IBP2161_17

ADVANCES IN THE GTAW PROCESS - CONTRIBUTION OF DYNAMIC FEEDING IN THE ROBUSTNESS OF WELDING OUT-OF-POSITION

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Abstract

The national energetic development is strongly linked to pipeline's construction sites, which became strongly dependent of welding processes and its automation. For this purpose, is required research and development focusing in new processes with higher robustness which ensure great quality to welding joints. One of the biggest problems on orbital welding applications is the variation on forces direction over the weld pool, which changes depending on welding position. That is evidenced by the necessity to change welding parameters according to weld position, which requires great ability and control of the welder in mechanized welding process. That represents greater tendency to occur welding defects along the weld bead. So, this also involves a reduction in robustness and process repeatability. To this purpose, dynamic wire feeding appears in order to eliminate or mitigate the problems related to emergence of welding defects, leading to improvements like porosity reduction and great weld bead wettability. However, many hypotheses around dynamic wire feeding are commercial statements reported by manufacture companies, without a scientific study. These affirmatives make the process attractive for applications in pipeline orbital welding where applies alloys with difficult weldability. Nevertheless, researches are necessary about the real dynamic wire feeding performance. This work aims to compare the dynamic wire feeding with constant wire feeding, in a multi-pass application inside a groove with filler metal Inconel 625. Tests were carried out in some welding positions as overhead position, vertical ascendant and descendant, using dynamic and constant wire feedings. Through filming of the weld pool and metal transfer it was observed an increase in process robustness using dynamic wire feed, decreasing discontinuities along the weld bead and the risk of electrode contamination. This allowed the application of weld process at three positions using constant current without changes in welding parameters.

1. Introduction

GTAW (*Gas Tungsten Arc Welding*) or TIG (*Tungsten Inert Gas*) welding process is a technique that has been applied for a long time in the industry, being one of the most important welding methods by electric arc. Thus, over the years, a lot of works have been conducted aiming automate and increase the process robustness and stability. GTAW manual welding is known for provide to welder great control over the weld pool, due to its independence between arc power and filler metal addicted [1]. Therefore, GTAW is recognized industrially as a welding process which provides great quality and it is used in application which requires high responsibility. In general, manual GTAW is recognized as a low productivity process, but a large percentage of industrial applications still use GTAW manually. So, this contributes severely to its low productive concept. Although this process concept has changed with the use of automated and mechanized systems like robots and the application of automatic wire feed through tractions rolls and wire spools [2]. In a sense the process automation remove the welder controllability over the filler metal added, so, on this situation the welding power must be set depending on the quantity of material that is fed.

In recent years, a dynamic wire feeding technique was created, this method works with a forward and backward movement imposed by an electro-mechanical system. This process is also known as dynamic feeding or intermittent

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feeding [3]. When the back/forth movement is made in a high frequency, this technique aims to vibrate the melted material and increase its wettability by changing convection lines on weld pool surface [4]. This phenomenon is also known as Marangoni effect. The agitation caused over melted material aims to reduce porosity through flux lines motion that facilitates gases expulsion from puddle, in addition to provide precipitates solubility.

Dynamic wire feeding is known as low frequency when its oscillation happens below 2 Hz, in this case, the goals and effects over weld pool are completely different than the oscillation in high frequency. In this situation the filler metal action simulates the welder hand movement which inputs the rod to add material and then take it out to let the arc burns over plate [5].

Mechanics systems which makes dynamic wire feeding were created around 1982, in order to work with low current levels in applications as aircraft engines repair [3]. Currently, the dynamic feeding is produced by just a few manufactures as Dabber TIG, TIP TIG and TIG Speed (EWM). After identify its benefits, nowadays this technique has been applied in pipeline girth welding and surface cladding using difficult weldability materials like nickel alloys and stainless steels [4,6,7]. However, there is a lack of scientific contributions approaching the phenomena, mechanisms and real benefits provided by dynamic wire feeding.

Thus, this paper presents a research over the phenomena existing in dynamic wire feeding technique with high frequency in GTAW process. Attempting to gather the advantages provided in increase of process robustness for welding out of flat position, comparing with constant wire feeding, conventionally applied. The application chosen for this work was a filling groove (multi-pass welding) using Inconel 625 as filler metal in joints made of carbon steel, aiming dissimilar welding between both materials.

