# INFLUENCE OF ACTIVE SHIELDING GAS ON THE MIG-MAG WELDING PROCESS: GLOBULAR TO SPRAY TRANSFER MODE

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## ABSTRACT

Due to its high productivity, gas metal arc welding with electrode wire is widely used in the industry. It is based on the creation of an electric arc between a consumable anode wire and the workpiece. The objective of this work is to understand some phenomena observed in MIG-MAG (Metal Inert Gas - Metal Active Gas) to improve the quality of the process and possibly suggest new operating methods.

For this purpose, this work will be based on a spectroscopic diagnostic to evaluate the distributions of temperature, density and metal vapor in the arc. Analysis by high speed camera is also used to observe the attachment of the arc column at the electrode wire, and the metal transfer. And finally, a micrographic analysis of electrodes is performed to study the influence of chemical and structural changes on the overall behavior of the process, and better understand the interaction between molten metal and plasma.

## 1. INTRODUCTION

The composition of the shielding gas has a strong influence on the process during MIG–MAG welding. In particular, the addition of carbon dioxide induces an increase of current necessary for the transition between the globular metal transfer mode, unstable and characterized by a significant release of smokes, and the spray arc generally preferred.

Diagnosis by optical emission spectroscopy of the plasma column, was carried out under pure argon and low percentages of carbon dioxide (spray arc), then with mixtures containing sufficiently high concentrations of $CO_2$ to obtain globular regime. Attempts have also been made with mixtures Ar-$N_2$ to overcome possible effects of oxygen. In each case, the distributions of temperature and electronic density were deduced from the broadening of spectral lines, and the content of metal vapor in the arc was calculated using the line ratios of Fe I, Fe II and Ar I.

Other tests were also conducted with mixture Ar-$O_2$ to study the influence of oxygen on the liquid stream, in other words, on the length of melted metal present in the welding plasma (Fig 1).

$N_2$ and $O_2$ were chosen for comparison with $CO_2$. First, we wanted to study the addition of a molecular gas such as $CO_2$ but without oxygen, and secondly, to study specifically the effect of oxygen.

## 2. PLASMA DIAGNOSTICS

The experiments were made with a Digiwave welding generator for arc generation, using the same experimental setup and presented in [1]. The observation using high speed camera with an adapted interference filter (centered on 469 nm) is performed to study the shape of the arc column and to obtain a qualitative estimate of the distribution of the metal vapor. It also enables to characterize the attachment of the arc to the wire anode, and to obtain information on the shape of droplets transferred into the plasma. This work was carried out with a high speed camera and image processing software which allowed determination of the desired values like: the length and surface of the liquid stream as well as, the diameter and surface of the droplet.

The electron density and temperature are obtained simultaneously without assumptions about the plasma equilibrium state, using a method based on measurements of stark width of spectral lines, originally developed by Sola [2, 3] and applied to the 538.3 nm Fe I and 696.5 nm Ar I lines. The main improvement of our experimental setup since our latest paper [9] concerns the acquisition of iron and argon lines, the acquisition of these lines is now simultaneous:

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

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

The measurements are performed side-on, and local values are obtained by Abel inversion.

Furthermore, two other Fe I lines (539.4 nm and 539.7 nm) can be recorded simultaneously: so it is possible to evaluate the excitation temperature in the arc by applying the Boltzmann plot method. The comparison between the excitation temperature and the electron temperature allowed determining region where the local thermodynamic equilibrium may exist [4]. It should be noted that a full validation of LTE (local thermodynamic equilibrium) would also need verification of the Saha equilibrium, taking into account the various ionization stages of the species present in the plasma.

The ratio of neutral iron and argon can be obtained from the previous spectra. Since no spectral line of ionized argon was observed in the plasma, the approximation that the total amount of argon in the arc corresponds to the density of neutral argon has been made. This is not the case for iron. Several spectral lines of Fe II are observed in the emission spectrum of the plasma, including the one at 501.8 nm which was chosen for determination of the ratio of ionized iron to argon. Since no spectral line of Fe III was observed, it can be considered that the proportion of iron in the arc can be calculated as the ratio:

$$\frac{[Fe\ I] + [Fe\ II]}{[Ar\ I]} \quad . (3)$$

All the results obtained in spray arc regime, and for different mixtures of protective gas, are given in figures 2 and 3.

