


Contributions of the High Frequency Dynamic Wire Feeding in the GTAW Process for Increased Robustness

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Abstract: The GTAW process is recognized as a process of high metallurgical quality, being widely used in the pipelines welding, mainly in the root pass. The relative independence between the heat delivered to the melting pool and the amount of material added helps to control the melting of the material and to avoid the appearance of welding discontinuities such as lack of fusion and lack of penetration. When orbital welding is carried out, mainly in the overhead position, there is a tendency of electrode contamination by the melted wire, reducing process productivity and quality. In this scenario, there are some strands of the GTAW process that aim for increased productivity, reconciled with the already present high metallurgical quality. These include low and high frequency dynamic wire feeding, preheating wire and tangential wire insertion. The present work deals with the contribution of the high frequency dynamic wire feeding for the increase of robustness in the GTAW process, evidencing through voltage monitoring and high speed filming the formation of regular and uniform drops for the process stability.

Key-words: TIG; Pulsed wire feeding; Oscillating wire; Automatic GTAW welding.

1. Introduction

Although there is a constant seek for improvement for the use of renewable energies, the oil and natural gas industry still represents an indisputable foundation in the world economic-industrial scenario. Not only for energy purposes, the products generated by this industry are used by many sectors of the economy, increasing the requirement for more efficient methods of producing pipelines to transport this commodity [1].

Arc welding is the main manufacturing process used in the construction, repair and maintenance of the pipeline, in order to provide structural integrity of the joints. In addition, more productive welding processes directly influence costs, schedules, analysis risk and project viability.

In the manufacture of pipes, the first step of welding, known as the root pass, is considered as a critical stage in the execution of the pipelines joint, given its structural importance of support for subsequent passes. Typically, the root pass is performed with the GTAW process and filled with the SMAW process, both manual [2], causing difficulty in maintaining the required quality [3-5]. In the orbital welding process, the welding torch is positioned automatically, so that it follows the geometric profile of the tubes to be welded, which remain stationary [6,7].

The GTAW process, while inherently permitting better metallurgical quality when compared to other traditional processes, such as the GMAW process, has a great disadvantage when analyzed for its deposition rate and consequent process productivity [8]. Still, when performed manually, it requires much greater experience and practical knowledge of the operator [9]. As advantages, the GTAW process presents a relatively low equipment cost [10]. The process, because it allows an independence in the rate of material fed with the heat supplied to the workpiece, allows a broad control of the aspects that contribute to a weld with high metallurgical quality, such as penetration control, wettability, dilution, etc. [11].

Due to the presence of a non-consumable electrode near to the addition material molten arc, there is a high tendency and possibility of contamination of this electrode by this molten material. This is critical especially in orbital welding procedures, where the out of position welding is more complex and susceptible to the appearance of defects and contamination of the electrode, because the gravity force acts as to displace the melt pool.

In this scenario, there are modalities of the GTAW process that aim to increase the productivity and robustness of the process. Among these, pre heating wire feeding (Hot Wire) [12,13], tangential wire feed [14] and dynamic wire feed at low [15] and high frequency [16,17] can be mentioned.

There are different options in the automatic wire feeders for the GTAW process that aim to feed at different frequencies, as for dynamic feeding. The present work has the goal of studying the influence of the high frequency dynamic wire feeding in the reduction of electrode contamination tendency by the added wire, and consequently the increase of the process robustness, contributing to the increase of the quality and the reduction of the work time and cost of the process as a whole.

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2. Materials and Equipments

SAE AISI 1020 steel sheets of 3/8 “(9.5 mm) thickness were used for the tests, and the ER 70S-6 wire-electrode, 1.0 mm in diameter, was used as the addition material. The workpieces had their surfaces previously cleaned by roughing in order to avoid opening defects and arc instability due to the presence of oxide layers.

The WIG 500i DC Pulse welding source, from Jäckle, was used. This source allows the regulation of current from 5 A to 500 A, using only constant current for its automatic application, in addition to allowing the approach with preheating wire (Hot Wire), the second not being discussed in the article.

