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Stability Analysis of the Tig-Mig Hybrid Welding Process Based on Digital Signal Processing

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Abstract

This work presents the analysis and development of the TIG-MIG hybrid welding process based on the analysis of the voltage and current signals generated during the metal transfer. The effect of the parameters on the stability of the process is evaluated using on stated stability indices. The stability indices evaluated showed little variation between them with respect to the stability classification by experimental conditions. A comparative analysis of stable and unstable conditions is developed based on images of the bead, arc current and voltage signals, y the time frequency diagram. Finally, the visual inspection of the weld beads and a statistical analysis for the validation of the obtained experimental results are carried out. As a result of the research, the effectiveness of the method used for stability analysis in hybrid TIG-MIG welding processes in the manufacturing area was demonstrated.

Keywords: Hybrid welding process; TIG-MIG; Stability; Digital signal processing

1. Introduction

Nowadays the industrial development demand for monitoring and control systems in welding has trended to grow. The necessity of a faster, more efficient and higher quality welding has resulted in the creation of advanced monitoring and control systems. In these senses, the signals of arc voltage and current arc are the most commonly used to obtain indices of stability of the welding processes (Norrish, 1992; Roca et al., 2005). However, the feasibility of employing the acoustic signal was verified as an effective method of stability analysis in GMAW process with short circuit transfer mode (Roca et al., 2005). As well as, a methodology was proved to obtain indexes based on image processing of the spectrograms of the acoustic signals generated by electric arc in GMAW process, in order to evaluate the relationship with the stability of process (Roca et al., 2007).

The innovation of the traditional welding processes to obtain different and hybrid welding processes that guarantee greater productivity and efficiency, has become a focus of attention and development.

New technological variants of the gas welding process use two and three electrodes, having as main advantage a higher performance, higher welding speed and the possibility of joining parts of greater thickness. Tusêk et al. (2005), in their article, carry out studies to compare the process of submerged arc welding with one, two and three wires. For their analysis they are based on cost-effectiveness calculations, final quality analysis of the welds and the measurement of technological indicators of the processes.

Research based on the study of hybrid welding processes has shown that the hybrid process can provide numerous improvements during welding, compared to the use of conventional MIG/MAG and TIG processes, etc. Among the main advantages of this type of process are: higher welding speeds, reduction in piece deformation due to a narrower heat-affected zone (HAZ), considerable reduction in spatter, among others (Tusêk et al., 2005).

Studies by Kanemaru et al. (2014) determine the optimal torch configuration to maintain process stability and obtain high quality joints. The authors determine that an angle of 0° for the TIG torch and 45° for the MIG torch is the optimal condition for the experimental conditions studied. The mathematical analysis of the welding process is decisive for a fundamental understanding of the synergy of the hybrid welding process. In their research Chen et al. (2014) modelling the TIG-MIG hybrid welding process by evaluating the influence of torch angles, temperature distribution and weld bead geometry with experimental results.

Kanemaru et al. (2014), perform a simulation and experiments to evaluate the influence of the current balance between TIG and MIG arcs as an important element to improve the stability and penetration of the arc. The authors show the range of suitable conditions both experimentally and through numerical simulation and conclude that the welding time can be reduced by 17-44 % compared to a conventional TIG process. Reports on stability analysis in TIG-MIG hybrid welding processes are limited, so any contribution in this direction is very valuable in this novel process.

2. Materials and Methods

To conduct the research, the TIG-MIG welding process with Argon (Ar) gas protection was used. An ESAB AWS ER316LSi wire with a diameter of 1.2 mm is used for the MIG process. The weld beads were deposited horizontally on AISI 316L steel specimens with a thickness of 1.8 mm, which were cleaned with sandpaper and alcohol to obtain a clean surface free of any contaminants.

A programmable TIGER 210 DC inverter is used for the TIG welding process and also EWM Picomig 180 inverter for the MIG welding process. Figure 1 shows a diagram of the experimental installation used for the tests. It consists of: two shunts for monitoring the welding currents, the arc voltages were acquired from the terminals of the welding sources. Conditioners and filters were used to processing the signals from the process (voltage and current). Finally, a USB-6211 data acquisition card coupled to a PC is used as the final element of the measurement system.

