INFLUENCE OF PROCESS PARAMETERS DURING THE PIPE WELDING OF LOW-CARBON STEEL USING RMD (REGULATED METAL DEPOSITION) PROCESS

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Abstract. *The RMD™ (Regulated Metal Deposition) process, which is a derivative one from MIG/MAG, is based on the current control of the metal transfer during the short-circuit period. The RMD process was developed in 2004 and has great weld pool stability as its main feature, which allows accomplishing quality root-pass welding on pipes. Due to the shortage of scientific literature on this subject, this work aims to study the influence of parameters ("Trim" and "Arc Control") on the current waveform and bead geometry. Moreover, it is aimed to determine and assess the process parameters on the joining of small pipe diameters with single-pass welding, on both directions upward and downward. Low-carbon pipes were employed with 2½" of nominal diameter and 5,5 mm of thickness. The results showed that the "Trim" parameter is the responsible for arc length adjustment, whereas larger "Arc Control" leads to current increase and, therefore, deeper penetration. It is concluded that for pipe welding, this process allows accomplishing quality beads with single pass preferable using downward progression, in accordance with practices recommended by manufacturer.*

Keywords*: RMD process, Trim, Arc Control, Pipe Welding*

1. INTRODUCTION

The RMD™ (Regulated Metal Deposition) process, which is a derivative one from MIG/MAG, employs the controlled short-circuit principle. It was developed by Miller Electric company and patented in 2004 (Miller, 2004). In this process, the welding current is electronic monitored and controlled during metal transfer phases (Machado, 2010). According to the manufacturer (Miller, 2010), its waveform for welding current is divided into seven phases, as shown in Fig. 1.

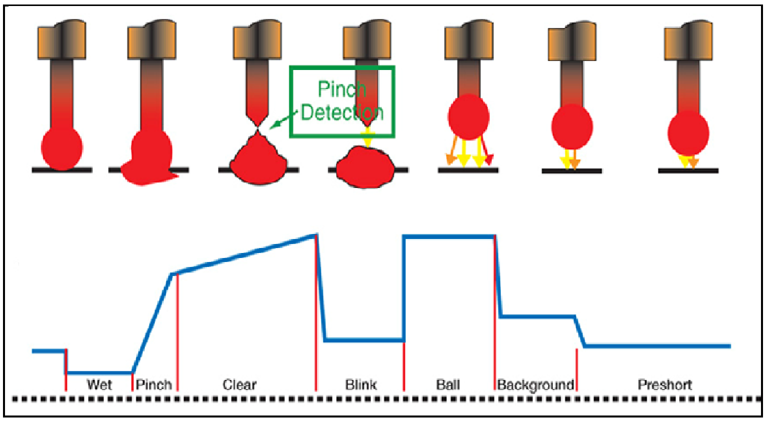

Figure 1. Current signal for RMD process (Miller, 2010).

During the initial phase of the metal-transfer cycle (*Preshort*), the droplet is formed in the melting tip of the electrode-wire and then in during the *Wet* phase the current is reduced until the short-circuit starts (since the wire-feed speed is not modified, the drop in the current reduces the melting rate and the arc length is reduced). During the short-circuit, the waveform of the welding current is divided into two phases. In the first one, so-called *Pinch* phase, the current is rapidly raised after the droplet touches the weld pool. In the second phase, so-called *Clear* phase, the current continues rising, but at moderate rates, until moment when the end of the short-circuit is detected by the power-source control. After the droplet detachment, the current is reduced again during a brief period (*Blink* phase), so the electric arc could smoothly reignite, which avoids spattering. Afterwards, the current is raised again (*Ball* phase), which promotes the formation of a new droplet in the wire tip. During the *Background* and *Preshort* phases, the current is gradually reduced (in step shape) to allow new contact between the molten tip and weld pool, which guarantees better weld-pool stability.

The control of welding current during metal transfer promotes a reduction of 5 to 20% in the heat input for the RMD process when compared to conventional short-circuit transfer and it also minimizes the spattering generation and allows using larger electrode diameters for thin plate welding (Machado, 2010). It must be pointed out that this author (Machado, 2010) indeed did not measure the heat input, but the process energy. Calorimetric techniques should have be used in order to correctly affirm such reduction in the heat input. On the other hand, Possebon (2009), during the welding of thick plates with RMD process, found that its lower heat input (again this author should have used energy) favors the presence of lack of fusion. But he also underlines the great weld-pool stability, as one of the main advantages of the RMD process. This feature promotes a uniform melting for the base material.

