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Review of Developments in arc welding of metals by gas mixtures

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Abstract:
In this review paper we review the developments in the technology of electrical arc welding methods of metals via different types of gas mixtures. The paper is divided into four sections based on process inputs, outputs, control systems and diverse advances in the GMAW process. Section 1 describes advances in power sources, wire electrode types, wire feeding and shielding gases. Section 2 includes a review of process analysis, sensing, monitoring and control. Section 3 reviews miscellaneous GMAW-related improved processes such as hybrid laser-GMAW, tandem GMAW welding, narrow groove GMAW welding.

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I. AdvancesinGMAW technologies:

1.1 Power mains

Usually, the electrical power supplies used in arc welding are Direct Current. The DC voltage and current are controllable via the rate of wire feeding of the electrodes. Figure 1 depicts the welding system.

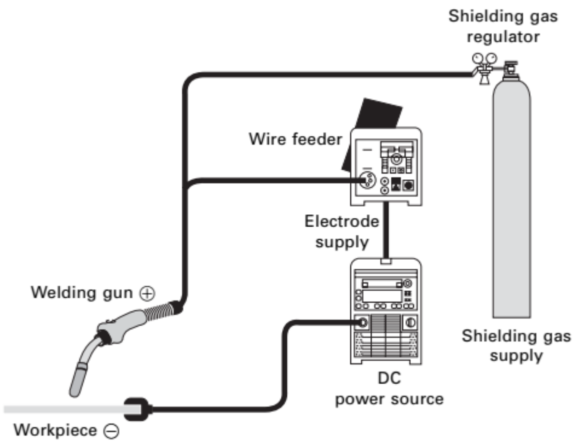

Figure 1. System for GMAW with its main parts.

To improve the efficiency of the power transformer, high frequency AC current is used instead of the DC; this reduces the dimensions of the iron core of the transformer and hence the losses are minimized. With the new digital technologies, more control options could be achieved: remote programmable control capabilities and hence the parameters of the welding processes could be adjusted remotely.

1.2 Feed wires

Traditional wire feeding techniques suffer from major drawbacks, like friction forces between the wires. This force increases dramatically when bents are encountered (Padilla *et al*., 2003). To reduce the friction force, a push–pull torch is used as depicted in figure 2. It should be pointed out that we may use some reduced-size spools attached to the welding torch as shown on figure 3, (Nadzam, 2003).

Figure 2. A traditional welding system that incorporate an additive feed wire motor in the handle.

Figure 3. Reduced-size wire spools attached to the welding system.

According to these modifications, the radiated heat energy from the welding arc are concentrated in the contact tip as

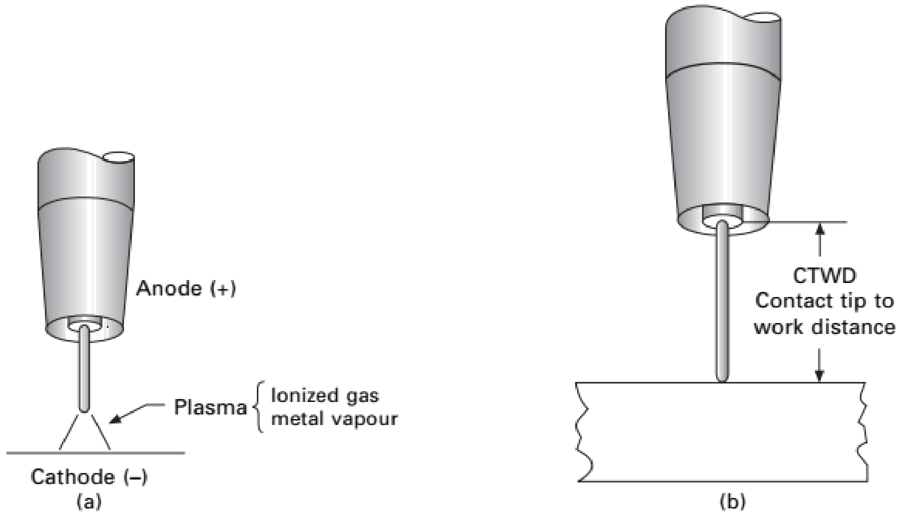

Figure 4. Plasma flow near the tip of the wire electrode (a) and the distance between the contact tip to work object (b).

pointed out by (Adam *et al*., 2001). Thus, the contact tip to work distance in figure 4 has the crucial effect on the overheating of the tip. This emphasizes that the heat radiated from the tip represent the major source of radiated heat energy.