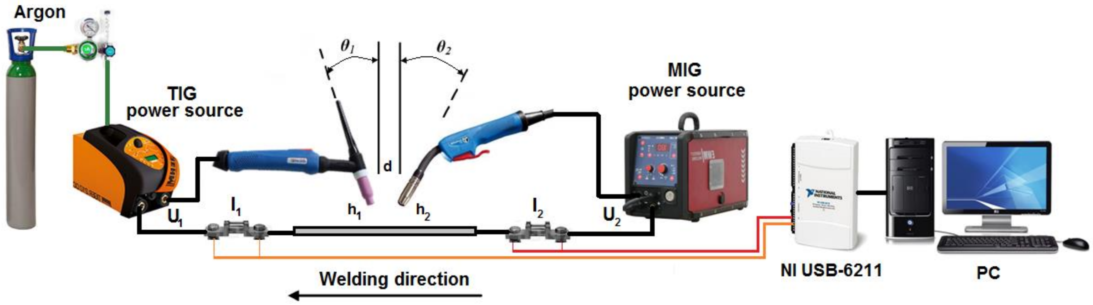

Figure 1. Schematic representation of the experimental setup.

The torches were mounted on an XYZ welding table which allows the control of the process parameters. The signals acquired in each experiment are stored for processing. The process variables evaluated were: the current TIG (IT), the distance between the arcs (d) and the welding speed (vs) whose levels are shown in Table 1. The others process parameters remained unchanged during the tests (gas flows, torch angles, and nozzle-to-piece distances, arc height, MIG process current, etc.). The experiments were carried out in order to analyze and compare the incidence of the variables on the stability of the process.

Table 1. Experimental region

Variable				
I_T (A)	140	160	180	200
d (mm)	10	12	10	
v_s(m/min)	1.2	1.6	1.2	

The statistical characterization of the signals is performed with the aim of evaluating the stability of the gas shielded welding process from established indices in the literature such as: Ccrit, k and Ws (Norrish, 1992).

$$C_{crit} = \frac{S_{t_{ab}}^{\;2}}{\overline{t_{ab}}^{\,2}} \tag{1}$$

$$k = \frac{\overline{t_{tc}}}{S_{t_{tc}}} \tag{2}$$

$$W_s = t_{sc}^{f} V_t^{sc} + t_{ab}^{f} V_t^{ab} + t_{oc}^{f} V_t^{oc} \tag{3}$$

Where: $S_{t_{ab}}$, $S_{t_{tc}}$ - standard deviation of the arc times and transfer cycles, respectively.

t_{ab}, t_{tc} – open arc time and total transfer cycle time, respectively

$t_{sc}^{f}, t_{ab}^{f}, t_{oc}^{f}$ - relative fraction of short circuit phases, open arc and open circuit.

V_t^{sc}, V_t^{ab}, V_t^{oc} - coefficient of variation of the duration of the open circuit phases.

3. Results and Analysis

The experimental results obtained from the characterization and study of the voltage and current signals of the arc are then analyzed and discussed. As it is corroborated in the consulted literature (Lucas, 1983; Xie, 1990; Sencák, 1994), in order to obtain conclusions about the stability and quality of the TIG-MIG welding process successfully, it is necessary to take into account the characteristics of the signals associated with the metal transfer. Equations 1-3 were used to calculate the stability indices, evaluating each experimental condition whose results are shown in Table 2.

Table 2. Calculated stability indexes

Exp.	Index k	Exp.	Index Ws	Exp.	Index Ccrit
21	2.8249	21	2.9543	21	4.5662
9	2.7434	9	1.1095	9	0.9213
16	2.467	11	0.8651	24	0.6667
31	1.7144	2	0.8265	11	0.6107
17	1.6843	24	0.8214	2	0.5637
2	1.6164	31	0.7762	31	0.5355
24	1.5621	17	0.7648	17	0.3774
20	1.494	16	0.5467	16	0.2416
14	1.4062	14	0.5384	14	0.1989
11	1.1786	20	0.5098	20	0.1782

As shown in Table 2 the most unstable conditions were those where the highest welding speed and arc distance were used. These conditions showed a high coefficient of variation of the arc times, coinciding with a very irregularly shaped arc voltage signal.

Based on the results shown in Table 2, experiments representative of a stable and an unstable condition are selected. In this case experiments 9 and 14 were selected, respectively. Figure 2 shows the macro images of the beads associated to both conditions. Figure 3 shows the behavior of the short-circuit duration extracted from the arc voltage signals for the selected representative conditions whose beads are shown in the Fig. 2.

