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GTAW COLD WIRE FEED: TRANSITIONAL TRANSFER MODE CHARACTERIZATION

Anna Louise Voigt
Universidade Federal de Santa Catarina, Centro Tecnológico, Florianópolis, SC, Brasil, alouisevoigt@gmail.com
Tiago Vieira da Cunha
Universidade Federal de Santa Catarina, Centro Tecnológico de Joinville, Joinville, SC, Brasil, t.cunha@ufsc.br
Carlos Enrique Niño Bohórquez
Universidade Federal de Santa Catarina, Centro Tecnológico, Florianópolis, SC, Brasil, carlos.nino@ufsc.br

Abstract. *Regarding the metallic transfer of cold wire applied to the GTAW process, there are basically two transfer modes in the literature: intermittent drop and uninterrupted bridge. Considering an intermittent transfer situation, as the wire-feed speed increases, the droplet frequency is expected to increase until the wire end touches the molten pool, resulting in an uninterrupted bridging transfer. Using a welding current of 100 A, bead-on-plate tests were performed on AISI 304 sheets using a 1.0 mm diameter AWS ER 307Si wire. The wire feed speeds were varied from 0, 3 to 1.0 m/min, moving from the intermittent drop transfer mode to the uninterrupted bridge condition (1.0 m/min). Through image acquisition and potential difference between wire and tungsten electrode, a transient transfer mode could be characterized, called an "intermittent bridge". Furthermore, experimental tests of bead on plate were carried out in order to evaluate the influence of the different transfer modes on the weld beads surface aspects. It was observed that the transfer frequency increases as the wire feed speed increases, reaching the maximum point, where the metallic transfer mode starts to assume a transient behavior of intermittent bridge. During the transition, the frequency decreases until it reaches the condition of an uninterrupted bridge.*

Keywords: *TIG, Cold wire, Metal transfer, Intermittent Bridge, Intermittent Drop*

1. INTRODUCTION

Over the last decades, the GTAW welding process has been widely applied in high-responsibility component joining, mainly due to its characteristics associated with weld-bead quality, despite its low productivity, historically pointed as a process deficiency. In that context, one of the alternatives to increase result productivity and repeatability is to employ a wire feeding process. Analogous to the GMAW process, in which there are different metal transfer modes depending on the employed welding variables, the continuous wire feed in the GTAW process also assumes different transfer configurations, although, in this case, the wire is not part of the welding electric circuit.

In the literature, two modes of metal transfer are commonly presented in the GTAW process: droplet (intermittent) and uninterrupted bridging (Yudodibroto et al., 2004, Geng et al., 2017, Hejripour et al., 2018, Silwal & Santangelo, 2018, Silva et al., 2019). Yudodibroto et al. (2004) state that the transfer mode in the GTAW process is influenced by the wire insertion position in relation to the arc and the molten pool, as well as the welding energy in relation to the wire feed speed. When the wire insertion position is increased or when the feed rate is slow, a continuously increasing droplet is formed at the wire tip. In that case, metal transfer occurs when the increasing droplet touches the molten pool and is transferred by surface tension, which is also known as intermittent transfer. At a lower wire insertion position or at a higher wire feed speed, the uninterrupted bridge transfer takes place, when the liquid metal found at the end of the wire smoothly flows into the molten pool and virtually no agitation is observed there.

Considering a condition of intermittent transfer mode, as the wire feed speed increases, the droplet transfer frequency is expected to increase (having smaller droplet sizes) to the point where the transfer of liquid metal from the wire end is then governed by the uninterrupted bridging transfer mechanism. However, according to the present study, there is a transition between those two widespread transfer modes. Through voltage readings between the wire and the tungsten electrode, along with an image acquisition system, a transient transfer mode, here called "intermittent bridge", could be observed.