In order to better observe the dynamic aspects of the melt pool during the procedure, the tests were monitored by means of the SAP - Acquisition Systems. The equipment, manufactured by the company *IMC Soldagem*, allows acquisition of current, voltage, gas flow and wire feeding speed at a sampling frequency of 5 kHz.

The voltage measuring channels were installed between the electrode and the workpiece (referred in the work as Arc Voltage), and between the electrode and the wire (referred in the work as Wire Voltage).

In the same way, to increase the understanding of the physical phenomena involved in the process, the IDT MotionPro Y4-S2 high-speed camera was used in conjunction with the IDT data acquisition module to observe details of arc behavior, the electrode, the wire and the melt pool, factors of profound importance for the understanding of the procedures static behavior.

For the goals aimed in this work, a welding wire feeder was adopted that allows continuous and dynamic wire feeding at high frequency, in a frequency of 18 Hz. Figure 1 shows the sketch of the equipment device for the welding tests.

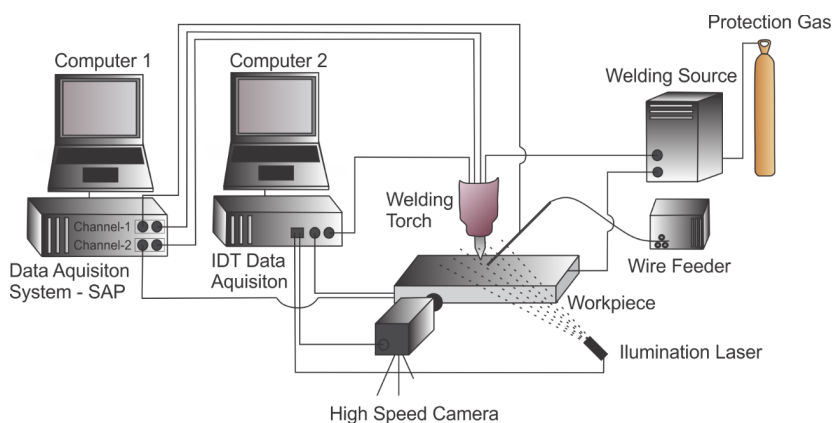


Figure 1. Sketch of experimental device.

The wire feeding was performed in front of the arc, with a distance of 4.8 mm between the electrode and the added wire.

3. Experimental Procedure

As the main goal of the work is to evaluate dynamic wire feeding on the robustness of the process, electronic parameters were set, listed in Table 1, changing only the dynamic feed forms, with an oscillation frequency of 18 Hz, and continuous (0 Hz).

Table 1. Parameters used for the execution of the welding processes with continuous and high frequency dynamic wire feeding.

Arc Current (A)	150
Welding Speed (cm/min)	20
Wire Feed Speed (m/min)	1.5
Dynamic Wire Feed Frequency (Hz)*	18
Electrode Composition	98% W 2% Ce
Electrode Diameter (mm)	3.2
Electrode Angle (°)	45
Wire Material	ER 70S-6
Wire Diameter (mm)	3.2
Base Material Composition	SAE AISI 1020
Base Material Thickness (mm)	9.5
Protection Gas	Ar
Gas Flow Protection (l/min)	12
Distance Between Electrode and Base Material (mm)	4.0

*Only valid for procedures that use the dynamic wire feed.

Thus, three replicates were performed for each of the scenarios analyzed.

Given the importance of understanding the real influence of dynamic wire feed at high frequency, a more detailed approach was required in the wire feed motion. In order to evaluate this behavior, high speed filming was carried out during the welding process (Figure 2).

