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A Review on the Effect of Various Process Parameters in Cold Metal Transfer (CMT) GMAW Welding

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Abstract: ***Cold metal transfer (CMT) is a modified metal inert gas welding process based on short- circuiting transfer process, characterised by low heat input and no- spatter welding. The CMT process is used to join various similar and dissimilar metals with good performance. The aim of this paper is to present a review the changes in various process parameters on weld attributes in cold metal transfer welding (CMT).***

Keywords: Cold metal transfer, short circuit transfer, arc length, wire speed.

I. Introduction

In most aerospace, nuclear power plants, automobiles, boiler applications, it is extremely necessary that the fusion arc welding process has low thermal input. Cold Metal Transfer Welding (CMT) is one of the potential welding processes with low heat input welding. Of course, the term "cold" has to be understood in terms of a welding process: when set against conventional GMAW, CMT-GMAW is indeed a cold process with its characteristic feature of alternating thermal arc pool, i.e. hot when an arc is initiated and cold when the arc is extinguished and the wire is retracted. This alternating hot and cold treatment has been made possible by a new technological development from Fronius International LLC, that incorporates the wire motions into the process control via a computer monitoring system [Fig. 1].

Some of the other features that make this unit unique when compared to conventional GMAW units include: two separate wire-drives (front and rear) that are separated by the wire buffer. The front drive, located in the torch moves the wire back and forth in a dabbing motion at a rate of up to 90 times per second. Simultaneously, the rear drive pushes the wire directly from the filler spool located in the wire drive. It is important to note that both drives are digitally controlled by the process control. To ensure a constant wire feed, a wire buffer is interposed between the two drives to decouple them from one another.[i, iv,v]

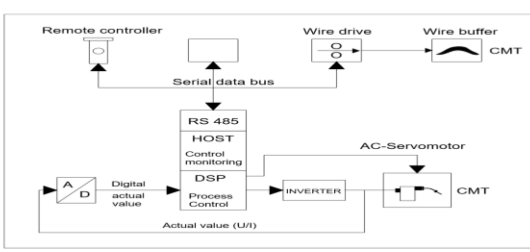

Fig. 1: Fronius CMT-GMAW process control diagram [i]

In the world of GMAW processes, there are essentially three types of metal transfer mechanisms that can be used: (1) short circuiting transfer, (2) globular transfer, and (3) spray transfer. The type of transfer is determined by a number of factors, the most influential of which include magnitude and type of welding current, electrode diameter, electrode composition, electrode extension, and shielding gas. CMT-GMAW in its most elementary form can be considered a short circuit GMAW process. Short circuit GMAW consists of the lowest range of welding currents and electrode diameters associated with GMAW. This type of transfer produces a small, fast-freezing weld pool. During the arcing process, metal is transferred from the electrode to the workpiece only during a short period when the electrode is in contact with the weld pool, hence the term "short circuiting transfer." It is important to note that no metal is transferred across the arc gap [vii,viii].

The sequence of events in the transfer of metal and the corresponding current and voltage for a typical short circuit transfer GMAW process can be seen in Fig. 2. As the wire touches the weld metal, the current increases [(A), (B), (C), (D), in Fig. 2]. The molten metal at the wire tip pinches off at D and E, initiating an arc as shown in (E) and (F). It is here that the rate of current increase must be high enough to heat the electrode and promote metal transfer, yet low enough to minimize spatter caused by violent separation of the drop of metal (one of the major disadvantages of conventional short circuit GMAW). Finally, when the arc is established, the wire melts at the tip as the wire is fed forward towards the next short circuit at (G). Overall, the open circuit voltage of the power source must be low enough that the drop of molten metal at the wire tip cannot transfer until it touches the base metal. [vii,viii].

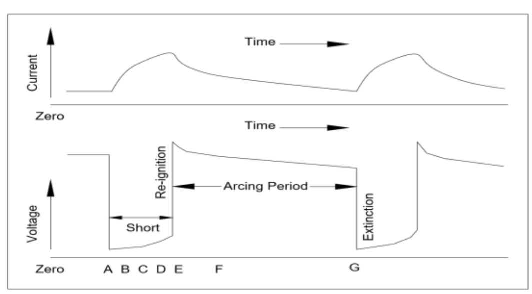

Fig. 2: Schematic representation of short circuiting metal transfer.

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Unlike its short circuit GMAW counterpart, CMT-GMAW incorporates a digital process-control that detects the short circuit at the work piece, and then mechanically retracts the wire to help detach the molten droplet [Fig. 3]. The wire retraction greatly reduces the spatter that is typically associated with conventional short circuit GMAW. Reduced spatter is the first essential difference from conventional short circuit GMAW processes; the second most notable difference is a reduction in thermal input since there is virtually current-free droplet detachment, hence the term “Cold Metal Transfer.” Lastly, unlike conventional short circuiting GMAW -where there is a constant push motor driven system, the CMT-GMAW uses a two motor drive system that pushes the wire forward, and as soon as the short circuit occurs, it pulls it back (i).

