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DEVELOPMENT AND EVALUATION OF TRANSFER MODES IN GMAW PROCESS ON VERTICAL CLADDING USING ALLOY 625

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Abstract

Metal cladding operations using GMAW have been studied and have been evolving along with its associated equipment and technologies. This work aims to evaluate the effects of the different transfer modes, pulsed current and controlled short-circuit with dynamic wire-feed (DWF), in vertical deposits using alloy 625. These modes were evaluated individually and acting together, through a mixed process called MIG/MAG AD-P, the result of Brazilian developments in equipment and technologies. For the evaluation of the combined process, standard ratios between the transfer modes were defined in 75%, 50% and 25% relative to the number of cycles in pulsed transfer and cycles in short-circuit DWF. Better wettability was observed using larger proportions of the pulsed mode, however aspects related to dilution were constant. It was found that the absence of dilution effects is due to the vertical position. By means of tests on flat position, it was concluded that the gradual increase of the thermal input causes a higher dilution rate.

Keywords: Welding. Dynamic feeding. Dilution rate.

1. Introduction

In the oil and gas industry, metallic cladding operations are commonly employed due to favorable conditions for the corrosion occurrence to which the components are exposed. In certain situations, the need to coat it's not only related to the high cost of producing a whole piece made of corrosion resistant material, there is also a need to guarantee mechanical properties that could not be reached by Corrosion Resistant Alloys (CRA). "A wide variety of metal alloys can be used as CRAs, among the most important of these are stainless steels and nickel-based alloys" (ASM International, 1993). In a context focused on the manufacture of coated components, welding processes have significant participation.

In general terms, the specifications for metal cladding operations are related to the thickness of the deposited layer and the dilution rate with the base metal, which in essence should have low values. In addition, features of an operational nature are also evaluated, such as the process automation capacity, the deposition rate provided and the quality of the deposited

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layer. The analysis of all these aspects influences the decision making about which process will be used in a given situation.

The GMA welding process, regarding its many versions, has a wide field of application for this purpose. "Versions that use pulsed current have prominence for cladding operations, due to their advantages of stability and controllability of the metallic transfer and the molten pool, additionally a lower tendency of lack of fusion and porosities" (Silva, 2013). Despite these characteristics, the pulsed current promotes high power for the amount of wire being deposited, which can impact on the dilution levels. For this reason, modalities that provide a relative lower heat input, such as the controlled short-circuits, have been explored. Several studies (Pickin et al., 2010, Silva et al., 2015, Egerland, 2009) evaluated Cold Metal Transfer (CMT) for cladding procedures. Figure 1 shows a comparative graph between the CMT and pulsed GMAW processes relating the rate of metal deposition as a function of the instantaneous arc power.

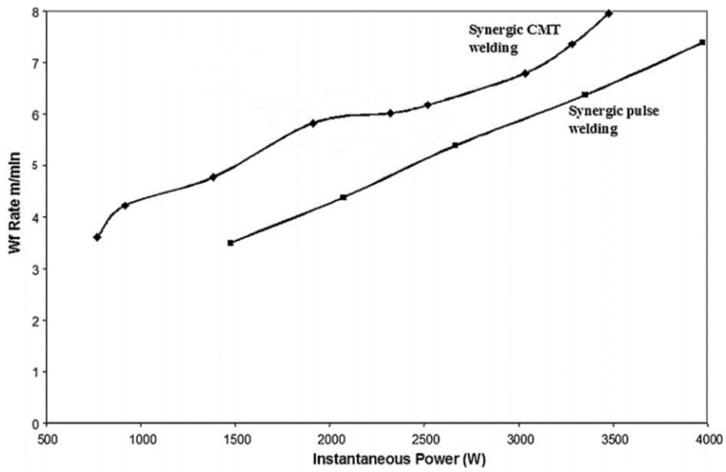

Figure 1. Comparison between deposition rates for the CMT synergic program and pulsed welding using 4043 wire (Ø1,2 mm). Adapted from (Pickin, Williams, & Lunt, 2010).

The work of Pickin et al. (2010) compares CMT and Pulsed processes in a multipass cladding using an aluminium alloy. Pickin et al. shows that with each successive pass the deposition using CMT exhibits a decreasing dilution ratio and increasing reinforcement height. In contrast, the use of pulsed current promotes a greater and more uniform dilution with a reduced reinforcement height. It concludes that the CMT process can be used in such an application and, with the refining of parameters, it can achieve a better control over the dilution rate.