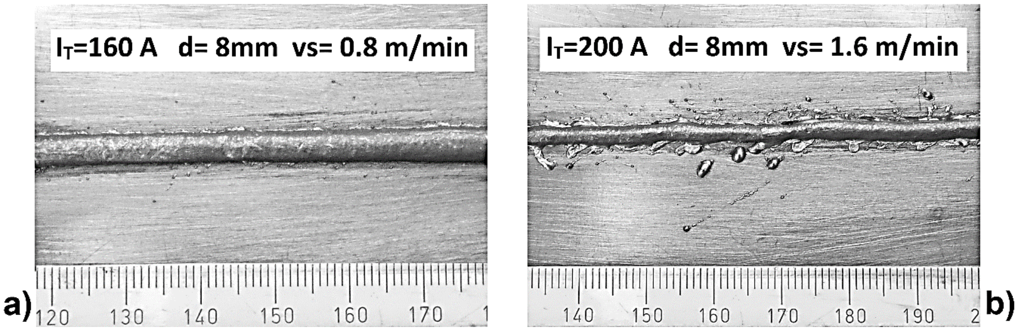

Figure 2. Macro images of weld beads. a) Exp09: Stable condition, b) Exp14: Unstable condition.

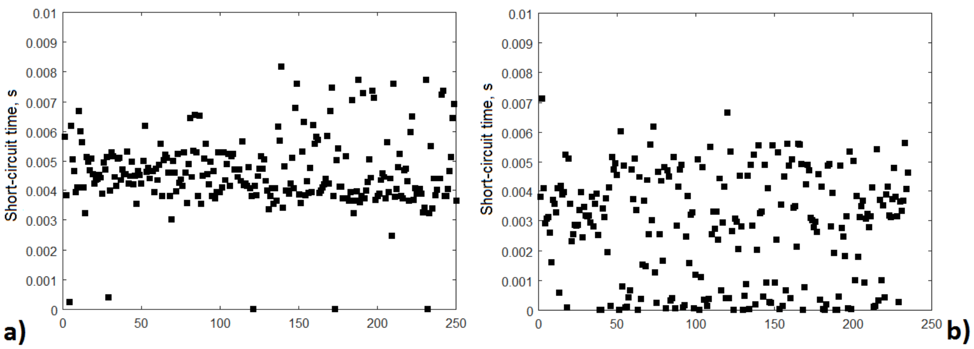

Figure 3. Time behavior of short-circuits. a) Condition 09, b) Condition 14.

From the comparative analysis in Fig.4, it is possible to verify the low dispersion of the short-circuits times for condition 9. In this case, it can be seen that the duration of the short-circuits for this condition was always very close to its average value. However, condition 14 showed a high dispersion of the short-circuit times as shown in figure 4b. The results shown in Fig.3, correspond to those presented by Adolffson et al (1999), who state that the standard deviation of the short circuit time increases when the process is operating out of optimal conditions, which causes the stability and final quality of the cord to be affected. The results shown, confirm the premise raised by Adolffson et al. (1999), Lucas (1983), Xie (1990) and Sencák (1994), authors who establish that for the short-circuit transfer mode an optimal process stability will be in correspondence with a minimum standard deviation of the short circuit time.

The behavior of the frequency of the short-circuits for the two selected conditions is shown in Fig. 4. It is possible to verify the low dispersion of the frequency of the short circuits for condition 9. However, condition 14 showed a high dispersion of the values as shown in Fig. 4b.

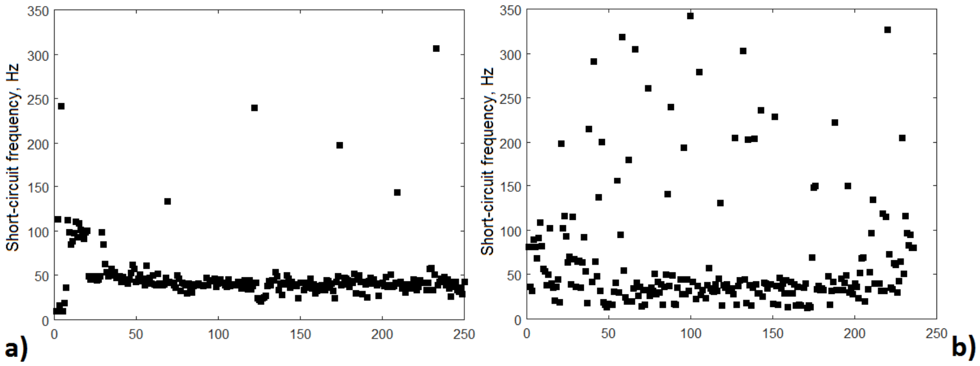

Figure 4. Short-circuit frequency behavior. a) Condition 09, b) Condition 14.

