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Initial assessment of a new approach for laser: tandem GMA welding

Avaliação inicial de uma nova versão para soldagem laser: MIG/MAG duplo-arame

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Abstract

Recently a large number of research and development has been made regarding the use of Laser in welding operations, turning this process into an important tool for a variety of applications. Although it is possible to use Laser as a unique source of heat to promote union of materials, the combination of the beam provided by a Laser system with an arc welding process has become largely studied and applied in the so called hybrid welding. Generally, the final result of such combination is an increase in the weld penetration depth, width and welding travel speed. Despite all these facts, there are many issues still requiring further research and development concerning the use of hybrid welding using Laser and arc welding, including more comprehensive understanding on the various welding phenomena involved and the exploitation of new combinations. This paper describes a new approach for hybrid welding combining LBW with Tandem GMAW (Laser beam placed between the Tandem GMAW wires). The first view on such hybrid process variation is described and some basic aspects regarding its performance are discussed. The Laser beam had a positive effect on the aspect of the weld beads produced and a 10 mm inter-wire distance showed to be the most appropriate among the distances tried.

Key words: *hybrid welding, LBW, tandem GMAW.*

Resumo

Recentemente, várias pesquisas e desenvolvimentos têm sido feitos sobre a utilização de Laser em operações de soldagem, tornando este processo em uma importante ferramenta para uma variedade de aplicações. Apesar de ser possível utilizar o Laser como única fonte de calor para promover a união de materiais, a combinação do feixe produzido pelo sistema de Laser com um processo de soldagem a arco tem se tornado largamente estudada e aplicada na chamada soldagem híbrida. Geralmente, o resultado final é um aumento na penetração e largura do cordão de solda e da velocidade de soldagem. Apesar de todos estes fatos, existem muitas questões que ainda requerem mais investigação e desenvolvimento em relação ao uso de soldagem híbrida usando Laser e soldagem a arco, incluindo um melhor entendimento dos fenômenos de soldagem envolvidos e a exploração de novas combinações. Este artigo descreve uma nova montagem para a soldagem híbrida combinando Soldagem a Laser e MIG/MAG Duplo-Arame (feixe de Laser colocado entre os arames do MIG/MAG Duplo-Arame). Os primeiros resultados do uso deste processo híbrido são apresentados e alguns aspectos básicos com relação à sua performance são discutidos. O feixe de Laser teve um efeito positivo no aspecto dos cordões de solda produzidos e uma distância de 10 mm entre os arames se mostrou ser a mais apropriada dentre as distâncias testadas.

Palavras-chave: *soldagem híbrida, soldagem a Laser, MIG/MAG duplo-arame.*

1. Introduction

There have been described systems for hybrid welding combining Laser with GTAW (Hu and den Ouden, 2005), with PAW (Swanson *et al.*, 2007; Page *et al.*, 2002), with GMAW (Kim *et al.*, 2006; Mulima *et al.*, 2006) and even with SAW (Tusek and Suban, 1999). Regardless of the process of choice to be combined with the Laser, the general and eventual result is the increase in the effectiveness of the welding. It is well known that LBW (Laser Beam Welding) is distinct for providing high power density, deep penetration, high welding speed, low distortion and precision. However, because of the small Laser beam spot, LBW shows poor gap bridge-ability and precision in joint preparation is always a requirement. On the other hand, arc welding processes have relatively lower power density and produce wider weld beads, delivering good bridge-ability for joint gaps and large tolerances for joint preparation. The combination of LBW and arc welding tends to enhance the advantages and compensate the limitations found in each process. Generally the final result is an increase in the weld penetration depth, width and welding travel speed. Despite the lack of information on the use of Laser with Tandem GMAW, a number of studies on hybrid welding employing Laser and single wire GMAW have been published, most of them using CO2 or Nd:YAG Lasers. Qin *et al.* (2007), for instance, studied hybrid Nd: YAG Laser - pulsed GMA welding and found that the Laser energy mainly decides the weld penetration, that the weld width depends on the arc process and the hybrid process increased the welding speed and improved the weld appearance for low currents. Cho and Farson (2007) showed that the use of a Laser beam in front of the GMAW weld pool prevents the formation of humping. Kim *et al.* (2006) found that the heat input delivered to the plate is dependent on the nature of the leading heat source (Laser or GMAW) and also the joint condition used in the hybrid setup. Kim *et al.* (2006) also mention that synergistic effects of the two heat sources are maximised when the Laser beam is located between the arc centre and the impact point of the molten droplets within the weld puddle. Tusek and Suban (1999) cites that the main advantage of the use of both heat sources is the more efficient use of the energy supplied. They also state that the synergic action of the Laser beam and welding arc shows that the Laser beam in the welding arc, when current intensities are low, affects ionisation, reduces arc resistance, and increases the number of carriers of electric current. The hybrid process has become even an option to be used in pipeline applications, where the demand for high speed welding is always present (Moore *et al.*, 2004). Besides being largely used in combination with pulsed GMAW, Mulima *et al*. (2006) presented the first trials using Laser (Diode) combined with GMAW in a controlled dip transfer mode and showed that, in this case, by adding the Laser beam in the front of the GMAW wire, the welding travel speed could be significantly increased and deep penetration achieved. In recent years Tandem GMAW (especially in pulsed mode) has been largely applied in production due to developments of digital welding power sources and advances in research on this process (Scotti *et al.*, 2006; Ueyama *et al.*, 2005; Ueyama *et al.*, 2006; Reis *et al.*, 2008). In pulsed Tandem GMAW the waveform control technique produces one droplet per each pulse of current, which results in a stable welding process and less spattering at high travel speeds. However, it is believed that a combination of this arc welding process with LBW can improve weld visual quality, provide even higher welding speeds and increase penetration. Thus, this paper describes a new approach for hybrid welding combining LBW with Tandem GMAW (Laser beam placed between the Tandem GMAW wires). The first view on such hybrid process variation is described and some basic aspects regarding its performance are discussed. More details of this hybrid welding approach can be found in Reis *et al.* (2009).

