A Didactic Computational Tool for Monitoring and Control of Arc Welding Processes—Teaching and Research

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ABSTRACT: This paper describes the development of a control and monitoring platform for arc welding processes, which provides versatility and efficiency in the scientific study and teaching of welding technology. The implemented system is capable of executing different welding modalities as well as effecting substantial changes in their function logic in a simple and didactic manner. One of the innovations promoted by the development of this system is the possibility of drawing waveforms of the welding current for the arc welding processes (MIG/MAG, TIG, Plasma) thus allowing a more visual and interactive method for demonstrating the characteristics of each variant. This also allows deepening of the studies related to the metal transfer (MIG/MAG) and, as a consequence, presenting technological innovations for this process. The control and monitoring platform developed was structured in such a way as to be able to incorporate new technologies, allowing its updating together with the evolution of welding processes. The generated files can also be exported and transferred online, so that several institutions are able to interact in synergic projects. In this context, this system is presented as an alternative with significant potential for welding studies in teaching and research institutions both in Brazil and abroad. Comput Appl Eng Educ; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20390

Keywords: welding teaching and research; MIG/MAG; TIG; plasma; automation

INTRODUCTION

Arc welding processes have been consolidated for over half a century. However, at the time of the original process it was considered impossible that many of the modern versions currently in commercial use could be made viable. This is the case, for example, of variable polarity MIG/MAG. The existence of such a version of the MIG/MAG was considered impossible because the arc is extinguished with polarity changes. Even if this extinguishing problem was resolved, by means of peak voltage systems (called high-frequency systems) the process would only be possible with the metal transfer in free flight. This is due to the fact that short-circuit transfer requires current peaks at the time of physical contact between the drop and the weld pool. Obviously, it would be impossible to avoid the coincidence of the current going to zero during the polarity changes with the need for the current peaks mentioned. However, with the advent of new welding technologies, allowed by the advances in power and control electronics, controlled metal transfer appeared, in which the drops are transferred in a synchronized manner with the waveforms adjusted in the welding equipment. This then enabled the development of the abovementioned AC welding modality.

Also, using controlled metal transfers, the surface tension transfer (STT) process appeared [1,2], which is a commercial solution, presented by the manufacturer of welding sources

The Advanced Control System provides a monitoring and control interface for arc welding processes. The synergetic system comprised software and power source permits ease of design, simulation, and realization of different waveforms, allowing flexible interactive teaching and research of Welding Technology.

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Lincoln Electric, for root passes. This process is derived from the consolidated conventional MIG/MAG with short-circuit metal transfer, presenting, as a fundamental difference in its working principle, the imposition of a current wave format pre-established by the equipment. The imposition of the current in the STT process, together with the monitoring in real time of the voltage between the contact tip and the piece, makes the welding source control, in a synchronized way, the metal transfer, besides guaranteeing, up to a certain point, a constant drop diameter and a significant reduction in the quantity of spattering. As in the AC MIG/MAG process, the STT technology only became possible with advances in control and power systems, which made the acquisition of signals, the data processing, and the performance of welding source output circuits at very high speed viable.

As can be observed, as power electronics and signals control and monitoring systems evolve, new possibilities for innovation in welding processes appear, inducing the research institutes to become interdisciplinary and diversify their activities in an even more intense rhythm. However, university laboratories and technological centers which study welding technology are often limited to the use of commercial equipment which is totally aimed at industry and does not allow significant manipulation of its working principles. The closed architecture of this equipment inhibits significant scientific advances or limits them to concepts pre-established by the manufacturers. Furthermore, a teaching and research institution needs to invest a considerable sum of financial resources in order to procure some variants of the welding processes since each one requires specific equipment.

For other manufacturing processes (like turning, milling [3,4], and rolling [5]) didactic control software has been developed. Concerning arc welding, it has already been superficially approached as a part of integrated manufacturing systems control software [6,7]. The present work goes deeper into the process itself and aims at a control platform dedicated to monitor and control several parameters of different arc welding processes in order to solve the aforementioned drawbacks.

DEVELOPMENT OF A RESEARCH PLATFORM FOR NEW ARC WELDING TECHNIQUES

The platform developed, called the Advanced Control System (ACS), was implemented with the aim of facilitating communication with the user and at the same time achieving a high degree of flexibility in terms of operation, allowing the researcher to carry out relatively complex interventions in different welding processes in a fast and efficient way. The ACS was also structured to be capable of incorporating new technologies, thus allowing its continued evolution according to the needs of each research and development center [8].

