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Microstructural analysis of the anode in gas metal arc welding (GMAW)

S. Zielińska[a,b], F. Valensi[b], N. Pellerin[c], S. Pellerin[b,*], K. Musioł[a], Ch. de Izarra[b], F. Briand[d]

[a] Institut of Physics, Jagellonian University, ul. Reymonta 4, 30-459 Krakow, Poland
[b] LASEP, Centre Universitaire de Bourges, BP 4043, 18028 Bourges Cedex 2, France
[c] CEMHTI, 1D avenue de la Recherche Scientifique, 45071 Orléans Cedex 2, France
[d] CTAS, Air Liquide Welding, Saint Ouen l'Aumone, 95315 Cergy-Pontoise Cedex, France

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A B S T R A C T

The nature of the applied shielding gas has a strong influence on arc stability and transfer metal mode of the welding process. In particular, increase of the percentage of carbon dioxide in argon induces the increase of the transition current value from the globular to spray metal transfer mode. This work shows that these effects are linked to the chemical and microstructural modifications of the anode tip during the gas metal arc welding process. The microstructure of the anode is investigated for various experimental conditions. Transition between the two transfer modes is linked to the existence and disappearance of a rather insulating oxide "gangue" at the wire extremity whose nature depends of the shielding gas. Chemical reactions at high temperature such as oxidation–reduction reactions between shielding gas and melted metal govern the transition of the spray-arc to globular transfer mode.

1. Introduction

The "Metal Inert Gas"–"Metal Active Gas" (MIG–MAG) type arcs have already been applied in welding processes for more than 50 years, as Lancaster (1984) reviewed in his book. In such devices the plasma arc burns between the extremity of a fusible electrode and metal plate. These processes are used usually with reverse-polarity direct current, where

* *Corresponding author at*: Université d'Orléans, Faculté des Sciences, Site de Bourges, Rue Gaston Berger, BP 4043, 18028 Bourges Cedex, France. Tel.: +33 2 48 27 27 46; fax: +33 2 48 70 75 41.
E-mail address: stephane.pellerin@univ-orleans.fr (S. Pellerin).
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the melting electrode is the anode. This operating condition assures better arc stability. Then the melted metal from anode is deposited on the metallic substrate acting as cathode. The discharge occurs in a surrounding atmosphere of shielding inert or chemical active gases. Lesnewich (1958) has listed the most frequently used gases or gas mixtures: argon or/and helium in MIG welding and carbon dioxide as well as various mixtures of argon or/and helium with CO_2, O_2, H_2, N_2, NO in MAG welding. These processes allow joining different kinds of steel, aluminium, magnesium, copper and nickel or titanium-based alloys.

The transfer mode of the melted metal in the arc depends mainly on nature of the used gas, electrode dimensions and composition, the wire feeding speed and the density of the welding current. Lancaster (1984) described the three manners in which metal transfer can occur, in accordance with arc current and gas mixtures: by short-circuits or "short-arc" (SA), "globular transfer" (G) and "spray-arc" (S).

These modes involve particular comportment of arc according to stability, quality of welding and penetrating power, gas consumption and emitted particles. In particular, addition of CO_2 in argon shielding gas involves a globular transfer mode less stable than spray-arc.

As demonstrated by Valensi et al. (2006) and Zielinska et al. (2008), working conditions of the process have also direct consequences on the plasma, and induce an evolution of its composition and shape: the images of the column of the gas metal arc welding (GMAW) plasma operating in different conditions and observed at different modes of the metal transfer using a fast camera and narrow bandwidth interference filter centered to 469.2 nm, are shown in Fig. 1; the plasma core is clearly in the form of a cone for the spray-arc mode and a bell for the globular mode (Zielinska, 2005). The electromagnetic forces are one of the main phenomena involved in the detachment of melted metal drops: Nemchinsky (1996) calculated that the change of their sign (from detachment force to attachment force) related to the change in the curvature of the current lines, explains the transition to globular mode (Nemchinsky, 1996). But to our knowledge, no satisfactory explanation has been proposed concerning the evolution of the current lines.