The addition of current pulses, promoting the droplet detachment and metal transfer by free-flight, combined with short-circuit transfer in the CMT process established a new version, the CMT Pulse (CMT+P). The addition of pulses interposed with short-circuits makes the process regulation more flexible with the possibility of adopting different levels of thermal input, without compromising the stability of the arc and remaining absent from spatter. In this way, the power range that the process operates increases significantly. According to the manufacturer, "this process reaches any value in the energy range between CMT and pulsed arc" (Fronius International GmbH, 2018). The chart b in Figure 2 illustrates the power range of these processes for the synergetic line of the 4043 wire with diameter 1.2mm.

The work of Pang et al. (2016) argues that the thermal input can be better adjusted and controlled using the CMT+P process when compared to the traditional CMT process. As a result, the penetration profile and weld bead dimensions can also be controlled by varying the number of CMT short-circuits and current pulses. Figure 2a shows the schematic for the waveform of the CMT + P for a weld cycle composed of 4 pulsed cycles and 2 CMT cycles.

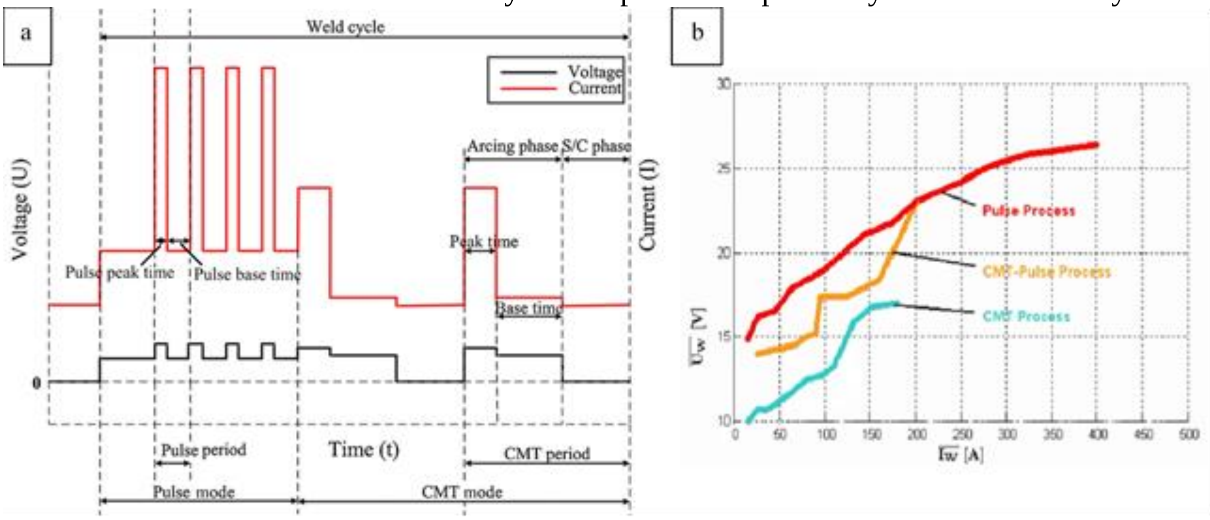

Figure 2. a) Waveform schematic for of the CMT + P process with 4 pulsed cycles and 2 CMT cycles. Adapted from (Pang, Hu, Shen, Wang, & Liang, 2016).
b) Relationship between average voltage and average current for the pulsed, CMT and CMT + P processes. Synergic line for wire 4043 1.2 mm diameter. Adapted from (Kazmaier, 2010).

The CMT's fundamental characteristic is the ability to control the metallic transfer using the retraction of the wire after the occurrence of the short-circuit. "Versions that use this strategy are being called GMAW with Dynamic Wire Feeding (DWF)" (Marques, 2017). The high level of control obtained on processes of this type opens up space for related developments, which combine different waveforms in order to extend the application range of the process, providing different relationships between welding power and deposited material. Thus, the present work aims to present the developments related to the implementation of own techniques of control for a DWF GMAW process, intercalating cycles with higher power level, provided by the pulsation of the current, and cycles of lower power, provided by a short-circuit DWF, creating a mixed process version, here called MIG/MAG AD-P. The number of cycles to be executed in each process is configurable and the effects of the relation between the number of transfer periods in each process is also object of study in this work.