1.3 Configuration of the electrodes

The old-style cylindrical wires are recently replaced by hollow tubular wires with inner core containing flux, thus flexible choices for welding materials. The metallic core is suitable for high usage steels yielding efficient strengthening. On the other hand, wires with large diameters up to almost 3 mm are usable for metal depositing at high rates as mentioned in (Himmelbauer, 2003).

While metallic strips of 0.5 x 4.5 mm rectangular cross-section have a major advantage for higher wire feed speeds up to 11m/min, thus high deposition rates are easily achieved as depicted in figure 5.

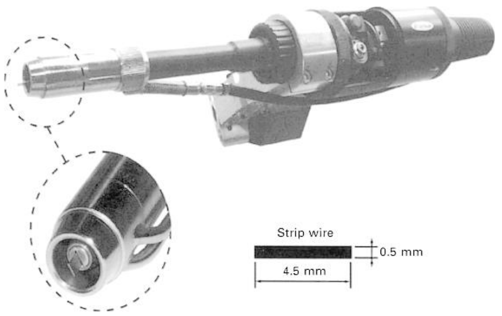

Figure 5. Strip wires of rectangular cross-section in a feeding system.

Generally, strip wires are more appropriate for surface welding.

1.4 Gas Shielding

There are tow main types of shielding using gases: either by inert gases or by active and reactive types. Standards in Europe use two or three types of mixing gases to optimize the chemical strength of the ionization voltage and the thermal conductivity as emphasized in (Vaidya, 2001; Zavodny, 2001).

It is worthwhile to note that these tailored gas mixers should be used cautiously, when Argon and carbon dioxide are mixed in welding stainless steels, because carbon pickup can occur as pointed out in (Kotecki, 2001).

1- Measurement and control in Gas welding

This section includes a review of recent advances in (Gas Metal Arc Welding) GMAW process analysis.
Topics include process sensing/monitoring, control, modelling, automation and robotics, droplet transfer modes and fume and spatter control.

Droplet transfer modes

One of the major topics in GMAW process analysis has been the molten metal droplet detachment and transfer modes. For given ranges of wire electrode diameter, welding current and shielding gas, five modes of detachment have been recognized (Nadzam, 2003): (1) short-circuit, (2) globular, (3) axial spray, (4) pulsed-spray and (5) surface-tension transfer modes (Fig. 6) (Nadzam, 2003).

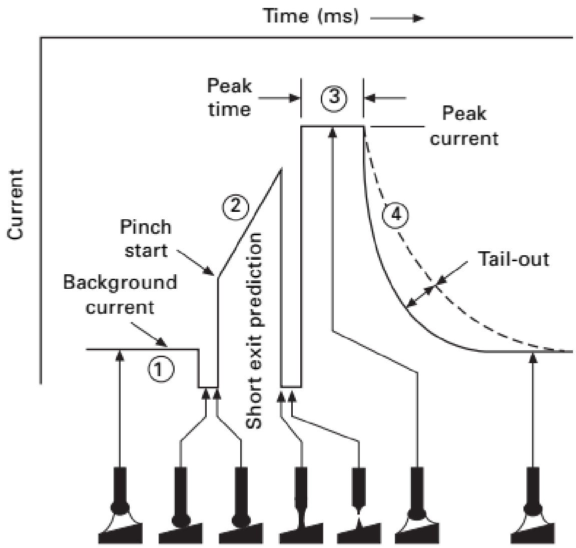

Figure 6. Schematic representation of the surface tension-controlled droplet transfer mode (STT).

