the world have developed several processes referred to as hybrids, such as Plasma-MIG, Laser-MIG, and TIG-MIG. For the latter, Kanemaru et al. (2014) cite that hybridization of the TIG and MIG processes is a new welding method that features both the weld quality of the TIG process and the high melting efficiency of the MIG/MAG process. Depending on the application, the ability of the TIG process to preheat the workpiece before the MIG process even deposits the weld bead, can result in dilution levels far removed from the same operation with the welding process acting alone. In addition, the effects of process gas ionization and voltage values, especially, are altered, and there is also the possibility of current circulation in the different circuits of the welding sources (KANEMARU et al., 2014) (KANEMARU et al., 2015). Zong et al. (2019) compared hybrid TIG-MIG and conventional MIG welding and verified the influence of relative electrode position and variation of TIG current on arc stability and conventional weld bead formation. In the work it was found that in hybrid TIG-MIG welding, the welding speed reached 1.5 m/min without causing weld bites when the TIG arc was in the front, relative to the welding direction. This result is quite interesting considering that there are rare cases where only the conventional TIG process, in practice, achieves travel speeds greater than 1m/min with satisfactory results.

However, regardless of the number of electrodes used in the same welding process, arc deflection can occur without the presence of a second or third arc nearby. Whereas an electric charge can be positive or negative, and when this charge is in motion, it produces a magnetic field and is then subjected to a force with direction and intensity. This means that when an electric current flows through a conductor, a magnetic field is generated. This is also true in the case of arc welding, where there is a flow of electrons from the electrode to the work piece or vice versa. In welding this effect is named arc blow, and it can also be triggered randomly for various reasons, as is usually the case when welding on the edges of thick sheets, or in the presence of a very high mass gradient in join welding. In order to avoid the tendency of arc deflection under the influence of local magnetic fields, techniques such as pulsed current at high frequency, double gas shielding or some magnetic stabilization device are used (NORRISH, 2006).

In this context, the studies denote that the multicathode welding is situated in a context where alternatives are explored to increase the performance of the TIG process, and allows its application with welding speeds considered relatively high for this process using high current without the occurrence of welding defects. Thus, the present work will have as main focus the characterization and feasibility analysis of a variant of the TIG welding process denominated as Multicathode TIG, composed of three tungsten electrodes and with wire feeding. In addition, the implementation and feasibility analysis of the development of the hybrid TIG-MIG Multicathode process, where the MIG/MAG process will operate simultaneously with the TIG process, will also be investigated through employment and visual analysis and electrical interactions between the processes.

2. MATERIALS AND METHODS

The experiment bench used in the present study, is composed of three welding power sources: an IMC/Digiplus A7 with dual output, having the capacity to supply currents of up to 450 A to two electrodes independently. It also allows the welding parameters of each electrode to be set individually. The characterization and performance evaluation of the multi-electrode welding process was possible through the use of the multi-method TIG welding torch, developed in LABSOLDA-UFSC. This welding torch allows the inclination of each electrode and the distance between them to be regulated. In the central axis of the torch body, an automatic MIG/MAG torch body was also positioned, so that it was possible to operate wire feeding and eventually to experiment the hybrid TIG-MIG Multicathode process. Figure 1 illustrates the design in CAD environment of the TIG-MC torch. The tungsten electrodes are doped with 2% lanthanum, with a diameter of 3.2 mm and a sharpening angle of 40°. The ER70S-6 wire with a diameter of 1.0 mm was used during the tests with fed TIG and later in the step with the multi-method TIG-MIG process. All tests were performed on 6.35 mm thick low carbon steel plates free of surface oxides. In all tests, pure argon (99.99%) was used as shielding gas at a maximum flow rate of 30 l/min divided among the three nozzles, also serving as protection gas for the arc of the MIG/MAG process.