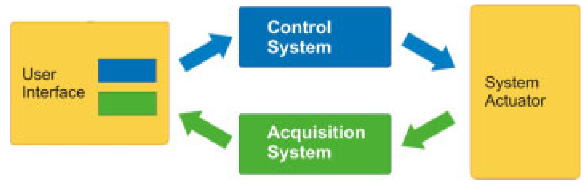

Figure 1 Conceptual layout of the Advanced Control System. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

In order to ensure such characteristics the platform was structured as shown in Figure 1.

The *User Interface*, besides having the function of configuring the different welding modalities, also has the role of exhibiting the signal acquisition in real time.

The commands provided by the operator, mediated by the *User Interface*, are decoded by the *Control System* of the platform which, in turn, acts on the *System Actuator*, the welding source. On the other hand, the *Acquisition System* takes the readings of the welding variables and displays them again for the user by way of the same interface.

Although different technological solutions can be used for the conception of this system, the first generation (Fig. 2) used two microcomputers, which communicate through their serial ports. This structure is derived from object-oriented modeling [9]. CPU 1 is responsible for the user interface, and CPU 2 is responsible for the signal acquisition and control. The system actuator is the Inversal 450 welding source, entirely developed at LABSOLDA and, therefore, well known to all laboratory team.

The use of two CPUs for the conception of the ACS originates from the fact that two different operating systems are required for the current platform, MS-Windows and MS-DOS. The MS-DOS operating system despite being outdated in relation to personal computers has highly functional tools for data treatment in real time, and until today is used in embedded systems. However, the user interface offered by MS-DOS lacks flexibility and agility in its handling, which inhibits the implementation of functions for the manipulation of welding processes and system navigation as a whole.

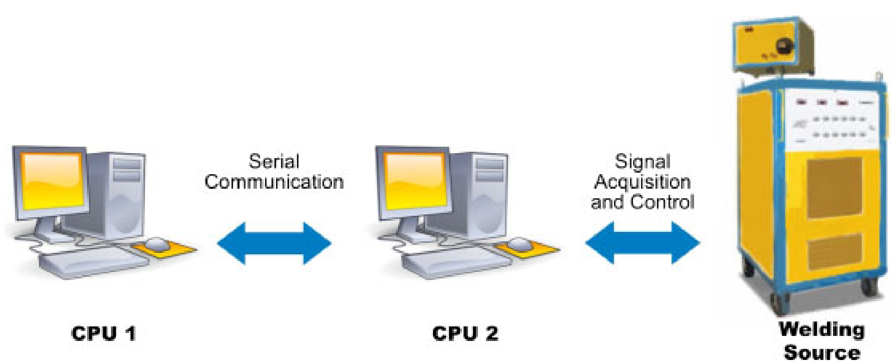

Figure 2 Physical layout of the Advanced Control System. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