In general terms, present works among the scientific community explores the CMT+P process for welding aluminium alloys in flat position. However, the use of new technologies can be helpful in situations closer to what is found in field operations, such as the use of noble alloys and positions unfavorable to the procedure. As a practical result of welding in an application of the developed MIG/MAG-AD equipment, procedures were performed aiming the vertical position cladding, using nickel alloy 625 as wire on a carbon steel surface. It is expected to conclude on the influence of the dynamic wire feed technique on the cladding results, as well as on the alternation between the pulsed mode and the short-circuiting metal transfer of the GMAW process.

2. Experimental

The tests were performed in order to simulate a cladding application in vertical position, downward direction. The specimens were prepared in dimensions of 200 mm in length,100 mm in width from a 12.7 mm (1/2 ") thick 1020 carbon steel plate. As electrode, a nickel 625 alloy was used, wire diameter 1.2 mm. The gas protection was made with a binary mix of argon (75%) and helium (25%).

In order to obtain a direct comparison of the results of each test, it was decided to standardize the wire feed speed and welding torch manipulator parameters for all experiments. By means of previous tests, the welding speed was defined due to limitations of the pulsed process, which presents a tendency for the weld puddle flow in a vertical position, requiring higher values of welding speed. Thus, the speed of 60 cm/min (10 mm/s) was established for all tests. The procedure specifications common to all samples can be seen in Table 1 and the schematic in Figure 3.

Table 1.Common procedure specifications.

Filler wire	Inconel 625; Ø1,2 mm
Base metal	Carbon steel SAE 1020
Protection gas	75% Ar + 25% He
Gas flow rate	17 l/min
Welding position	Vertical downward
Drag angle	20º
CTWD	17 mm
Welding speed	10 mm/s

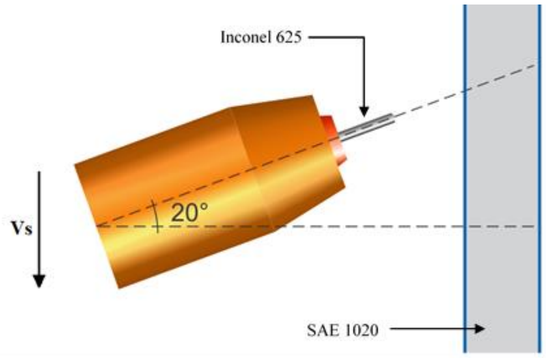

Figure 3. Procedure schematics.

The processes were configured so that they resulted in a wire average speed of 5.0 m/min. For the pulsed GMAW the parameterization a premise of one droplet per period was followed, so that the process reach stability and controllability, according to the methodology proposed by Amin (1983). For the process with dynamic feeding, the parameter survey was carried out empirically with the help of welding variables measurement tools. The essential parameters set for both processes can be seen in Table 2.

Table 2. Main processes parameters.

		Pulsed GMAW	Shor-circuiting DWF
Current Pulse	Ip (A)	380	280
Pulse duration	tp (ms)	1,9	4,0
Base current	Ib (A)	95	100
Base duration	tb (ms)	7,7	-
Short-circuit current	Isc (A)	-	70
Wire feed speed	Wfs (m/min)	5,0	5,0

In order to perform the analyzes, in all the tests were acquired the electric parameters of welding with acquisition sampling rate of 5 kHz. The deposition results were evaluated in visual inspection and cross-sectional images. The calculation of the dilution was performed according to Equation 1, where A represents the area of the reinforcement and B the infiltrated area, as defined by AWS (American Welding Society, 2009).

$$\%\, \boldsymbol{dilution} = \frac{\boldsymbol{B}}{\boldsymbol{A+B}} \cdot \mathbf{100} \qquad (1)$$

Initially, single pass tests were performed for different ratios between pulsed cycles and GMAW DWF cycles, as indicated in Table 3. The objective is the analysis of the influence of the alternation of transfer modes as well as the proportion between modes in the dilution and in the superficial aspect of the deposit without the influence of the subsequent passes in vertical operations. To reach the defined proportions, the weld cycle is also determined as 4 metal transfer periods, being it by free-flight, in the case of pulsed GMAW, or short circuiting.

Table 3. Sample definitions.

