Improving Surfacing Performance with GMAW

The synchronized polarity gas metal arc welding technique shows promise for applying coatings where the risk of perforating the base material is a critical factor

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A new technique for the production of a coating using the gas metal arc welding (GMAW) process is presented in this article. The technique fulfills two important requisites for this type of operation: low dilution and high productivity.

In order to carry out a welding task, some characteristics associated with the process and its respective procedure need to be sought in order to fulfill the technical requirements specified. In the case of coating applications, beside the absence of defects in the weld beads and in their overlaps, penetration and dilution must be minimized in order to guarantee the intended quality.

Despite the fact that this study encompasses the parameters mentioned above, the intention herein is not to apply them as comparison parameters. What is of fundamental relevance is the possibility of using the GMAW process with direct current electrode negative (DCEN) polarity, a welding condition traditionally considered inappropriate due to the instability of the arc and a weld bead geometry that is completely unsuitable. The instability is currently resolved through the use of a specific gas composition within a certain range of electrical current. The geometry of the deposit is then solved by the synchronized polarity gas metal arc welding (SP-GMAW) technique proposed here, which consists of the synchronization of the welding power

Table 1 — Weld Beads Obtained in the Flat Position on an ABNT 1020 Carbon Steel Plate (AWS ER70S-6) Wire with Diameter of 1.2 mm, Mixture of Ar and O_2, Welding Speed of 348 mm/min, and Current of 250 A

Test	Polarity	Feed Speed (m/min)	Weld bead appearance	Cross section
1	DCEP	7.2		
2	DCEN	11.7		

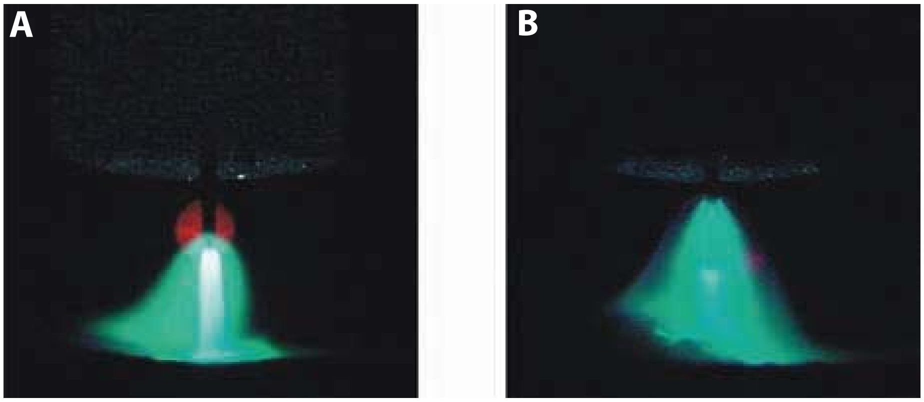

Fig. 1 — Electric arc showing the behavior of the GMAW arc in the following polarities: A — DCEP; B — DCEN.

source output polarity with the torch position in relation to its oscillatory motion.

Welders discard the use of DCEN with solid electrodes as an option because of the allegation that the electric arc is unstable and produces a globular metal transfer with a significant amount of spatter. The geometry of the bead deposited is unsuitable due to the low wettability, which results in an almost circular cross section that can lead to discontinuities due to incomplete fusion at the joints with adjacent weld beads. However, for coating operations, other characteristics, such as low levels of penetration and dilution, are required.

Recent studies on the GMAW process with DCEN polarity have verified, via high-speed digital filming, that the type of shielding gas has a significant influence on metal transfer behavior and weld bead geometry (Ref. 1). Good results were obtained with an appropriate composition of argon and oxygen. The metal transfer was globular at 150 A and axial spray at 250 A without drop repulsion, in contrast to descriptions in the classical literature. The bead profile has low wettability (inappropriate format) but acceptable penetration, as shown in Test 2 (Table 1).