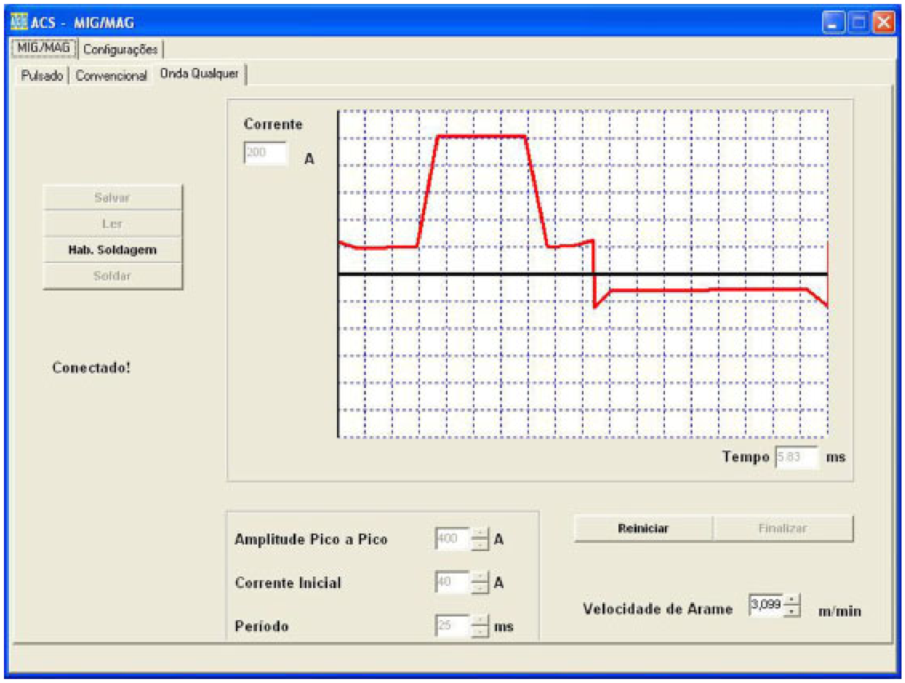

Figure 3 Interface for the drawing of current waveforms of the ACS. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

In order to compensate for the restrictions of the interface with the operator imposed by the MS-DOS platform, this interface was implemented in the MS-Windows system, widely known by PC users, which provides significant support of programs for the conception of database management and manipulation of variables. For this, object-oriented programming was applied [10]. However, MS-Windows presents significant difficulties in terms of hardware intervention, that is, this operating system does not offer, in a relatively simple way, tools to aid the programming and implementation of systems in real time, an aspect which is absolutely necessary for the effective control of welding processes.

Thus, the alternative adopted to combine the benefits of both operating systems, as well as to facilitate the development of the ACS, was the use of two processing units, as mentioned above. The unit managed by MS-Windows, responsible for the user interface and manipulation of variables of the welding processes, and the CPU which uses the operating system MS-DOS, with the functions of managing control routines and signal acquisition.

User Interface (CPU 1)

The software responsible for the interface with the user was implemented on a structure offered by Borland C++ Builder, which provides a layout for the construction of control platforms suitable for the purposes of ACS.

The interface with the user was conceived with two operation modes, conventional manipulation of the variables of the welding modalities and the intervention in the working principles of the processes by way of drawings of waveforms.

The conventional interface for the manipulation of the variables of each process allows access to the parameters of the welding modalities in a way similar to that in panels of equipment found commercially.

The second mode of ACS operation, that is, the interface developed for the drawing of waveforms (Fig. 3) allows the operators to freely manipulate the welding current totally according to their criteria, making it viable to study the behavior of processes according to significant variations in their waveforms.

Systems that provide the operator with the aforesaid freedom in welding waveform development are found commercially available already for sometime like Wave Designer [11], developed by Lincoln Electric. However, these systems generally limit the user to certain adjustments, not allowing significant variations of the procedures operation principles. In many cases, for example, polarity changes during welding is not allowed. Due to these limitations the ACS differs significantly from its commercially similar, since complete wave shaping freedom is provided. It enables the user to draw any waveform through mouse dragging, as in an image editor software.

On the other hand, the free drawing of current waveforms allows the operator to impose non-factual working conditions on a certain welding process. The versatility offered by ACS, when not used coherently, may lead to an unstable process, or even to non-operation. Thus, the welding source, developed to operate as the system actuator, has circuits which monitor the welding process in real time, with the aim of verifying possible arc extinction, promoting its reigniting from appropriate circuits. It is known, however, that arc extinction is not the only problem which can be caused by poorly dimensioned current waveforms. However, it is expected that, for a powerful tool such as ACS, the users have some knowledge of welding technology to enable them to edit the waveforms coherently with the requirements of each process.

For both of the operation modes of ACS, the software responsible for the control routines imposes on the system actuator the waveforms for each process, whether conventional or created according to the criteria of the user. Apart from auxiliary control logic, such as the detection of short-circuits and actuating of trigger relays, the code implemented by these processes does not receive any other type of feedback from the welding source, being able to be identified almost as a command system only.

However, in the welding modalities with controlled metal transfer there is generally the need to monitor the process variables throughout the time period. The dependence which exists between the welding parameters and the instantaneous conditions of the process leads to a need for a permanent feedback channel between the welding source and the control software of the system.

The signal of the feedback system comes from the arc voltage or from the arc current. It is derived from the data already stored and processed by the ACS's monitoring system, thus allowing easy implementation of different operating and control characteristics on the system. Among the developments that were made possible from these special features of the ACS, there is the CCC [12,13] (Controlled Short-Circuit), which uses voltage feedback and has similar characteristics to the STT, which was already mentioned.