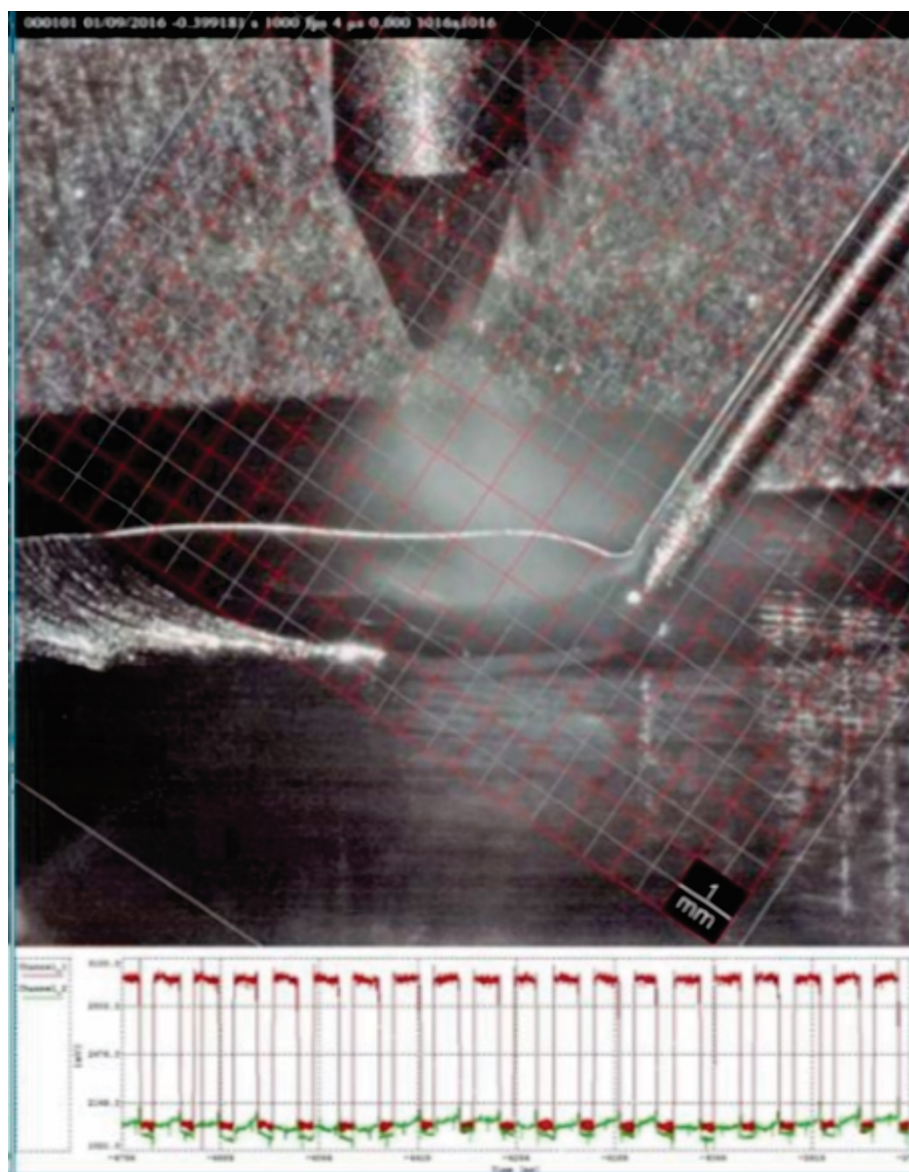


Figure 2. High speed filming for analysis of instantaneous speed and wire feeding period [18].

4. Results and Discussion

From the analysis of the high speed filming, it was possible to measure the instantaneous wire feed rates during the advance and stopped period. For the parameterized wire speed of 1.5 m/min (set speed), it was found that the actual wire feed rates in the wire torch, at the moments of wire forward movement, averaged 10.7 m/min. This measured average speed value is due to the short period in which the wire remains in forward movement as compared to the time it remains stopped. While the wire is stopped for 44 ms at each oscillation period, it is in forward motion for only 7 ms.

During the welding tests, the data acquisition via SAP becomes necessary, as already mentioned, for a deeper analysis and understanding of the electronic phenomena and their physical consequences that are occurring in the arc and in the melt pool.

This way, factors such as the period of detachment and the dynamic behavior of the electric arc can be evaluated.

In tests conducted with continuous wire feeding, a lack of periodicity can be easily observed in the periods where the wire is detached from the melting pool (Figure 3). This fact is justified by the lower instantaneous speed of wire feed, making it more susceptible to the thermal influence of the electric arc, whereby a large droplet is formed, followed by its detachment due to

the surface tension from the weld pool. Due to the heterogeneity of the droplet size, caused by the randomness of its mechanical oscillation and that of the pool until it touches the weld pool, the detachment time is also heterogeneous.