	% Pulsed GMAW	**% GMAW DWF**	**Weld cycle composition**
Sample 1	100	0	4P
Sample 3	75	25	3P + 1DWF
Sample 4	50	50	2P + 2DWF
Sample 5	25	75	1P + 3DWF
Sample 2	0	100	4DWF

For all the tests, the DIGIPlus welding power source manufactured by *IMC Soldagem,* with a current capacity of 600 A, was used. Both the software and the electronic control architecture of the power source were unlocked by the manufacturer and modified for the development of this work. The prototype welding torch has an integrated servomotor to the torch structure to promote the dynamic feeding, which was result of earlier developments of LABSOLDA/UFSC’s team.

The high-speed camera model Y4-S2 from the manufacturer IDT was used for the acquisition of metallic transfer images. The images were recorded at a rate of 5000 frames per second, synchronized with the acquisition of the arc electric parameters, voltage and current.

3. Results and Discussion

The first sample consisted of the execution of a weld pass using the plainly pulsed process (100% Pulsed). The process was properly parameterized, as result one droplet per period is being detached during the base stage. The data acquisition performed during the test can be visualized in Figure 4.

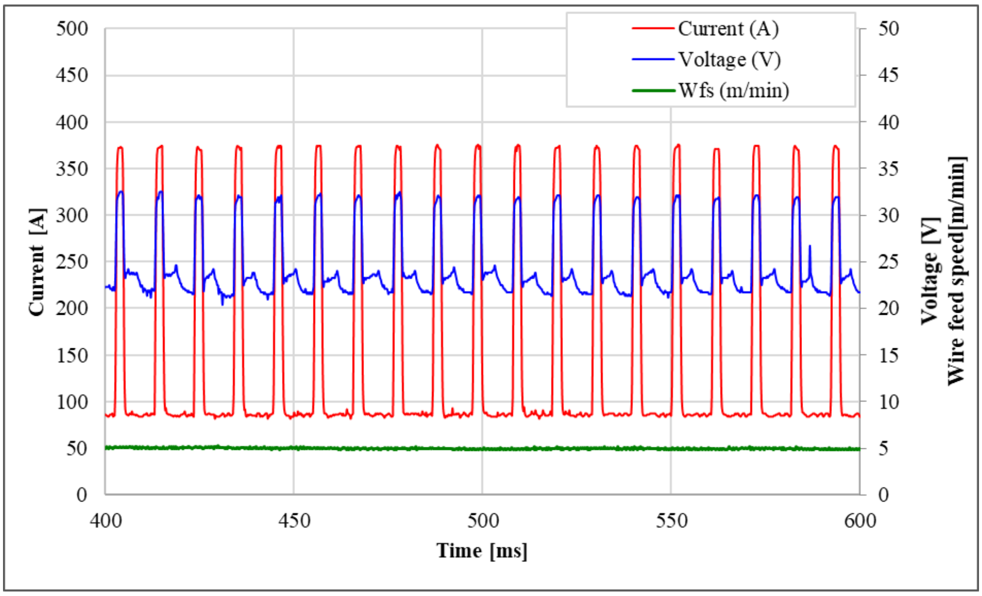

Figure 4. Acquired data from Sample 1 experiment.

During the base stage a voltage spike can be noticed, this indicates the droplet detachment for processes that the metal transfer occurs by free-flight, as the pulsed GMAW. This phenomenon was described by Amin (1983). The transfer regularity observed in the oscillogram of Figure 4 indicates the reached stability and control over the process. The detachment of droplets, the regularity and the general process behavior was confirmed by means of high-speed images. Some frames, as well as their respective instants in the period, of the Sample 1 are shown in Figure 5.