For pipe welding, the results from the manufacturer indicates that the RMD process allows accomplishing root pass for downward progression with better tolerance rather than upward one, for root gap between 3,2 and 5 mm (Miller, 2009). Apart from this technical note from the manufacturer (Miller, 2009), few technical literature is found for the RMD process. Therefore, this work aims to study its parameters influence on the waveform of the welding current and weld-bead geometry. Moreover, it also aims to determine and assess these parameters for the welding of small pipe diameters with thin wall and only one pass for both downward and upward progressions.

2. EXPERIMENTAL PROCEDURE

Weldments were carried out in one single pass and using, as general parameters, contact-tip-work-distance (CTWD) equal to 12 mm, ER70S-6 wire with 1,2 mm of diameter, Ar+25%CO_2 as shielding gas and ABNT 1020 carbon-steel pipes. These pipes have 2 ½" of nominal diameter and 5,5 mm of thickness, which joint preparation was carried out by machining (turning) and following the directives of AWS D10.12. Analyses will be carried out for three approaches: visual analyses (basing on AWS D1.1, 2006), macrography and observing the effect of selected factors on the bead geometry.

These factors are specific parameters for the RMD process (power source model PipePro 450 RFC) and they are shown in Tab. 1, with respective levels. The main two specific parameters are the *Trim* and *Arc Control*. Besides the wire-feed speed (V_A), weaving was also varied (its presence or not). It must be pointed out that the same amount of deposited material was used by keeping constant the relation between wire-feed speed and travel speed (V_S). These factors (V_A, *Trim*, *Arc Control* and Weaving), plus the progression (upward and downward), were varied according to a Central Composite Design experimental design, as shown in Tab. 2. The upward progression runs are defined as "RA", whereas the downward progression runs are defined as "RD", both followed by the run number according to Tab. 2.

Table 1. Operational levels employed for the RMD process.

V_A [m/min]	V_S [cm/min]	*Trim*	*Arc Control*	Weaving
2,3	12	50	0	Yes
2,8	15	65	25	No
3,3	18	80	50	

V_A is wire-feed speed and V_S is travel speed

Table 2. Experimental design used for the operational levels.

Run	Progression	Weaving	V_A [m/min]	*Trim*	*Arc Control*
1	Upward/Downward	No	2,3	50	0
2			2,3	50	50
3			2,3	80	0
4			2,3	80	50
5			3,3	50	0
6			3,3	50	50
7			3,3	80	0
8			3,3	80	50
9			2,8	65	25
10		Yes	2,3	65	25
11			3,3	65	25
12			2,8	50	25
13			2,8	80	25
14			2,8	65	0
15			2,8	65	50
16			2,8	65	25

3. RESULTS AND DISCUSSION

3.1. Visual analyses

Visual analyses comprise the evaluation of superficial features, such as suitable penetration, minimal undercut, sufficient root penetration and bead uniformity. By using AWS D1.1 (2006), it is possible to split the beads into two sets, namely Discarded Operational Set and Recommended Operational Set. These two are indentified as followed.

a) Discarded Operational Set

For the weldments carried out by using upward progression, mostly of the bead were discarded due to excessive penetration leading to burn-through (an example is shown in Fig. 2 for Runs RA6 and RA14), as this progression is normally associated with deeper penetration (rather than downward progression). In this case, the occurrence of this type of defect is more frequent for the beads welded without weaving, since the weaving tends to reduce penetration by “spreading” the heat into a larger area, when compared to straight (string) beads. Thus, Runs RA3, RA4, RA5, RA6 (Fig. 2a), RA7, RA8 and RA9 were discarded, i.e., almost all straight (string) beads for upward progression. Meanwhile when weaving is used, only Run RA14 (Fig .2b) was discarded. When weaving is used a better heat distribution is achieved for the both sides of the bead face, which allows better weld-pool control, larger bead width and avoiding burn-through.

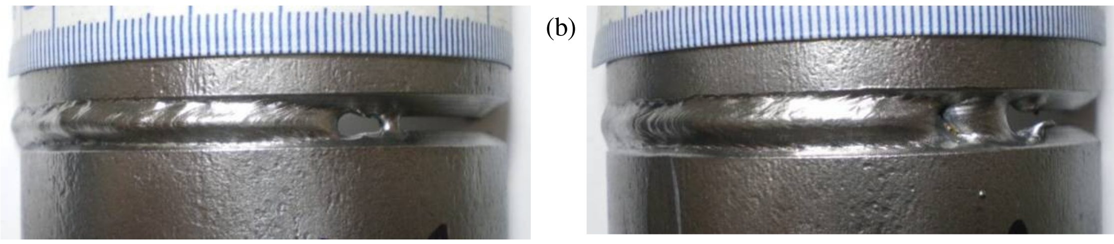

Figure 2. Burn-through (a) Run RA6 without weaving; and (b) Run RA14 with weaving.