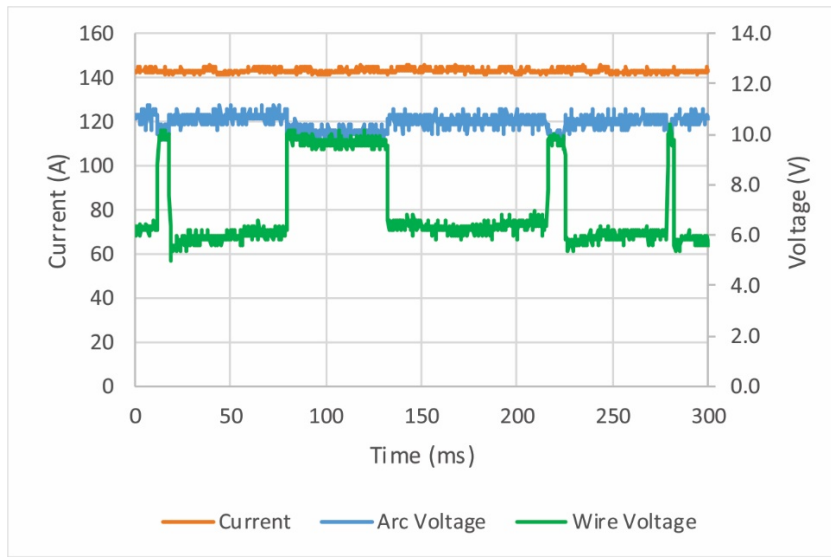


Figure 3. Acquisition of procedure data using continuous wire feeding.

Analogously, the wire detachment profile of the procedures performed with high frequency dynamic wire feeding (Figure 4) can be analyzed.

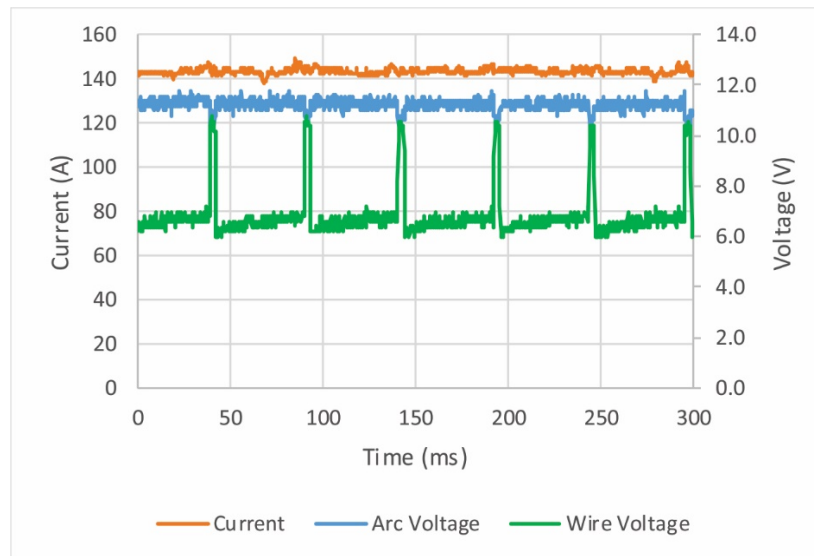


Figure 4. Acquisition of procedure data using high frequency dynamic wire feeding.

In the tests carried out with high frequency dynamic wire feeding, a regular, homogeneous droplet detachment profile can be observed, supporting the fact that the dynamic wire feeding assists in the formation of periodic and regular cycles in the formation and detachment of drops. This is due to the high instantaneous forward speed, which allows only for a small droplet to be formed, whose detachment is then governed by the retraction or stall of the wire, in a periodic fashion.

The electric data profiles of the performed procedures support the construction of the theory of this work, in the sense of increasing the robustness of the GTAW process with high frequency dynamic wire feeding. However, only with high speed filming is it possible to understand and assess the observed behavior.

The variation of both measured voltage signals observed by the data acquisition proves to be a mechanical disturbance of the electric arc. When the wire is in contact with the melt pool (Figure 5B), the arc is anchored closer to the wire, due to the

formation of a smaller minimum distance between the two electrodes of the system, unlike the moment when the wire is detached from the melt pool (Figure 5A).