Control and Acquisition of Signals (CPU 2)

By means of a communication protocol, CPU 1 sends all of the parameterization of the welding processes, via serial port, to CPU 2 which, from the storage of the variable provided by the operator, starts the welding operation.

All welding processes control logic was implemented in the CPU 2, as well as the necessary software routines for the acquisition of signals. Both the sampling rate and the response in frequency of the system were adjusted to 10 kHz, which was assumed to be sufficient for the applications so far implemented in the laboratory. In this CPU, as previously described, the operating system used is MS-DOS, since it allows, in a more simple way, access to the hardware components of the PC. Thus, it is expected that this processing unit contains the device for the conversion of digital signals (used by the microprocessing unit), to analog signals (recognized by the welding source). The device for the signal conversion is a board also developed at LABSOLDA, which carries out both the control and the acquisition of the welding source signals. Denominated INTERDATA, this acquisition and control board comprises: a 16-channel A/D converter, an 8-channel D/A converter, a frequency meter, and a digital port with eight inputs and eight outputs.

In the interface created for the signal acquisition (Fig. 4) oscillograms of the current and arc voltage are available, enabling the adjustment of sampling times as well as the synchronizing of the acquisition from the events (trigger), and also the storage of these obtained data into table files, which can be plotted later in electronic worksheets.

Welding Source

As previously mentioned, the ACS uses as an actuator the Inversal 450 welding source, completely designed by LABSOLDA. The equipment is configured in such a way that it receives external signals and it is able, from these signals, to command the welding process in a way predetermined by the user. This system, in its complete configuration, can be observed in Figure 5.

RESULTS AND DISCUSSION

The ACS, in its current configuration, is being used as a support tool in teaching and different lines of research at LABSOLDA and also at other research institutions in Brazil and one in Chile. The results here presented relate to different tests carried out in different situations in which the ACS provides differentiated

Figure 4 Sample of signal acquisition carried out in ACS. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

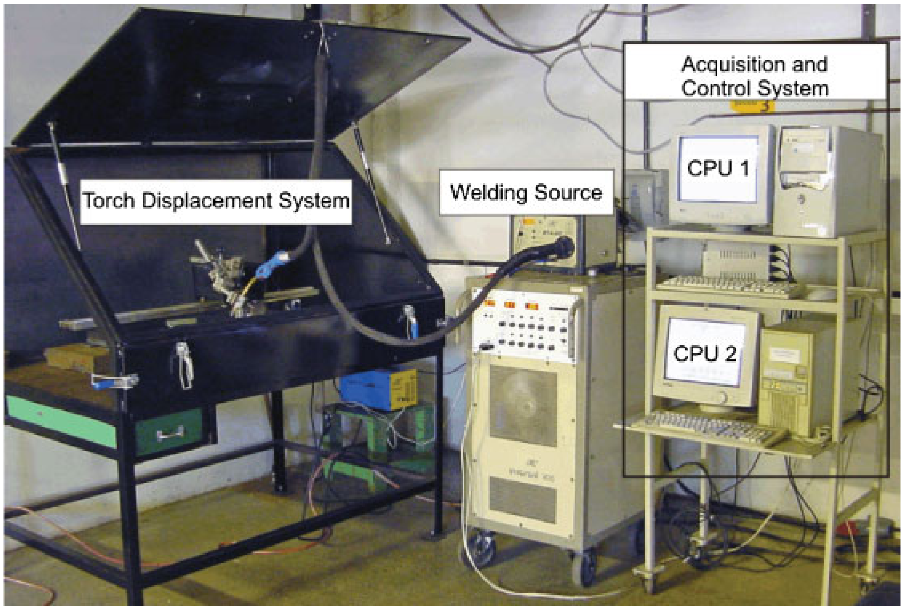

Figure 5 Complete rig of the Advanced Control System. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