On the other hand, even with penetration reduction achieved when weaving, Runs RA13 and RA16 presented underfill (insufficient joint filling) during flat position, since when the torch passes through this position, a penetration increase happens (Fig, 3a). In addition, weaving and only one pass welding promoted undercut formation on bead sides with 1,2-mm deep, as shown in Fig. 3b.

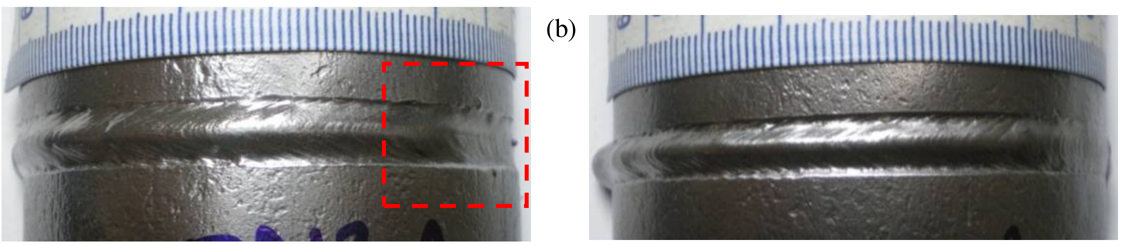

Figure 3. (a) Run RA13 with underfill; and (b) Run RA12 with undercut.

For Runs RA1 and RA2, lack of fusion is present on bead sides, especially because the narrow bead deposition (Fig. 4). It is assumed here that this behavior comes from the use of low level adopted by parameter *Trim* (50 in this case). Since this parameter is responsible for the arc length adjustment, its low level led to a short arc and therefore a narrow bead.

As a general observation, the beads welded in downward progression presented a higher tendency of runoff the molten pool, which contributed to better penetration control for this progression, i.e., no burn-through was observed and lower root reinforcement. Also, it contributed to larger bead. However, the weld-pool runoff also contributed to the occurrence of discontinuities, such the ones observed for Run RD10 (Fig. 5a), i.e., incomplete penetration through the whole joint extension. Discontinuities were also observed for Run RD16 (Fig. 5b) and Runs RD1, RD2, RD12, RD13 and RD15, which presented incomplete penetration in some regions. These discontinuities are aggravated by the use of low current and/or the weaving presence, since they reduce penetration. Finally, the joint misalignment can also aggravate the achievement of a minimum penetration.

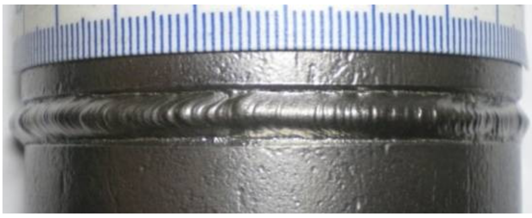

Figure 4. Run RA2 with lack of fusion on the sidewalls.

(a) (b)

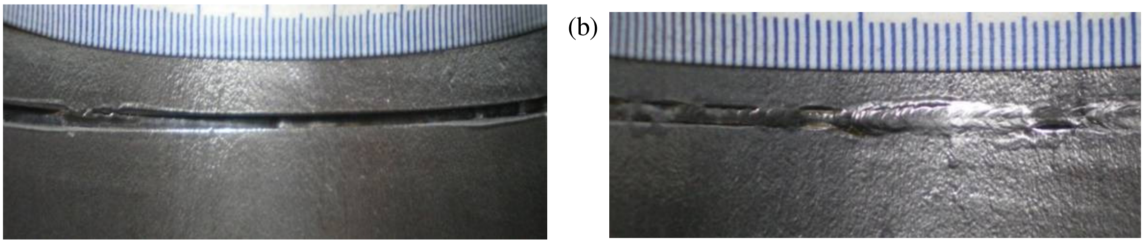

Figure 5. (a) Run RD10 with incomplete of penetration; and (b) Run RD16 with lack of fusion in the root.

For Runs RD5 and RD6, the higher current (adjusted by higher wire-feed speed of 3,3 m/min) and shorter arc (*Trim* equal to 50) promoted narrower beads with deeper penetration, which led to sidewall lack of fusion (Fig. 6).