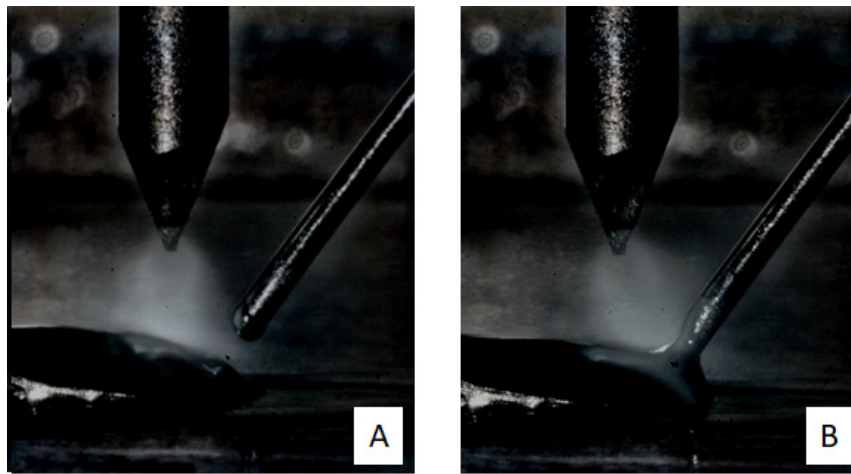


Figure 5. High speed filming of the welding procedure with dynamic wire feeding, at times with detachment (A) and anchoring (B) of the wire in the melt pool [19].

This perturbation can be better observed by joining the two moments analyzed above (Figure 6).

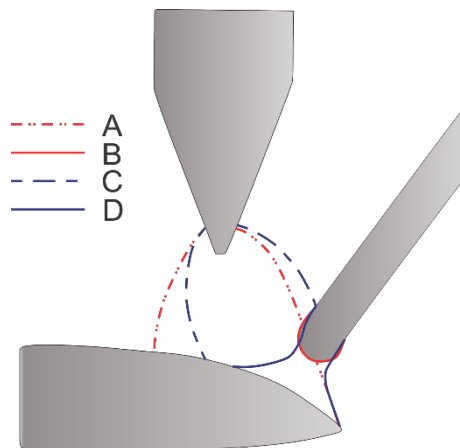


Figure 6. Analysis of the disturbance behavior of the arc during the detachment and anchoring of the wire from the melt pool. (A) Profile of the electric arc with the detached wire; (B) Detached wire profile; (C) Profile of the electric arc with the wire anchored in the met pool; (D) Anchored wire profile.

Figure 6 illustrates the morphological difference of the electric arc between the moments where the wire is in contact (A) and detached (C) from the melt pool. Captions (B) and (D) correspond to the profile of the wire while it is in contact and detached from the melt pool, respectively.

The perturbation of the arc caused by the detachment and anchoring of the wire in the melting pool, is reflected in the variation of the instantaneous average voltage (Figure 7).

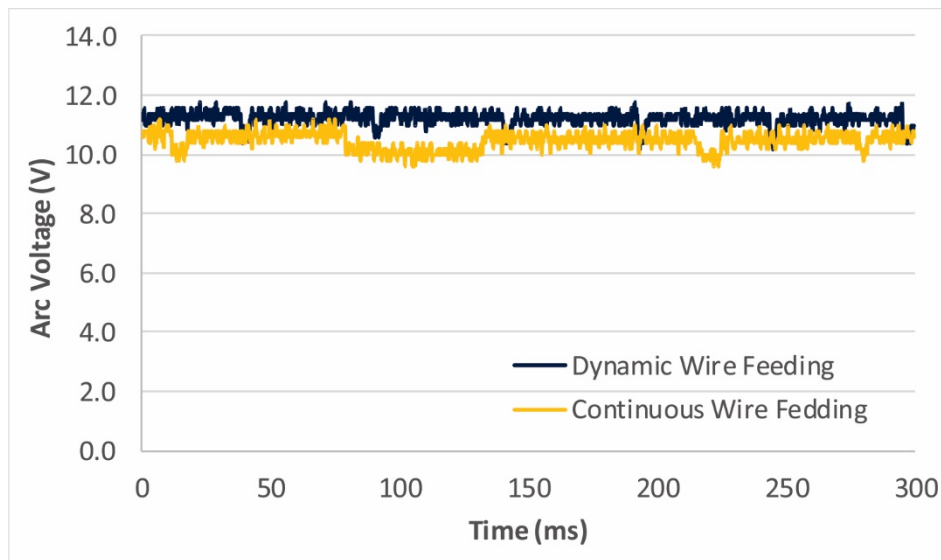


Figure 7. Average arc voltage of the continuous and dynamic wire feeding.