The use of DCEN in the GMAW process is a real possibility for tubular electrodes with a slag-forming flux, but in the case of solid electrodes, it is limited only to the context of alternating current. In this latter case, the frequency of the polarity switching is associated with the frequency of the drop transfer and, coincidently, is close to the frequency (50 or 60 Hz) the electricity-generating companies provide. One sought-after property is the greatest amount of molten electrode material for a certain arc power. This provides the process with particular characteristics in order to achieve specific objectives. For example, researchers at Fronius, a manufacturer of welding power sources including CMT Advanced (cold metal transfer), revealed the gap-bridging capacity of the molten material of the joint faces in root passes, which they designated as the bridgeability (Ref. 2).

Another important characteristic of DCEN that is favorable for the application of the coating is the high wire-melting rate for a certain current in comparison with direct current electrode positive (DCEP) polarity. This distinctive melting rate, also represented by the differentiated wire feed speed in Table 1, can be explained by the behavior of the electric arc. In DCEN polarity, the electric arc does not anchor only at the end of the electrode as in DCEP (Fig. 1A), but instead, widely embraces the electrode (Fig. 1B), seeking points where the electron emission is favorable for the presence of oxides. This characteristic leads to a greater parcel of the arc energy being transferred to the electrode, enhancing its relative melting at the expense of the melting of the workpiece (Refs. 3, 4).

The objective of the new SP-GMAW technique is to minimally affect the base material and provide high productivity with a reduced amount of defects. A potential application for this technology is the repair of in-service pipelines that undergo a reduction in wall thickness due to corrosion. In this application, more than the need for low dilution, the obtainment of highly reduced penetration and the possibility of carrying out the repair in a short time are of fundamental importance. However, this type of coating is still carried out with coated electrodes, where the result is fundamentally dependent on the ability of the welder and the execution time is long.

The SP-GMAW Technique

The developed technique was given the denomination of synchronized polarity (SP) due to the characteristic of the change in polarity during the GMAW process in synchrony with the torch po-

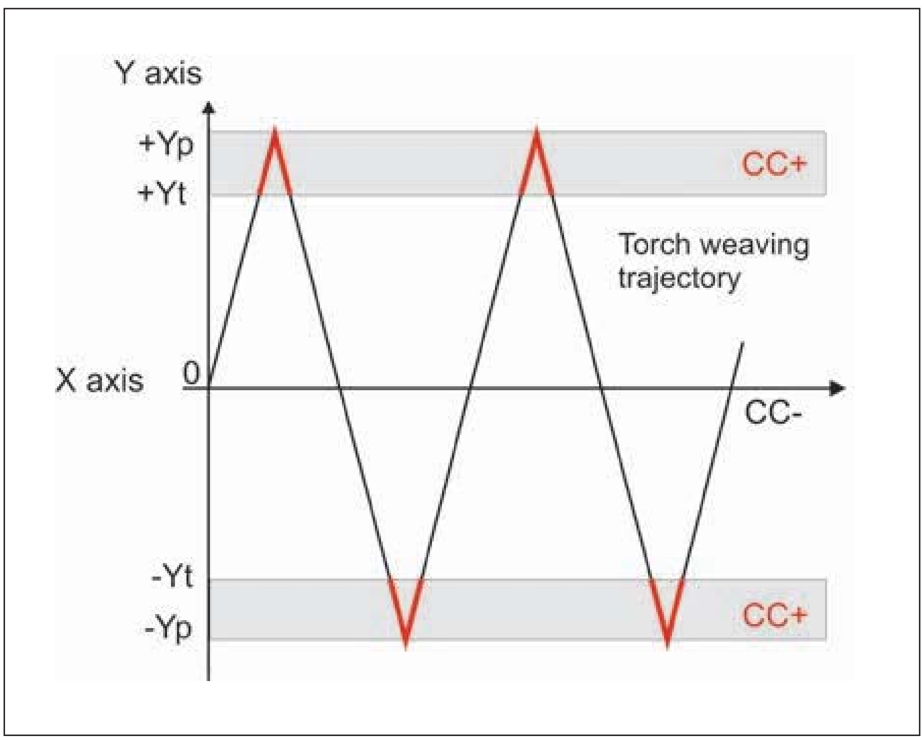

Fig. 2 — Functioning strategy for the SP-GMAW technique (Ref. 5).