2. Methods and Materials

2.1. Methodology

Tests were conducted to simulate the variations existing in pipelines orbital welding. Thus, welding beads were carried out at mainly welding positions found in an orbital process which are overhead, vertical ascendant and vertical descendant. In this step the flat position was not carried, which according to previous works is easier than other welding positions [5].The relation encountered between welding positions for pipes and plates are given according to AWS 3.0 representation, as shown in Figure 1.

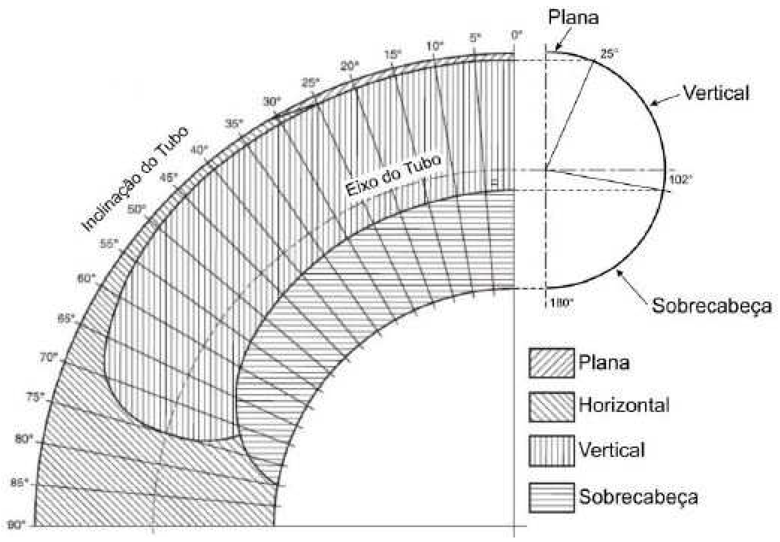

Figure 1. Welding positions equivalence for pipes. Adapted from [8].

Thus, the behavior observed at plates laid in positions showed (vertical, overhead and flat) seems closely with that observed to pipes at corresponding angular range.

Therefore, it was applied two feeding methods (dynamic and constant) with two welding current control techniques (pulsed and constant), therewith getting the welding table as shown in Table 1. From this, just the stable processes which had a good regularity and resulted to satisfactory welds were repeated at three welding positions previously mentioned.

Table 1. Tests chart.

Nº	Feeding type	Current type
1	Constant Feeding	Pulsed
2	Constant Feeding	Constant
3	Dynamic Feeding	Pulsed
4	Dynamic Feeding	Constant

During welding process, it was monitored by video focusing on puddle behavior depending on feeding type applied. This way, it was possible to identify phenomena hardly identified macroscopically. Finally, it was compared the characteristics observed in shooting as well as weld beads surface appearance, it was also realized a transversal section analysis through macrography.

2.2. Samples

The samples were carried out for simulate the welding multi-pass situation through a simple way. Thus, it was utilized carbon steel SAE 1020 plates as base metal. The specimens were prepared with 300 mm long and 100 mm width in plates with 6,35 mm (1/4") thick, and then machined a "V" groove with 40º. The plates were welded to opposite side to V groove with GMAW (*Gas Metal Arc Welding*) process and ER 70S-6 as filler metal, this was carried out just for create a surface where it was possible to deposit Inconel 625. This groove was filled by GTAW welding process as shown in Figure 2.

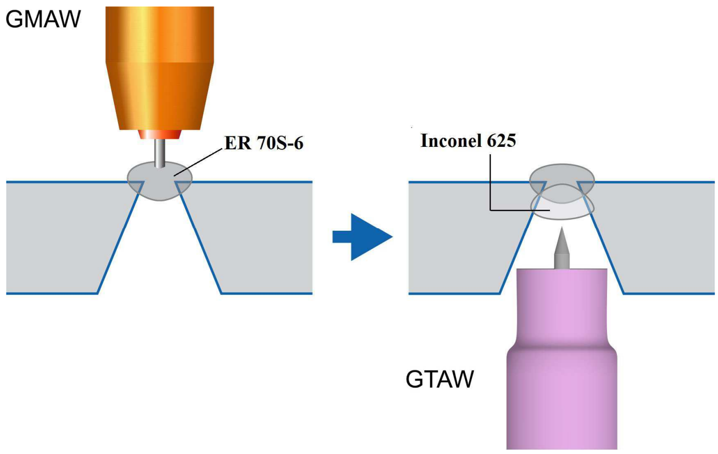

Figure 2. Samples welding steps.