(a) (b)

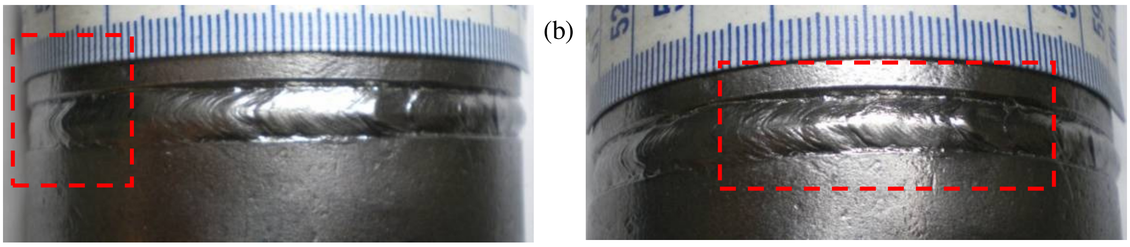

Figure 6. Run RD6: (a) underfill, and (b) sidewall lack of fusion.

b) Recommended Operational Set

The recommended operational set, based on AWS D1.1 (2006), is formed by the excluding runs showed up to now. Thus, for upward progression, only Runs RA11 and RA15 were selected, whereas for downward progression, Runs RD4, RD7, RD8, RD9, RD11, RD13 and RD14 represent successful bead profiles.

Therefore, as a main result from visual analyses, it is possible to conclude that the obtained results (penetration control and uniform beads) are in agreement with recommendations from the manufacturer (Miller, 2009), i.e., the RMD process is more suitable for downward progression, which indicates that this process leads to deeper penetration and therefore faster cooling rates that are characteristics of the downward progression. For upward progression, defects like burn-through greatly reduced the operational set for only two studied conditions (Runs RA11 and RA15).

3.2. Macrographic analyses

The selected beads from the recommended operational set were analyzed by using macrograph for both upward and downward progressions, as shown in Figs. 7 and 8. None indicators of internal discontinuities were found, which indicates that successful beads were achieved under the aspects of both visual and macrographic analyses.

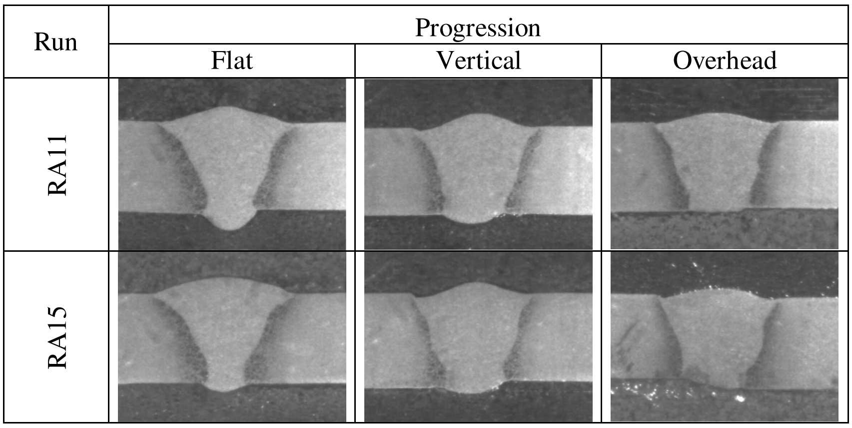

Figure 7. Macrograph for beads welded using upward progression (as scaled, adopt 5,5mm as plate thickness).