sition in the trajectory of the weld bead execution. Robots or manipulators automatically execute the weld beads, and combine the qualities of both polarities in the GMAW process. The negative polarity is used in the center of the bead trajectory in order to obtain greater melting rate and welding speed, and lower dilution and penetration. The positive polarity is used only at the ends of the oscillation trajectory to prepare the weld bead for adequate overlapping with another that will be deposited alongside it, thus avoiding fusion defects. In the qualification of the procedure the values for Yt and Yp of the transversal Y axis (Fig. 2) need to be appropriately considered. The aim is to obtain weld beads with the geometric characteristics shown in Fig. 3.

The task of synchronizing the polarities with the oscillation trajectory of the gun is carried out via a digital synchronization signal generated in the manipulator controller and recognized at the welding source, as shown in Fig. 4. Thus, the welding equipment involved — manipulator and power source — must be based on digital technology with the possibility for the programming and parametrization of electrical signals.

For a certain weld speed and oscillation amplitude/frequency, configured at the programming interface of the manipulator, the position of the transversal Y axis is constantly compared with the transition amplitudes –Yt and +Yt, as shown in Fig. 5. When the position of the Y axis surpasses one of the transition amplitudes, –Yt or +Yt, the synchronization signal shifts to logic level 1, which, in turn, commands the welding power source to impose the I+ current on the electric arc through the application of DCEP polarity. If the position of the Y axis is between these transition amplitudes, the synchronization signal switches to logic level 0, and commands the welding source to impose the I– current on the electric arc through the application of DCEN polarity.

The value in the current module imposed by the source, I+ or I–, must be in agreement with the respective wire feed speeds established, since the melting rates are different for each polarity when the current values are the same. If the reaction dynamics of the wire feeder used is low, then the same wire speed can be applied for the two polarities. In this case, the process equilibrium is achieved through the adjustment of the intensity of each current, I+ and I–.

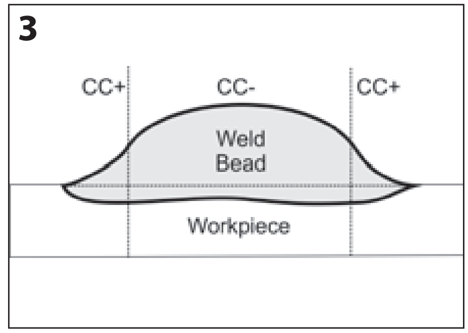

Fig. 3 — Characteristics expected of the weld bead cross section.

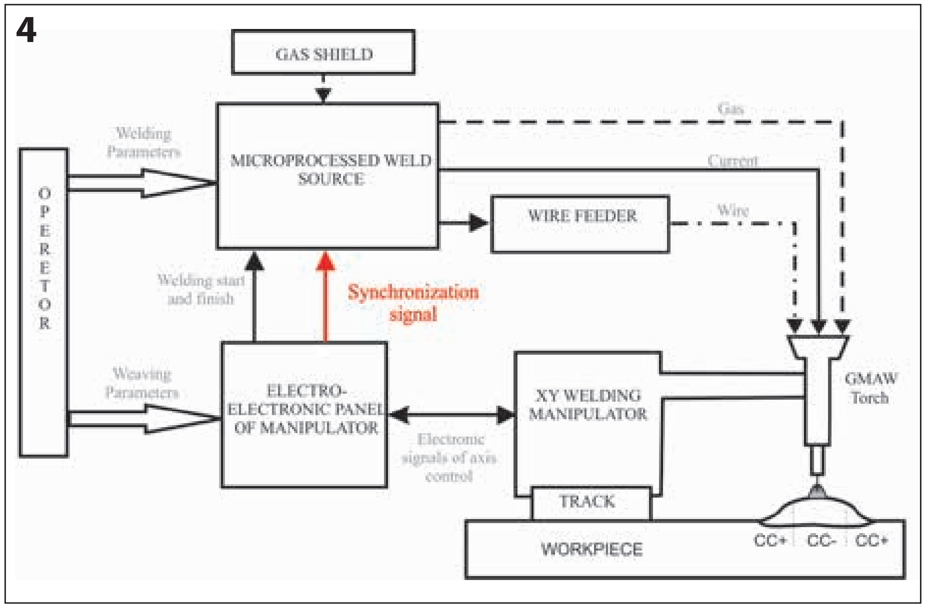

Fig. 4 — Functioning diagram of the SP-GMAW technique.