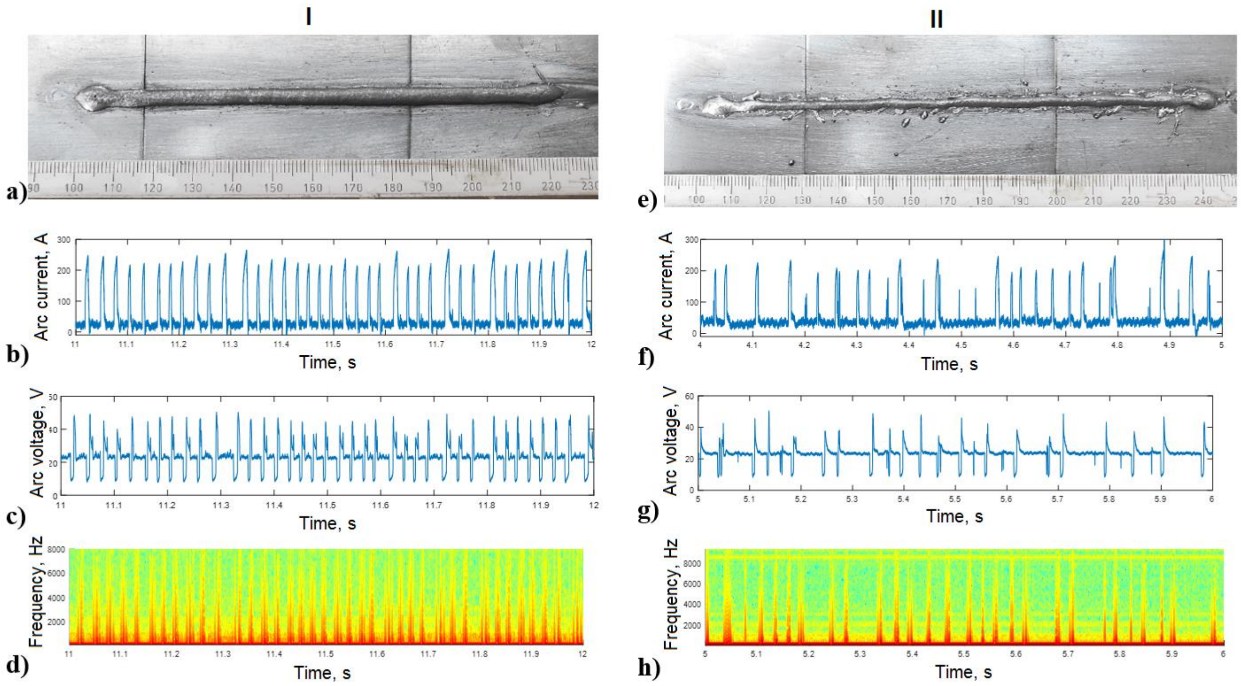

Figure 5. Comparative analysis of stable and unstable conditions: I. Stable condition (Exp. 9): a) macro image of the bead, b) arc current signal, c) arc voltage signal, d) time frequency diagram II Unstable condition (Exp. 14): e) macro image of the bead, f) arc current signal, g) arc voltage signal, h) time frequency diagram.

Figure 5a to 5d shows the images of the bead obtained for the stable condition 9 and the voltage and current signals of the arc. As can be seen in the figure, the parameter levels in the TIG-MIG welding process for this condition guaranteed a bead with good appearance and total absence of spatter. The current and voltage signals of the arc shown in Fig. 5b and c respectively, show a regular transfer cycle, low scatter at the peak levels of the welding current and the maximum restart voltages of the welding arc which is another indicator of stability in the welding process. Fig. 5d shows the time - frequency graph during the performance of the metal transfer, this combination of graphs allows a more complete interpretation of the spectral behavior of the arc signal and the process as a whole. Vertical lines can be seen on the time scale, associated with the arc's restart instants. It can be seen that the signal has spectral components in the whole frequency band. Uniform spectra were observed during the arc instants.

Figure 5e to 5h shows the images of the bead obtained for the unstable condition 14 as well as the voltage and current signals of the arc. As can be seen in Fig. 5e, the parameter levels in the TIG-MIG welding process for this condition did not guarantee a good appearance of the bead. On the contrary, an irregular bead with the presence of spatter can be seen. The current and voltage signals of the arc shown in Fig. 5f and g respectively, show an irregular transfer cycle, with high dispersion in the peak levels of welding current and maximal restart voltages of the welding arc which is an indicator of instability in the studied welding process.