2. MATERIALS AND METHODS

Bead-on-plate welding employing a 100 A current and a 100 mm/min welding speed was performed on 4 mm thick AISI 304 stainless steel plates. Argon was used as the shielding gas with a fixed flow rate of 10 l/min. In all tests, a ceramic nozzle with a 124 mm^2 of gas outlet cross-sectional area was used. A EWTh-2 electrode, with a 2.4 mm diameter sharpened at 30°, was employed. The distance between the electrode and the specimen was kept at a constant 4 mm. An AWS ER 307Si wire with a 1.0 mm diameter was inserted in front of the arc with a 25° angle to the specimen. The test bench was equipped with a torch shifter device and a data acquisition system to monitor the voltage between the wire and the torch, as well as the wire feed speed (Figure 1). For image acquisition, the methodology developed by Voigt et al. (2017) was employed with an acquisition rate of 30 frames per second. In order to evaluate the effect of different detachment frequencies on the characteristics of the weld beads, images of their surfaces were performed after a cleaning procedure with Nitric-Hydrofluoric Acid according to ASTM A380 standard.

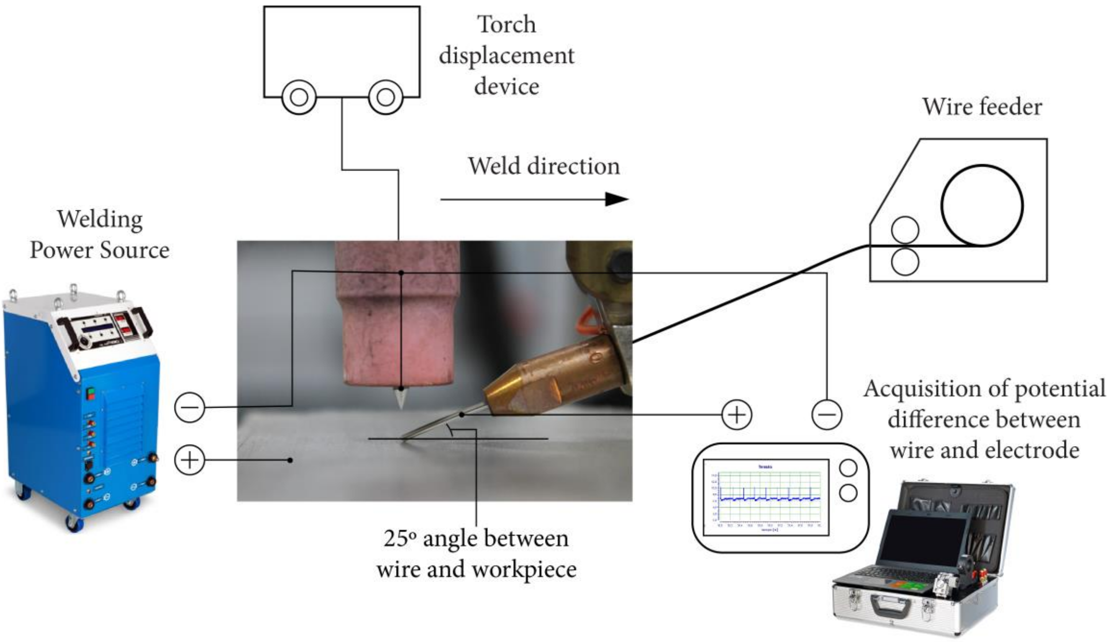

Figure 1 - Test bench schematic

The droplet transfer frequency was obtained through the voltage oscillogram. When the wire end is in the voltaic arc, the potential difference between the electrode and the wire is about 70% of the arc's voltage (approximately 11 V under the present work's conditions). When the liquid metal from the wire tip touches the molten pool, the voltage reaches a similar value to the arc's, which allows the detection of both the drop detachment frequency and how long the wire remains in contact with the molten pool.

3. RESULTS AND DISCUSSIONS

Having the potential difference oscillograms between the wire and the tungsten electrode allowed the droplet detachment frequency to be measured. Initially, with wire-feed speeds of 0.3 and 0.4 m/min, the detachment times are approximately 7 and 4 ms, and the frequency 1.5 and 4.5 Hz, respectively. However, as the wire-feed speed is increased, alternating detachment times of 3 ms with average times of 79 ms are observed. Such prolonged periods suggest the occurrence of uninterrupted bridging, however, for short periods of time. As the wire-feeding speed increases, those extended periods become longer and the transfer characteristics of the intermittent transfer mode decrease. For a wire-feed speed of 0.8 and 0.9 m/min, average times of 146 ms and 264 ms are respectively observed. In Table 1, the confidence intervals for the average values of the detachment times and between their occurrence are presented.