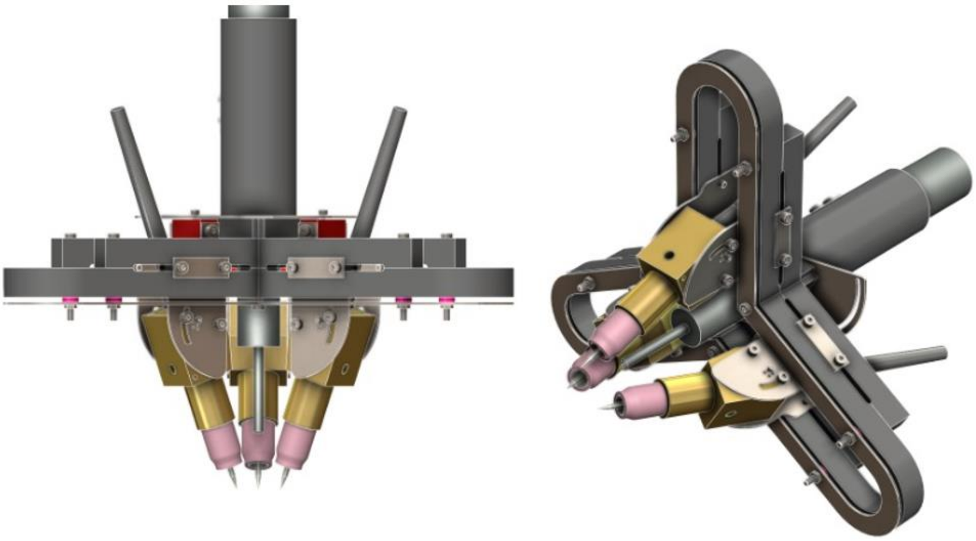

Figure 1 - CAD environment model of the TIG-MC torch

The TIG-MC torch handling was performed by means of a Cartesian welding system that enables automated torch movement in three axes assisted by an arc length control (AVC). The measurement of the electrical signals was performed by means of a portable welding signal acquisition system (SAP.v4). With this process monitoring equipment, it is possible to take instantaneous readings of the magnitudes current, voltage, wire speed and gas flow rate with a sampling rate of 5 kHz. The tests were filmed in order to make it possible to observe the behavior and the interaction between the electric arcs. The equipment used consists of a Canon 60D DSLR camera with 180mm Macro lens and 2x duplicator. In addition, a 671 ± 4 nm band pass filter was used.

As a starting point regarding the fixed parameters in all experiments were the TIG current, set at each electrode at 100A, the electrode-to-piece distance at 3 mm and the welding speed at 30 cm/min in all tests. The electrode voltage signals were measured to evaluate the stability of the process, first with 2 electrodes and then with 3 electrodes. The torch was positioned so that one of the three electrodes was in front of the deposited weld bead. In addition, in order to be able to perform the wire feeding concentrically to the tungsten electrodes and achieve a stable condition, the distance between the electrodes was 6 mm. The wire feed speeds tested were 2, 3 and 4 m/min during the fed TIG. The TIG-MIG process was initially parameterized by maintaining the current of 100 A at each TIG electrode (300 A) and varying the voltage and wire speed parameters of the MIG/MAG process.

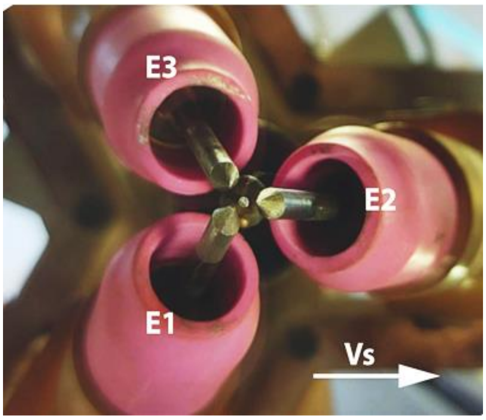

Figure 2 - Arrangement of the electrodes according to the displacement of the torch (Vs)

3. RESULTS AND DISCUSSION

3.1 Autogenous MulticathodeTIG with 2 and 3 electrodes

The results obtained in the tests performed without any addition of material are shown in Figure 3, 4 and 5. As illustrated in the generated voltage and current graphs, it is possible to note that the process, for both conditions (2 and 3 electrodes), remained stable, considering the stability in voltage signals. As expected, because it is a process where its operating principle controls the current, the measured welding current signal remained in the range of 200A (two electrodes) and 300A (three electrodes), since the hall sensor was positioned in a common cable to the welding torches, thus representing the sum of the currents imposed by each TIG welding source. For the operation with two electrodes, it can be seen that the voltage signals from both electrodes presented the same behavior, even when there are small disturbances (Figure 2). At the end of the procedure, the descending current curve characterizes a reduction in the arc voltage, but from a certain plateau, close to 100A (current of only one arc), the voltages rise again, characterizing the natural behavior of the TIG process (static curve behavior). The average voltages in this case were 9.3 and 9.5V for electrodes 1 and 3 respectively (Figure 3).

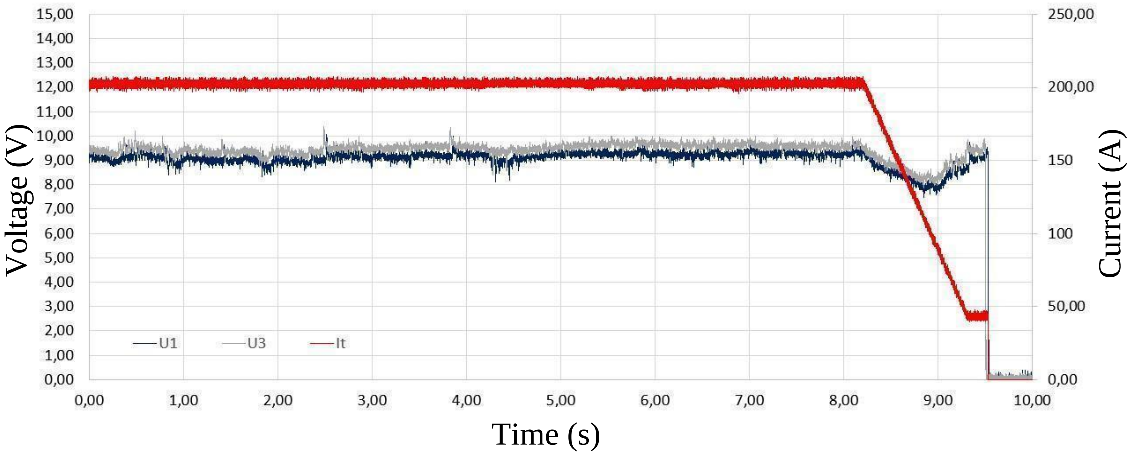

Figure 3 - Double electrode TIG: current (red) and voltages (gray and blue)