Similarly, through the direct relation between power and voltage (Equation 1), the same occurs in the variation of the average power of the evaluated procedures (Figure 8).

$$P = U * I \tag{1}$$

where P is the arc power, U is the arc voltage, and I is the arc current.

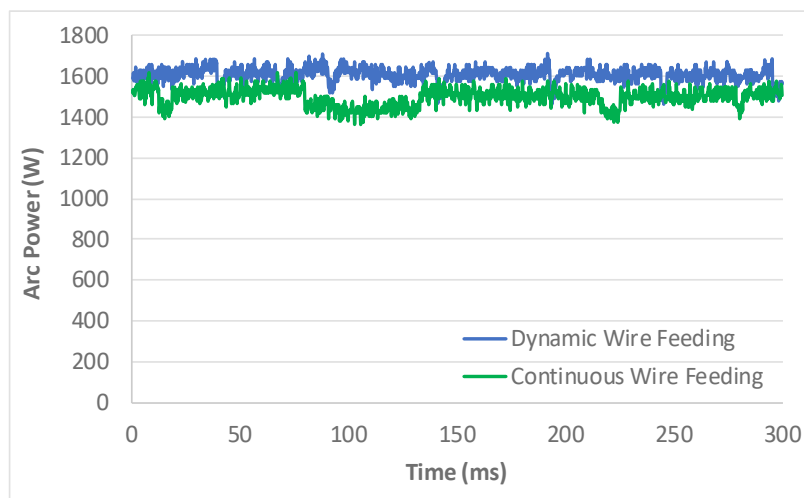


Figure 8. Average arc power of the continuous and dynamic wire feeding.

Based on the static behavior of the two procedures, the total average arc voltage and the total average arc power (Table 2) were calculated. Given a period large enough to allow a satisfactory number of repetitions of the wire detachment cycle for both processes, the influence of dynamic wire feed on the process power is evident.

Table 2. Total average arc power and average arc voltage obtained for the continuous and dynamic wire feeding procedures.

	Average Arc Power (W)	Average Arc Voltage (V)
Dynamic Wire Feeding	1609	11.2
Continuous Wire Feeding	1499	10.5

While the process with dynamic wire feed presented an average arc power of 1609 W, with a very stable and homogeneous pattern, the continuous wire feed process had an average arc power of 1499 W, with a comparatively heterogeneous pattern. This variability can be further analyzed through the histograms in Figure 9.

