IMPLEMENTATION OF DOUBLE AR/(AR+CO$_2$) SHIELDING ON GTAW OF AISI 316L STAINLESS STEELS

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Abstract. In the present study, a modified GTAW torch operating with an inner flow of pure Ar gas and an outer flow of mixed Ar-CO$_2$ gas was employed for welding AISI 316L stainless steel plates. Cross-section samples from the welds were analyzed in terms of their general macrographic aspect. The influence of the torch modification on oxidation and deterioration of the tungsten electrodes was also investigated. It was verified that an increase in the percentage of CO$_2$ in the outer layer led to an increase in penetration depth. In addition, the results indicated that the inner Ar layer worked properly as a barrier protecting the electrode from destructive oxidation.

Keywords: GTAW, Double Shielding, Penetration, Stainless Steel

1. INTRODUCTION

Gas tungsten arc welding (GTAW) or Tungsten Inert Gas (TIG) is one of the most used processes for joining low carbon steels and stainless steels due to the high quality of the bead surface. The penetration obtained in GTAW is shallower when compared to other welding processes such as gas metal arc welding (GMAW), and plasma arc welding (PAW) when using the same welding speed. Therefore, in many situations, a single pass is not enough to weld thick plates and the process productivity is lower compared to other processes.

The productivity of GTAW can be increased by the addition of surface active elements such as O or S in the weld pool. Such elements can modify convection in the molten metal during the welding process increasing the heat transfer rate to the backside of the welded joint and increasing penetration (Fuji et al, 2008). In this sense, the E.O. Paton Institute of Electric Welding was the first one to propose in the 1960s the A-TIG process (Gurevich and Zamkov, 1966). The A-TIG process consists of an adhesion of a solid flux on the plate before the welding. According to Leconte et al (2006), this process would be able to increase the weld penetration 2-4 times, however, it depends on the amount and the particle size of the flux, which is difficult for the operator to control. An alternative solution to promote surface active element incorporation in the weld pool is the addition of active gases such as CO$_2$ or O$_2$ to the Ar shielding gas (Lu et al, 2004 a,b) The mixed shielding gas is easier to be controlled by the operators and the process can be automated. However, in presence of the active gases O$_2$ or CO$_2$ the tungsten electrode undergoes severe damage by oxidation. In order to prevent this oxidation, a double shielding torch for GTA welding was recently developed as shown schematically in Fig. 1. The novel torch operates with an inner flow of pure inert gas and an outer flow of mixed (inert-active) gas. (Lu et al, 2010)

In the present study, a new modified GTAW torch was developed to operate with an inner flow of pure Ar gas and an outer flow of mixed Ar-CO$_2$ gas for welding AISI 316L stainless steel plates. Cross-section samples from the welds were analyzed in terms of their general macrographic aspect. The influence of the torch modification on oxidation and deterioration of the tungsten electrodes were also investigated.
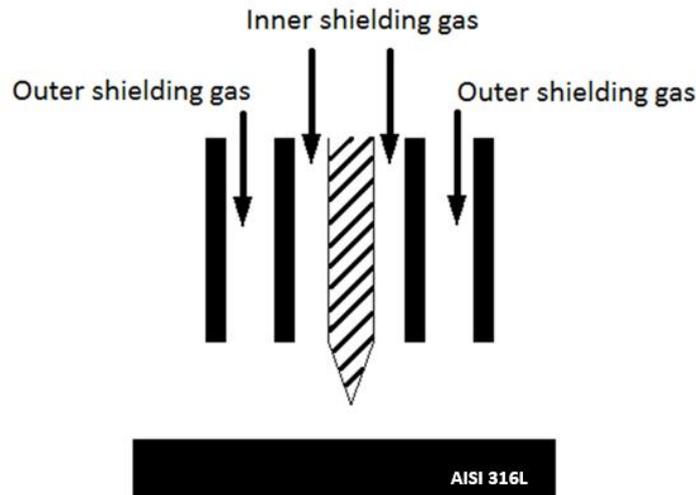
Figure 1. Schematic diagram of designed double shielding GTA welding torch

2. EXPERIMENTAL PROCEDURE

AISI 316L stainless steel plates with dimensions of 150 mm x 20 mm x 11 mm were used for the bead-on-plate welding tests. In order to achieve microstructure homogenization, the plates were annealed at 1100 ºC for 30 minutes and cooled in water. Then, the surfaces of the plates were machined and cleaned with acetone to remove contamination.