It was necessary two weld passes for groove fulfillment with application of welding torch triangular weaving with amplitude of 3,5 mm and 10 mm respectively. The weaving frequency was 0,8 Hz in first pass and 0,6 Hz for second pass. Others welding parameters were acquired in preliminary tests and its values are shown in Table 2.

Table 2. Welding parameters applied in tests.

Parameter	Pulsed Current		Constant Current	
Feeding	Pulsed	Dynamic	Constant	Dynamic
I_{mean} (A)	115	115	115	115
I_{pulse} (A)	150	150	---	---
I_{base} (A)	80	80	---	---
t_{pulse} (s)	0,4	0,4	---	---
t_{base} (s)	0,4	0,4	---	---
U_{mean} (V)	---	---	11,3	11,3
U_{pulse} (V)	12,3	12,3	---	---
U_{base} (V)	10,3	10,3	---	---
Wf_{mean} (m/min)	1,3	1,3	1,3	1,3

Wf_{pulse} (m/min)	1,6	1,6	---	---
Wf_{base} (m/min)	1,1	1,1	---	---
Ts (cm/min)	7,5	7,5	7,5	7,5

It is important to emphasize that in pulsed current it uses a wire feeding different between I_{pulse} and I_{base}, so, sometimes it can be called pulsed wire feeding. However, this pulsation occurs in a single direction, in the other words, without back and forward movement present in dynamic feeding. This technique must be used due to melting capacity is different between I_{pulse} e I_{base}.

2.3. Workbench and Equipment

In this work development it was applied a workbench for samples fixation, with this table was possible to variate the weld position without take out the welding bug. The amperage and voltage were tracked by PAS (Portable Acquisition System). Figure 3 shows the tests workbench and others equipment.

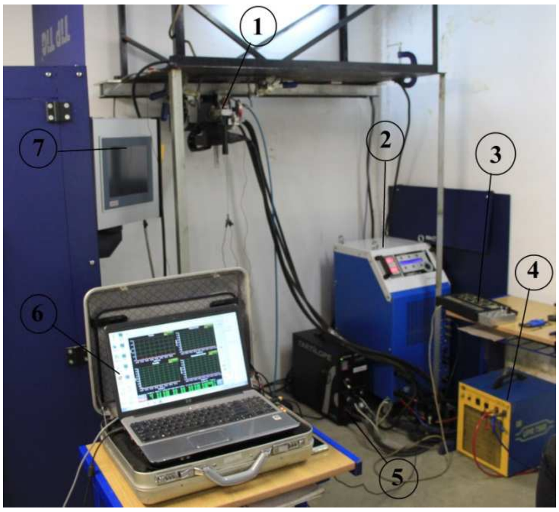

Figure 3. Equipment used in tests: 1) Welding bug Tartílope V4; 2) Welding power source; 3) Welding bug interface; 4) Refrigeration center; 5) Welding bug CPU; 6) Data acquisition system; 7) TIP TIG interface.

For tests with dynamic feeding in high frequency it was applied a feeding head manufactured by TIP TIG, which works with wire frequencies of 16 Hz to 20 Hz and an amplitude set in 5 mm [10]. Its wire feeding range is of 0,2 to 18 m/min. This means, that in TIP TIG dynamic feeding the welding operator sets the average value between back/forth movement, and the oscillation occurs independently of this mean. In filming tests it was applied a welding camera XIRIS XVC 1000 with HDR (*High Dynamics Range*) function at an acquisition rate of 55 Frames/s at 1280 x 1024 p [11].

3. Results and Discussions

In its larges applications, the GTAW welding process applies a welding supply with current control, which can be used to welder in some basics configurations as constant current, pulsed current and alternate current. Depending on application or welder's discretion which technique is most suitable. In order to analyze the dynamic feeding characteristics with 625 nickel alloy, this section presents the results obtained applying constant and pulsed current at overhead, vertical descendant and vertical ascendant welding positions.

3.1. GTAW with Pulsed Current and Pulsed Wire Feeding (GTAW Thermic Pulsed)

The pulsed current is known to allow welding out of flat position due to its characteristic of expansion and contraction of the welding pool, when the current oscillates between a high and low level [2]. This method is also called as thermic pulsation, since this variation occurs at low frequency modifying the heat input to the part depending on the current level. In this procedure, it is applied commonly a pulsed wire feeding (as mentioned previously), but in only one direction, and the feeding head feeds more or less filler metal depending on current level [12].

The

Figure 2 shows the surface appearance and macrography of the joints at three welding position tested to GTAW Thermic Pulsed.