2. Materials and Methods

As a means of allowing a new approach for hybrid welding using LBW and Tandem GMAW, a rig was designed to provide fixture for the components of a Tandem GMAW torch whilst providing accommodation for a Diode Laser head between them. In this approach, as the Laser head is placed between the wires, its beam can be used perpendicular to the work piece, meaning that the Laser beam can deliver its energy with maximum efficiency. Figure 1 presents the test facility diagram for the Laser - Tandem GMAW approach used (left hand side) with the hybrid welding head in detail (right hand side).

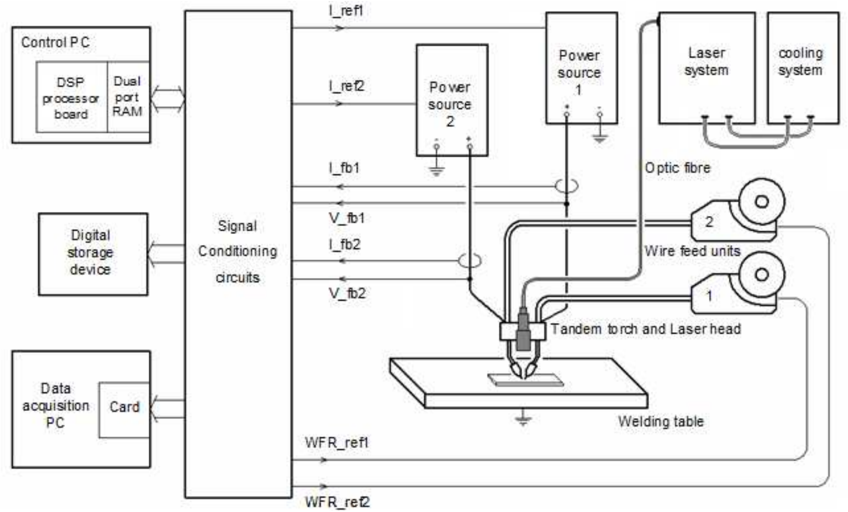

Figure 1: Test facility diagram for the Laser - Tandem GMAW approach used (left hand side) with hybrid welding head in detail (right hand side).

As the use of a Laser beam between the wires in a tandem torch is a new approach for hybrid welding, some basic evaluation of the process is needed, such as weld bead visual quality produced, whether the laser beam allows increased inter-wire distances to be used, the Laser beam position (in relation to the wires) influence, and the effect caused by adding the Laser beam between the wires on the weld bead profile. In order to accomplish an evaluation on the first two aspects, tests were carried out varying the distance between the wires (inter-wire distance) for two levels of Laser beam power (1 and 2 kW). Bead on plate welding on 2 mm plain carbon steel sheets without backing was used throughout the tests.

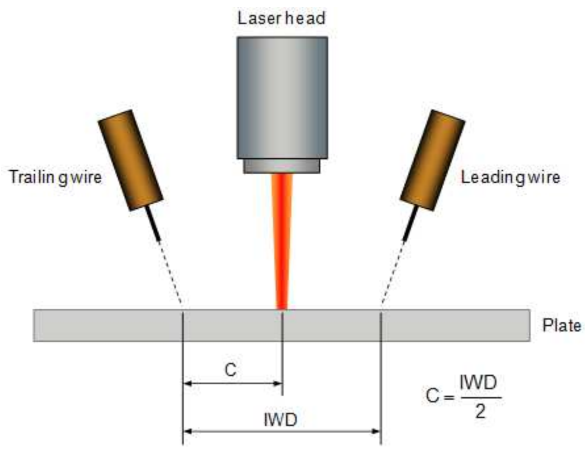

Figure 2: Position of Laser beam in relation to the wires (IWD = inter-wire distance).

The tandem GMAW process welding mode chosen to be tried in this new hybrid welding approach was the pulsed mode since it is more common to the process. A condition derived from an optimized low mean current condition was tuned (0.1 ms of delay between the current pulses in an 'almost-in-phase' synchronization providing one droplet per pulse and no arc interruptions) (Reis *et al.*, 2008). For each Laser beam power level, two weld beads were produced; one to provide opportunity to capture images synchronised with transient electrical data and one to provide longer transient electrical data acquisition time and to verify the repeatability of the process. For the cases in which the Laser beam was set with higher level of power, the conditions were tried also using out-of-phase pulsed welding (10 ms of delay between the current pulses, delivering the pulse of current in the trailing wire when the leading wire was in the middle of its base current time). Weld beads were produced also using only the GMAW process as a comparison basis. Table 1 shows the welding parameters used in the pulsed control program (Reis *et al.*, 2008) developed for Tandem GMAW whilst Table 2 shows extra welding parameters. Figure 3 shows the angles for the wires in the tandem torch (as a requirement to accommodate the Laser head between the wires, the angle used was bigger than usual).

Table 1: Welding parameters selected for GMAW.

Welding Parameter	**Value**
Ipulse1 = Ipulse2 (A)	350
Tpulse1 = Tpulse2 (ms)	2
Ibase1 = Ibase2 (A)	50
Tbase1 = Tbase2 (ms)	18
Ramp_up1 = Ramp_up2 (A/ms)	2000
Ramp_down1 = Ramp_down2 (A/ms)	2000
Tailout1 = Tailout2 (dimensionless)	45
WFR1 = WFR2 (m/min)	3.8
Delay (ms)	0.1
Arc Voltage Control (wire 1 and 2)	ON

Table 2: Additional welding parameters utilised.

Welding Parameter	**Value**
CTWD* (both wires) (mm)	18
Welding Travel Speed (m/min)	1.63
Shielding Gas [98% Ar + 1.5% O_2] (l/min)	35
Wires diameter [AWS ER 70S-6] (mm)	1.2
Inter-wire Angle (º)	68

* The CTWD parameter was considered as the vertical distance measured from the contact tip to the work piece.

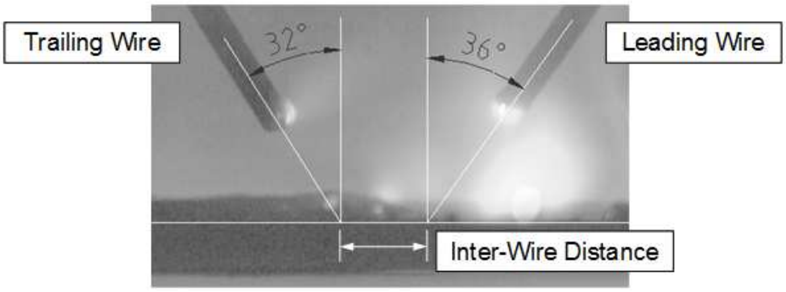

Figure 3: Angle measured between the electrodes and inter-wire distance parameter.