The forces governing the dynamic equilibrium during droplet detachment have been identified. They are: (a) electromagnetic forces associated with the welding current self-induced magnetic field, (b) gravity, (c) surface tension and (d) cathodic jet forces (Lancaster, 1984). Lately, variable polarity (VP-GMAW) has been shown to be effective also in controlling metal transfer and melting rate. Traditionally, using a CV power source with inductance control proved to be excessively sensitive to arc length variations, responding with large wire speed and current responses. Therefore, feed-forward controls – also known as digital or reactive controls – have been introduced where the current can be modified independently from the wire speed. Advances in process control have been made especially using feed-forward algorithms, as demonstrated by their excellent adaptability to step responses when compared to the traditional feed-back control (Adolfsson, 1999). Process control can also be very different in aluminum(AL) alloys when compared to that in steel. For the same wire electrode extension, the Al GMAW was found to be up to 28 times more sensitive to variations in wire feed speed than the mild steel electrode (Quinn, 2002). Because of the higher electrical and thermal conductivity of Al compared to steel, conductive heat transfer dominates the dynamic equilibrium between burn-off and feed rate, compared to convection and resistive heating in steels. For instance, the voltage drop across the same electrode extension length was one order of magnitude less in Al than it was steels (0.03 V compared to 0.3 V). In most cases, the GMAW process responds in aluminum more dramatically to perturbations in welding current or wire speed setpoints.

3. GMAW hybrid processes and other developments

This combination of high penetration laser beam welding (LBW) and good gap bridge ability (GMAW) processes builds on the intelligent combination of the advantages of each process. The resulting welds (Staufer *et al*., 2003) can be made at high speeds, have good penetration and are less sensitive to gap variations. The GMAW arc stability and droplet transfer are also improved by the intense metal vaporisation caused by LBW. Apparently, the greater amount of ionised metal and electrons in the LBW plasma reduces the need for high ionisation potential and exceeding the electrode work function in the GMAW arc thus provides better arc stability. Disadvantages include: high capital cost and the need for automation and precise beam/arc alignment. Typical GMAW/LBW heads are expensive and complex, as shown in Fig. 7.

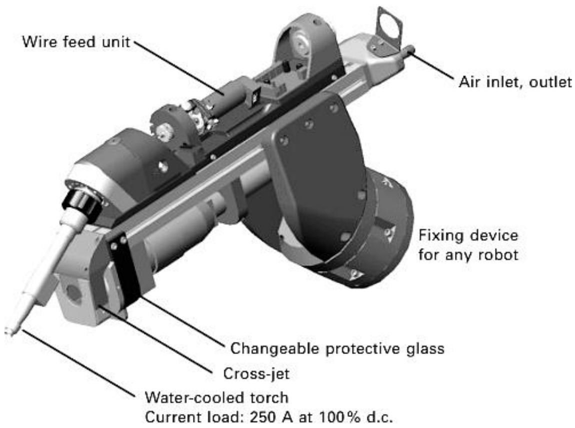

Figure 7. Schematic representation of a laser beam welding/GMAW hybrid welding head.

Using low-melting point electrode wire consumables such as Cu-Si, Cu-Ag, Cu-Al alloys allow for low current GMAW-P deposition without melting of the base metal (i.e. electric brazing). This significant development reduces the width of HAZs and damage to Zn coatings in the automotive sheet and produces minimal distortions (Himmelbauer, 2003). The roof panel joint does not require any post weld processing. Additionally, arc-brazing is also being accomplished using traditional and STT forms of GMAW-S. GMAW with a CuAl wire electrode also makes possible joining of dissimilar materials with very different melting points such as steel and aluminium.

One disadvantage of GMAW brazing is the low joint strength that can be compensated by using lap joint design. Additional problems have been associated with zinc pickup in the silicon bronze weld and the result is transverse cracking of the weld deposit. This occurs in welds of those members where there is a gap. The gap, via capillary action picks up zinc from both surfaces of the plated base material. Finally, the presence of Cu in the recycled car bodies lowers the quality of the scrap and increases cost because of the difficulty of removing Cu which is very detrimental in steel making (solidification cracking susceptibility).

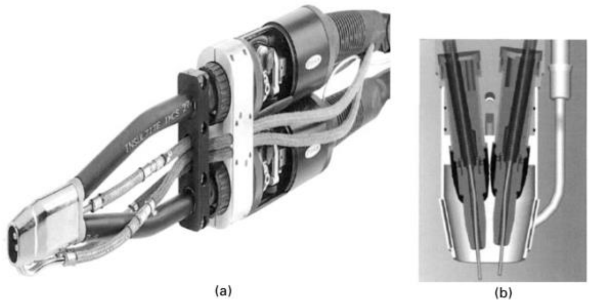

Figure 8. Tandem GMAW torch view (a) and cross-section (b).