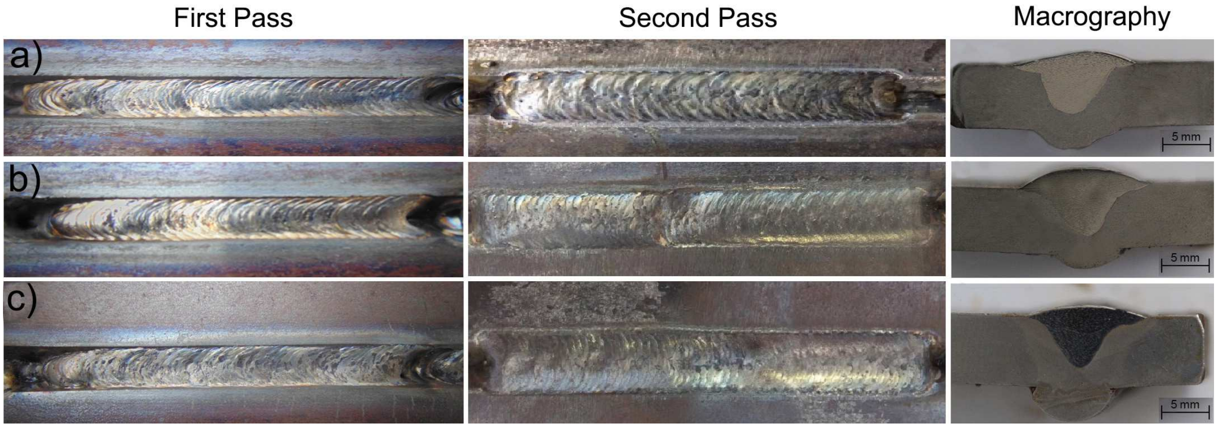

Figure 2. Surface appearance and macrography in GTAW Thermic Pulsed. In a) Vertical ascendant; b) Vertical descendant; c) Overhead.

Looking at

Figure 2, it is possible to see good weld bead wettability at three positions. With the pulsed current application, it becomes important a weaving synchronism which matches the torch weaving and current level with its pulse period occurring on edge of groove, according to Pigozzo' work [13]. Along the process it was noted that current pulses at groove's edge assisted on wettability an stability maintenance, avoiding discontinuities and weld bead geometry alterations. Observing the welding joints geometric profile, it is noted at three positions the lack of macroscopic discontinuities, as well as the beads geometry is similar in all positions. In respect to process, its behavior was stable at all welding conditions and it was possible to keep the same welding parameters, and heat input consequently, along the tests at all positions. This can contribute to keep the same metallurgy along the joint what was not evaluated in this work.

Just with process visual analysis from welding operator, often it is not possible to notice some fundamentals phenomena which are important for a good process mechanization or automatization. A number of events occurring during the welding can be crucial in the choice of what process is more robust and less susceptible to defects. In the process tracking through filming is possible to identify phenomena linked to filler metal transfer, its type (bridge or intermittent), what the droplet sizes in the intermittent case and detachment frequency, which can be evaluated after process execution in video. The Figure 5 shows a frames sequence taken from tracking shooting at vertical ascendant welding position.

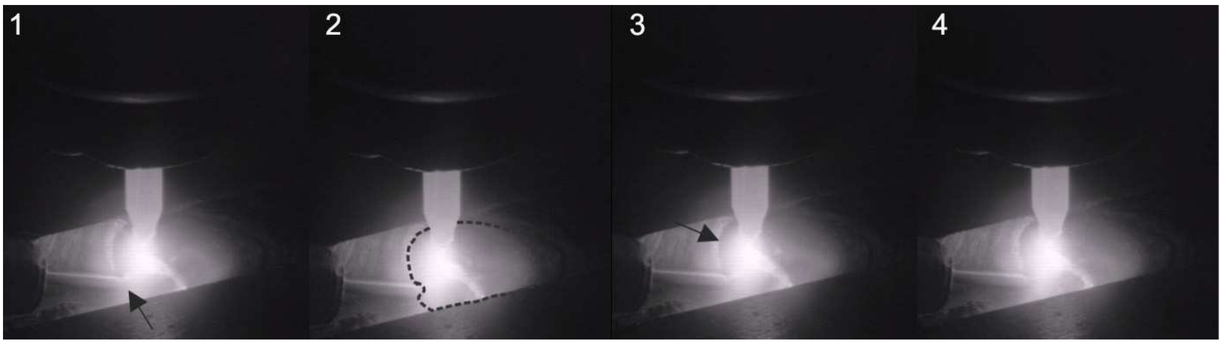

Figure 5. Welding process tracking in GTAW Thermic Pulsed (*First pass*).