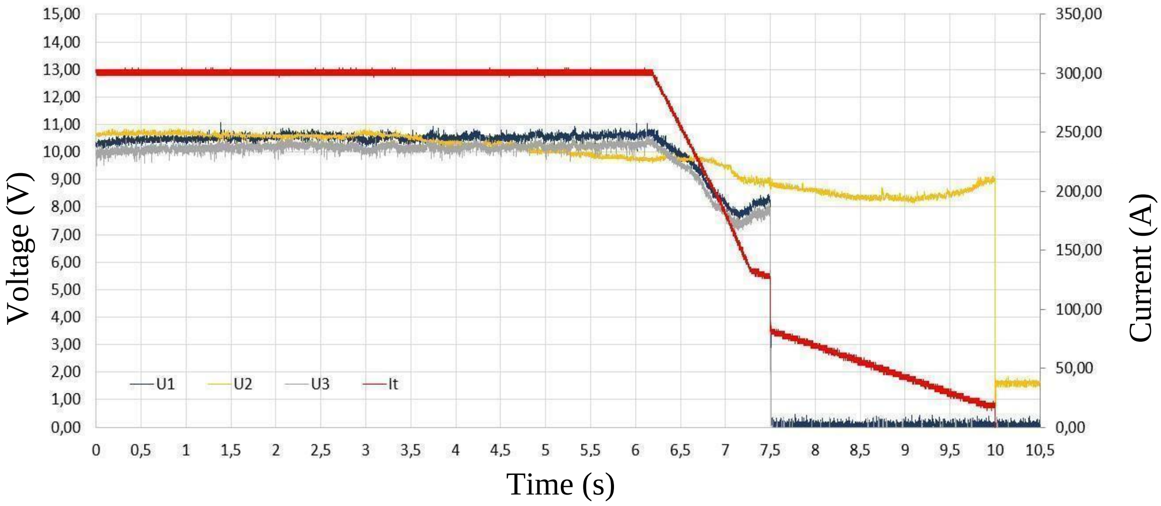

Figure 4 - Triple electrode TIG: current (red) and voltages (gray, yellow and blue)

In the two-electrode procedure, the average voltage values were slightly higher than for the previous two-electrode case. The measured values were 10.1 V, 10.0 V and 10.3V for electrodes 1, 2 and 3 respectively. The behavior of the current at the end of the procedure with three electrodes is explained by the fact that electrodes 1 and 3 were connected to the same welding source, and, since the trigger buttons of the two sources were independent, in this case, arc 2 remained open in a downward current ramp after the switching off of the other arcs (instant 7,5 s of Figure 4). As in the previous case, for the three electrodes, the voltage signal followed the natural behavior relative to the static curve of the process.

Simultaneously with the acquisition of the electrical signals, photographic images of the arcs were recorded in the configuration with two and three electrodes. Comparing the images generated from the two arcs Figure 5, it is notable the greater concentration of light radiation for the double electrode arc in addition to the upward projection of the arc in welding with three electrodes, where the plasma column is displaced upward concentrically to the three electrodes. This behavior eventually compromised the life of the ceramic nozzles, which in turn deteriorated in prolonged contact with the plasma. In some more serious cases, due to the proximity between the plasma and the ceramic nozzle, the nozzles broke during the procedure.