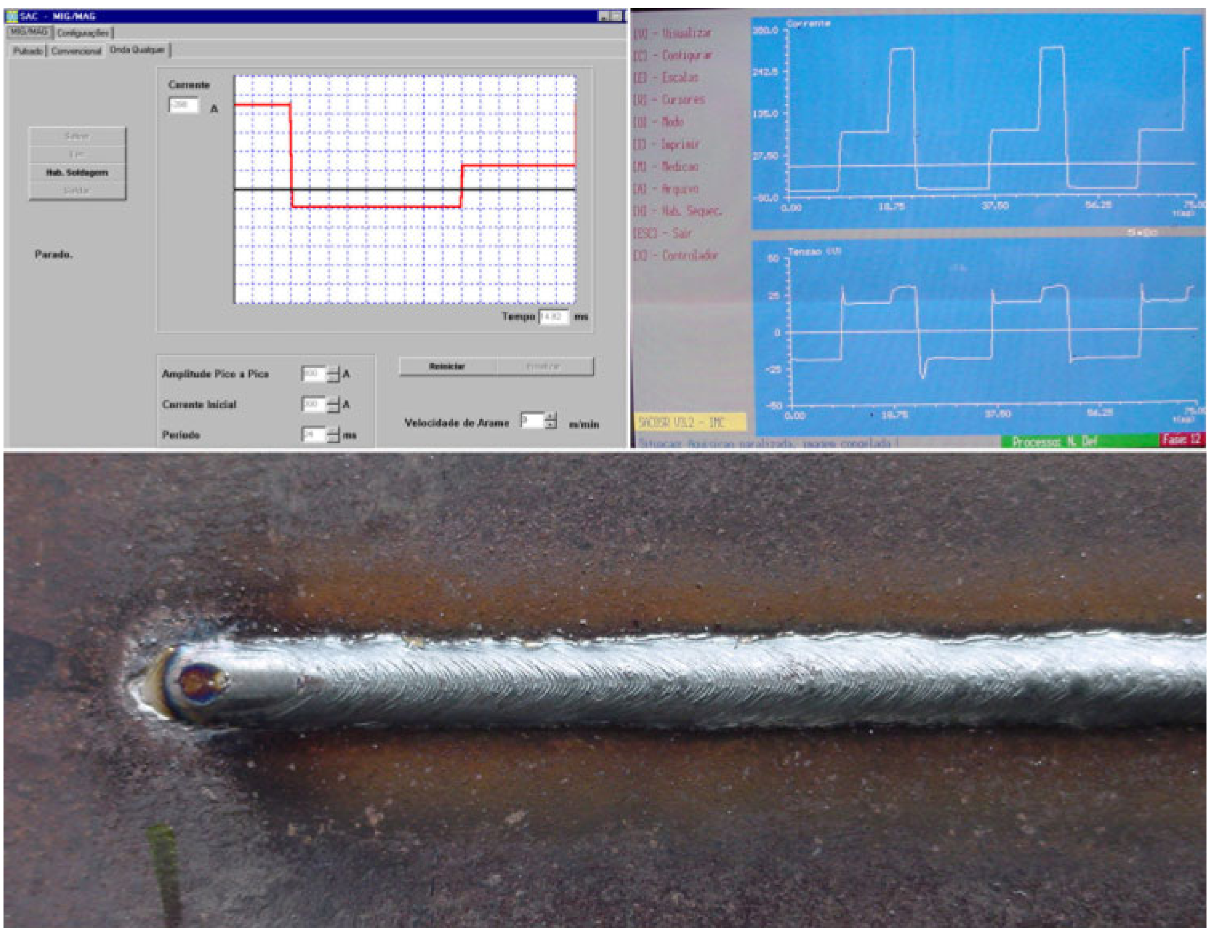

Figure 6 AC MIG/MAG welding in steel. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