It is observed in Figure 5, a metal transfer called in welding terms as bridge (indicated by arrow in first frame), this means that the filler metal is in constant touch with the puddle. The frame 2 indicates a puddle geometry characteristic from a good wettability in the groove's edge, according to indicated by arrow in frame 3. This melted metal spreading derives from constant current applying in synchronism with torch weaving what melts homogeny the groove's edge.

However, the stable behavior is not always observed along the welding process. Since the process stability is dependent on many factors, as the forces working during welding execution which change depending on welding position. In addition, filler metal variations can change its behavior due to the wire curvature originated from its spooling and conduite arrangement. In this context the Figure 6 shows a frame sequence in the second welding pass, using GTAW thermic pulsed, where occurred intermittences in filler metal transfer with formation of big size droplets on wire's tip. This increases largely the probability of electrode contamination.

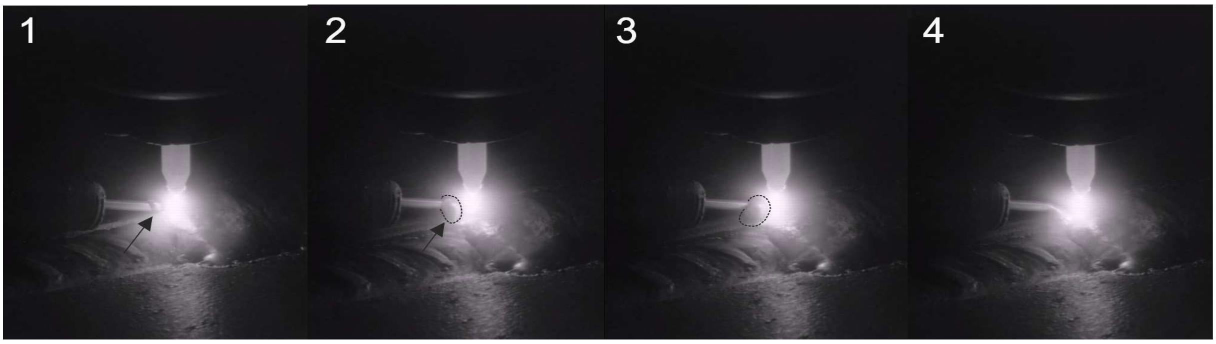

Figure 6. Welding process tracking in GTAW Thermic Pulsed (*Second pass*).

The frame 1 in Figure 6 shows the exactly moment which occurs an interruption in metal transfer bridge, the wire is out of the weld pool and receiving arc heat. At this moment, it starts a big droplet formation in wire's tip which grows until touch the puddle and be transferred by surface tension. The detachment is assisted by pulse current, which increases the arc pressure resulting in a mechanic force that assists the big droplet transfer.

3.2. GTAW with Pulsed Current and Dynamic Wire Feeding

Applying the same parameters used previously, it was changed the feeding type from dynamic feeding in high frequency. The Figure 7 shows the weld bead surface appearance carried with 625 alloy and its relevant macrography at three welding positions tested.

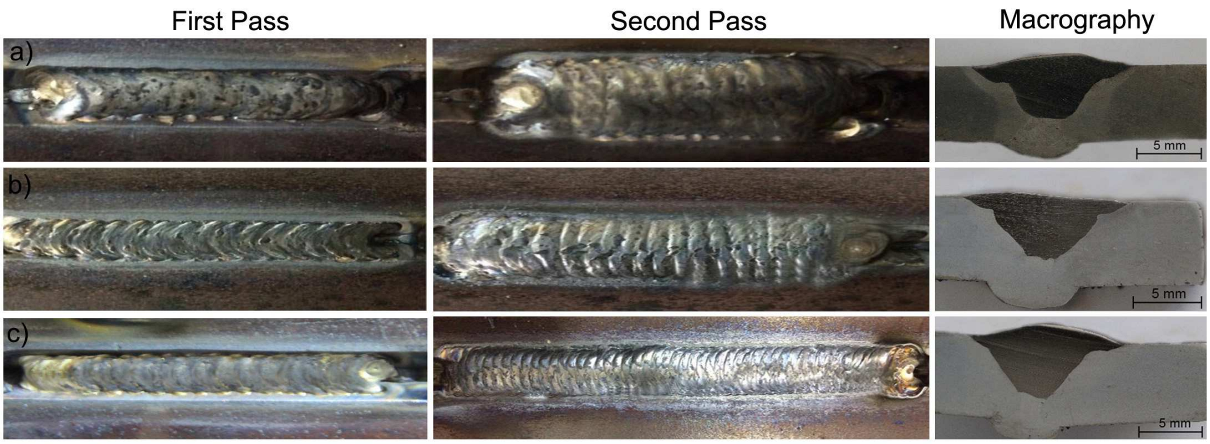

Figura 7. Surface appearance and macrography in GTAW Thermic Pulsed with dynamic feeding. In a) Vertical ascendant; b) Vertical descendant; c) Overhead.