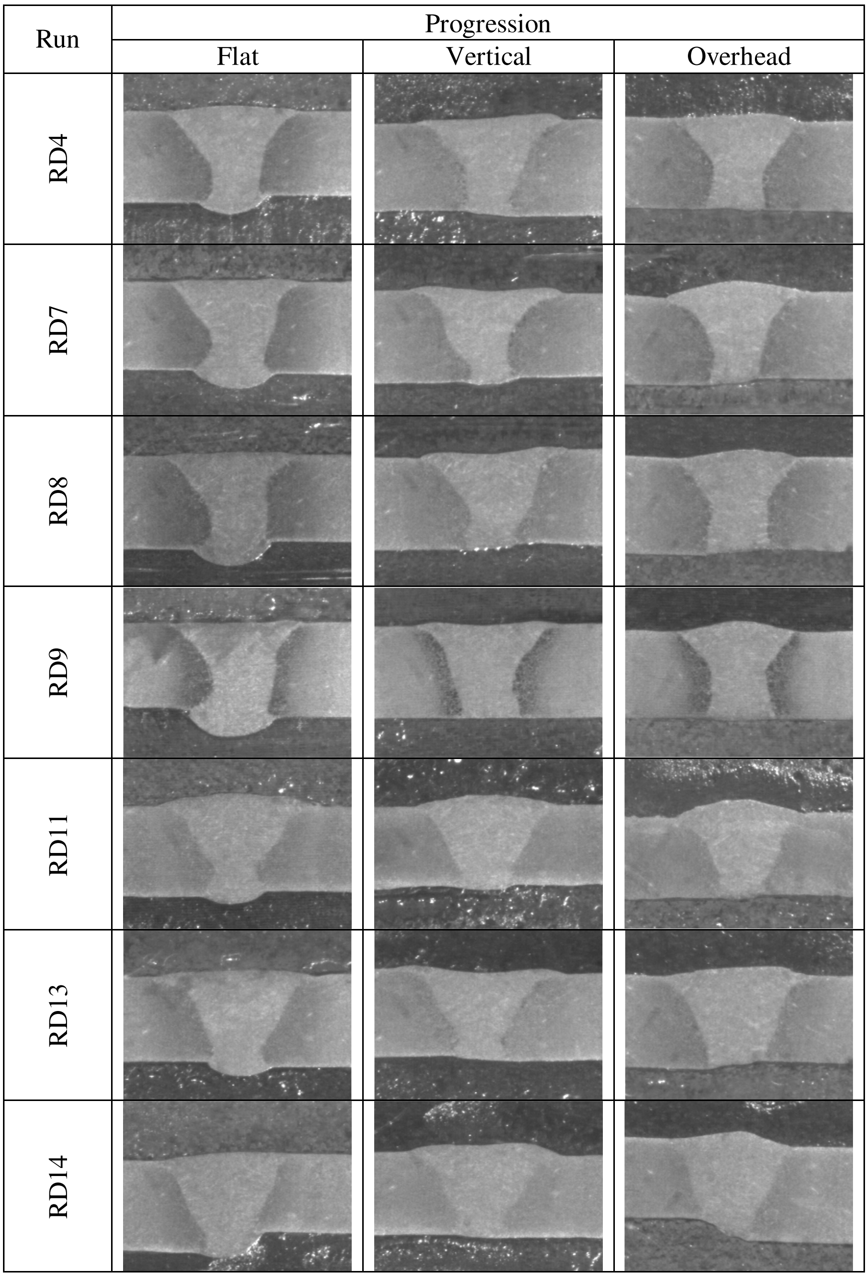

Figure 8. Macrograph for beads welded using downward progression (as scaled, adopt 5,5mm as plate thickness).

3.3. Factors effect on the bead geometry

Table 3 brings the significance levels (p) obtained by global variance analyses when using the factors described in the Experimental Procedure for upward progression. It is possible to observe that weaving significantly affected the weld profiles welded using upward progression, as shown in Fig. 9. In this figure, it is possible to observe that when weaving is used, the penetration decreases, the bead width enlarges and root reinforcement is reduced.

In Table 3 is possible to observe that wire-feed speed presented a significative effect on both face and root reinforcements, as shown in Fig. 10. The wire-feed speed increase promotes the penetration increase with increase in the root reinforcement and reduction in the bead width.

Concerning the other factors, the parameter *Trim* significantly affects the face reinforcement when it interacts with the wire-feed speed, as shown in Tab. 3. In Figure 11, it is also possible to observe that the intermediate level of *Trim* (65) presented a tendency of increase the bead width. The parameter *Arc Control* did not present a significative influence on bead geometry. However, in Fig. 12, its intermediate level (*Arc Control* equal to 25) tends to slightly reduce the root reinforcement and to increase both reinforcement and width face.

Table 3. Significance levels "p" for the analyzed responses: face reinforcement (RF), root reinforcement (RR) and face width (LF) for upward progression.