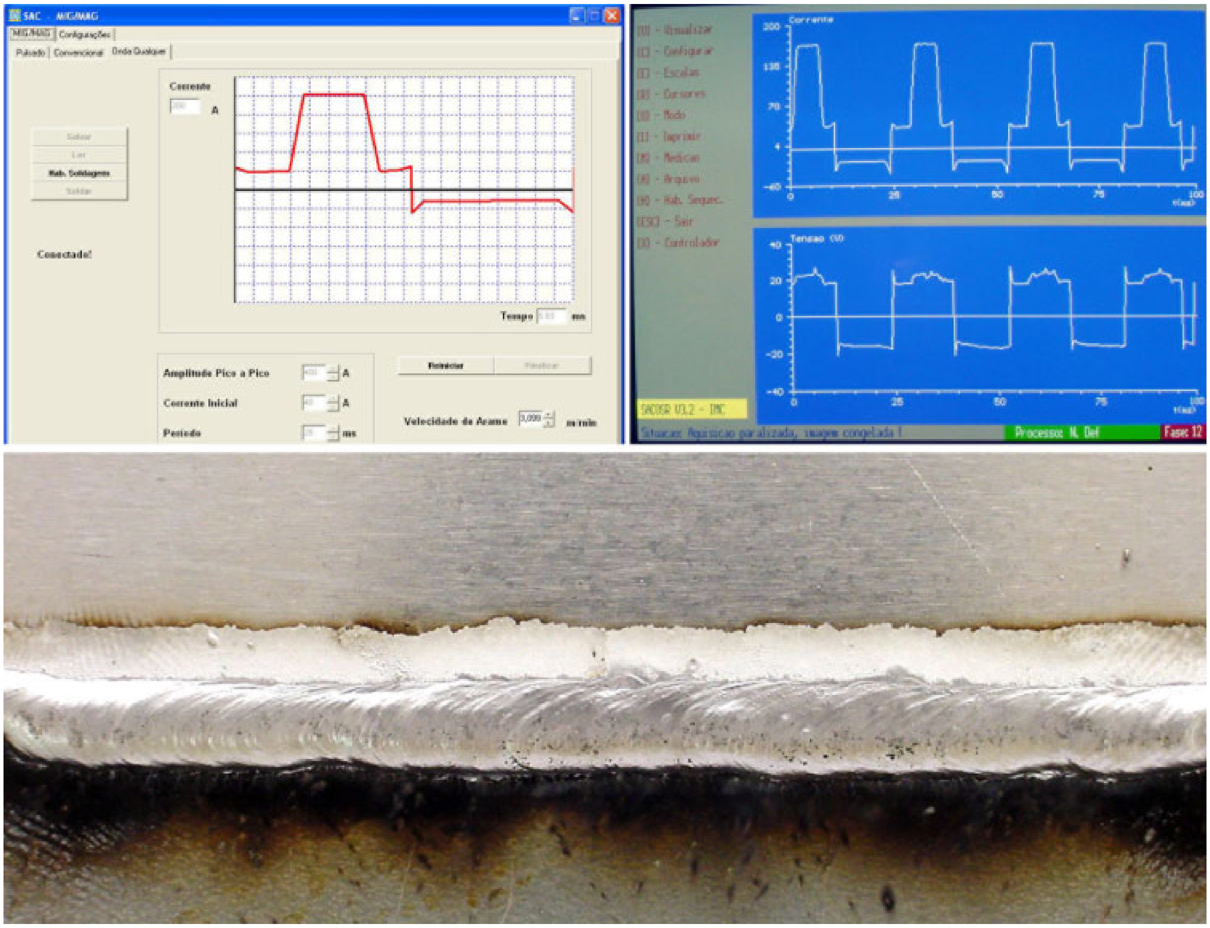

Figure 7 Joining of aluminum plates with galvanized steel. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

support to studies such as the possibility to draw waveforms and simulation of innovative welding processes such as Controlled Short Circuit.

In the studies related to the AC MIG/MAG welding process the ACS was used for the drawing of differentiated waveforms for the modality, varying the percentage values in each polarity, in order to analyze the stability, penetration profiles, and fusion rates (Fig. 6).

Through simply redrawing the current waveform it is possible to vary the duration of each polarity, allowing, due to its simplicity, batteries of tests to be performed, with the aim of carrying out different analysis with a velocity, flexibility, and efficiency which is rarely found in other development rigs. In the specific case of the AC MIG/MAG, using ACS it was possible to carry out conclusive analysis due to the real effectiveness of this modality, as well as to verify the applicability of the process in different situations.

In a different line of development at LABSOLDA, AC MIG/MAG welding is also used for the joining of aluminum plates with galvanized steel. Due to the low currents used in this joining, adaptations need to be made to the waveforms of the process [14], as can be seen in Figure 7.

For studies related to the CCC process, the objective of which is to obtain high-quality root passes, as also proposed by the STT, the system provides a platform for the complete manipulation of the CCC variables, from current levels and temporizations up to fine adjustment of the drop detachment conditions of the process.

Figure 8 shows an example of a welding procedure with a screen of the command data, the form of the waves of the current and voltage, and the weld obtained with the surface aspect and the root.

CONCLUSIONS

The ACS was consolidated as a teaching and research platform at LABSOLDA. Currently, it is being used for different lines of development in the laboratory, it being a fundamental support tool for academic and technological studies.