In a weld bead surface analysis it was not noted a great discrepancy between results of GTAW thermic pulsed and these ones. Both process resulted in good beads with good surface appearance for first and second passes, at all positions. Analyzing the Figure 7 it is observed weld beads with good wettability and a joint without macrography discontinuities. It is important to highlight that in this configuration with dynamic feeding, the welding operator sets the wire feed mean (Wf_{mean}) which was set with 1,35 m/min, equivalent to average value of the tests with pulsed feeding.

Thus, with the use of wire oscillation it was possible to applies the same Wf_{mean} in a I_{pulse} (150 A) as well as in I_{base} (80A) without problems like big droplet formation and process destabilization. The Figure 8 shows the behavior noted during process shootings.

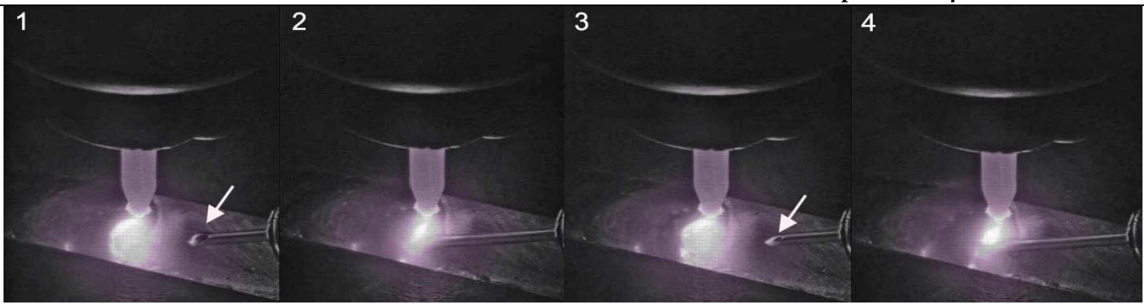

Figure 8. Welding process tracking in GTAW Thermic Pulsed with dynamic feeding (*First pass*).

The Figure 8 shows four frames which illustrate the filler metal back and forth movement along the welding. It is noted small melted droplets formation in wire's tip reducing the electrode contamination susceptibility and consequently process destabilization. The Figure 8 apply to current pulse period moment which power is higher. Thus, even the melting heat being higher than current base period, it exists just a small droplet in wire's tip, according indicates by arrows in frames 1 and 3. This fact is assigned to wire across arc isotherms quickly due to its high instantaneous speed presents in back/forth.

3.3. GTAW with Constant Current and Constant Wire Feeding (GTAW Conventional)

At many applications the GTAW process is used with constant current without the necessity to synchronism between torch weaving and current waveform, this condition becomes the process manually and mechanized easier than pulsed process. However, with constant current it has difficulties in its execution related to puddle sustainability out of flat position. In addition, it should follow a relation called by Delgado [2] as Wire feeding X Arc Power. This relation tries to guarantee that the filler metal quantity be melted in a continuous way, but without assurance in weld bead quality.

Without the high level of current pulse, in the current pulse case, the bead with constant current tends to result in a weld with low wettability, and consequently a bead with high convexity and great probability in welding defects, mainly in groove's edge (Figure 9). This fact worsen when it is applied filler materials with high viscosity in melted state. These are known in welding terms as difficult wettability materials, like Inconel 625.

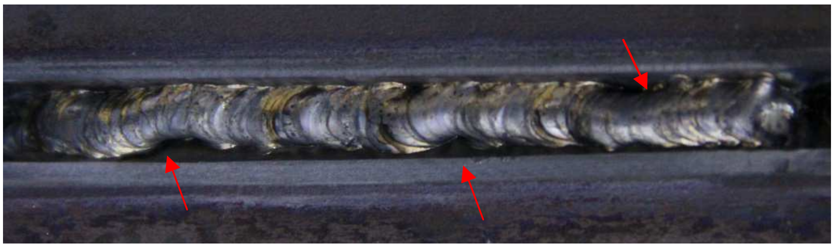

Figure 9. Joint Surface appearance in GTAW Conventional, in the first pass at vertical ascendant position.