3. Results and Discussion

3.1. Inter-wire distance of 5 mm

The first Laser - Tandem GMAW conditions tried were using only 5 mm for the inter-wire distance. Figure 4 shows a sequence of images synchronised with electrical transient data for the case of using a 2 kW Laser beam and 'almost-in-phase' current pulses and Figure 5 with out-of-phase current pulses as a general representation of the hybrid process with an inter-wire distance of 5 mm.

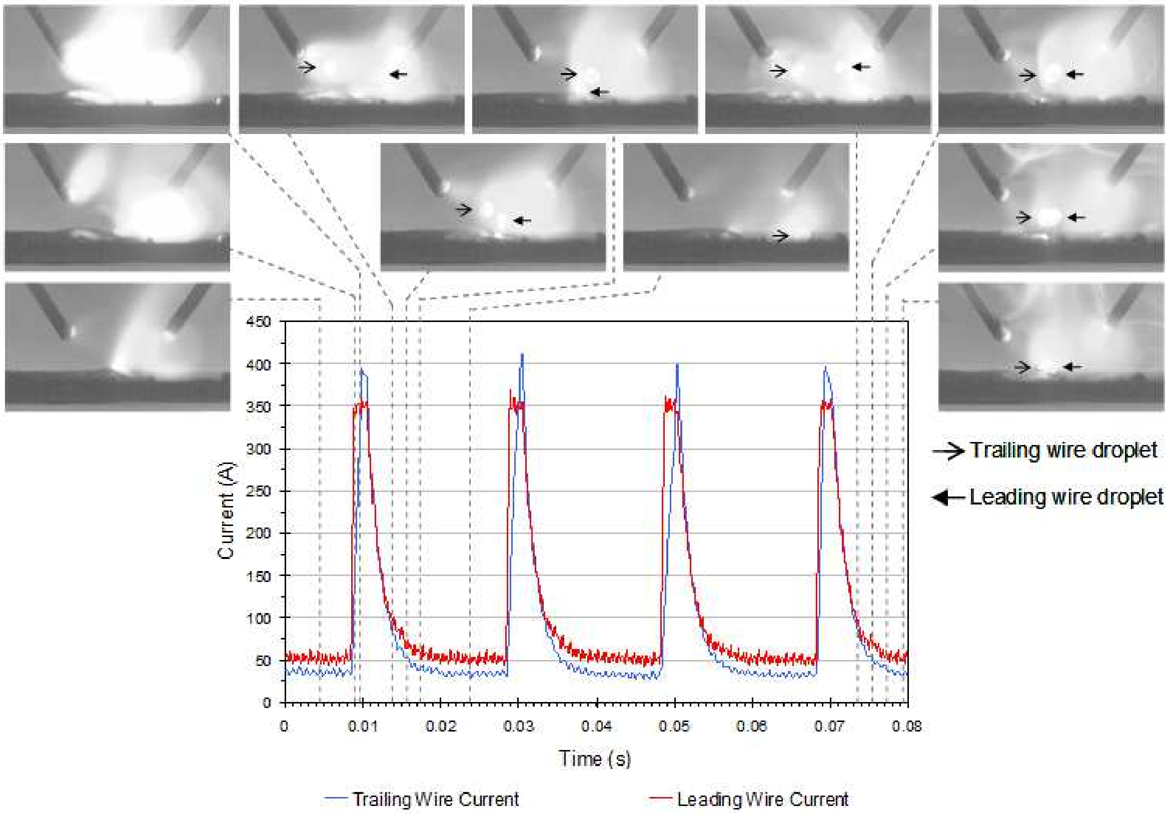

Figure 4: Images synchronised with electrical transient data for Laser - Tandem GMAW using 'almost-in-phase' current pulses (Laser beam power = 2 kW and inter-wire distance = 5 mm).