An automated system of the designed torch (Fig. 1) was used to weld the stainless steel samples. A 2% thoriated tungsten electrode (W–2%ThO_2, 2.4 mm diameter, included angle of 60º) was used by direct current in each experiment. The electrodes were weighed in a high precision balance and photographed before and after experiments.

The double shielding gas torch was fed by pure Ar in the inner layer and a mixed gas of Ar and CO_2 in the outer layer. The different concentrations of CO_2 used in the experiments are indicated in Table 1.

Table 1. Gas concentrations

Bead Samples	Inner Gas	Outer Gas
1	100% Ar	100% Ar
2	100% Ar	Ar + 1% CO_2
3	100% Ar	Ar + 2% CO_2
4	100% Ar	Ar + 4% CO_2
5	100% Ar	Ar + 8% CO_2
6	100% Ar	Ar + 15% CO_2
7	100% Ar	Ar + 25% CO_2
8	100% Ar	Ar + 50% CO_2
9	100% Ar	Ar + 100% CO_2

The experiments were made using a welding speed of 2 mm/s, current equal to 80 A, inner and outer flow rate of 10 l/min. The distance between the electrode and the plate was 4mm.

A 100 mm weld bead was done for each variation presented on Table 1. After that, small samples were cut from the middle of the bead. The samples were polished and etched using an electrolytic process with oxalic acid $(COOH)_22H_2O$ to reveal the bead profile. The prepared cross-sections of the weld beads were photographed in a macro scale.

3. RESULTS AND DISCUSSION

3.1. Welding Profile

Nine different experiments were carried out by changing the concentration of the active gas in the outer layer of the double shielding GTA welding, from pure Ar to 100% CO_2. The cross-sections of the weld beads thus obtained are shown in Tables 2 and 3.

When using the 100% Ar or Ar - 1% CO_2 configuration, the weld shapes were wide and shallow. When the percentage of CO_2 in the outer layer was varied between 2.5 and 15, the weld became increasingly narrow and deep. The highest depth/width (D/W) ratio was achieved for the Ar - 2.5% CO_2 configuration, with a value of 0.37. Compared to the 100% Ar, the D/W ratio increased 2.98 times. When using Ar-25% CO_2, Ar-50% CO_2 and Ar-100% CO_2 the

weld shapes became wide and shallow again. However, the D/W ratio of those samples remained higher than the D/W ratio of sample 1, without the addition of the active gas, Fig.2.