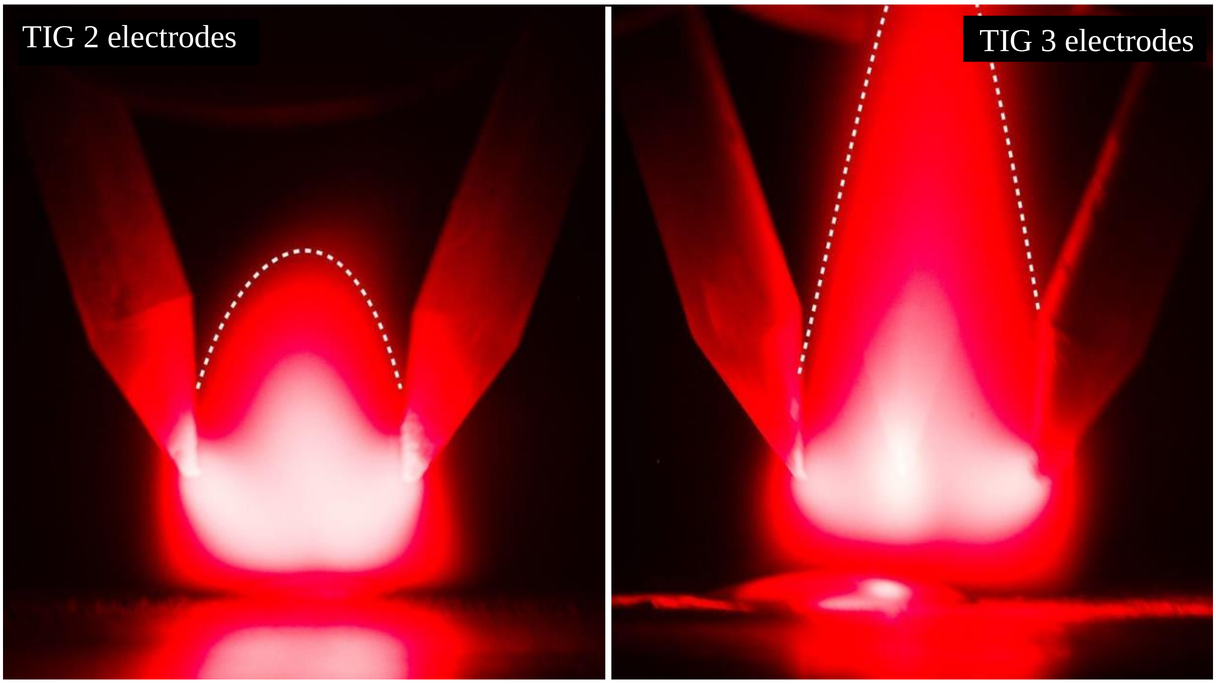

Figure 5 - Multicathode TIG arcs for the 2 and 3 electrodes process

3.2 Multicathode TIG: Cold-Wire Feeding

The present work also characterized the wire fed TIG-MC process. Some initial tests were performed with the cold wire insertion technique. The wire feeding was performed concentric to the three TIG arcs, i.e., perpendicular to the workpiece (90°) at different feeding speeds.

The graphs in Figure 6, Figure 7 and Figure 8 show the voltage signals at each electrode obtained by the portable acquisition system for the tests with average wire feeding at 2, 3 and 4 m/min and total current of 300 A. In a very preliminary manner, it was measured and observed through recorded videos of the process that, regardless of the wire speed employed in these cases, it is possible to verify that there is not a large variation between the voltage values at the electrodes during the process. For example, the average voltage values measured at electrodes 1 and 3 in the first oscillogram (Figure 6) are almost identical, resulting in 9.2 and 9.1 V respectively. However, electrode 2 presents a relatively higher value compared to the others, of approximately 10.7 V. This is because this electrode remains ahead of the deposited weld bead, thus resulting in a greater electrode-to-part distance than the others. While the average voltage of electrode 2 had an average value of 10.5V. This fact becomes more evident when the images in Figure 9 are observed. As can be seen in the sequence, the electric arc of electrode 2 exhibits a morphological characteristic of not being fully anchored to the workpiece. Thus, due to the aforementioned reasons, it is possible to justify the higher voltage presented by electrode 2 in the tests with wire feeding.

By reading the signals presented in the graph of Figure 6, Figure 7, Figure 8, it is also possible to verify that the voltage of the electrode 2, does not decrease to 0 V at the moment of interruption of the process as the others. This fact is verifiable in all the other acquisitions with 3 electrodes due to the type of connection configuration used in the welding sources, that is, electrode 2 that is connected to a separate welding source will always present a delay in the closing of the process in relation to the signals from electrodes 1 and 3 that are interrupted at the same time in a welding source with two outputs with isolated potential. This delay in arc closure at electrode 2 can also be analyzed in the current signal. By means of the measurement configuration employed in the present study, it is possible to verify that the current signal decreases to 100 A at the moment of arc closure fed from source 1 (2 outputs). Thus, the electrical signal acquisition system starts to measure only the current signal from source 2 (100 A). The current and voltage signals show a decreasing behavior, which corresponds to the current ramp down programmed in the source.

