Study of modifications of metal transfer mode in GMAW with different shielding gas mixtures: cases of Ar-CO_2 and Ar-O_2

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The arc welding with consumable wire is a process widely used, but the understanding of the mechanisms governing its functioning still has some questions because of its complexity. The composition of the shielding gas has a strong influence on the process: the addition of active gas changes, for example, the current required for the transition between the different regimes and is responsible for the appearance of an iron oxide (gangue) at the end of the consumable wire. In this section, additional experimental approaches are presented to characterize the process: high speed video using an adapted interference filter, optical spectroscopy of the plasma column emission allowing estimation of the plasma temperature, and finally physicochemical analyzes by microprobe of Castaing of the end of the consumable wire, will demonstrate the influence of the active element (CO_2 or O_2) present in the shielding gas (Ar) on the welding process.

1. Introduction

The composition of the shielding gas is one of the most influential parameters, may be the most important, on the GMAW (Gas Metal Arc Welding) process with consumable electrode, also referred to by MIG-MAG welding (Metal Inert Gas - Metal Activ Gas). In particular, the addition of active gas in the shielding gas induces an increase of the current required for the transition from the globular regime, highly unstable, characterized by metal droplets projected, by a significant release of smoke, and by the existence of an iron oxide (gangue) at the end of the consumable wire, and the spray regime that is generally desired [1, 3, 5].

Studies by high speed camera and optical spectroscopy of the plasma column emission, and by scanning electron microscopy and microprobe of Castaing of the consumable wire, were achieve for various compositions of the shielding gas (here Ar-CO_2 or Ar-O_2) and different percentages of active gas in the mixture in order to perform tests in spray regime and for some studies in globular mode.

The analysis by high speed camera could provide information on the geometry of the arc column. Spectroscopic diagnosis allowed to obtain the distributions of electron densities and temperatures from Stark broadening of spectral line [3, 5]. Finally, chemical analysis by microprobe of Castaing allowed to obtain accurate data of composition of the end of the consumable wire removed after welding sequence, and in particular of the gangue formed in the different modes and for the different types of mixtures (Ar-CO_2) and (Ar-O_2) obtained by different concentrations of the active gas.

2. Plasma diagnostics

The experimental setup was described in detail in a previous article [1] and is recalled in Figure 1. The experiment consists in creating an arc with a welding machine (Digiwave 500) between a consumable electrode (anode) and a workpiece (cathode). Observation by using a high speed camera with an adapted interference filter (centered at 469 nm) is performed to examine the shape of the arc plasma and possibly provides qualitative information on the distribution of metal vapors [3]. It also allows to characterize the shape of the attachment of the arc on the electrode wire, and get information on the type of metal transfer in the arc.

The main improvement of our experimental concerns the simultaneous acquisition of iron and argon lines with the establishment of two spectrometers (Acton and Sopra). Local values of electron density and temperature are obtained by Abel inversion.

The temperature distributions were deduced from two complementary methods:

- The Sola method [2, 3, 4]: based on the Stark broadening of iron and argon lines (Fe I at 538.3 nm and Ar I to 696.5 nm):

$$\Delta\lambda_S^{Fe} = 0.2648 \cdot \frac{N_e}{10^{23}} \cdot \left(\frac{T_e}{13000}\right)^{1.6700} \quad (1)$$

$$\Delta\lambda_S^{Ar} = 0.0814 \cdot \frac{N_e}{10^{23}} \cdot \left(\frac{T_e}{13000}\right)^{0.3685} \quad (2)$$

this method gives simultaneously the electron density and temperature without assumption on the local thermodynamic equilibrium (LTE) of the plasma.

- The classical Boltzmann plot method [1] applied on three iron lines, with assumption of existence of the excitation equilibrium.