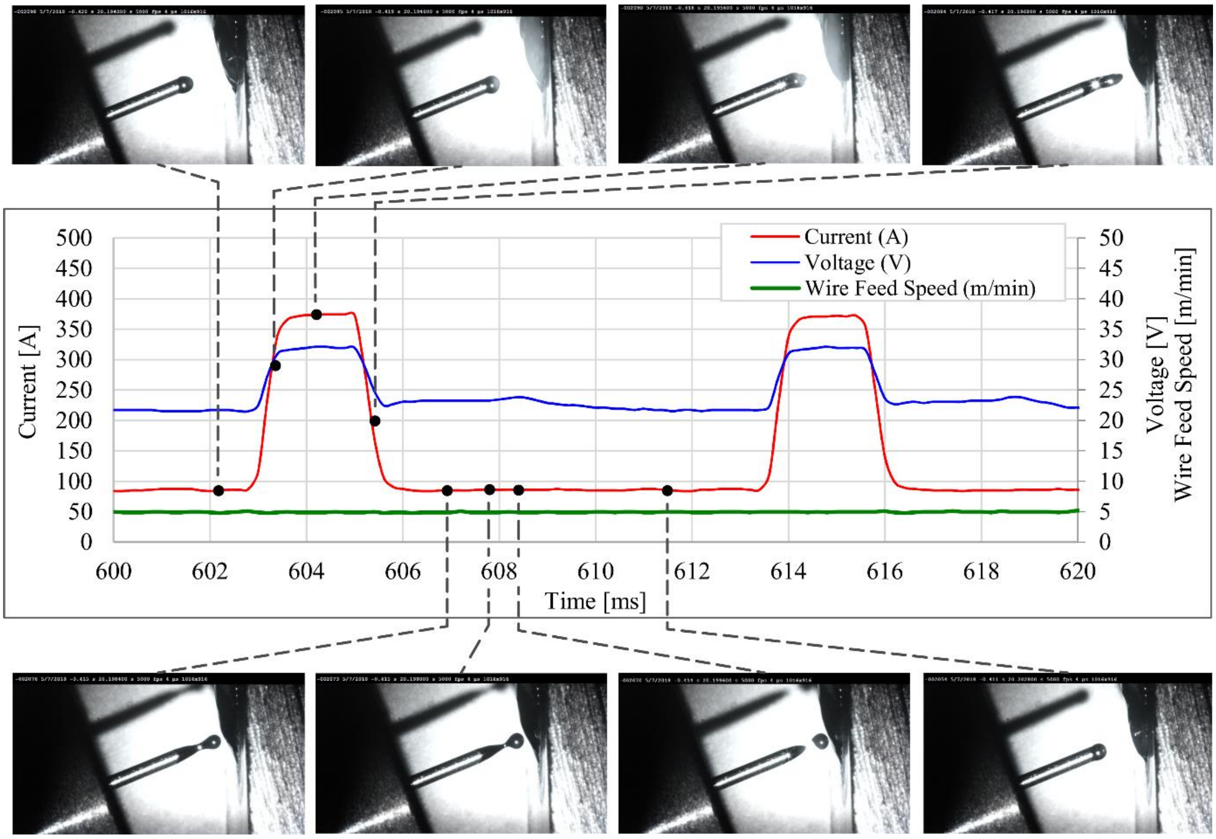

Figure 5. High speed frames detailing the parametrized Pulsed GMAW.

In a similar way to the first experiment, the Sample 2 consisted of the execution of a weld pass using the GMAW DWF process with transfer by short-circuit only (0% pulsed), in a controlled and synchronized way with the wire movement. The oscillogram for this sample is shown in Figure 6. The GMAW DWF modality was based on the work of Marques (2017), which achieved good results in aluminum and carbon steel alloys.