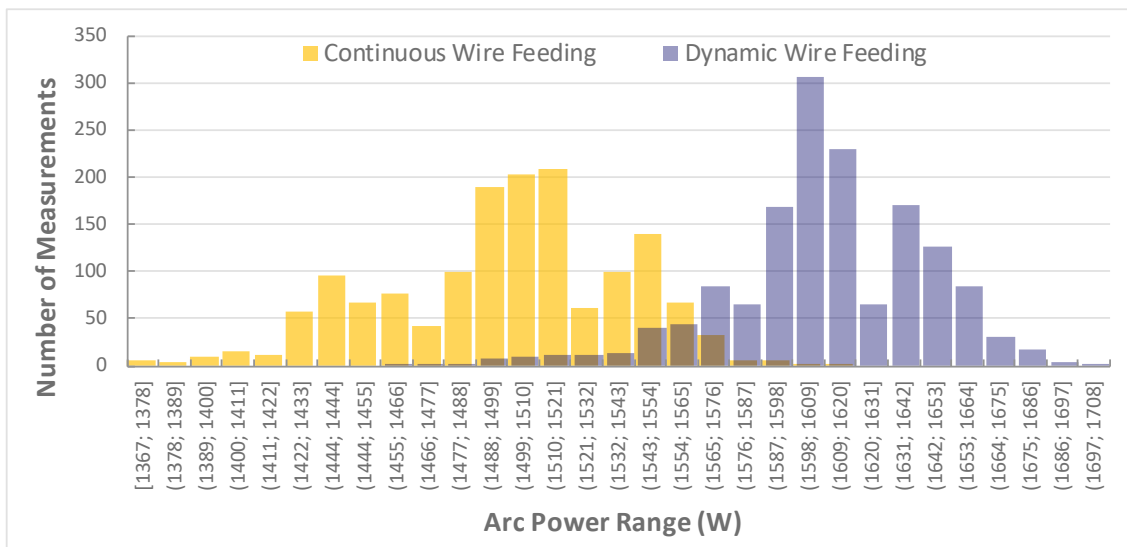


Figure 9. Histograms of the average arc power continuous and dynamic wire feeding GTAW Welding.

The formation and detachment of non-uniform and inconstant droplets has as main consequences the formation of coarse droplets which, due to their high volume and mass, can compromise the execution of the repeatability of the process and the electrode used. These aspects were observed using continuous wire feeding (Figure 10).

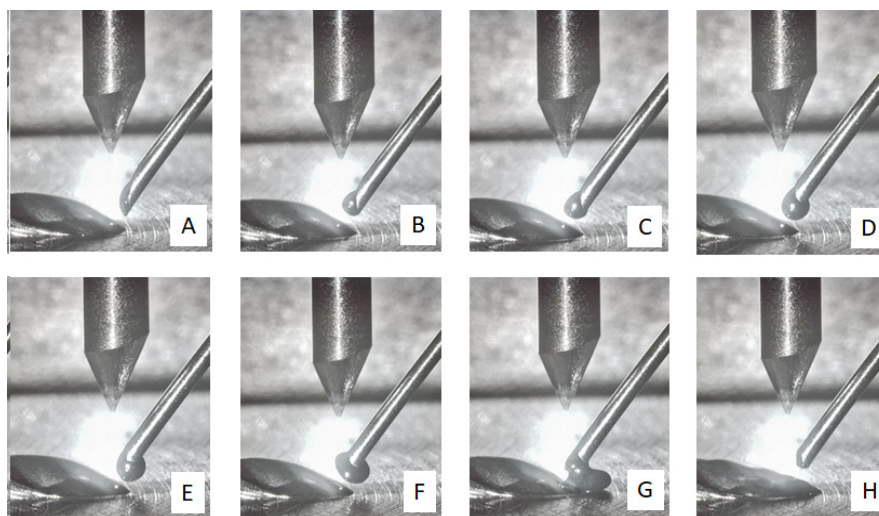


Figure 10. Formation behavior and detachment of droplet in the process performed with continuous wire feeding. (A-F) Formation of the coarse drop; (G) Coarse drop contact with material and base and detachment; (H) Cycle restart [20].

In the high speed filming of the process with continuous wire feeding, the formation of coarse drops, with an average volume of 2.14 mm³, can be observed, compromising the integrity of the process.

In the procedure with the use of high frequency dynamic wire feeding, the wire, due to its high instantaneous speed of advance, does not suffer as much influence of the electric arc heat, arriving at the melt pool with a smaller liquid region when compared to the process with continuous wire feeding, as show in Figure 11. The average volume of the droplets formed for the dynamic wire feeding process was measured at 0.63 mm³, approximately 3 times lower than the droplets formed from the continuous feed process.