Factors	Responses		
	RF	RR	LF
Mean/Interaction	**0,010051**	**0,000036**	**0,000013**
Weaving	0,050217	**0,022830**	**0,006956**
V_A	**0,000209**	**0,007141**	-
V_A^2	**0,049003**	0,234156	0,255447
Trim	0,100175	-	-
Trim^2	-	-	-
Arc Control	-	-	0,182607
Arc Control^2	-	-	
V_A * Trim	**0,017878**	-	-
V_A * Arc Control	-	-	-
Trim * Arc Control	-	-	-

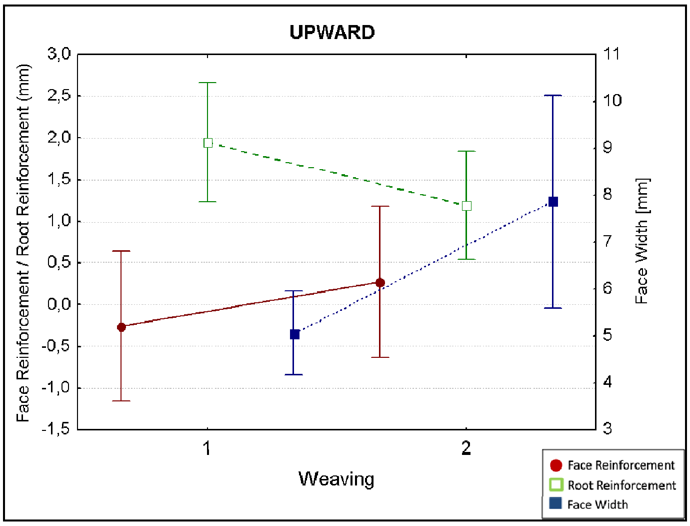

Figure 9. Weaving effect on the bead geometry welded with upward progression (“1” is without weaving and “2” is with weaving).

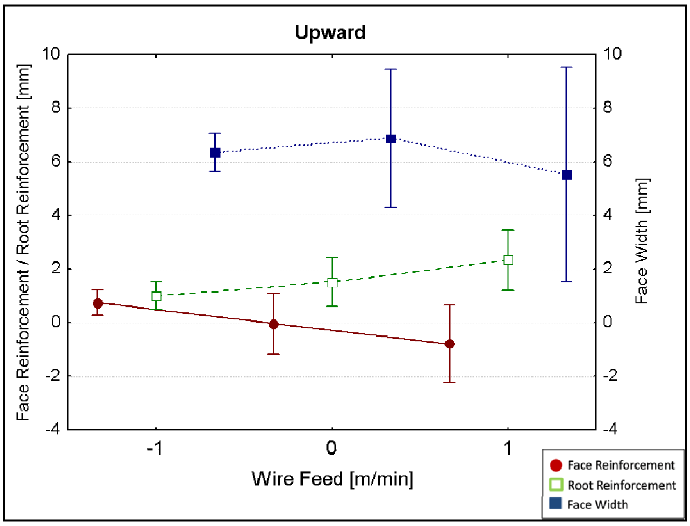

Figure 10. Wire-feed speed effect on the bead geometry welded with upward progression ("-1" is 2,3 m/min; "0" is 2,8 m/min; and "1" is 3,3 m/min).

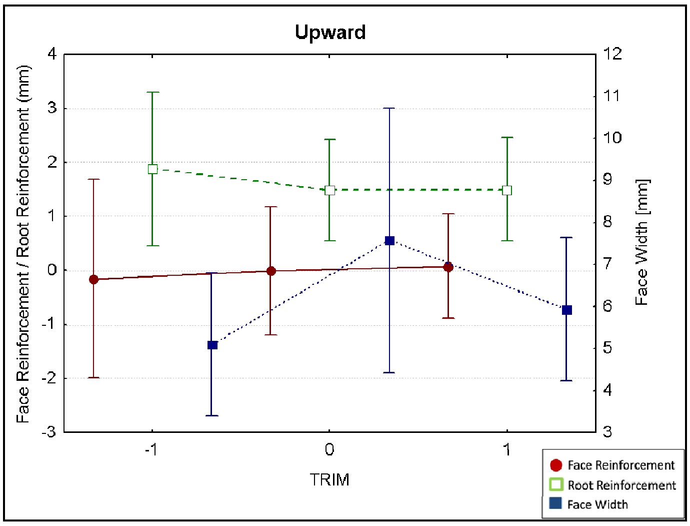

Figure 11. *Trim* effect on the bead geometry welded with upward progression ("-1" is 50; "0" is 65; and "1" is 80).