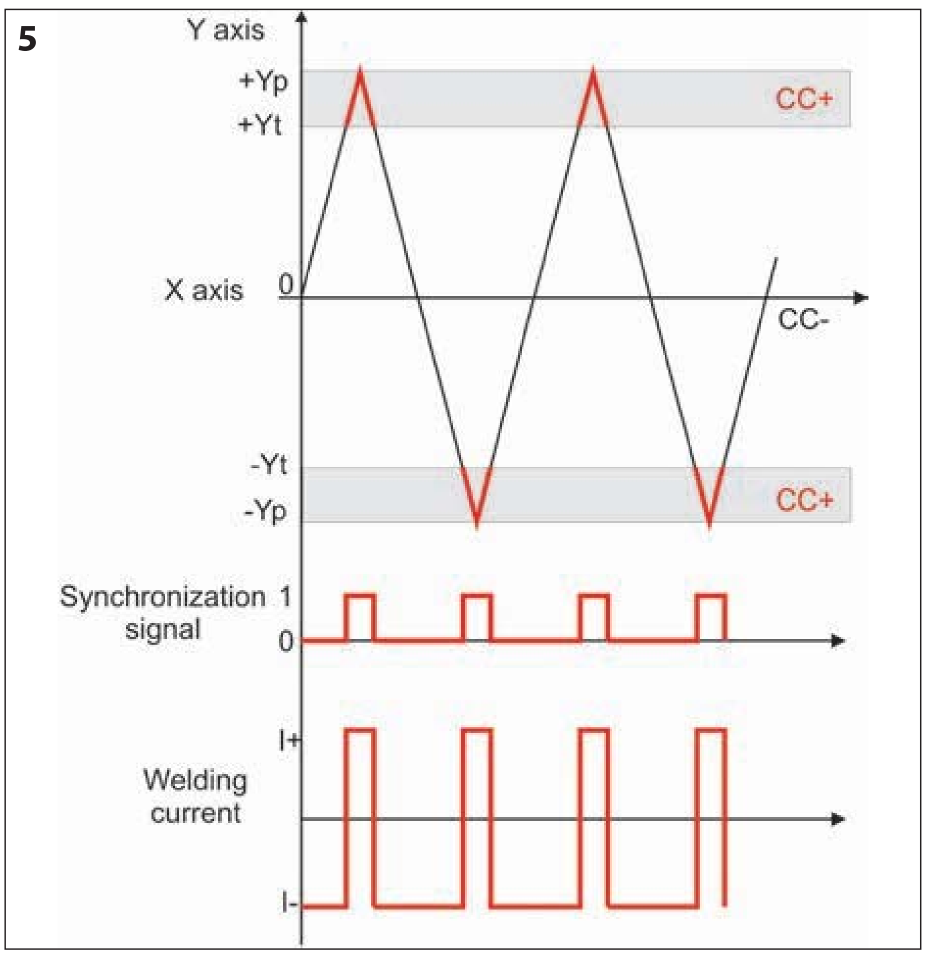

Fig. 5 — Synchronization logic of the SP-GMAW technique.