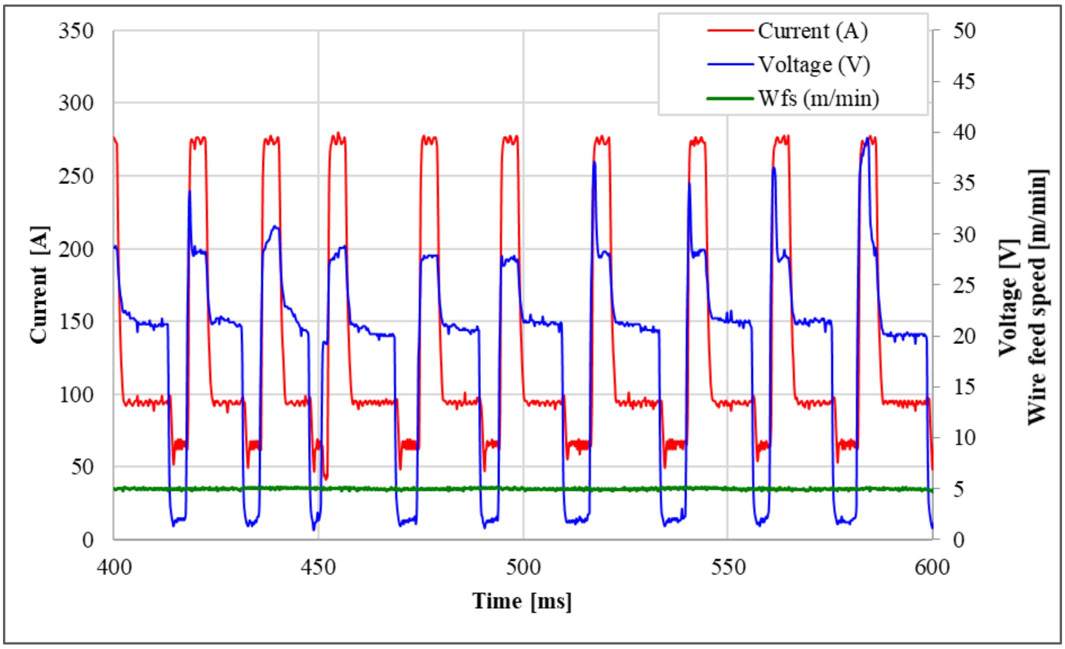

Figure 6. Acquired data from Sample 2 experiment.

The further experiments were performed with the MIG/MAG AD-P process, resulting from the alternation between the pulsed and short-circuiting DWF modes. The same parameter set for the previous test procedures were used, varying only the number of periods in pulsed transfer/short-circuit. In an analogy one can compare to what is observed in the thermal pulsed GMAW, with two levels of energy. The main difference is that in the MIG/MAG AD-P the energy variation is supplemented by different transfer modes and, considering the conditions tested, the resulting wire speed in each phase would be the same.

The tests followed the proportions previously defined in the experimental section. Sample 3 was performed with a ratio of 75% of the weld cycle in the pulsed process, Sample 4 with 50%, and finally Sample 5 with 25%. Table 4 shows the average of electrical parameters acquired during the tests and their oscillograms are shown in Figure 7.

Table 4. Average of electrical parameters acquired on the experiments.

Average values	Sample 1	Sample 3	Sample 4	Sample 5	Sample 2
Current (A)	143	127	125	121	129
Voltage (V)	24,6	22,1	20,1	18,9	18,5
Power (W)	3899	3159	2898	2669	2920

The cross section of the specimens was prepared for metallographic analysis. The images obtained are shown in Figure 8, along with the surface appearance of the weld bead. Measurement of data concerning the width, height and contact angle of the reinforcement of the samples can be seen in Table 5.