## 3. RESULTS AND DISCUSSION

The effects of the addition of $CO_2$ upon the parameters of welding plasma were studied in spray arc and globular regime. The results show that the temperature on the axis of the column increases while the electron density decreases with the addition of $CO_2$. The most important modification concerns the radial distribution of temperature. In pure argon or at low concentration of carbon dioxide, there is a drop of the temperature on the axis of the column close to the wire electrode. This effect disappears when concentration of $CO_2$ is increased, even though the electron density decreases, and the temperature reaches higher values. Models of the arc welding which neglect the influence of the metal vapor, or assume homogeneous plasma, do not predict such drop of the temperature on the axis of the column. As a result the calculated temperatures are higher than measured experimentally. However, the most recent models [5, 6], which take into account the influence of metal vapors in the column, already give the off-axis maxima of the temperature in accordance with experiments.

The results of the experiments with mixture of Ar-$N_2$ as protective gas, indicate disappearance of temperature drop on the axis which can be related to higher thermal conductivity of the plasma, rather than the effect of oxygen.

In general, the amount of metal vapor is higher in the upper part of the arc column, it means under the wire electrode. Their concentration is even higher when the shielding gas contains $CO_2$. Although there are some discrepancies with respect to other works [7, 8], the results are generally in good agreement.

The appearance of metal vapors near the anode induces significant changes of plasma properties, particularly an increase of its electrical conductivity. The transition from a conical arc very marked, in spray arc, to a bell shape, more diffuse, in globular regime, can be related to variations of the current lines that is to variations of the sign and magnitude of the Lorentz forces.

The change of the spatial distributions of the temperature under the anode wire and of metal vapors in the arc column will affect the thermophysical characteristics of plasma as, which confirms calculations based on its composition, assuming the local thermodynamic equilibrium. These phenomena may be associated with the transition between the spray arc and globular regime. In particular, our results suggest that the change in viscosity of the plasma can influence the transfer of drops of liquid metal.

The second study, concerning the effects of oxygen on the liquid stream was performed in spray arc with different proportion of oxygen in the shielding gas.

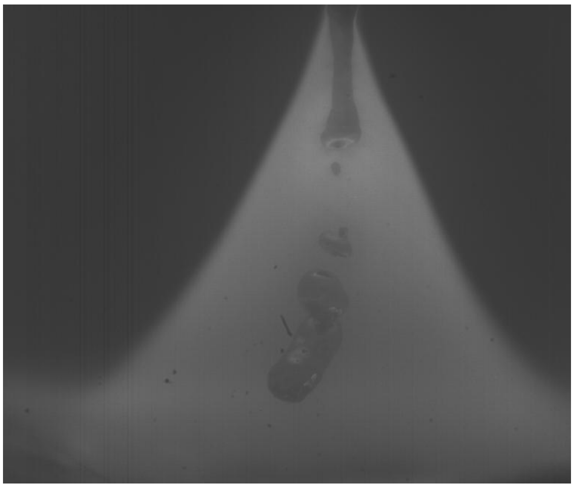

*Fig 1: Plasma column and liquid stream (2 000 frames per second, filter 469 nm)*

Figure 2, illustrating the variations of the length of the liquid stream with the percentage of oxygen in the shielding gas, indicates that the length decreases with oxygen.

Indeed, a production more important of oxide causes a higher viscosity, and therefore, the length of the liquid stream is shorter. Regarding the diameter of the drops, it also increases with percentage of oxygen for the same reason. Furthermore, the graph shows that the length of the liquid stream increases with the current of the welding process. If the intensity increases, the energy present in the arc also increases, the amount of molten metal grows and so the length of the liquid stream is longer.

Figure 3 shows the evolution of the surfaces of the liquid stream and the droplet. The surface of the liquid stream increases with the intensity and the surface of the droplet increases with the percentage of oxygen in the shielding gas for the same reasons previously explained.