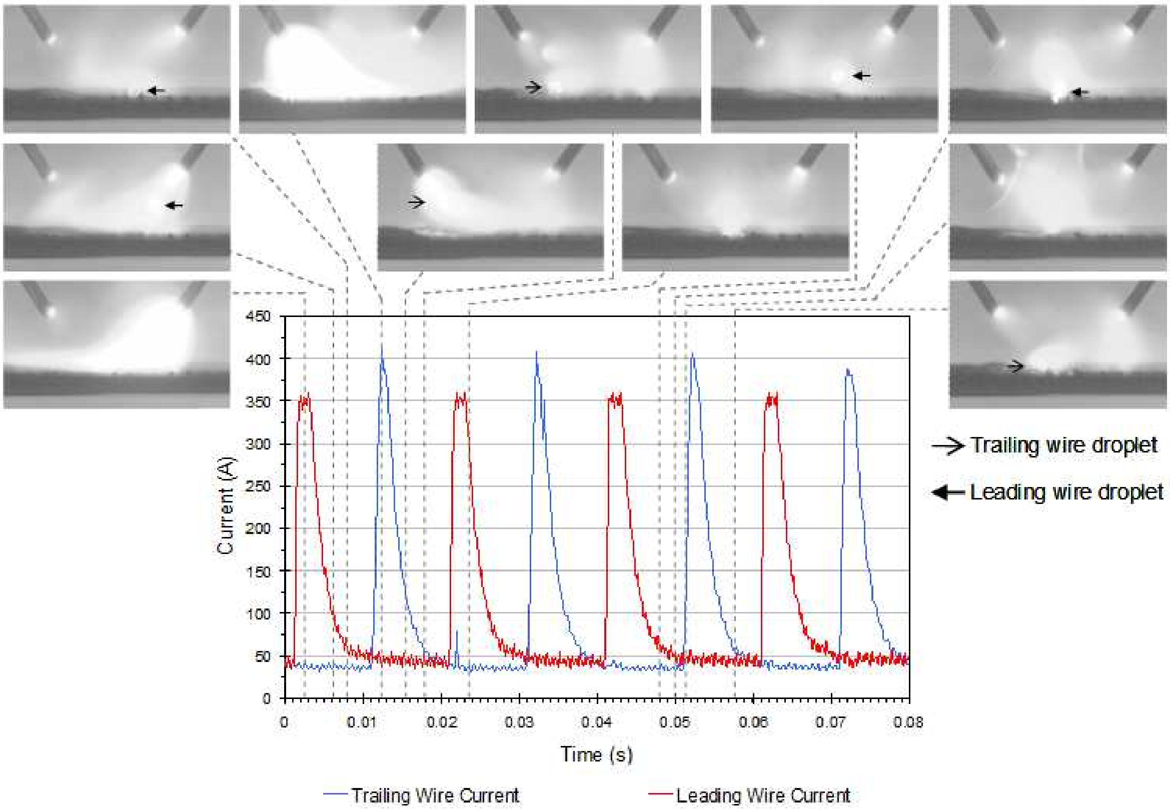

Figure 5: Images synchronised with electrical transient data for Laser - Tandem GMAW using out-of-phase current pulses (Laser beam power = 2 kW and inter-wire distance = 5 mm).

In the case of 'almost-in-phase' pulses the trailing wire had a tendency of being attracted by the leading arc but no arc interruptions were observed since the small delay between the current pulses showed to be efficient in avoiding such interruptions, as described by Reis *et al.* (2008). A curious fact was detected regarding the metal transfer. The droplets were remarkably deviated and, as a consequence, two situations occurred; the droplets hit the plate out of the weld pool region (especially the droplets from the trailing wire) or they merged close to or right underneath the Laser beam forming a large droplet. In the first case the weld bead aspect was deteriorated since the droplets hit the plate not necessarily aligned with the weld bead, remaining beside the weld bead and easily identified for their large-spatter shape (Figure 6). In the case of merging under the Laser beam, part of the energy provided by this process is lost since the beam causes partial evaporation of the droplet producing high levels of fume (Figure 7).

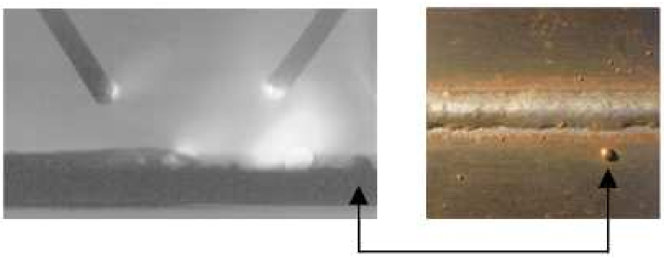

Figure 6: Detail of droplet missing the weld pool.

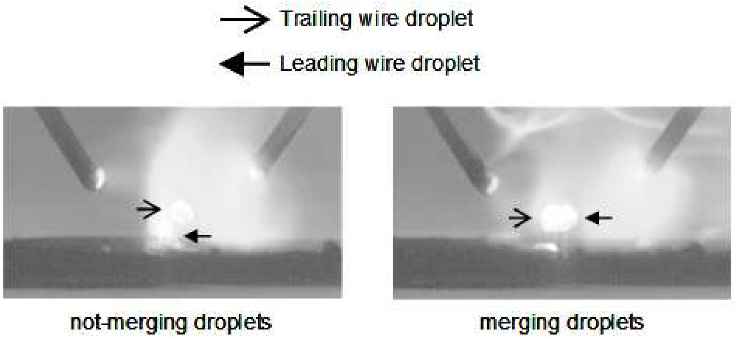

Figure 7: Increase in fume generation when merging droplets are partially evaporated by the Laser beam.

In the case of out-of-phase current pulses, arc interruptions were verified in the trailing wire for all the conditions regardless of adding the Laser beam to the tandem GMAW process or not. Despite these undesirable occurrences, some observations could still be made. The droplets were not deviated as much as in the 'almost-in-phase' case and they always hit the weld pool without merging. As they were detached from the respective wires at different times, they reached the region underneath the Laser beam at different times. However, the droplets still hit the plate very close to or under the Laser beam, case in which they were partially evaporated generating more fumes and probably reducing the process efficiency.

Regardless of welding with 'almost-in-phase' or out-of-phase current pulses for the GMA process, the Laser beam seemed to have a positive effect on the aspect of the weld bead. While the travel speed used was too high for the case of welding without the Laser beam, as the Laser power was increased the bead aspect was improved (Figure 8).

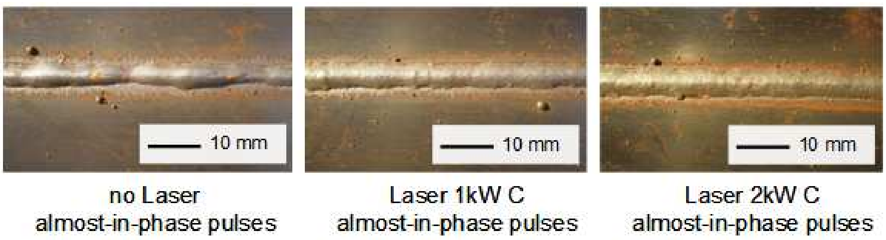

Figure 8: General aspect of weld beads produced with Laser - Tandem Pulsed GMAW using an inter-wire distance of 5 mm.

As briefly discussed before, a kind of 'cross transfer' occurred when using 'almost-in-phase' current pulses and an inter-wire distance of only 5 mm. This adverse effect had negative consequences in the weld bead aspect, fume generation and probably in the process efficiency. Despite avoiding arc interruptions, it seems that the fact of having high current levels in both arcs when the droplets are detached left these droplets under more 'attraction' by the opposite arc than when using out-of-phase pulses. With out-of-phase current pulses the droplets tended to follow the projection of the respective wire towards the weld pool. In order to give an idea of the magnitude of these deviations, some measurements were carried out (Figures 9 and 10). Figure 11 congregate the results of droplet deviation measurement for an inter-wire distance of 5 mm. The deviation of the droplets coming from the trailing arc tended to be longer, attesting that the trailing arc is more disturbed than the leading one.