Table 1 - Measured values about the times and characteristics of the detachment. SDN and LDN corresponding to the number of short and long detachments, respectively, in a period of 5 seconds

ADJUSTED WIRE FEED SPEED	DETACHMENT CHARACTERISTICS	SDN	LDN	TIME BETWEEN DETACHMENTS	DETACHMENT TIME	DETACHMENT FREQUENCY
0.4 m/min	Short	8	-	633 ± 60 ms	7 ± 2 ms – curtos	1.5 Hz
0.5 m/min	Short	22	-	225 ± 55 ms	4 ± 1 ms – curtos	4.5 Hz
0.6 m/min	Long and short	15	13	141 ± 35 ms	79 ± 15 ms – longos	5.5 Hz
0.7 m/min	Long and short	3	21	110 ± 32 ms	110 ± 27 ms – longos	4.5 Hz
0.8 m/min	Long	-	21	95 ± 15 ms	146 ± 46 ms – longos	3.5 Hz
0.9 m/min	Long	-	15	57 ± 12 ms	264 ± 42 ms - longos	3.0 Hz

Figure 2 shows a transfer-frequency graph as a function of wire-feed speed. Along with the graph, the 2s duration voltage acquisitions are presented, showing the above-mentioned transient transfer behavior. For a wire-feed speed of 1 m/min, an uninterrupted bridging transfer was observed.