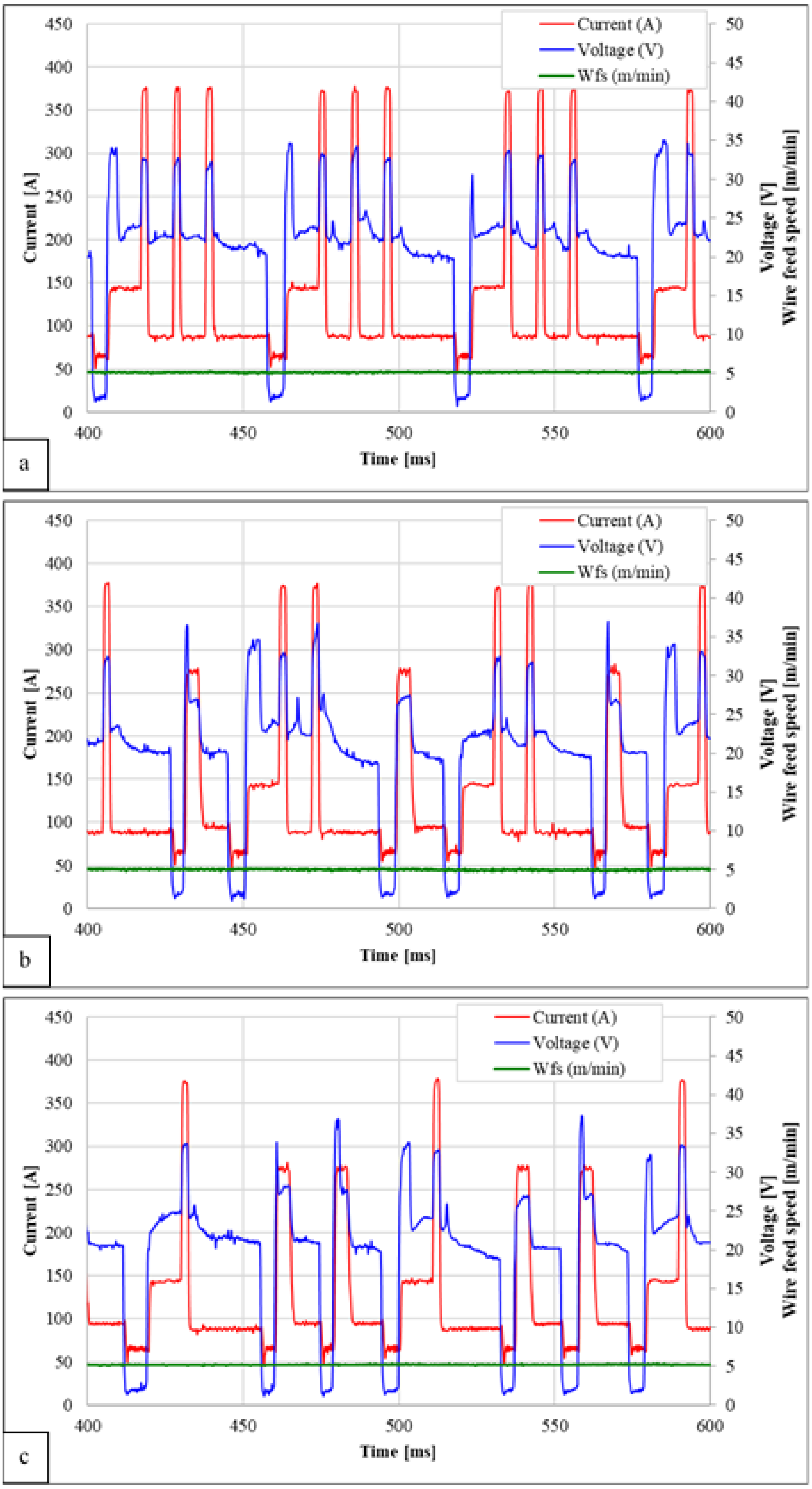

Figure 7. Acquired data from experiments carried out with the MIG/MAG AD-P process.
a) Sample 3 (75% Pulsed); b) Sample 4 (50% Pulsed); c) Sample 5 (25% Pulsed).

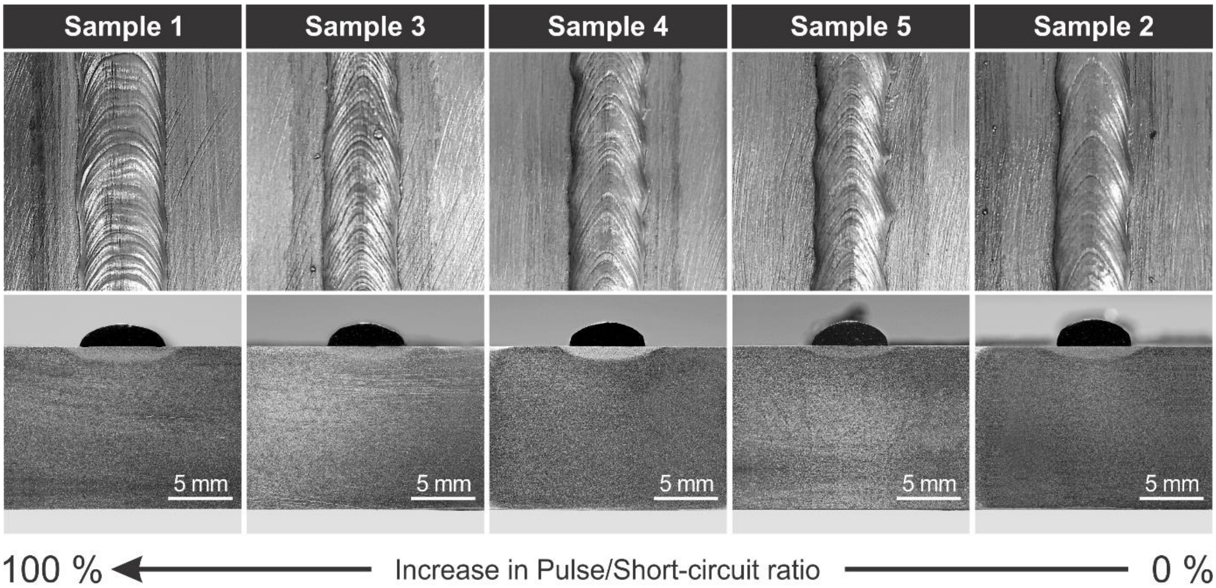

Figure 8. Cross section and surface appearance of vertical samples.