The arrows in Figure 9 indicate low wettability areas which create a favorable condition to defects appearance like lack of fusion. In this way, it was not carried out the second pass for fulfillment, being the process with constant current quite robust and inappropriate to execute orbital process with the same welding parameters. With process shooting it was observed some phenomena as shows the Figure 10.

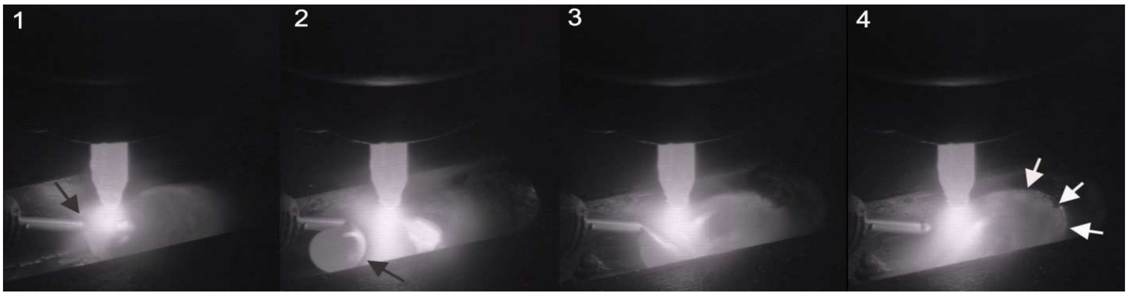

Figure 10. Welding process tracking in GTAW Conventional with constant feeding (*First pass*).

The first frame in Figure 10 shows a bridge type metal transfer. But, at a particular time occurs an interruption in metallic bridge. Such as the wire forward is constant it is verified a big size droplet in its tip. This event creates a critical condition to electrode contamination, because the melted droplet has a large mass which is pulled to gravity force direction. In third frame it shows the moment at the droplet touch the puddle and is pulled by surface tension, and in fourth frame the wire will keep in forward movement forming another droplet. This interruption in metallic bridge can change the bead geometry in addition to its high convexity, as shown in Figure 9. It is known that with constant current in welds out of flat position, is important the application of lower current levels, creating a small weld pool and so avoiding its run off. However this creates a critical condition facilitating breaks in metallic bridge with wire melts occurring before it touches the puddle, due to low wire feeding values.

3.4. GTAW Constant Current and Dynamic Wire Feeding

In this topic, it shows the results in application of dynamic feeding in GTAW with constant current. It is important to emphasize the impossibility in process application at previously condition with constant current.

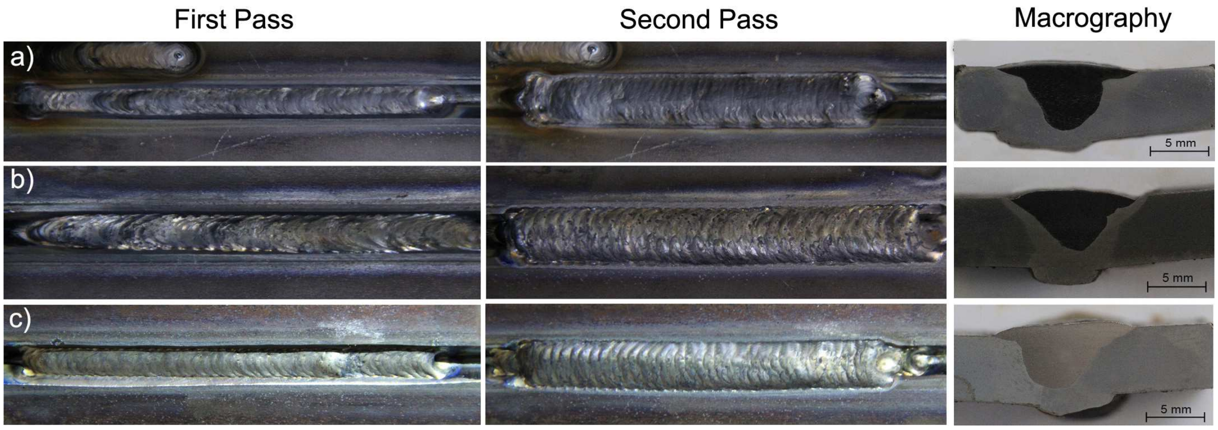

Figura 11. Surface appearance and macrography in GTAW with constant current and dynamic feeding. In a) Vertical ascendant; b) Vertical descendant; c) Overhead.