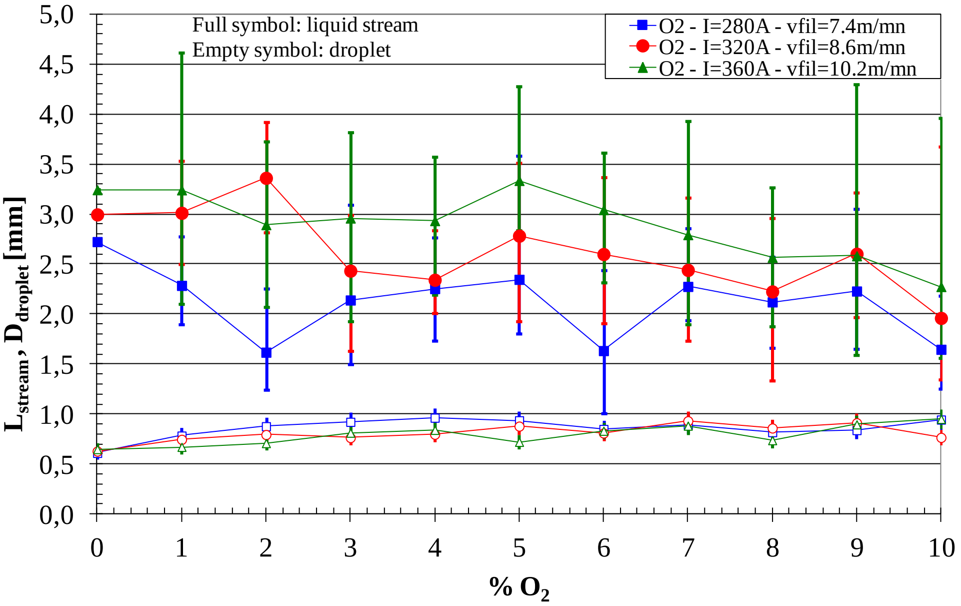


*Fig 2: Length of the liquid stream and diameter of the droplet*

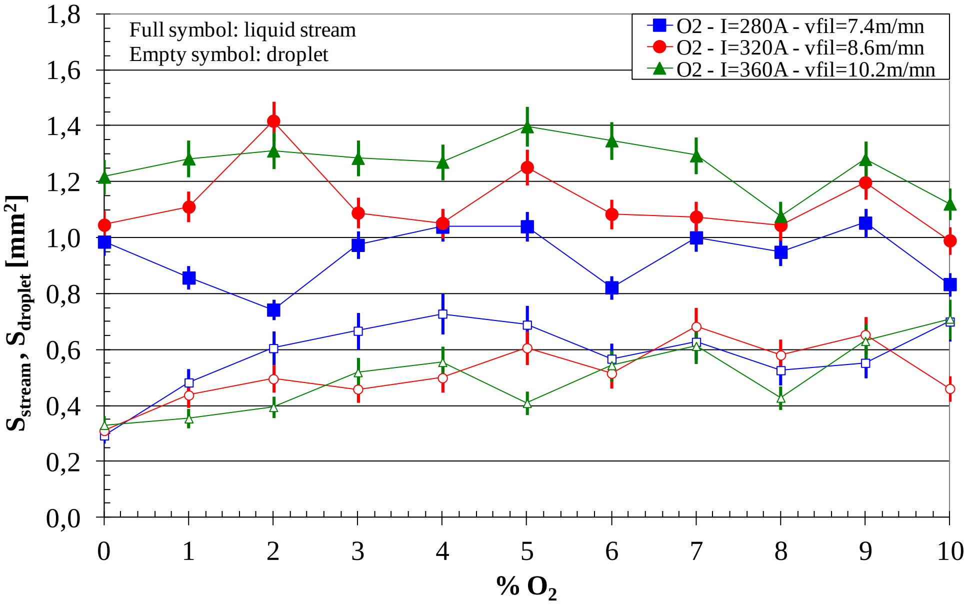


*Fig 3: Surface of the liquid stream and the droplet*

Our future investigations of welding plasma will concentrate on plasma diagnostics while using anodes wire with specific composition for instance wires doped with alkaline metals. The welding process itself, plasma parameters and the anode microstructure will be studies.

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