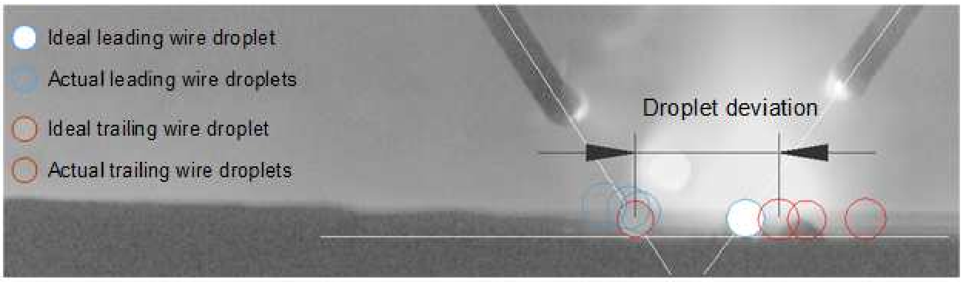

Figure 9: Droplet deviation for 'almost-in-phase' current pulses (inter-wire distance = 5 mm and Laser beam power = 2 kW).

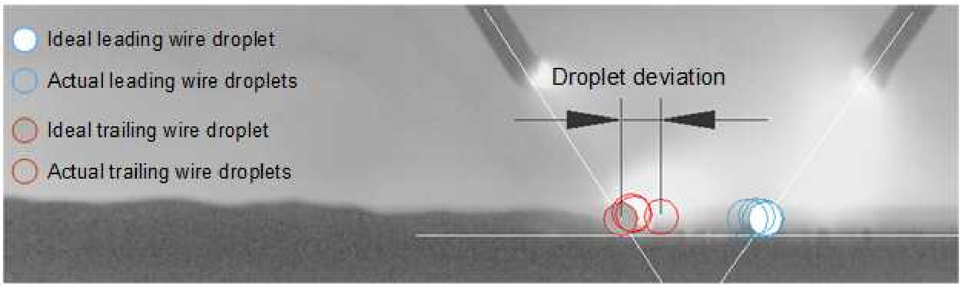

Figure 10: Droplet deviation for out-of-phase current pulses (inter-wire distance = 5 mm and Laser beam power = 2 kW).

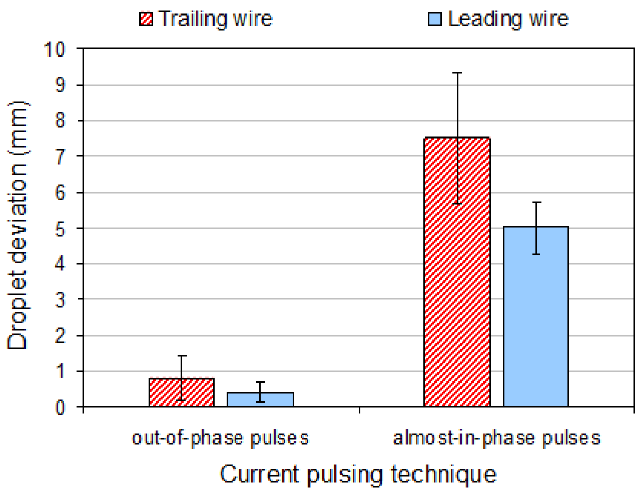

Figure 11: Droplet deviation in the leading and trailing arcs for different pulsing techniques (inter-wire distance = 5 mm and Laser beam power = 2 kW).

As the droplets are under the influence of the same magnetic fields that affect the arcs, it is possible to make an analogy to the model of arc displacement proposed by Ueyama *et al.* (2005) for pulsed tandem GMA welding to explain the deviation taking place in the droplets. Despite the fact that the use of 'almost-in-phase' pulses helps in avoiding the occurrence of arc interruptions by making the trailing arc 'stiffer' as the leading arc is at high levels of current, the condition using out-of-phase current pulses decreases the displacement of arcs (force of attraction) at the moment that the droplets are detached (Figure 12). As the force of attraction is reduced, the deviation of droplets from the expected path is probably also reduced. This decline in the arc deviation (force of attraction) does not take place with 'almost-in-phase' (or in-phase) pulses (Figure 13).

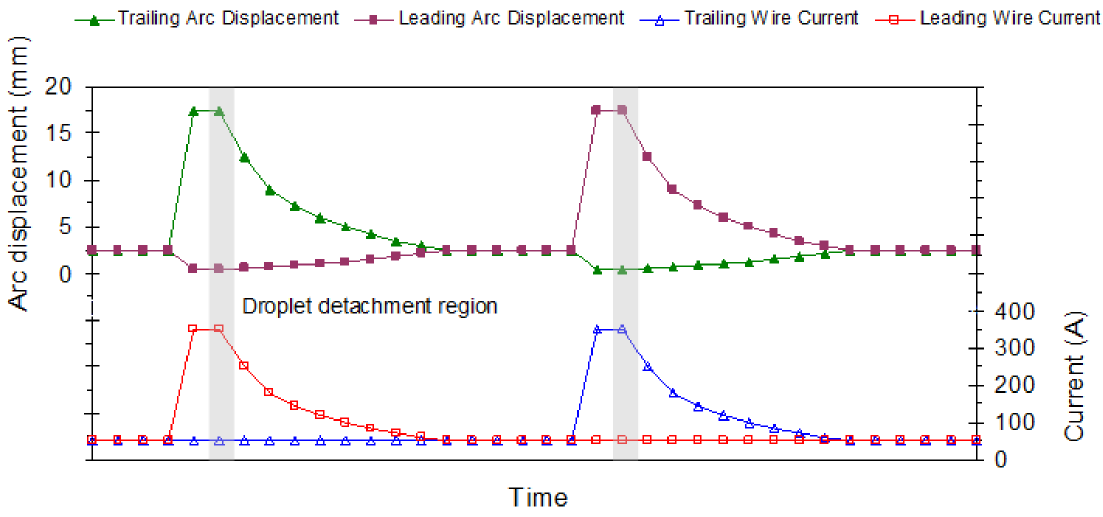

Figure 12: Simulation of arc displacement for out-of-phase pulsed tandem GMAW.