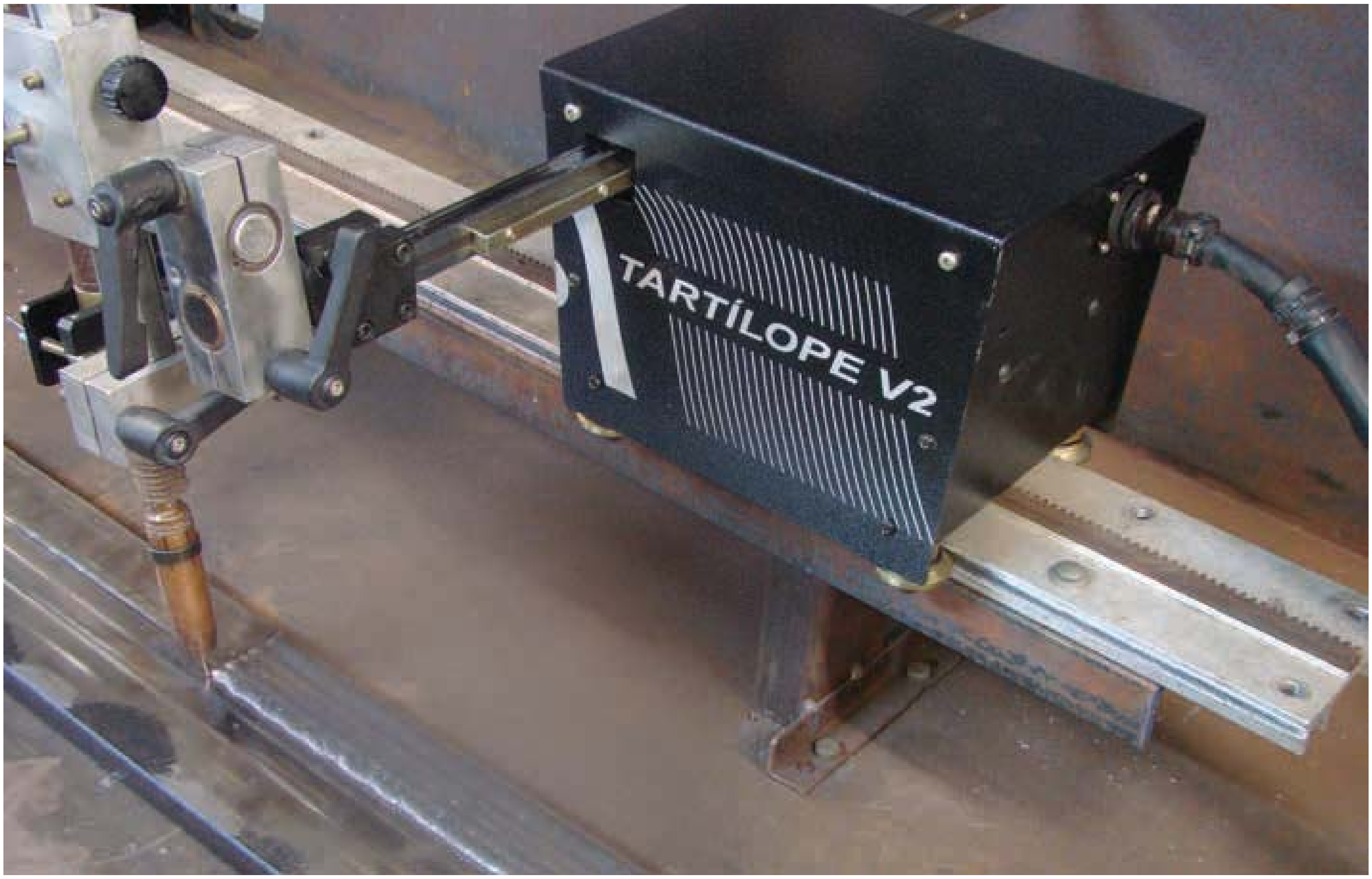

Fig. 6 — The equipment setup for demonstrating the validity of the synchronized polarity gas metal arc welding technique.

Setting up the System

The tests performed to demonstrate the validity of the SP-GMAW technique simulated the recovery of the thickness of a worn low-carbon steel workpiece through the addition of 1.2-mm-diameter ER70S-6 wire in the flat welding position. The equipment used for the tests consisted of a microprocessor-controlled welding power source (Model IMC Inversal 450) with its respective wire feeder, a Cartesian XY manipulator (Model SPS Tartílope V2F), and a portable data-acquisition system (Model IMC SAP-V4.01) (Ref. 6) — Fig. 6.