Table 2. Weld cross sections for different concentrations of active gas (CO_2) in the outer layer of the double shielding GTA welding process
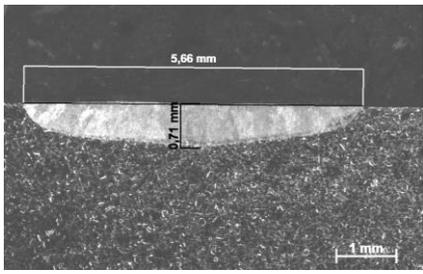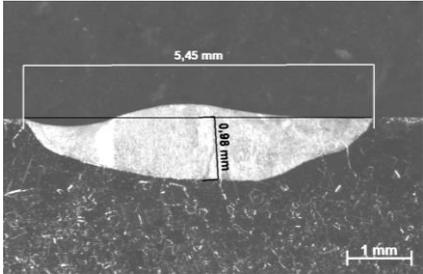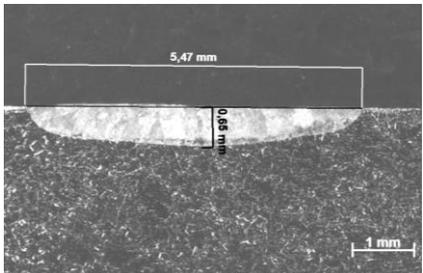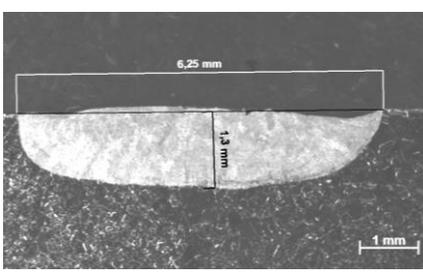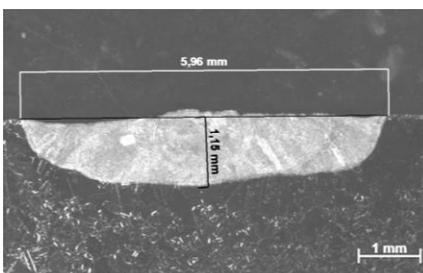
Sample #	Weld Bead Macroscopic Morphology	Sample #	Weld Bead Macroscopic Morphology
1 (100% Ar)		6 (100% Ar + Ar-15% CO_2)	
2 (100% Ar + Ar-1% CO_2)		7 (100% Ar + Ar-25% CO_2)	
3 (100% Ar + Ar-2,5% CO_2)		8 (100% Ar + Ar-50% CO_2)	
4 (100% Ar + Ar-4% CO_2)		9 (100% Ar + 100% CO_2)	
5 (100% Ar + Ar-8% CO_2)			
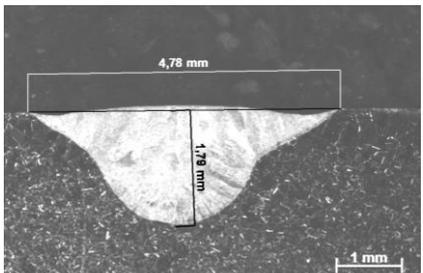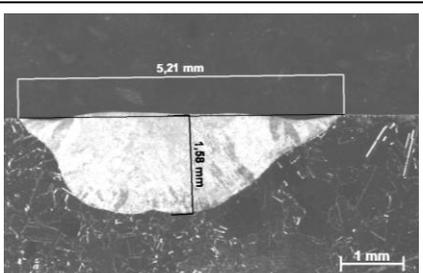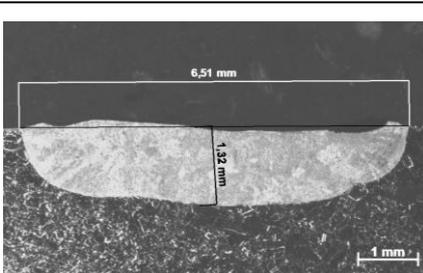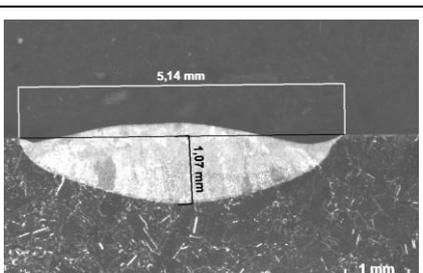
Table 3. Numerical results of the weld bead geometry for different concentrations of active gas (CO_2) in the outer layer of the double shielding GTA welding process

Gas Composition	Weld Bead Width [mm]	Weld Bead Depth [mm]	Weld Depth/Width ratio
100% Ar	5.66	0.71	0.13
100% Ar + Ar- 1% CO_2	5.47	0.65	0.12
100% Ar + Ar-2,5% CO_2	4.78	1.79	0.37
100% Ar + Ar-4% CO_2	5.21	1.58	0.30
100% Ar + Ar-8% CO_2	5.14	1.07	0.21
100% Ar + Ar-15% CO_2	5.45	0.98	0.18
100% Ar + Ar-25% CO_2	6.25	1.30	0.21
100% Ar + Ar-50% CO_2	5.96	1.15	0.19
100% Ar + Ar-100% CO_2	6.51	1.32	0.20