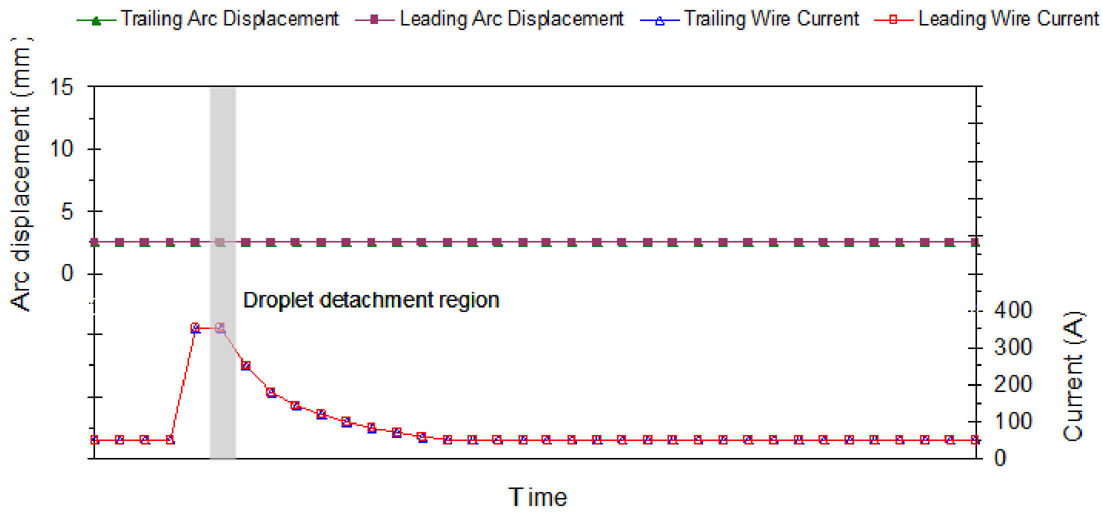

Figure 13: Simulation of arc displacement for in-phase pulsed tandem GMAW (the trailing and leading arc displacement curves are overlaid, so are the trailing and leading arc current curves).

3.2. Inter-wire distance of 10 mm

In order to continue the evaluation of the Laser - Tandem GMAW process, the inter-wire distance was increased to 10 mm. Figure 14 shows a sequence of images synchronised with electrical transient data for the case of using a 2 kW Laser beam and 'almost-in-phase' current pulses and Figure 15 with out-of-phase current pulses as a general representation of the process with an inter-wire distance of 10 mm.

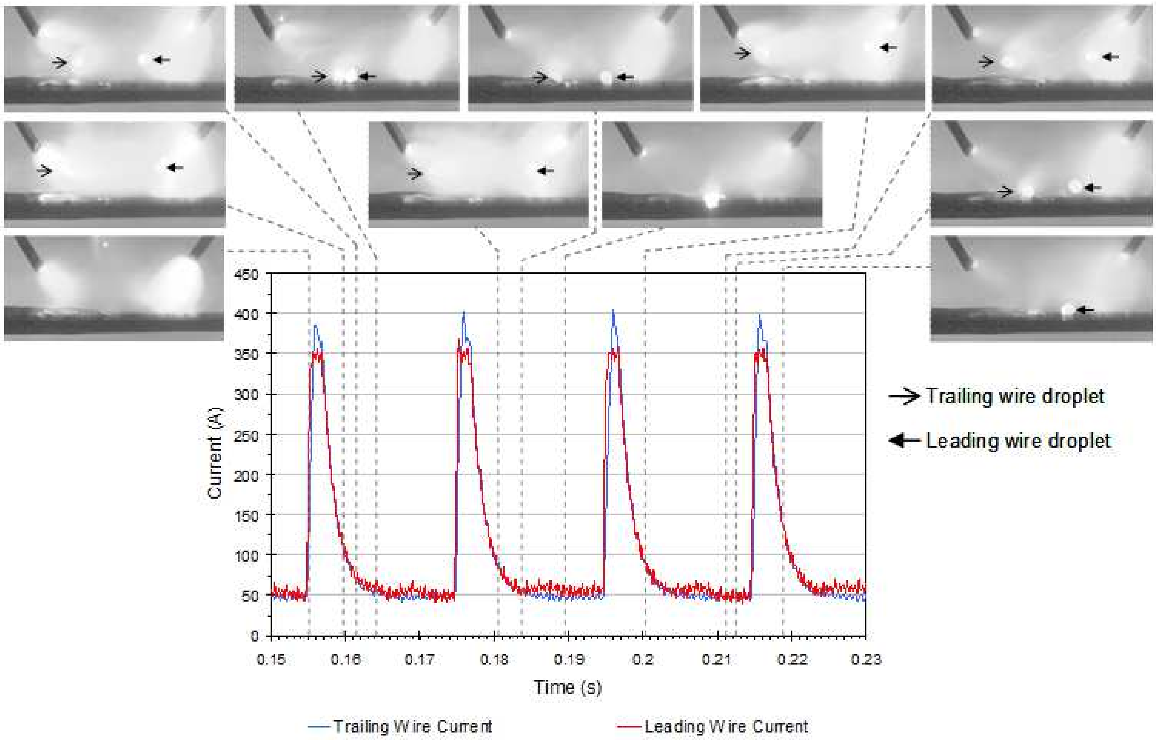

Figure 14: Images synchronised with electrical transient data for Laser - Tandem GMAW using 'almost-in-phase' current pulses (Laser beam power = 2 kW and inter-wire distance = 10 mm).