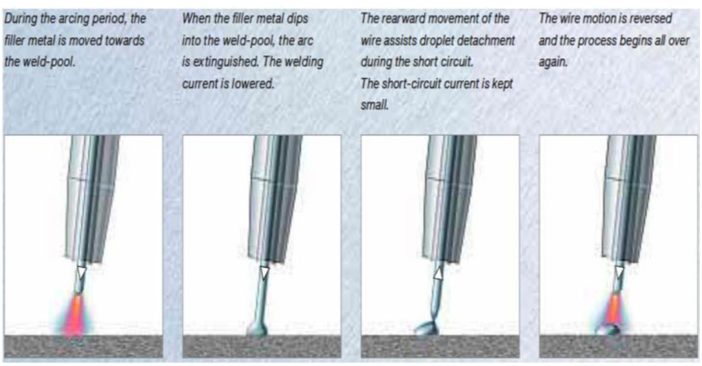

Fig. 3: CMT-GMAW wire retraction process[i]

The rearward movement of the wire assists droplet detachment during the short circuit. In this way, the arc itself only inputs heat very briefly during the arcing period. The thermal input is immediately reduced after arc is extinguished, creating an oscillating hot/cold weld pool. During the CMT-GMAW process, the average current is kept very small by controlling the short circuit, resulting in virtually spatter free metal transfer [see Fig. 4] illustrating the reduced thermal input required for metal transfer as compared to other conventional metal transfer processes. Also worth mentioning, precision droplet detachment of the CMT-GMAW ensures that after every short circuit, a near-identical quantity of filler metal is melted off. [i, iv, v and vi].

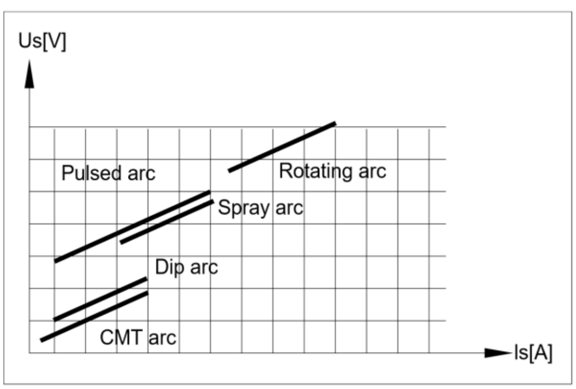

Fig. 4: Comparative thermal inputs for various metal transfer processes.

The most important variable of any GMAW process, including CMT-GMAW, which affects the weld penetration, bead geometry, and overall weld quality are: (a) welding current (wire feed speed), (b) polarity, (c) arc voltage (arc length), (d) travel (traverse) speed, (e) electrode extension, (f) torch angle, and (g) electrode diameter. Knowledge and control of these variables are essential in order to consistently produce welds of acceptable quality. However, changing one variable generally requires altering additional parameters to retain an acceptable quality weld because the variables are not completely independent of each other. This paper reviews the effect of various process parameters i.e. arc length, wire feed speed, traverse speed and electrode orientation on the weld attributes.

II. Process Parameters Effecting CMT

1. Arc Length

Arc voltage and arc length are related terms that are often used interchangeably, however they are quite different in practice. Arc voltage is the electrical potential between the electrode and the work piece. Arc voltage is generally lower than the voltage measured directly at the power source because the voltage drops at the connections and along the length of the welding cable. Consequently, an increase in arc voltage will result in a longer arc length. It is also important to note that excessively high arc voltage can cause weld porosity, spatter, and undercut; therefore, arc length is a variable of interest and should be controlled as it can have a profound impact on the overall weld quality.(vii,viii). In conventional GMAW, the surface of the work piece (i.e. jagged or flat) and the welding speed can both have a marked effect on the stability of the arc. The arc length is acquired and adjusted mechanically with the CMT-GMAW. This means that the arc remains stable, regardless of the surface condition of one’s work piece. In addition to a mechanical response, the CMT-GMAW utilizes a self-correction mechanism via a constant-potential power source as illustrated in Fig. 1 Where L is the arc length, the length between the melting electrode tip and the base metal. As the contact-to-work distance increases, the arc voltage and arc length would tend to increase with a conventional GMAW power source. However, with the CMT-GMAW power source, the welding current decreases with a slight increase in voltage, while the mechanical drives in the torch adjust appropriately to maintain a consistent arc length. Conversely, if the distance is shortened, the lower voltage would be accompanied by an increase in current and a mechanical adjustment in wire feed speed to compensate for the shorter wire stick out. [vii and viii].

2. Wire Feed Speed

In conventional GMAW welding, as the electrode feed speed (wire feed speed) is varied, the welding current varies in a similar manner with the arc length. This occurs because the current output of the power source fluctuates dramatically with the slight changes in the arc voltage when alterations are

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made to the wire feed speed. If all other variables were held constant, an increase in welding current would result in the following: (a) an increase in the depth and width of the penetration, (b) an increase in the deposition rate, and (c) an increase in the size of the weld bead. [vii and viii]. Unlike conventional GMAW units where current and voltage can be changed independently, these two key parameters are linked together in the CMT-GMAW via a digital process control namely arc synergic line. Arc synergic line is a linear mathematical relationship (proprietary to Fronius International LLC) which incorporates the voltage and amperage process controls into the wire feed speed, and is dependent on the thermal and electrical resistivity properties of the material substrate/filler used. Therefore, each synergic line is uniquely different: that is, every synergic line consists of several points on a voltage current diagram (U-I diagram), which are formed from the connection of a series of certain current and pertinent voltage levels for any given wire composition and gas. Each point on the synergic line is recorded with the same arc length, despite different performance, through the whole power range. An arc synergic line is experimentally determined via high-speed video techniques. [vi, vii and vii].