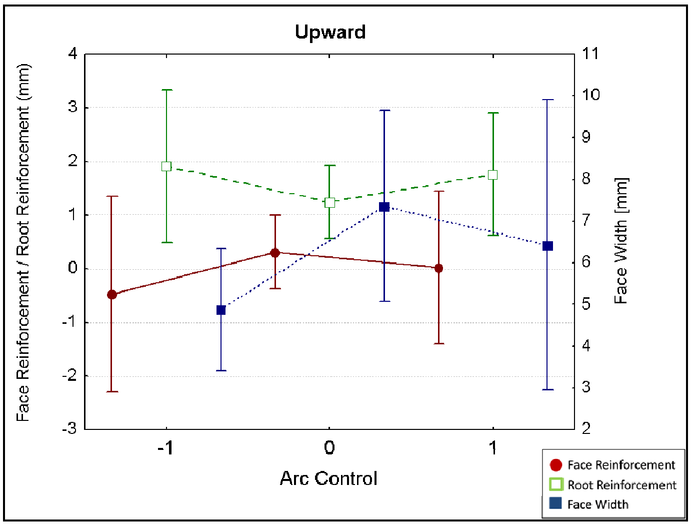

Figure 12. *Arc Control* effect on the bead geometry welded with upward progression ("-1" is 0; "0" is 25; and "1" is 50).

For downward progression, Tab. 4 brings the significance levels (p) obtained by global variance analyzes. From this table it is possible to observe that similarly to upward progression, the torch weaving presented a significative influence on the penetration reduction. In Fig. 13 it is shown that the weaving presence reduces the root reinforcement and increases both reinforcement and width of the bead face.

In these analyses, the wire-feed speed influences only the root reinforcement, as shown in Tab. 4, i.e., it increases the root reinforcement, as shown in Fig. 14. Moreover, in this figure, it is possible to observe that both face width and its reinforcement tends to slight increase with the increase of the wire-feed speed. In Tab. 4 it is also possible to observe and interaction between wire-feed speed and *Trim* for the root reinforcement. Also, the parameter *Trim* significantly changes the bead width, since it is straightly related to the arc length (Fig. 15 shows that the bead width increases with the *Trim* increase).

Concerning the *Arc Control*, it promotes a reduction in the face reinforcement and also there is a tendency for level “0” (*Arc Control* de 25) reduces penetration (root reinforcement) and increases the bead width.

Table 4. Significance levels "p" for the analyzed responses: face reinforcement (RF), root reinforcement (RR) and face width (LF) for downward progression.

Factors	Responses		
	RF	RR	LF
Mean/Interaction	**0,000006**	**0,005379**	**0,000000**
Weaving	**0,002860**	**0,002762**	0,166590
V_A	0,112348	**0,000151**	0,231058
V_A^2	**0,008290**	**0,017701**	-
Trim	-	-	**0,000459**
Trim^2	-	-	-
Arc Control	**0,026396**	-	-
Arc Control^2	-	-	-
V_A * Trim	-	**0,017716**	-
V_A * Arc Control	-	-	0,188479
Trim * Arc Control	-	-	-

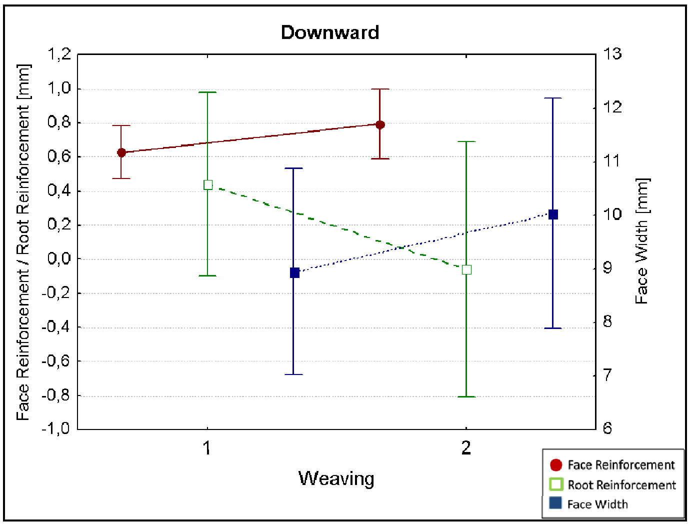

Figure 13. Weaving effect on the bead geometry welded with downward progression (“1” is without weaving and “2” is with weaving).