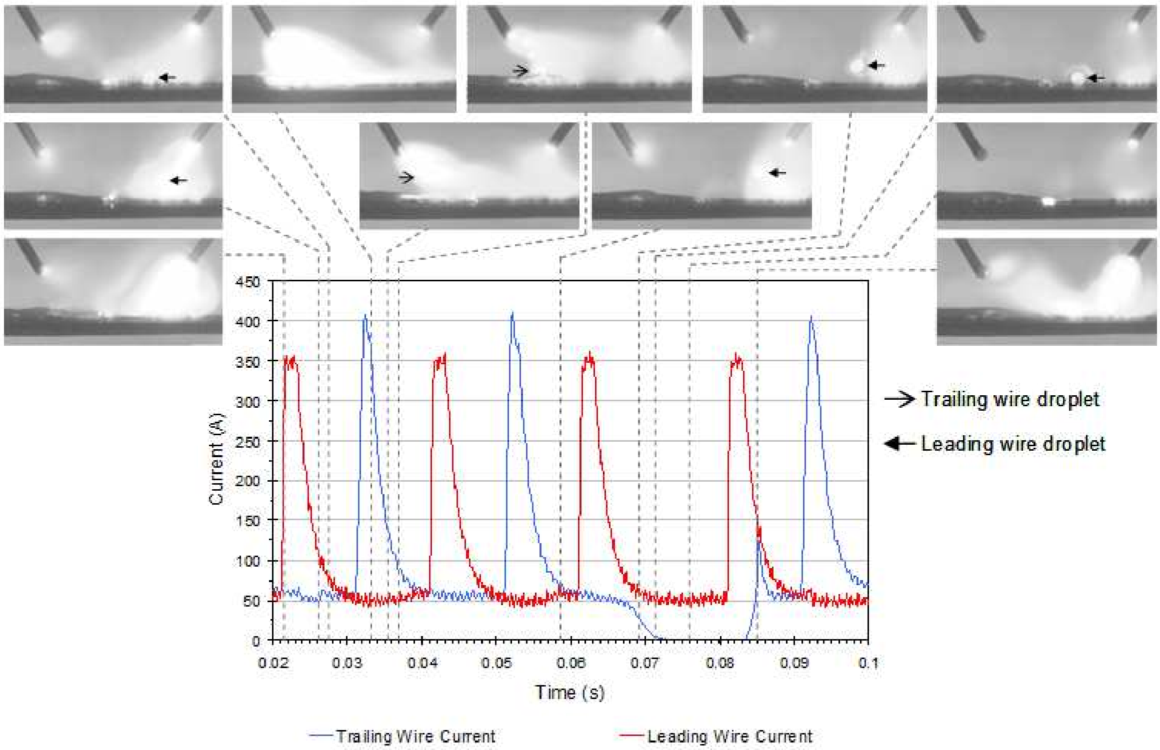

Figure 15: Images synchronised with electrical transient data for Laser - Tandem GMAW using out-of-phase current pulses (Laser beam power = 2 kW and inter-wire distance = 10 mm).

As was noticed for the case of an inter-wire distance of 5 mm, the use of 'almost-in-phase' pulses caused the trailing wire a small tendency to being attracted by the leading arc but no interruptions were observed. As expected, the droplets were not deviated as much as when using only 5 mm between the wires. They hit the plate in the weld pool region right next to the Laser beam without crossing their paths or merging, which probably led to the good visual quality of the weld beads produced. The droplets from the leading wire hit the plate close to the leading edge of the weld pool, fact that indicates that the inter-wire distance value may be close to the limit for the welding travel speed used (or the travel speed may be close to the limit for the inter-wire distance used).

In the case of out-of-phase pulses for an inter-wire distance of 10 mm, arc interruptions were verified in the trailing wire for all the conditions regardless of adding the Laser beam to the tandem GMAW process or not. The droplets were slightly less deviated than when using 'almost-in-phase' pulses and similar to the case of using out-of-phase pulses for 5 mm between the wires.

The effect of the Laser beam on weld bead quality followed the tendency found for an inter-wire distance of 5 mm, that is, the Laser beam seemed to have a positive effect on the aspect of the weld bead produced and higher the Laser beam power the better (Figure 16).

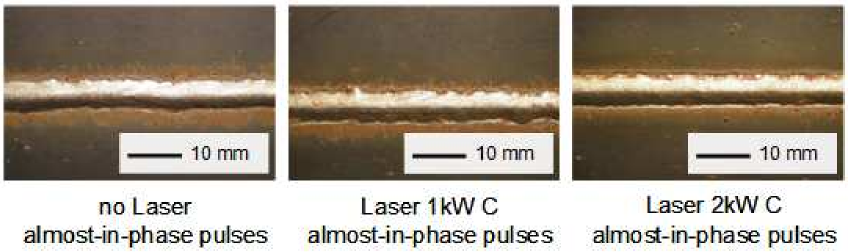

Figure 16: General aspect of weld beads produced with Laser - Tandem Pulsed GMAW using an inter-wire distance of 10 mm.

A quick view in the droplets deviation was carried out following the same procedure used for an inter-wire distance of 5 mm. The results for this measurement are congregated in Figure 17. As the inter-wire distance was increased, the deviation of the droplets when using 'almost-in-phase' pulses tended to decrease, with the droplets originated from the trailing arc being slightly more deviated. The droplet deviation for the out-of-phase case practically did not change in comparison to the case of an inter-wire distance of only 5 mm with the same pulsing technique. The fact of having less deviation in the droplets for the 'almost-in-phase' case was expected since the magnetic force acting in the arcs and droplets decreases as the distance between the electrodes increases.

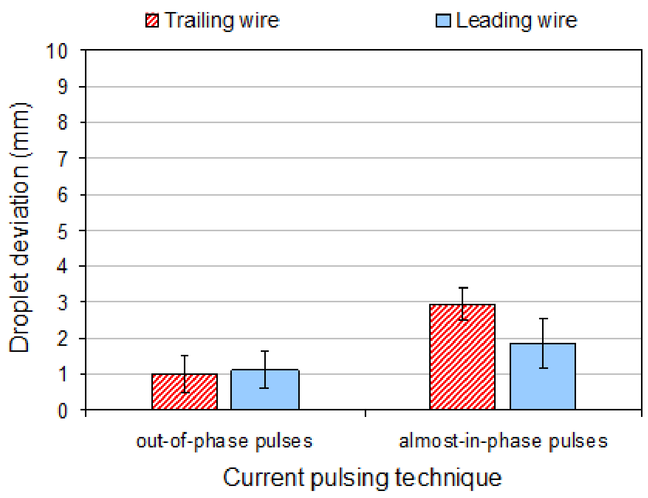

Figure 17: Droplet deviation in the leading and trailing arcs for different pulsing techniques (inter-wire distance = 10 mm and Laser beam power = 2 kW).

3.3. Inter-wire distance of 15 mm

As a means of continuing the evaluation of the Laser - Tandem GMAW process, the inter-wire distance was increased to 15 mm. As it was already verified in previous experiments using low levels of current for pulsed tandem GMA welding (Reis *et al.*, 2008), the use of 15 mm for the inter-wire distance caused interruptions in the trailing arc for both out-of-phase and 'almost-in-phase' pulsing techniques. Nevertheless, some observations regarding the effect of such inter-wire distance were still possible to be made. By observing Figure 18 it is possible to notice that 15 mm is out of the limit of the inter-wire distance range suitable for the level of welding travel speed used. The droplets from the leading wire tended to hit the plate too far away from the weld pool leading edge, forming a concentration of molten metal on the plate before being absorbed by the weld pool. This phenomenon took place in a cyclical basis.