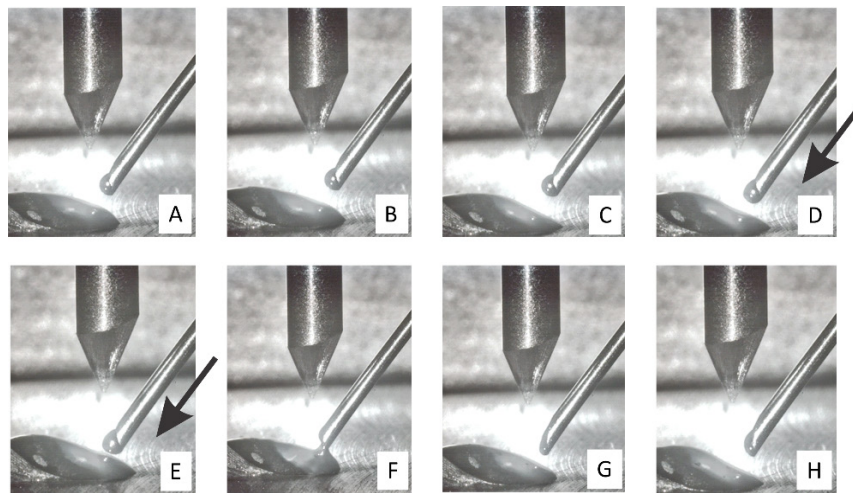


Figure 11. Behavior of formation and detachment of droplet in the process realized with high frequency dynamic wire feeding. (A-C) Gout formation; (D-E) Moving Wire; (F) Drop contact with the melt pool and detachment; (G-H) Cycle restart [21].

Finally, forced welding tests were carried out, with the intention of reaching the approximation limit between the electrode and wire and observing the tendency of contamination of the electrode in the two scenarios, with continuous wire feeding and high frequency dynamic wire feeding.

While the tests performed with dynamic wire feeding presented satisfactory results of repetition and exemption of electrode contamination, the tests performed with continuous wire feeding presented very different and unsatisfactory results, as can be observed in Figure 12.

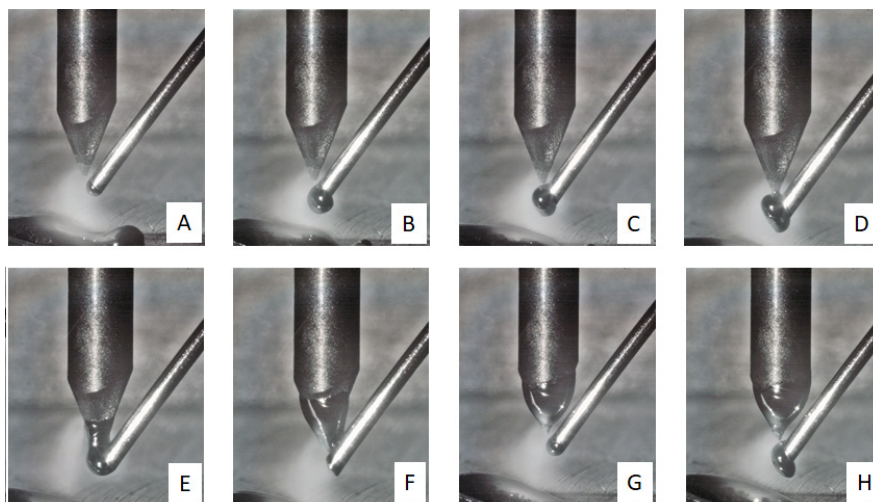


Figure 12. Formation behavior and detachment of droplet in the process performed with continuous wire feeding. (A-C) Coarse droplet formation; (D-F) Contact of the coarse drop with the tungsten electrode; (G) Detachment of the coarse drop for the tungsten electrode; (H) Formation of a new coarse drop [22].

Through this test, the robustness of the process proposed by the high frequency dynamic wire feeding has been proven, achieving satisfactory repeatability and electrode integrity during the process.

5. Conclusions

The huge difference between the instantaneous wire feed rate during the forward movement in dynamic wire feed (10.7 m/min forward speed, for an average set speed of 1.5 m/min) and the average set speed parameterized for continuous feed (1.5 m/min) are responsible for the distinguishing features of dynamic wire feeding. The higher instantaneous wire feed speed implies in a shorter period of time in which the wire is subjected to the electric arc heat.

Due to this aspect, one can understand the absence of the tendency of coarse droplets to form during the dynamic feed process. The formation of droplets and its consequent detachment becomes more uniform, regular and homogeneous, which can be observed and concluded from the analysis of arc voltage and power of the processes with continuous and dynamic wire

feeding. Thus, the process benefits not only from the more regular electric behavior, and consequent more regular heat input to the piece, but also from the higher robustness against instabilities caused by electrode contamination.

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