3. Traverse Speed

As with any GMAW process, including CMT-GMAW, the traverse or travel speed has a profound impact on the weld quality. Travel speed is the linear rate at which the arc is moved along the surface of the work piece. The filler metal deposition rate per unit length increases when the travel speed is decreased. The welding arc impinges on the molten weld pool rather than the base metal at very slow speeds, thereby reducing the effective penetration and resulting in a wider bead. As travel speed is increased, the thermal energy per unit length of weld transmitted to the base metal from the arc is at first increased because the arc acts more directly on the base material. However, further increases in travel speed impart less thermal energy to the base metal. Melting of the base metal therefore first rises and then decreases with increasing travel speed. As the travel speed increases, there is a tendency for undercutting along the edges of the weld bead because of insufficient deposition of filler metal to fill the path melted by the arc. [vii and vii].

4. Electrode Orientation

Electrode orientation affects bead shape and penetration to a greater extent than arc voltage and travel speed. The electrode orientation is described in two ways: (a) by the relationship of the electrode axis with respect to the direction of travel and (b) the angle between the electrode axis and the adjacent work piece surface. When the electrode points in a direction opposite to the travel direction, it results in a trail angle, which is known as the backhand method. Similarly, when the electrode points in the direction of travel, it results in a lead angle and is called the forehand method. The electrode orientation and its effect on the width and penetration of the weld bead are illustrated in (see Fig. 5). [vii and viii]

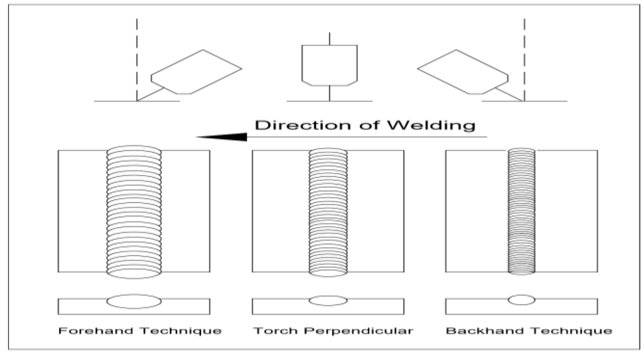

Fig. 5: Effect of electrode position and welding technique

When the electrode is changed from perpendicular to the lead angle technique with all other conditions unchanged, the penetration decreases and the weld bead exhibited is wider and flatter. Maximum penetration is obtained in the flat position with the drag technique, at a drag angle of about 25 degrees from perpendicular. The drag technique also produces a more convex, narrower bead, an increasingly stable arc, and less spatter on the workpiece. [vii and viii]. The effects of various process variables on deposit attributes are shown in Table 1. [vii]

Welding variables to change	Desired changes							
	Penetration		Deposition rate		Bead size		Bead width	
	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease
Current and wire speed	Increase	Decrease	Increase	Decrease	Increase	Decrease	Little effect	Little effect
Voltage	No effect	No effect	Little effect	Little effect	Little effect	Little effect	Increase	Decrease
Travel speed	No effect	No effect	Little effect	Little effect	Decrease	Increase	Decrease	Increase
Electrode extension	Decrease	Increase	Increase	Decrease	Increase	Decrease	Decrease	Increase
Electrode diameter	Decrease	Increase	Decrease	Increase	Little effect	Little effect	Little effect	Little effect
Shielding gas %	Increase	Decrease	Little effect	Little effect	Little effect	Little effect	Increase	Decrease
Torch angle	Drag	Push	Little effect	Little effect	Little effect	Little effect	Push	Drag

Table 1. Effect of changes in process variables on weld attributes

III. Conclusions

It was observed that the key attribute of the CMT-GMAW process is its electronically controlled short circuit droplet detachment method. This precision process control is optimized by the push-pull servomotor located within the torch head and is controlled by the synergic line. The synergic line is a linear mathematical relationship that incorporates the voltage and amperage process controls into the wire feed speed. The synergic line helps with the detachment of the molten droplet during the short-circuiting, drastically reduces weld spatter, and provides a low thermal gradient during arcing. It was also found that the traverse and wire feed speeds had a profound impact on the weld quality and overall bead profile shape. As with any arc welding process, when all other controls were held constant, varying the traverse speed could change the bead shape and wire feed speed. In contrast, the other process controls parameters had little effect on the overall weld quality, since the synergic line dictates the majority of the process controls which simplified the overall weld process and parameter optimization. However, it was noted that fine-tuning parameters could greatly affect the initial wetting of the filler material.

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