Table 5. Data from the samples' cross section.

	Sample 1	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 2**
Reinforcement height (mm)	1,71	1,77	1,88	1,95	2,01
Reinforcement width (mm)	6,73	5,96	5,99	5,98	5,77
Contact angle (°)	109,4	98,0	103,6	102,8	91,1

Regarding the width of the reinforcement, it can be verified that the increase in the number of pulses produces a greater spreading of the bead, fact that comes from the greater thermal input provided by this process, since the wire feeding speed remains constant. In a similar way, the effects of the higher heat input on the reinforcement height are also observed. As there is a greater tendency to improve the wettability levels of the sample with the increase in the ratio of pulses, consequently the height of the reinforcement goes in the reverse direction, the higher the power supplied, the lower the height of the reinforcement. In this way, there is always a trade-off between wettability and height of the reinforcement that should be considered in the specifications of a cladding procedure.

The information about these samples revealed a very low dilution rate for all conditions, opposing to the information found in the work of Pang et al. (2016). However, a work conducted by the LABSOLDA-UFSC team states that "vertical penetration and dilution are significantly lower than in the flat position" (Carvalho, 2015).

To verify the effects of the welding position on the dilution, using the alloy 625, tests were also performed in the flat position. The parameters of Sample 1 (100% pulsed), Sample 2 (0% pulsed) and Sample 4 (50% pulsed) were maintained and further experiments were conducted. The cross sections of the specimens were properly prepared and the result of the increased power provided by the pulsed mode was evidenced, as reported by Pang et. Al. Figure 9 shows the cross-sections of the deposits in the flat position, along with dilution rate, determined by software.

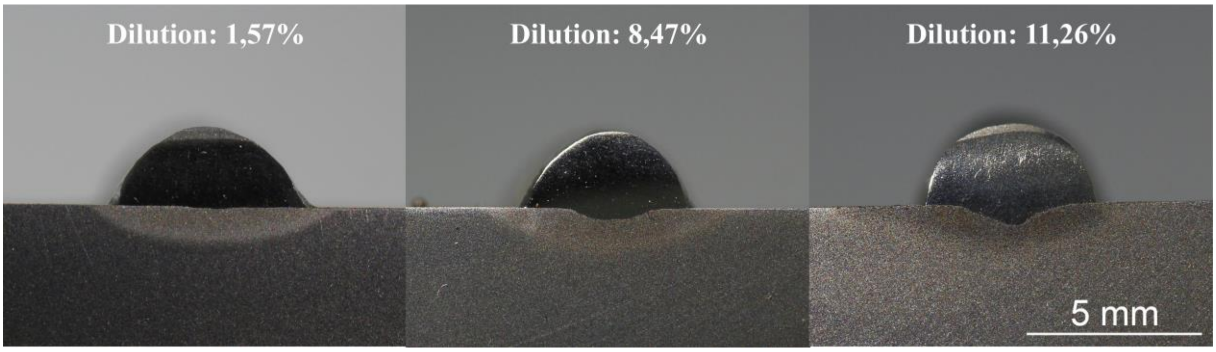

Figure 9. Cross section of samples made in flat position and their respective dilution rates.
a) GMAW DWF; b) MIG/MAG AD-P (50%); c): Pulsed GMAW.

4. Conclusions

For the conditions tested in this work, the increase in the ratio of current pulses in a given weld cycle in the MIG/MAG AD-P process is beneficial with respect to the wettability of the deposit. No dilution effects are observed when it comes to vertical applications. On the other hand, in flat position, this effect was evidenced, increasing the dilution rate as the number of pulsed current transfer periods increases.

For cladding procedures using the alloy 625 in vertical applications, the use of processes that provide a higher thermal input has been shown more indicated. The use of the MIG/MAG AD-P can be beneficial when adjusted in ranges of higher energy, such as 90% pulsed. The use of short-circuit transfer events, even in low proportions, can promote better thermal control over the molten pool, avoiding observed effects of the purely pulsed process, such as the undesired flow of the molten puddle, even at low deposition rates. Another factor that makes the MIG/MAG AD-P attractive is the fact that it is possible to control the height of the arc periodically for the process, since there is a cyclical contact between the wire tip and the molten pool followed by the retraction of the wire by a predetermined length. This contact and return of the wire can bring balance to an eventual instability in the metallic transfer and avoid oscillations in the average length of the arc.

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