As the name implies, two wire electrodes are used in tandem to produce welds. The two wire electrodes are insulated from each other in tandem welding, thus the droplet transfer mode can be adjusted independently, in contrast to double-wire welding. Typically, one electrode can work in continuous arc (synergic CV or synergic CC) and the other in pulsed arc mode (also known as 'master' and 'slave' wires or 'lead' and 'trail' wire). Accordingly, the modified process allows for great flexibility, increased travel speed, higher deposition rates, as well as lower spatter. Disadvantages include equipment complexity, as well as the need for automation. Seam tracking may or may not be required (Fig. 8). The system employs two power sources, two wire drives, and a control. It is adapted for either repetitive side-beam type applications or is employed with a welding robot. This variant of the gas metal arc welding process is capable of higher travel speeds, 1.5–2.0 times the speed of a single electrode. Some travel speeds may exceed 150 in/min (3.81m/min). Deposition rates of 42 pounds/h (19.1 kg/h) are achievable for heavier plate welding (Nadzam, 2003).

The modes of metal transfer used for the tandem GMAW are axial spray metal transfer or pulsed spray metal transfer. The combinations of the modes that are popularly employed include:

- Spray + pulse: Axial spray transfer on the lead arc followed by pulsed spray transfer on the trail arc.
- Pulse + pulse: Pulsed spray transfer on both the lead and the trail arc.
- Spray + spray: Axial spray transfer on both the lead and the trail arc.

The higher energy spray + spray configuration is used for special heavy plate welding where deeper penetration is required. Pulse + pulse allows for heavy welding or high-speed sheet metal welding.

Central to the successful operation of tandem GMAW is proper understanding of the set-up of the special tandem GMAW welding torch. In most cases, the central axis of the torch should be normal to the weld joint. The lead arc has a built in 6 degree lagging electrode angle, and the trail has a built in 6-degree leading electrode angle.

The contact tip to work distance (CTWD) for higher speed sheet metal type applications should be set at 0.625 in (16 mm). The electrode spacing is critical and the shorter CTWD establishes the correct spacing. When the CTWD is held at this position the two arcs become more distinct from one another and shorter arc lengths are used to provide higher travel speeds. Use of tandem GMAW for heavy plate fabrication requires a longer CTWD,1.0 in (25.4 mm). The longer CTWD provides the correct spacing between the two arcs, and in this scenario, the arcs tend to move very closely together. When held at the longer CTWD the arcs lend themselves for use with much higher wire feed speeds.

Narrow groove GMAW welding

An excellent application of GMAW is for low heat input welding of thick plate, the resulting welds have often been plagued by occasional lack of sidewall fusion. Wire electrode bending and rotating (twisted wire) have been used in the past to overcome this problem. Korean researchers used electromagnetic arc oscillation to alleviate the same problem in the narrow groove (Khang and Na, 2003).

Future trends

The following trends can be anticipated in GMA welding within the next five years. The following areas are important:

(1) process simulation and modelling,
(2) sensing and control,
(3) cost reduction and
(4) new applications.

- Improved computer *simulations* of the welding process and implementation in production welding;
- Improved *sensing* and signal acquisition before, during and after welding and inclusion in a comprehensive control system. This effort will

require increased sensitivity to downstream manufacturing practices to improve part fit-up;

- Improved power source technology via digital controls and improved control of the welding arcs;
- *Applications*: extension of the process to reduced base metal thickness and higher deposition rates. Even further miniaturization (or MEMS: micro-electro-mechanical systems) can be expected to penetrate the GMAW equipment world;
- *Automation*: remote operation (depths, heights, hazardous environments);
- In semi-automatic applications: integration of all essential functions in the welding torch;
- Deposition rates and cost reductions – more hybrid and new process
variants, lower cost filler wires and shielding gases (push toward self- shielded fluxed core arc welding;
- *Controls*: digital networks, qualifications.

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