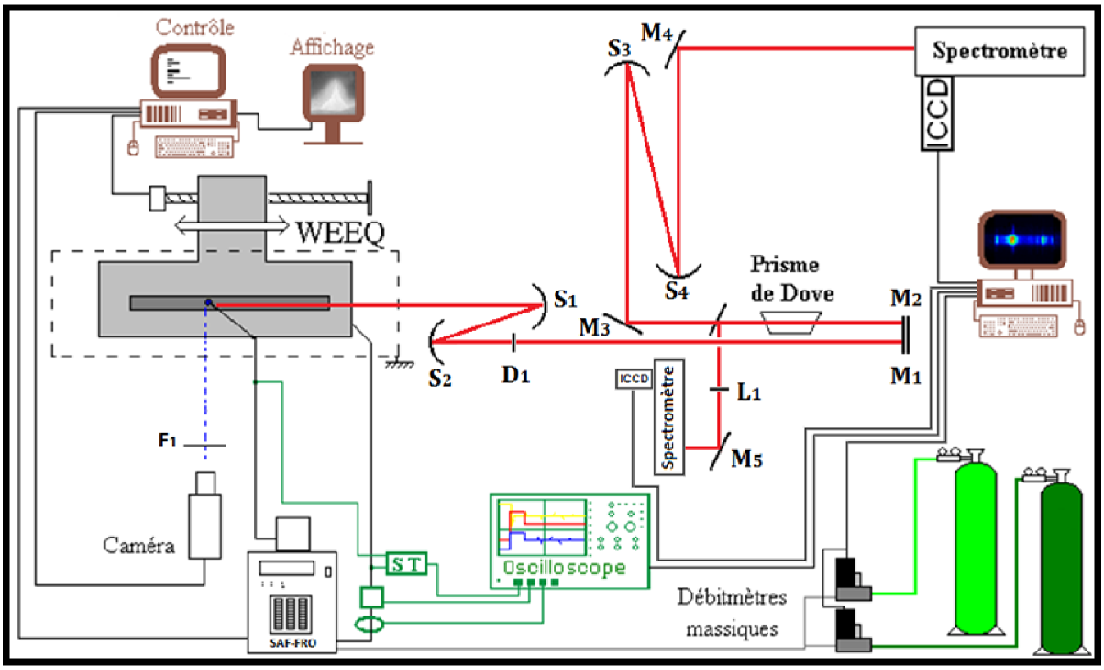

Figure 1 : Experimental set-up

3. Results and discussion

3.1. Shielding gas and metal transfer

The composition of the shielding gas is a very important parameter in the selection of the metal transfer. First, we determined the type of the different metal transfers (spray or globular mode) as a function of the intensity of the arc current and the percentage of CO_2 or O_2 in the used shielding gas. The results are given in Tables 1 and 2. Except, in oxygen, the shifting of the spray-globular limit to the higher active gas rates, the distribution of metal transfer type (spray and globular mode) is generally the same for both mixtures Ar-CO_2 and Ar-O_2: the spray mode for high current and low percentages of active gas, and globular mode for low arc current or high rates of active gas.

% CO_2	200A	220A	240A	260A	280A	300A	330A	360A	380A	400A
0%	Globulaire	Globulaire	Globulaire	Spray	Spray	Spray	Spray	Spray	Spray	Spray
2%	Globulaire	Globulaire	Globulaire	Spray	Spray	Spray	Spray	Spray	Spray	Spray
5%	Globulaire	Globulaire	Globulaire	Globulaire	Spray	Spray	Spray	Spray	Spray	Spray
8%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Spray	Spray	Spray	Spray
10%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Spray	Spray	Spray
15%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Spray	Spray
20%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire
25%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire
30%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire
40%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire
45%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire
50%	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire	Globulaire

Table 1: Metal transfer in Ar-CO_2

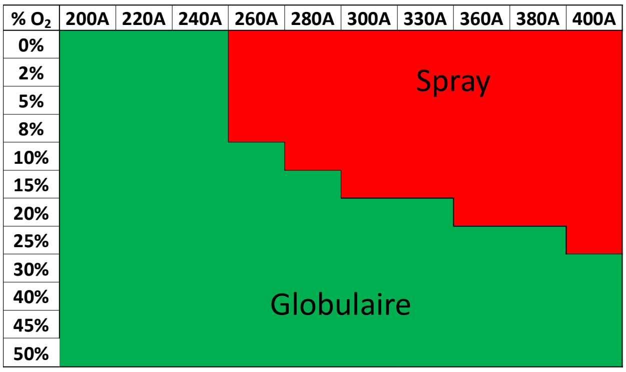

Table 2: Metal transfer in Ar-O_2

Likewise the thickness of the gangue (iron oxide) is particularly important with the percentage of active gas (CO_2 or O_2), but the thickness of the gangue is up to 20 times greater in the mixture Ar-O_2 (Figure 3) that in the Ar-CO_2 (Figure 2).

This result is related to the fact that the main element responsible for the formation of the gangue is oxygen; over this element is present in the shielding gas, over the formation of the gangue will be accentuated. This same argument explains the difference of thickness of the gangue between the two mixtures. Under oxygen, the gangue is also characterized by the presence of large pores.

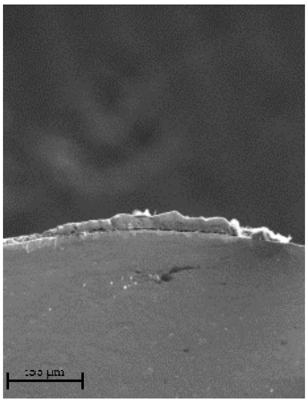

Figure 2 : Globular mode 30% CO_2 240A [×150]

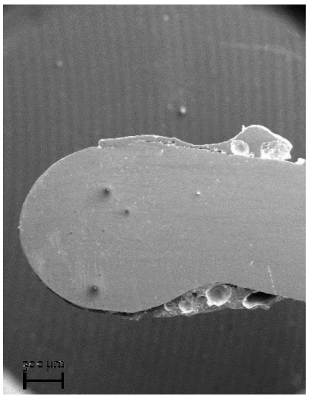

Figure 3: Globular mode 30% O_2 300A [×25]

The analysis by high speed camera of the welding process shows that for similar settings (including speed wire fixed), there is a notable difference of the arc length between the two types of mixtures (30% higher under O_2 than with CO_2). This difference in arc length, linked to higher a metal fusion rate, could be the result of different plasma temperature between the two types of mixtures.