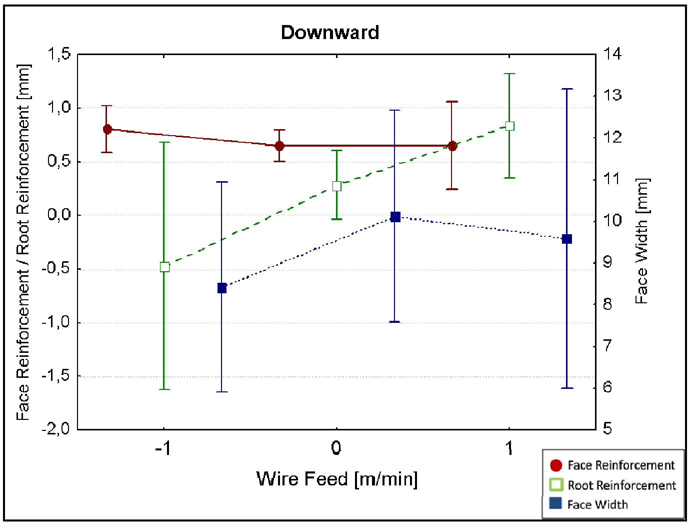

Figure 14. Wire-feed speed effect on the bead geometry welded with downward progression ("-1" is 2,3 m/min; "0" is 2,8 m/min; and "1" is 3,3 m/min).

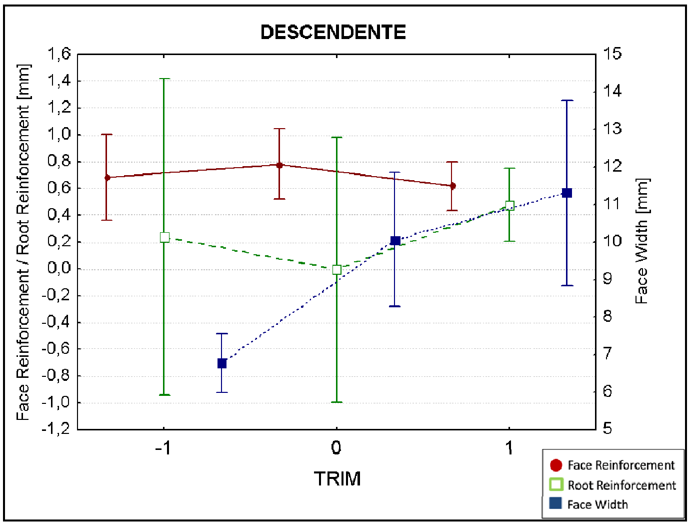

Figure 15. *Trim* effect on the bead geometry welded with downward progression ("-1" is 50; "0" is 65; and "1" is 80).

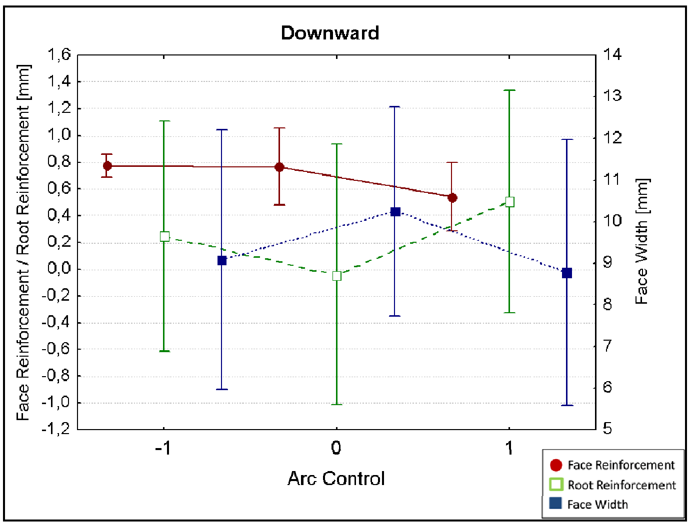

Figure 16. *Arc Control* effect on the bead geometry welded with downward progression ("-1" is 0; "0" is 25; and "1" is 50).

4. CONCLUSIONS

From the tests performed using the RMD process for both downward and upward progressions is possible to conclude that:

- Internal discontinuities (specifically, porosity, inclusion, lack of fusion and cracking) were not found;
- The obtained results are in agreement with manufacturer recommendation, i.e., the welding should be carried out by using downward progression;
- Weaving presented significant influence for penetration reduction, since the increase in the weld-bead width favored the reduction in the root reinforcement;
- As predictable, the wire-feed speed increase led to a penetration increase, a root-reinforcement increase and face-reinforcement reduction;
- The *Trim* parameter showed a slight trend to increase the bead width, which led to face-reinforcement reduction;
- An intermediate level for the *Arc Control* parameter showed a slight reduction for the root reinforcement and an increase of the face reinforcement and face width for the beads welded in the upward progression.

5. ACKNOWLEDGEMENTS

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