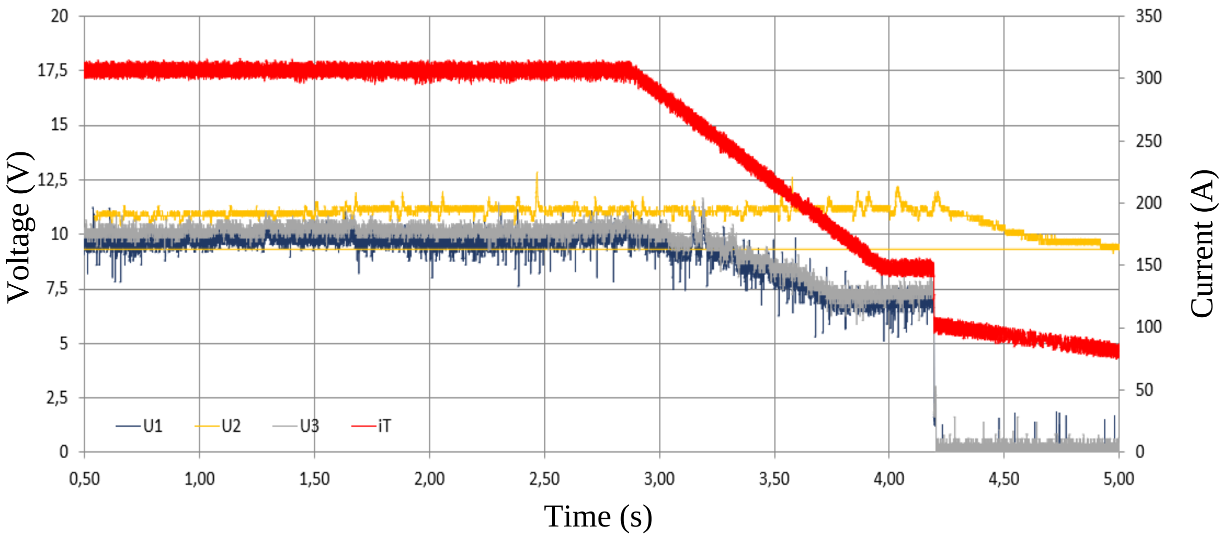

Figure 6 - Multicathode TIG with 3 electrodes and wire feed speed of 2 m/min

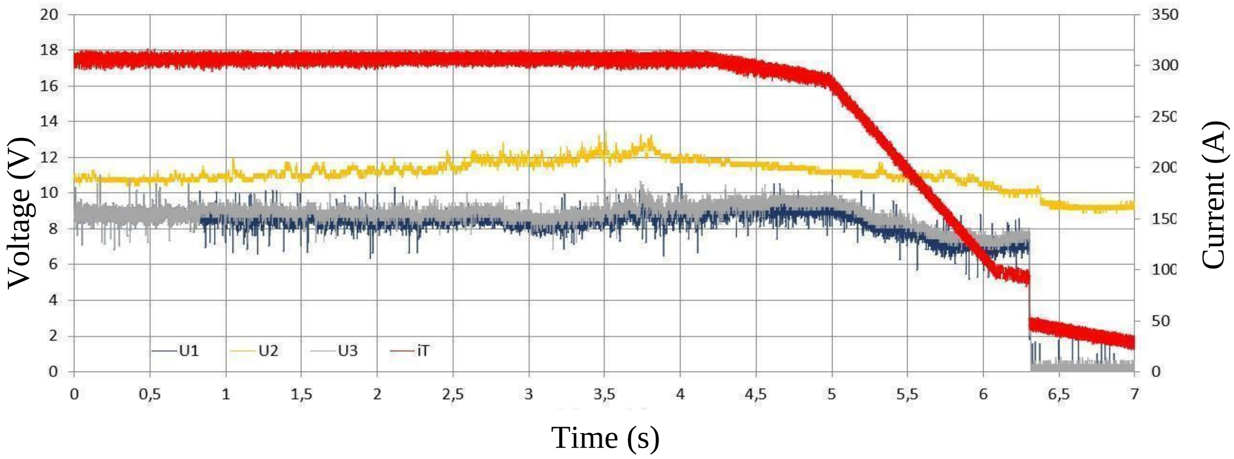

Figure 7 - Multicathode TIG with 3 electrodes and wire feed speed of 3 m/min

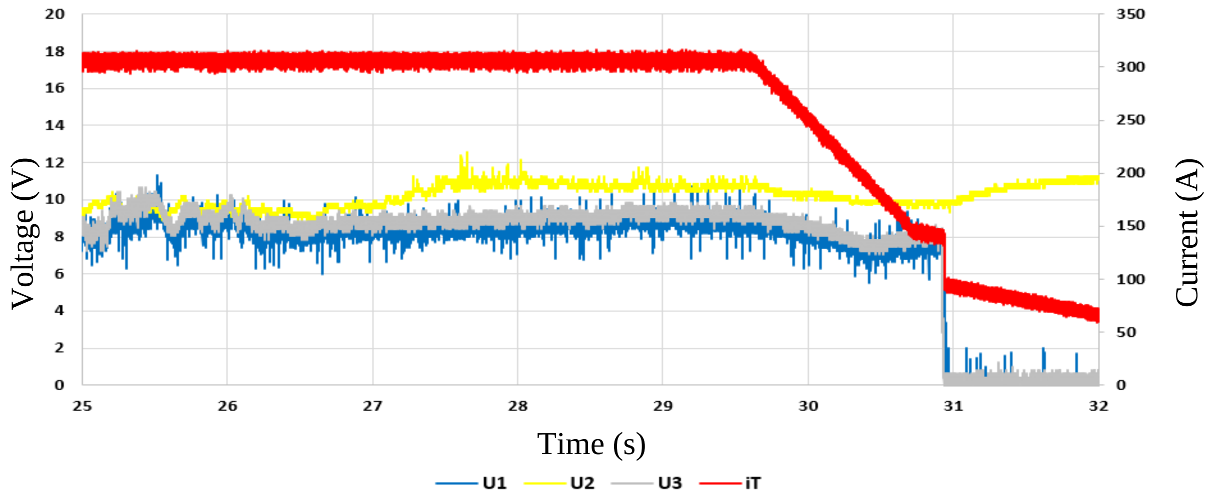

Figure 8 - Multicathode TIG with 3 electrodes and wire feed speed of 4 m/min

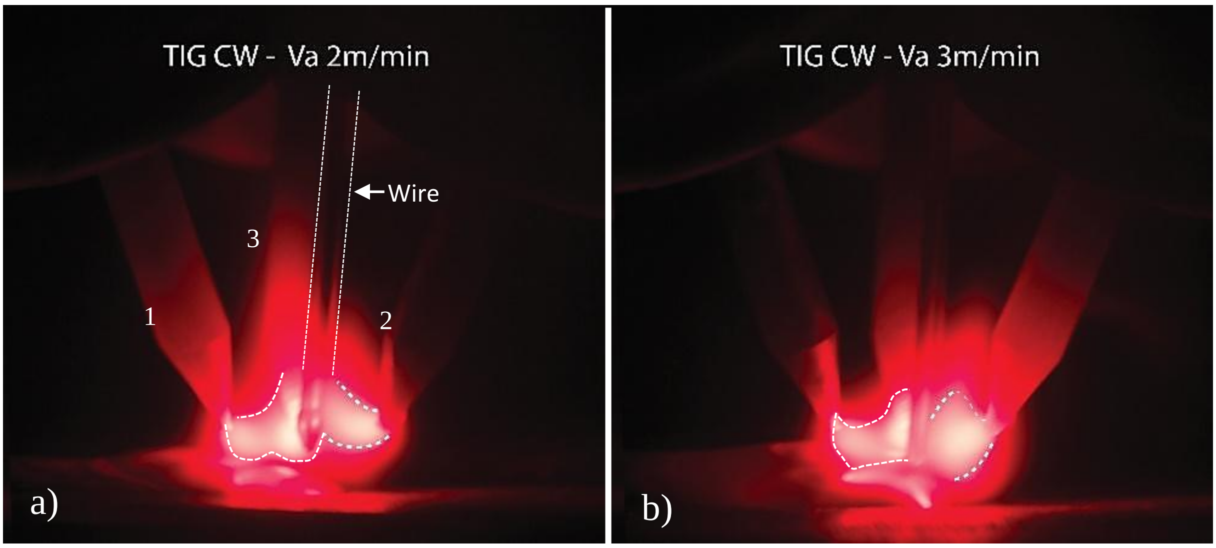

Figure 9 - Interactions of arcs with cold wire (CW) feed: a) intermittent transfer b) bridge transfer. Va: Wire feed speed

Through the images of the arcs, it was possible to characterize the type of metal transfer of the multi-method TIG-MIG process. It is worth mentioning the extreme importance of the uniform arrangement between tungsten electrodes of the TIG, that is, to ensure that they are arranged at relatively small distances from each other to generate a condition of balance in the metal transfer in cold wire mode. This is because the wire is fed from the top and center of the combined

arc, and as a result, it is situated in the center of the magnetic fields generated by TIG arcs, which promote a kind of random rotational repulsion of the molten droplets at the tip of the wire, thus causing contamination of the tungsten electrodes if the electrodes are too close together. In addition, another recommended practice, especially to improve the operability of the opening of the process, at least at this level of maturity of the work, is to pull back the entire free extension of wire that remains outside the feeder nozzle, because this portion of wire is melted instantly after the opening of the arcs contaminating the tungsten electrodes.
In the condition where 2 m/min wire feed was used, it was possible to verify that the resulting metal transfer was of the intermittent type. Only at speeds set at 3 m/min did the transfer occur in bridging mode (uninterrupted wire melting). At wire feed speeds set at 4 m/min and above, the wire did not have a complete melt and was still inserted in the solid state in the weld pool. This difference in the metal transfer mode had a strong influence on the weld bead cross section profile. Verified in Figure 10, for wfs of 3 m/min, the weld bead wetting was lower than the result of the bead for Va of 2 and 4 m/min, which presented higher wettability. It is believed that in this case, the metal transfer is being strongly influenced by the insertion positioning of the wire in the arches centrally between the electrodes. Thus, the arc anchors itself to the wire promoting metal transfer still somewhat randomly in the three conditions tested. Due to the difficulty in fully melting that amount of wire set, the wire still solid, stirs the weld pool and this fact was linked as a hypothesis for the higher wetting of the weld bead even performed with the highest wire feed speed tested.