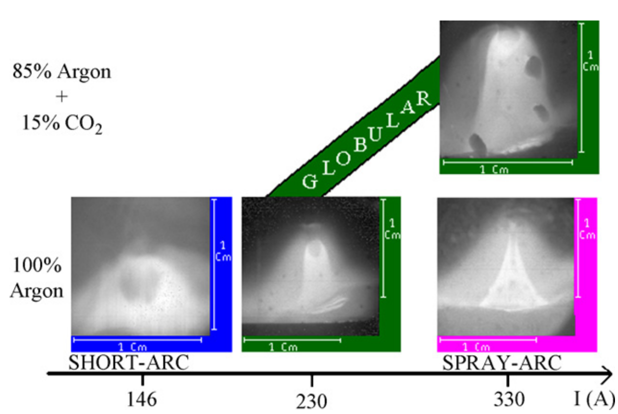

Fig. 1 – Images of the gas metal arc welding (GMAW) arc operated with different gas mixtures and discharge currents: short-arc in pure argon, 146 A – globular in argon or with 15% CO_2 – spray-arc in pure argon, 330 A transfer modes of the molten metal to the weld pool. The method of plasma imaging was developed by Valensi et al. (2006) and Zielinska et al. (2008).

In the same way, working conditions of the GMAW process will give rise to some physicochemical transformations of the anode wire. However, such transformations are currently rather unknown and their influence on the molten metal transfer mode is to be investigated.

Particularly, there are very few results in literature for the study of the microstructure of the consumable electrode. In their paper, Wang et al. (2003) present some metallographic results obtained by optic microscopy about the macroscopic limit between the melted and the non-melted part of the electrode tip. Some results on metal droplets microstructure can be also found in studies of material properties; for example, Wille (2002) presents a set-up designed to create and study an oxide gangue wrapping a small liquid metal droplet. However this work relates no links to any welding application.

The aim of this study is to investigate the evolution of the transfer mode of the melted metal, interesting in particular to the transition between globular and spray-arc mode, in the point of view of chemical transformations of anode. This paper presents a comparison of the microstructural and chemical properties of the anode tip in MIG and MAG type arcs, according to the current value and the nature of the shielding gas (Ar, Ar + CO_2) used in the welding process.

2. Experimental

2.1. *Set-up*

The experimental set-up is presented on Fig. 2. It is organized around a welding generator SAFMIG 480 TRS Plus equipped with a SAFMIG 480 TR 16 kit, both delivered by the 'Centre Technique d'Applications de la Soudure' (CTAS) of Air Liquide Welding (1999): it is a manual MIG–MAG welding installation using a transistorized power source controlled by a 16-bit microcontroller. This last also assures management of the welding cycle, memorization of parameters, safety system and management of the front panel. The no-load voltage is 70 V, and the power supply allows to obtain welding currents in the range 20–450 A with welding voltage between 14 and 44 V (Air Liquide Welding, 1999). The experiments are performed under reverse-polarity (wire-anode, workpiece-cathode) direct current in the constant current mode. The thickness of the workpiece in mild steel is 8 mm for all experiments. The welding torch is fixed on a table that can be displaced manually in vertical direction, in order to adjust the distance between the contact-tip and the metal plate. This parameter, which affects the arc voltage, is set at 20 mm.

The steel plate is displaced using a micrometric table driven by step motor, with horizontal velocity of 4 mm/s, in order to induce a relative motion between the torch and the workpiece, as in the case of standard welding.

The gas is provided by two bottles of industrial gas. All kinds of gas mixture could be considered, but for this study, we used a mixture based on argon (ARCAL 1) and carbon dioxide (gas characteristics shown on Table 1). Two mass flow meters