The welding power source was programmed to operate in GMAW mode with the current imposed instead of the voltage. This produces better dynamics for the alternating polarities. The shielding gas used was a mixture of 98%Ar + 2%O_2 with a flow rate of 13 L/min that was recommended by researchers (Ref. 1).

Table 2 shows the parameters of the movement and of the welding used to produce the weld bead shown in Fig. 6. This deposit was obtained using the push technique with an angle of 10 deg. The application time for DCEN was twice that of DCEP. Despite the occurrence of spattering (Fig. 7A), a regular weld bead with an average width of 15.4 mm and maximum height of 3.1 mm was obtained. The maximum penetration (Fig. 7B) was only 0.5 mm and the dilution was approximately 13%.

The oscillograms of the voltage and current of the electric arc, as well as the wire feed speed (Fig. 8), were captured during the production of this particular weld bead. The temporal behavior of the electric arc voltage indicates that short circuiting does not occur. The spattering observed can be explained by the projection of drops of the electric arc to the outside of the weld pool due to the inversion of the direction of the weld torch movement. This inversion of movement occurs during the application of DCEP polarity and at both lateral ends of the trajectory of the torch oscillation.

It can also be observed that in DCEP polarity, when the I+ current reaches its reference value (270 A), the voltage gradually reduces. This signals the decrease in the length of the electric arc due to a lack of wire consumption. When the po-

Table 2 — Values for the Parameters Applied in SP-GMAW

Parameters	Values
Weld speed (mm/min)	436
Oscillation frequency (Hz)	1.5
Oscillation amplitude, 2.Yp (mm)	12.0
Polarity amplitude DCEN, 2.Yt (mm)	8.0
Wire feed speed (mm/min)	11.5
Electric current in DCEP polarity, I+ (A)	270
Electric current in DCEN polarity, I– (A)	250

larity is switched to DCEN, the length of the electric arc is reestablished, indicated by an increase in its voltage. In this case, the electric arc is stable, but operating close to the limit of instability. To make the process more stable, the DCEP current of the DCEP polarity (I+) must be corrected, that is, increased until an appropriate wire feed speed is reached. Also, other factors, such as nonlinear electromagnetic force variations of the arc, influence the transitory characteristics that can contribute to the previously mentioned voltage variation.

Another unstable and undesirable situation is when one or both currents, I+ and I–, are higher than the currents suitable for a certain wire feed speed. In this case, the arc length increases excessively and melts the contact tip of the torch.

The same set of parameters used in the previous test (Table 2) was applied to make the weld shown in Fig. 9. In order to ensure the overlap of the weld beads only in the region of DCEP polarity, the following criteria were applied: distance between the longitudinal axes of two adjacent weld beads equal to the value of the oscillation amplitude, that is, 12.0 mm. The layer obtained (Fig. 9A) has good superficial appearance with a maximum height of 3.1 mm and a maximum undulation of less than 0.3 mm. Its cross section (Fig. 9B) reveals a shallow penetration and the absence of weld defects.

Conclusions

The SP-GMAW technique offers a real possibility for the application of coatings where the risk of perforating the base material is a critical factor. This is due to the achieved appropriate geometric characteristics for the task of coating surfaces, such as shallow penetration, a surface with almost no undulation, and good dimensional ratio (width/height) of the weld beads.

The coating criteria adopted in the SP-GMAW technique for the overlap of adjacent beads produced good results in the flat welding position. There is no increase in the height of the weld layer due to this overlap. The maximum undulation generated was lower than 0.3 mm. The weld layers produced do not present discontinuities and have an excellent visual aspect with the presence of very little spatter.