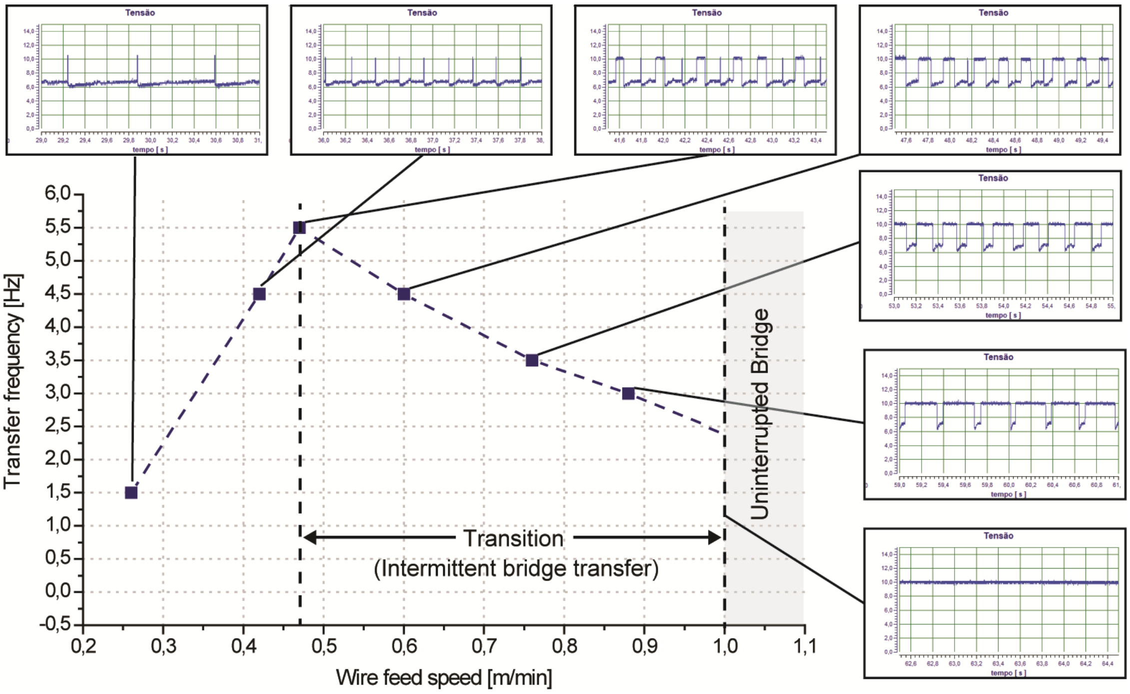

Figure 2 - Transfer frequency as a function of wire feed speed

Frames that allow a better understanding of the presented transient transfer could be obtained from the voltaic arc image acquisition. Figure 3(a) shows frames at 67 ms intervals demonstrating the intermittent transfer condition, and Figure 3(c) shows the uninterrupted bridge transfer, both mechanisms already widespread in the literature. The mentioned transient transfer, where no droplet formation occurs at the wire end, can be observed in Figure 3(b), however, the contact with the molten pool does not remain constant. During such transfer, no droplet is formed at the end of the wire, and there is no continuous liquid-metal stream between the wire and the molten pool. The period discussed in Figure 3(b) comprises the transient-transfer time of the wire-feed speed of 0.9m/min, corresponding to 3Hz. The first and last frames show the moments when the wire is no longer in contact with the molten pool. This transient phenomenon has mixed characteristics of intermittent and uninterrupted-bridge transfer modes. This is probably due to an instability condition associated with the surface tension. As the frequency of short circuits increases before the uninterrupted bridge condition is established, there is less overheating of the molten metal at the end of the wire due to the shorter times in which it remains exposed to the high arc temperatures. As a result, the surface tension declines (Keene, 1993) and is therefore unable to maintain the continuous liquid-metal stream. This will only be achieved by reducing the distance between the end of the still solid wire and the molten pool surface, then, with a further wire speed increase.

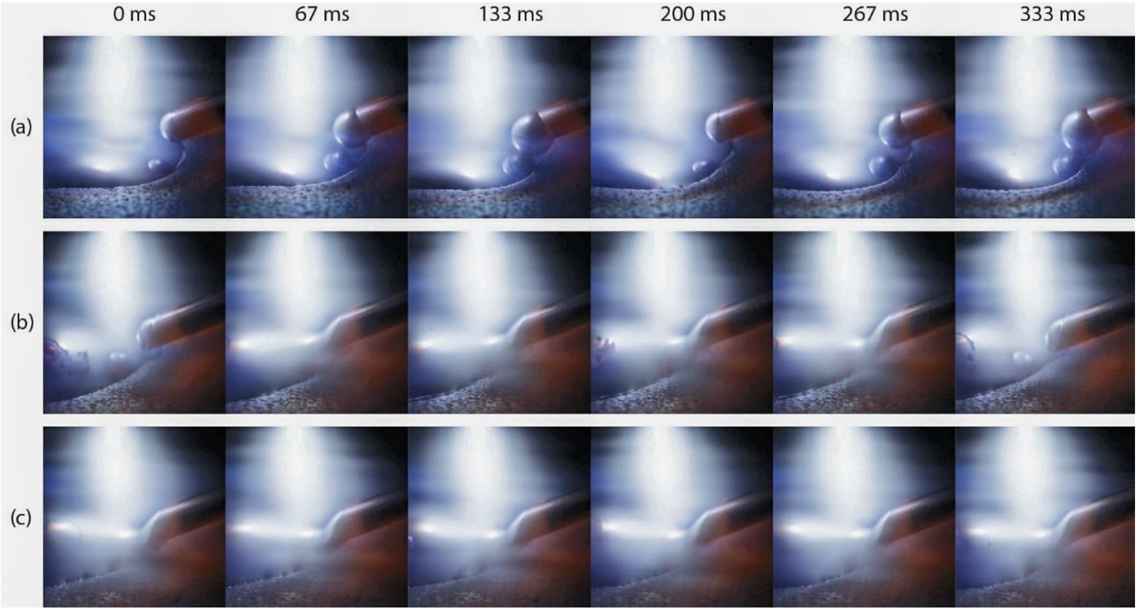

Figure 3 - 67-ms time-lapse image sequence of (a) intermittent, (b) intermittent bridge, and (c) uninterrupted-bridge transfer modes