The welds presented in Figure 11 show a weld bead with good wettability for first and second passes, with great repeatability at three welding positions. The macrographies show the characteristics noted in joints surface analysis, a bead without macroscopic discontinuities. At all positions it was possible to process realization applying the same welding parameters, what prove an increase in process robustness with dynamic wire feeding.

In the use of pulsed current, the dynamic wire feeding just showed a reduction in electrode contamination probability and weld beads surface appearance were similar for both conditions. However, with constant current the results show more evident benefits, being possible to achieve welds with good aspects similar to pulsed current.

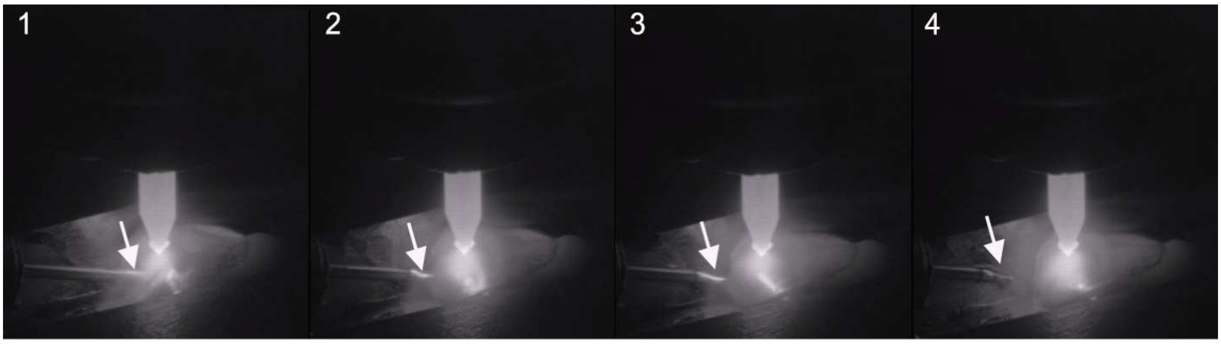

Figure 12. Welding process tracking in GTAW with constant current and dynamic feeding (*First pass*).

The Figure 12 shows the moment when wire retreats and by surface tension the puddle is pulled at the same direction until the brake in melted bridge. At an isolated occurrence, the puddle would keep oscillating up to the energy of the wire perturbation be dissipated through its own system reaction mass-spring-damper. However, the most important is that this phenomenon occurs at each cycle of forward and backward movement in the filler metal, around 20 Hz. Thus, the puddle dynamic reaction is slow and damping ratio low enough for does not mitigate its oscillation until next wire movement cycle. Therefore, it is possible to affirm that the weld pool surface in the processes with dynamic wire feeding is in constant vibration.

4. Conclusions

In a results evaluation, it is possible to conclude that the dynamic feeding provides an increase in process robustness, due to higher instantaneous feeding speed of the wire. This makes the filler metal run through the arc isotherms faster until touch in the puddle. At this moment it melts dropping a small portion of filler metal, when begins its backward movement. This decrease the arc heat input over the wire avoiding big droplets formation which can contaminate the electrode, inducing the process stop. This phenomenon repeats for pulsed and constant current, without significant difference over the weld beads regardless of energy available for melting.

The benefits of dynamic feeding in pulsed current were less significant than the results with constant current, this fact derive from current pulse influence over proceedings, which assists in weld bead wettability when synchronizing the pulse with groove's edge. When applied the Thermic Pulsed synchronized, the mechanic action imposed by arc in current pulse helps to droplets detachments formed in wire's tip, this push them toward the weld pool.

In constant current the wire dynamic and puddle agitation, changed its behavior increasing its wettability. Most likely for the change in surface tension gradient to negative, this creates a force on puddle surface acting from high temperature area to low temperature area (puddle's edge).

In grooves fulfillment out of position with Inconel 625, the dynamic wire feeding shows a great technique when it applies constant current. Enabling apply simpler welding manipulators and welding power sources which do not have weaving torch synchronism and pulsed current.

5. Acknowledgements

The authors gratefully acknowledge all LABSOLDA's staff which contributed to results achieved in this work, to POSMEC, the Santa Catarina Federal University, Brazilian National Agency for Petroleum, Natural Gas and Biofuels, and Petrobrás which incentives the research and in some way collaborated with this work.

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