The use of DCEN polarity during times that extend beyond the period of drop transfer should not be discarded. If used with certain wires in conjunction

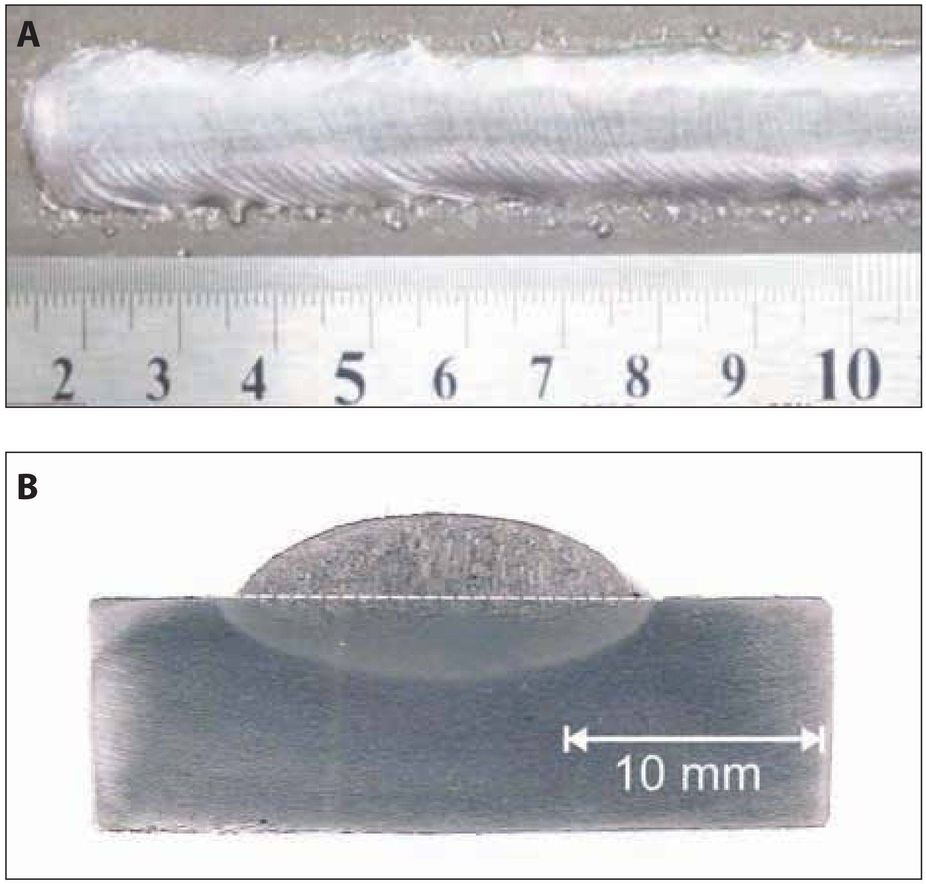

Fig. 7 — A — The weld bead obtained with the SP-GMAW technique; B — cross section of the weld bead.