In Figure 4, it is possible to visualize the surface appearance of the weld beads with intermittent transfer and by intermittent bridge, together with the graph previously presented in Figure 2, in order to facilitate the correlation with the transfer modes. In the condition of lower wire feed speed, which resulted in the intermittent transfer of a lower droplet detachment frequency, the "scaly" effect of the weld bead characteristic of this metallic transfer mode is observed. With the increase in the wire feed speed, and the consequent increase in the droplet detachment frequency, there is a smoothing of this scaling effect as a function of the higher frequency. At maximum detachment frequency, however, the effect of scales is more evident than in the aforementioned condition. This is believed to be due to the transient characteristics of transference at this point. According to Figure 2, at this point of maximum transfer frequency, a mixed transfer of intermittent and intermittent bridge is observed. Therefore, it is believed that the scales are due to the formation of droplets that occur between the metallic bridge events. In this way, the droplet formation frequency of the 5.5 Hz transfer frequency condition is lower than the condition that results in the purely intermittent 4.5 Hz transfer frequency, without the occurrence of intermittent metal bridge. In the transition region where the transfer is predominantly by intermittent bridge, there are weld beads with a smooth surface and very close to those obtained with the transfer mode by uninterrupted-bridge.

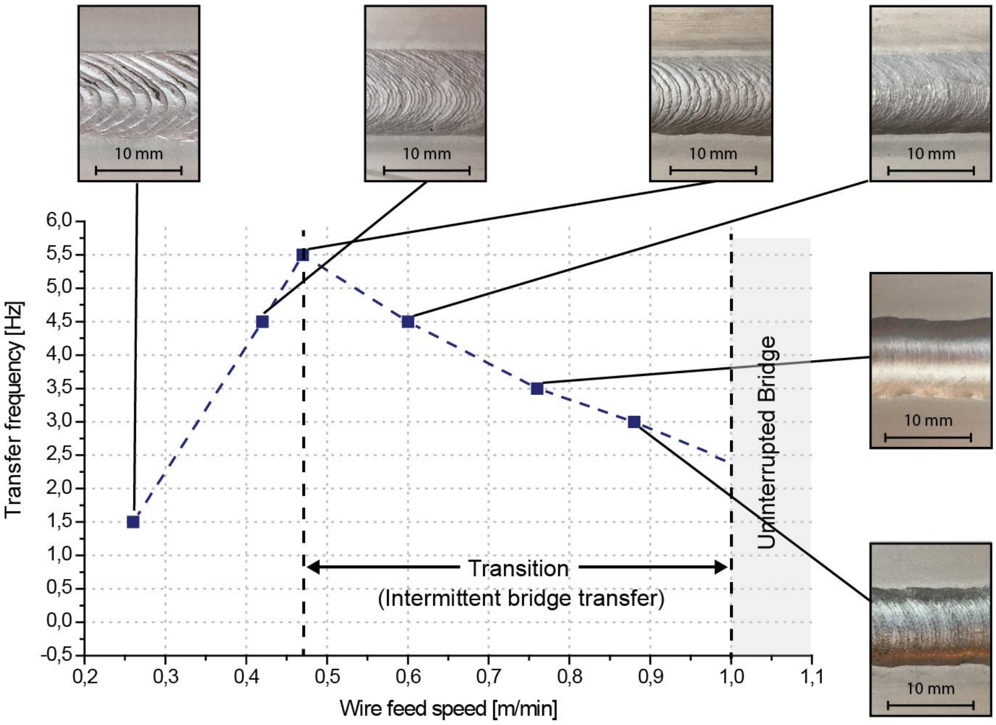

Figure 4 - Transfer frequency as a function of wire feed speed and surface appearance of the weld beads

4. CONCLUSIONS

Measuring the detachment frequency of the drops in intermittent transfer was possible through the arc's image acquisition along with the voltage between the wire and the tungsten electrode. Thus, the presence of a transient transfer mode could be identified, called an "intermittent bridge", between the intermittent and the uninterrupted-bridge mode, presenting characteristics of both modes, which are widely disseminated in the literature. This mode presented application potential, while allowing to operate with a smaller input of material than the condition that results in an uninterrupted bridge transfer, without the occurrence of large volume drops that often make the application of the droplet transfer mode (intermittent) unfeasible. As for the surface aspects of the weld beads, it was possible to observe the characteristic scaling effect in the intermittent metal transfer tests. In the test with mixed characteristics in the intermittent and intermittent bridge modes, the same scaling effect was observed, however, corresponding to a droplet detachment frequency lower than the measured detachment frequency. In the transition region where the transfer mode is characterized by intermittent bridging, the surface appearance resembles what is expected from the uninterrupted bridging transfer mode.

5. ACKNOWLEDGMENTS

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