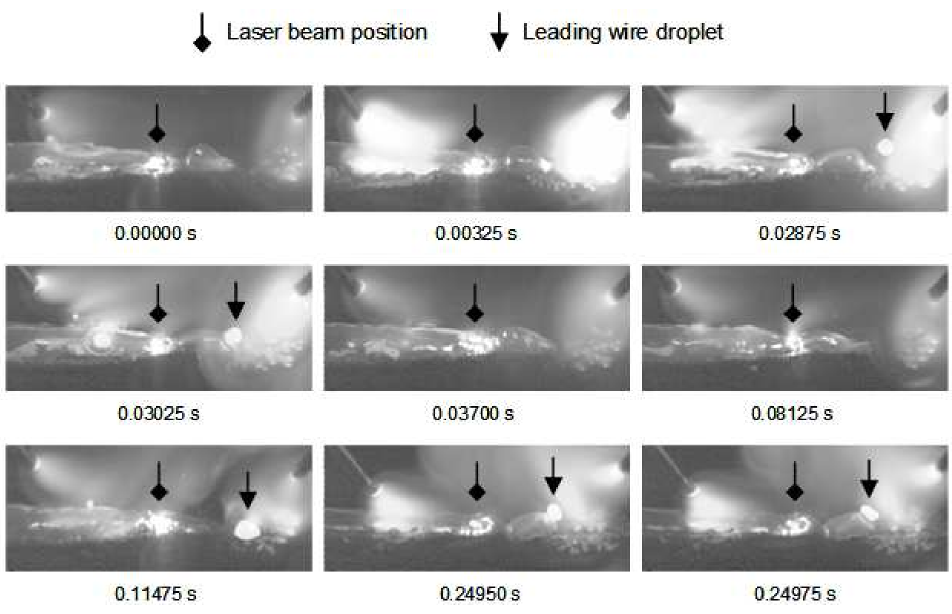

Figure 18: Sequence of images showing tendency for accumulation of molten metal originated from the leading wire close to the leading edge of the weld pool ('almost-in-phase' pulses, Laser beam power = 2 kW and inter-wire distance = 15 mm).

The fact of using 15 mm between the wires and having such a high welding travel speed level combined with trailing arc interruptions deteriorated the aspect of the weld beads significantly (Figure 19). Without the Laser beam, lack of molten metal and porosity were largely present. However, the defects were minimized by using the Laser beam. As the Laser beam adds more heat to the weld pool, porosity is minimized (more time is allowed for escaping of gases before solidification) and more even weld beads produced (the wetability between the molten metal and the work piece is improved).

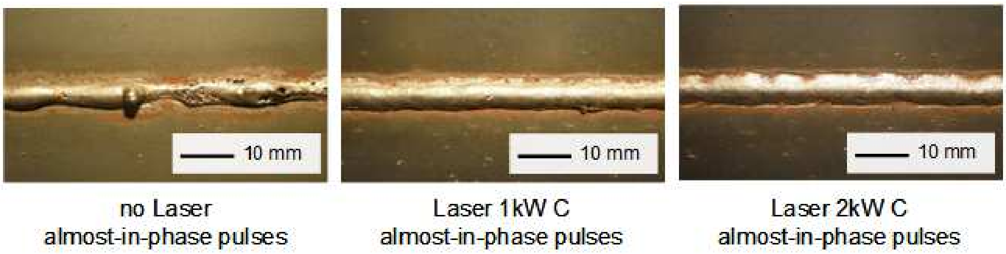

Figure 19: General aspect of weld beads produced with Laser - Tandem Pulsed GMAW using an inter-wire distance of 15 mm.

Despite the presence of arc interruptions and the difficulty of achieving good weld bead quality for an inter-wire distance of 15 mm, a look was taken at the effect of utilizing such a distance between the wires on the deviation of the droplets. The same procedure used for an inter-wire distance of 5 mm and 10 mm was followed. The results for the deviation measurements are showed in Figure 20. The tendency verified when increasing the inter-wire distance from 5 to 10 mm was confirmed for 15 mm, that is, the droplets originated from both leading and trailing wire had just a slight deviation towards the opposite arc. The deviation values were even similar for both 'almost-in-phase' and out-of-phase current pulses.

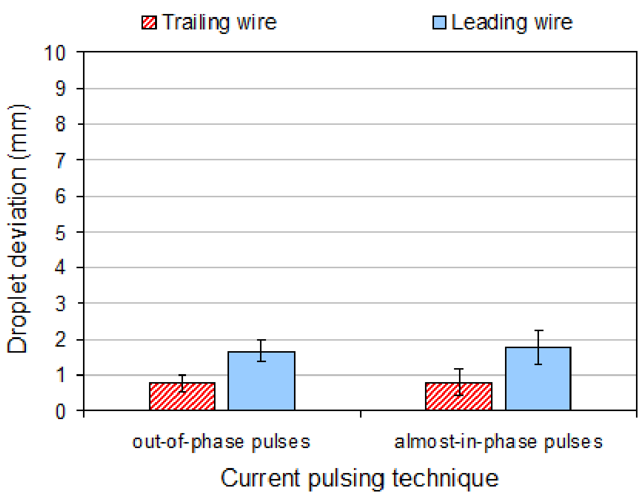

Figure 20: Droplet deviation in the leading and trailing arcs for different pulsing techniques (inter-wire distance = 15 mm and Laser beam power = 2 kW).

4. Conclusions

Based on the assessment of a new approach for hybrid welding combining Laser Beam Welding and Pulsed Tandem GMAW, the following conclusions can be made:

- Regardless of welding with 'almost-in-phase' or out-of-phase current pulses for the tandem GMAW part of the hybrid process, the Laser beam had a positive effect on the aspect of the weld beads produced (the higher the Laser beam power the better);
- The trials indicated that an inter-wire distance of 10 mm promoted the best welding results with the Laser beam located half way between the Tandem GMAW leading and trailing wire; and
- The fact of having the Laser beam between the wires did not help to avoid the occurrence of arc interruptions if out-of-phase current pulsing technique is used for the Tandem GMAW part of the hybrid welding process.

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