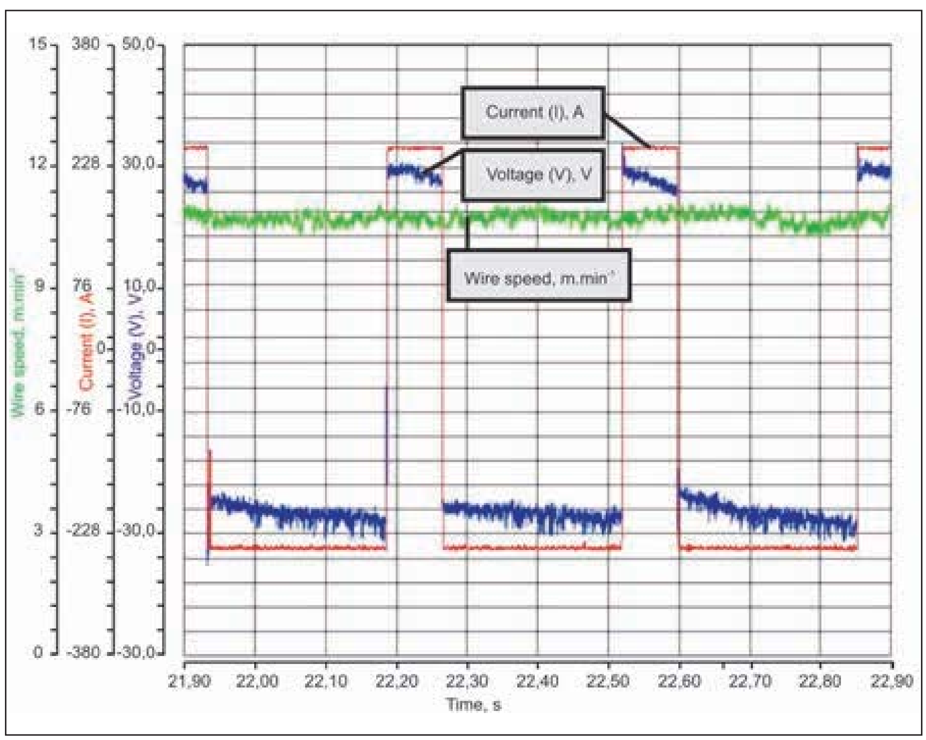

Fig. 8 — Behavior of the main variables of the SP-GMAW technique.

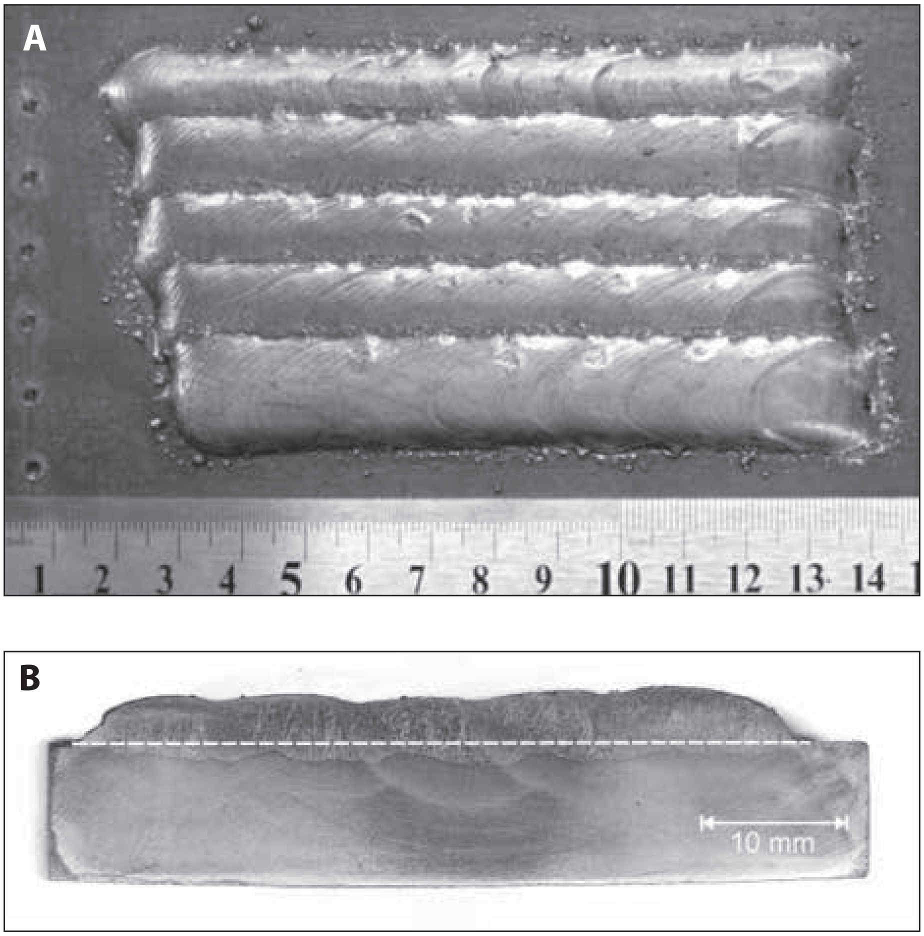

Fig. 9 — A — The coating obtained with the SP-GMAW process; B — a cross section of the coating.

with adequate gas mixtures and a suitable current range, it can represent a good alternative for specific cases of welding. However, this technology requires pieces of equipment that communicate with each other and considerable dedication in the qualification of the set of variables and parameters for the GMAW process as well as for automatic torch displacement.◆

Acknowledgments

The authors are grateful to the team at Labsolda/UFSC whose efforts made this multidisciplinary task possible and to the Brazilian government agency CNPq and the company Tractebel Energia for financial support.

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