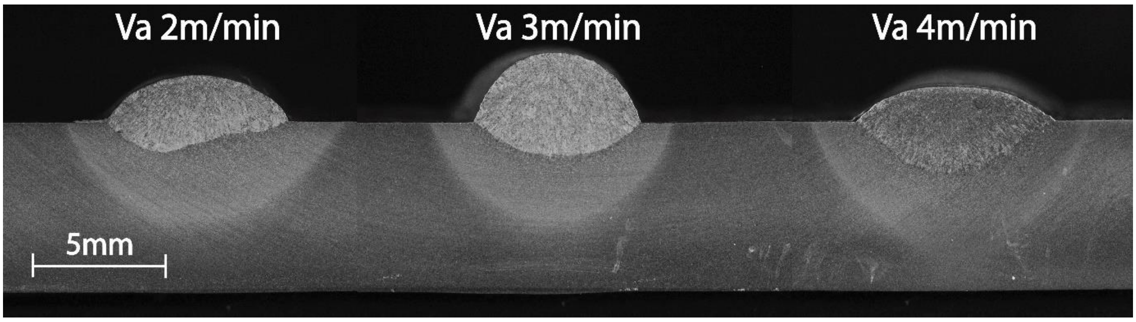

Figure 10 - Macrographs of the multicathode TIG with wire feed. Va: Wire feed speed

3.3 Hybrid Multicathode TIG-MIG

A secondary objective of this work is to experiment with using the TIG-MC process synchronously with the MIG/MAG process. In this case, the MIG/MAG process will act between the tungsten electrodes, resulting in the combination of four simultaneous electric arcs. In the present work, this process is called Hybrid Multicathode TIG-MIG. The advantages or limitations of this practice are not yet known, only that it is possible to use both processes acting at the same time. That is, at this stage of the work, it is only possible to demonstrate the feasibility of operating the two processes in the same torch (Figure 11).

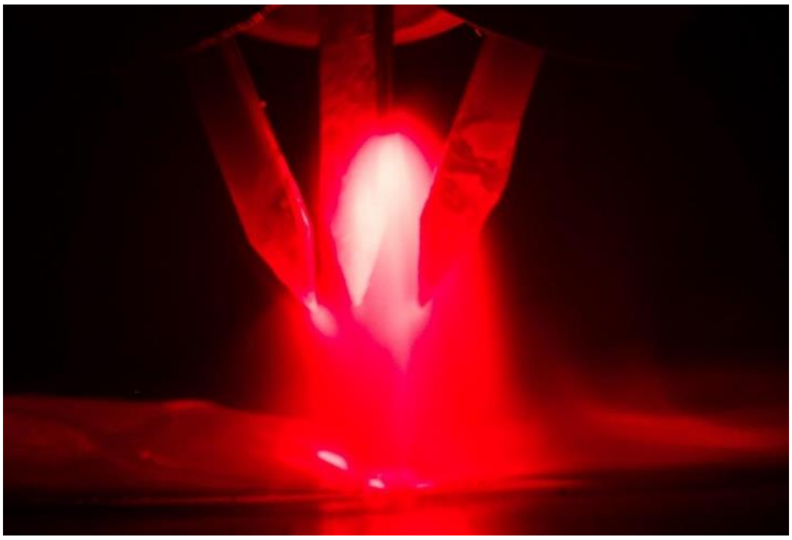

Figure 11 - Demonstration of the feasibility of operating the TIG-MIG process

From the perspective of application and productivity, it was evaluated that the use of the MIG/MAG process acting in the contact metal transfer mode (short-circuit variations) would not present a favorable condition for the stability of the TIG process, and the tungsten electrodes could be contaminated by spatter caused by the short circuits inherent in this transfer mode of MIG/MAG. The goal was to achieve a stable welding condition with a free-flight metal transfer mode in the spray mode. Figure 12 shows this welding condition, with three TIG arcs and a MIG arc in the center in two versions of the same image. Demarcation and magnification was performed on the left image to make it easier to identify the arcs.

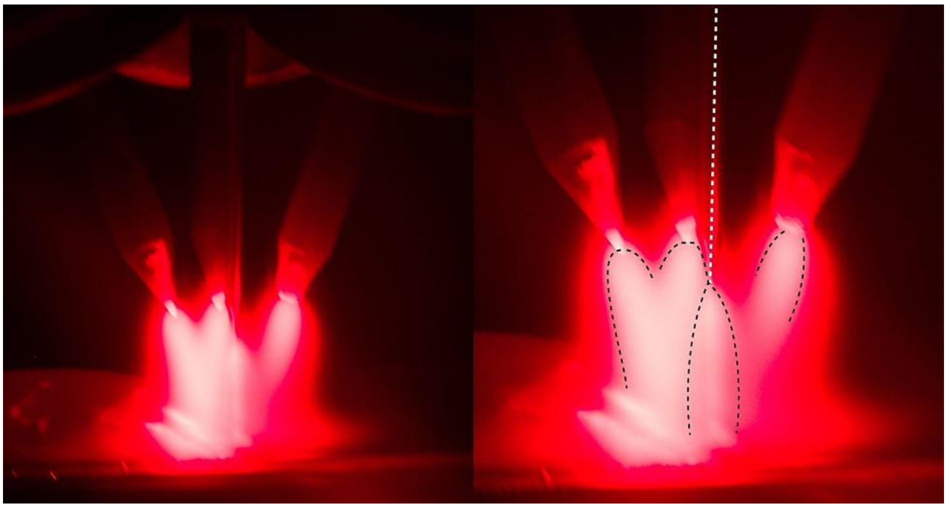

Figure 12 - Morphology of the simultaneous arcs in the TIG-MIG Multicathode Hybrid process