3.2. Spectroscopic diagnostics

The implementation of a new device with two spectrometers, allows simultaneous recording of different spectral regions (Fe I at 538.3 nm and Ar I at 696.5 nm) for diagnosis, but also to eliminate the eventual problem of repeatability of process between two successive tests.

During a diagnosis in previous studies [6] it was shown that the plasma welding under Ar-CO_2 contains a lot of metallic vapors. Similar work has been performed to a mixture Ar-O_2, with a very similar result: the plasma spectrum is characterized by the predominance of many iron lines characteristic of “metallic” plasma.

The temperature of the arc plasma was calculated using the two methods described above (symbol "□" Boltzmann plot method and symbol "-" Sola method), for both types of gas mixtures (5% CO_2 or O_2). The results are presented in Figures 4 and 5: contrary to what was expected, the electron temperature under Ar-O_2 is similar with that under Ar-CO_2.

This result can be explained by the fact that the concentrations of metal vapors are also more important under oxygen and favor the cooling in the center of the column (by increasing radiation). Do not overlook the fact that the arc length increases in oxygen: the study area is not exactly at the same distance from the end of the wire anode than in CO_2.

Finally, it should be noted that the temperatures obtained by Sola method (without assumption LTE) and the Boltzmann plot method remain close and seem to confirm the existence of the LTE in plasma.

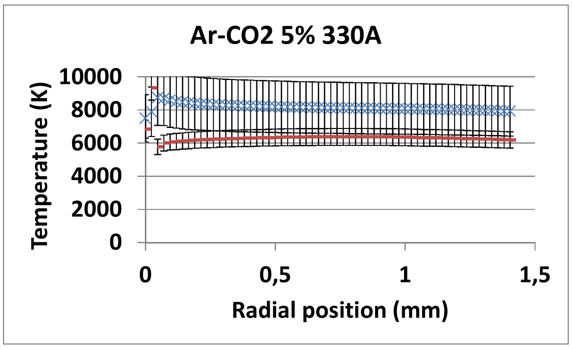

Figure 4: Electron temperature distribution [5% CO_2 at h = 11mm above the cathode]

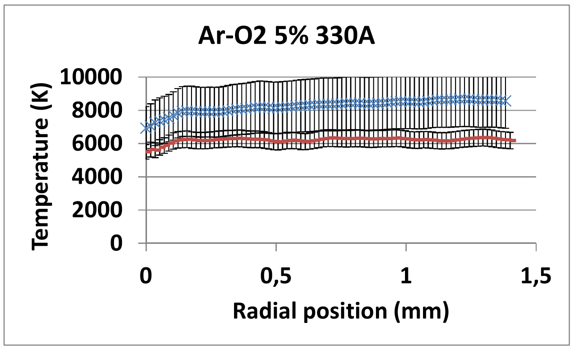

Figure 5: Electron temperature distribution [5% O_2 at h = 11mm above the cathode]

3.3. Study of the anode wire

The composition and the microstructure of the anode wire, and its evolution during the welding process, play a major role on the operating regime [7]. A chemical analysis was carried out by microprobe of Castaing to obtain information on the wire electrode (anode).

Qualitative analysis on a sample taken after operation in Ar-O_2 reveals the following information:

- Absence of carbon.
- Silicium and manganese enrichment in the gangue.
- Low presence of oxygen in the gangue.

The results obtained on the sample after working with Ar-CO_2 give the following information:

- Absence of carbon also.
- Low enrichment of silicium and manganese in the gangue.
- Strong presence of oxygen in the gangue.

The comparison of these two studies underlines the differences in the chemical nature of the gangue under these different atmospheres: minority elements (manganese and silicium) are less concentrated in the Ar-CO_2 sample, while the oxygen content is less important in Ar-O_2 sample.

4. Conclusion

Various analyze and techniques have been performed in order to correlate the results from the GMAW under Ar-CO_2 and Ar-O_2. It has been demonstrated that the modification of the shielding gas brought significant changes in the plasma arc and the electrode wire.

The modification of active gas generates a shift of the transition between spray and globular mode (Table 1 and 2) with a longer arc and a larger thickness in the gangue under mixture Ar-O_2.

Spectroscopic analysis did not allow to show a significant difference of the temperature between the two mixtures, but this can be explained by the significant presence of metallic vapors which encourages cooling at the center of the column which causes an almost uniform temperature.

Finally, chemical analysis by microprobe of Castaing revealed differences in composition of electrodes between mixtures Ar-CO_2 and Ar-O_2. Further studies will be developed to understand the possible correlation between these observations and the modification of the observed transfer mode.

5. References

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