Figure 6 shows the graph of the arc time behavior for both conditions (9 and 14), during the metal transfer. Fig. 6a shows a good behavior of the arc time, while Fig. 6b shows a higher dispersion indicating a more unstable process.

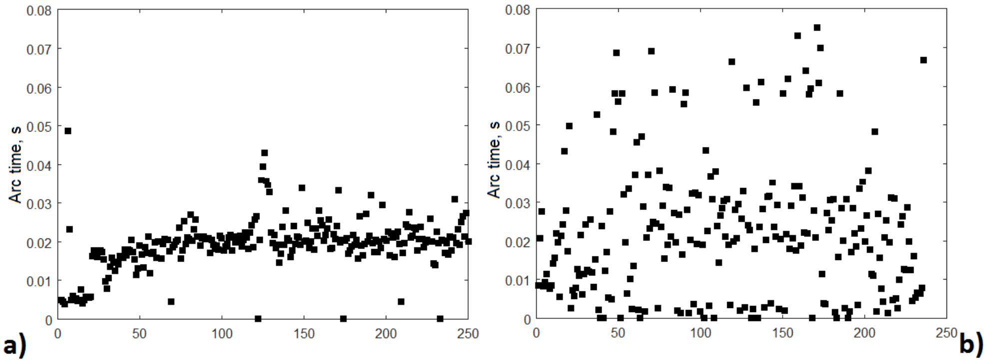

Figure 6. Arc time behavior. a) Condition 09, b) Condition 14.

4. Conclusions

The results and analysis of the present investigation, allow us to arrive at the following conclusions:

- The feasibility of the use of arc voltage and current signals as an effective way of stability analysis in the TIG-MIG process was demonstrated and its validity was proved, based on analysis and visual inspection of the deposited weld beads.
- The stability indices evaluated showed little variation between them with respect to the stability classification by experimental conditions.
- The statistical analyses showed that the variables analyzed had an influence on the stability and quality of the weld beads obtained.

References

Adolfsson, S., Bahrami, A., Bolmsjö, G., & Claesson, I. (1999). On-line quality monitoring in short-circuit gas metal arc welding. Welding Journal, Welding Research Supplement, 59s-73s.

Chen, J., Wu, C. S., & Chen, M. A. (2014). Improvement of welding heat source models for TIG-MIG hybrid welding process. Journal of Manufacturing Processes, 16(4), 485-493.

Jiménez, E. M., Roca, A. S., Fals, H. C., Fernández, J. B., & de la Parte, M. P. (2010). Time–frequency diagram applied to stability analysis in gas metal arc welding based on acoustic emission. Science and Technology of Welding and Joining, 15(3), 226-232.

Kanemaru, S., Sasaki, T., Sato, T., Mishima, H., Tashiro, S., & Tanaka, M. (2014). Study for TIG–MIG hybrid welding process. Welding in the World, 58(1), 11-18.

Lucas, W. (1983). Process stability in MIG welding. In: Proceedings of the 2nd International Conference on Computer Technology in Welding, 329–336, Cambridge.

Norrish J. (1992). Advanced welding process. In: New manufacturing processes and materials series (Wood J. and Apelian D. Eds.). Nottingham, Nottingham University, Worcester, MA, Worcester Polytechnic Institute

Roca, A. S., Fals, H. C., Fernández, J. B., & Adán, F. S. (2005). Application of U versus I diagrams for process stability evaluation in gas metal arc welding in short circuit transfer mode. Revista Soldagem e Inspeção, 10(2), 85-91.

Roca, A. S., Fals, H. C., Fernández, J. B., Macías, E. J., & Adán, F. S. (2007). New stability index for short circuit transfer mode in GMAW process using acoustic emission signals. Science and Technology of Welding and Joining, 12(5), 460-466.

Sencák, V. (1994). Method of stability evaluation of free flight arc process. , Zvaranie – Svarovani – Welding 3, 6-8.

Tušek, J., Umek, I., & Bajcer, B. (2005). Weld-cost saving accomplished by replacing single-wire submerged arc welding with triple-wire welding. Science and Technology of Welding and Joining, 10(1), 15-22.

Xie, X. (1990). Process Monitoring as a Mean to Ensure Quality and to Increase Productivity in Robotized GMA Short Arc Welding. International Journal for the Joining of Materials, 2(4), 117-126.