Through experimentation during the execution of the procedure, an interesting behavior of the hybrid process was observed. Under the influence and contribution of the TIG arcs in the wire fusion it was possible to achieve an average wire speed of 9 m/min, with an average voltage of 12.0 V for the MIG/MAG process, resulting in an average MIG arc current of approximately 190 A. It is not uncommon to find different values in the MIG/MAG technical literature than those measured here when this process is operating in isolation. The voltage value considered normal for MIG/MAG operating in spray transfer mode with argon gas and 1.0 mm ER70S-6 carbon steel wire is generally above 20 V. Furthermore, what can be observed with the aid of the images in Figure 12, is that the arc length is considered appreciably high for such welding conditions and that, for this reason, the plasma generated by the combination of the arcs decreases the resistance generated between the wire-electrode and the workpiece, thus reducing the voltage value. The TIG arc length is approximately 10 mm in this procedure, and the MIG arc length varies as the voltage value is changed at the source during experimentation. It is considered here that these arc length values, especially of the TIG arcs, do not result in an ideal welding condition considering the morphological result of the weld bead and arc fusion efficiency (Figure 13).

Figure 13 - Multicathode TIG-MIG process weld bead

It is still unclear the real reason for this discrepancy found in the voltage values especially for the MIG/MAG process operating in free flight transfer mode with a considerably low voltage value. Another hypothesis presented, would be from electrical interference between the welding sources, where the current and voltage signals can circulate between the different circuits of the welding sources. The electrical interactions of the circuits during the procedure do not present triviality in the analysis, nor are they among the main objectives of the work, but further studies will be carried out in order to improve the operability of the TIG-MIG MC process.

After a detailed analysis of the voltage oscillogram of the MC TIG-MIG process, it can be seen that the opening of the MIG arc has an influence on the voltage electric parameter of TIG arcs, where this is evident at the instant of arc opening and arc extinguishing. At the instant of MIG arc striking, there is a noticeable drop in the voltage values of the TIG arcs, which were previously in the regime, and at the instant of MIG arc fading, the voltage values of the TIG arcs are restored. To increase the understanding of this effect, the voltage values of the three TIG arcs and the MIG arc are plotted superimposed on the oscillogram in Figure 14.

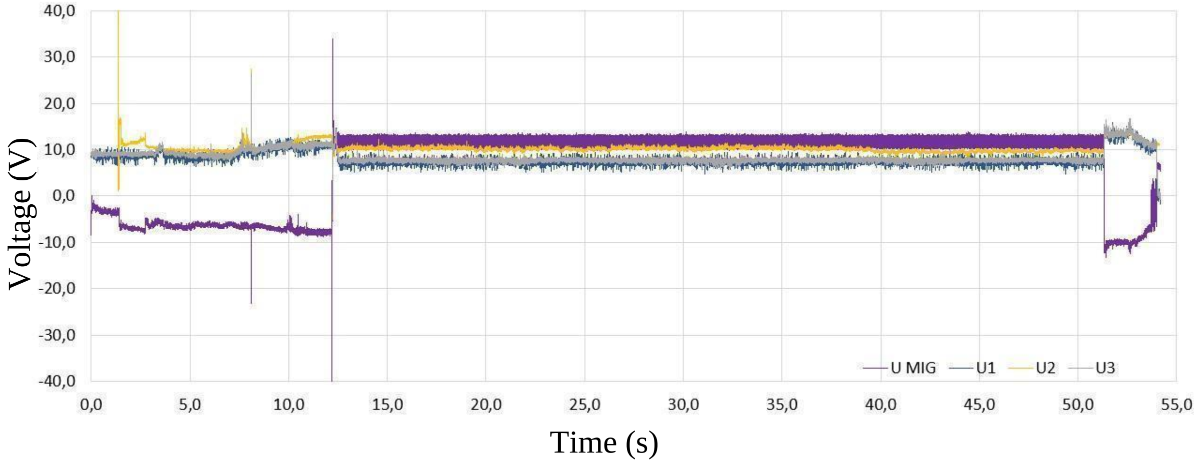

Figure 14 - Voltage signals of the hybrid TIG- MIG Multicathode process

4. CONCLUSIONS

The information in the literature that deals with welding with more than one arc acting simultaneously, together with the information obtained through the practical tests of this work, point to the extreme instability and obstacles that permeate the achievement of a highly robust process and that can figure, right away, its use in an industrial way. However, highly stable conditions were found, especially in autogenous welding. After brief familiarity with the technique, initial tests showed that the procedure performed only with the TIG arcs with two and three electrodes presented the behavior where there was the formation of a combined arc with upward projection as the slope applied to the electrodes. The voltages of each electrode were significantly close and the process remained stable throughout the experiments. The phase of the study comprising the use of wire feeding, in general, presented an extremely convex bead morphology, which in practice can still be considered unusable for industrial applications, a result of possible anchoring of the arc directly to the wire. Nevertheless, when a situation was reached where the wire was stably deposited, results were obtained that showed adequate wettability for process applications. Even in the face of difficulties of application in a first moment, the viability of operation was evidenced and this allows for the continuation of studies with the intent of finding the practical application that is most favorable to the abilities of this welding process.

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