The flexibility of the ACS makes it a versatile and polyvalent tool for teaching and training support since it gathers, on the same rig, different welding processes, each with its different particularities, dealt with by the platform in a simple and practical way.

Essentially, the ACS offers technological and economic advantages which replaces, on a single platform, different pieces of welding equipment, which, if acquired individually, would require substantial budgets.

Besides the features mentioned and welding processes which the ACS is able to command, the platform has a great

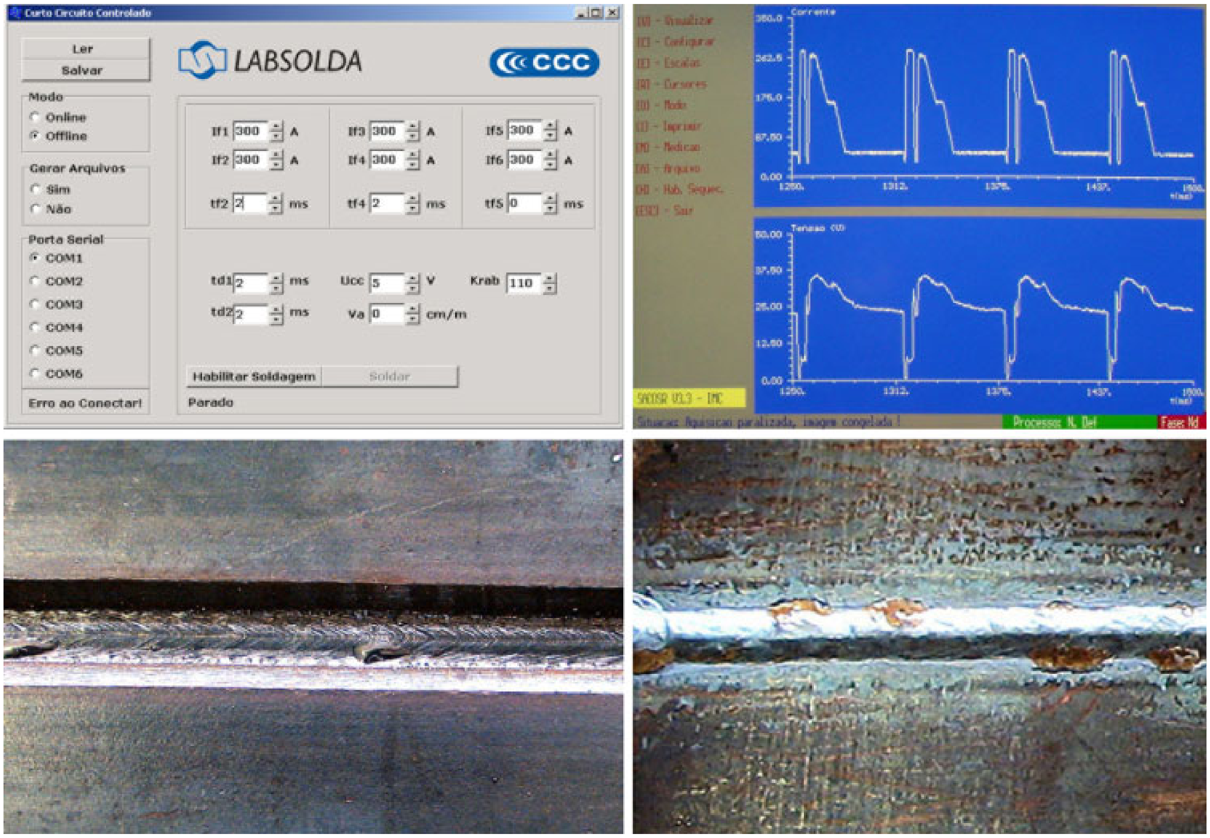

Figure 8 Welding of root carried out with the CCC process. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

potential for adaptation to the different needs of each research line, enabling easy evolution for the control of more complex welding modalities, as well as it being suitable for the specific requirements of each line of development, with reduced costs and significant advantages.

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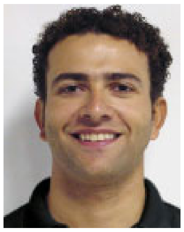
BIOGRAPHIES



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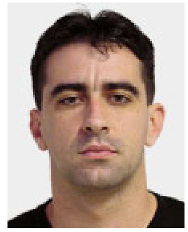

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