In comparison to the conventional GTAW process (sample 1) the addition of an active gas increased the D/W ratio. Once all the other process parameters were fixed, the effect of the composition of the outer layer in the double shielding GTA welding process was significant. This effect can be more easily visualized in Fig. 2, in which the tendencies reported in Tables 2 and 3 are summarized in graphical form.
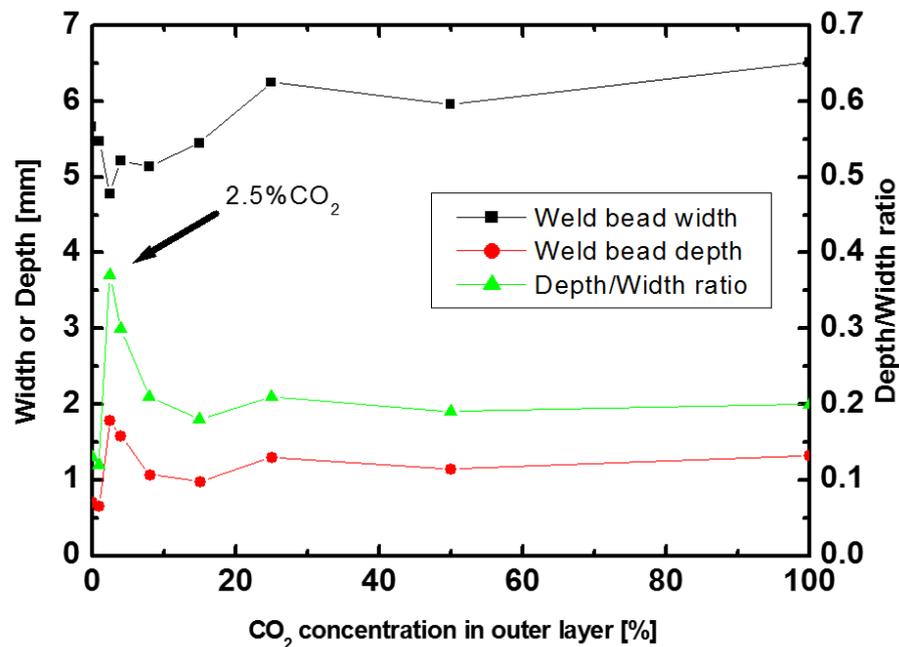

Figure 2. Graphical representation of the weld geometry parameters

3.2. Marangoni convection

Generally, the weld shape is a result of the mode in which the heat transfers along the metal pool. The heat transfer mode is a combination of conduction and convection. The relation between those transfer modes can be expressed by the Peclet number, which is the ratio of convection and conduction, Lu et al (2004c). Based on Lu et al (2010), the calculated Peclet number for the double shielding GTAW process in a AISI 316L with welding velocity of 2 mm/s was greater than 1. Therefore, the convection is the main heat transfer mode in the weld pool.

Previous studies shown that Marangoni convection is the main mechanism that affects the fluid flow in the molten pool. Marangoni convection is based on the surface tension difference on the pool surface. For some materials the surface tension decreases while the temperature increases. The weld pool presents a significant temperature gradient and consequently a surface tension as well. Due to the weld bead temperature distribution (the edges are cooler than the center), Marangoni convection will flow from the center to the edge, Fig 3(a).

The present study, Mirzae et al (2016), Lu et al (2010) and other recent studies have been proving that the presence of an active element in the liquid pool reverses the direction of the Marangoni convection, from outward to inward, Fig 3 (b). According to Heiple and Ropper and Lu et al (2003) the O and S are active elements for stainless steel. The

oxygen from the decomposition of the CO_2 at a high temperature dissolves in the molten pool during the welding process. When the concentration of the active element achieves a critical value the weld bead changes from a wide and shallow shape to a narrow and deep one. Increasing the D/W ratio when compared to weld bead from the conventional GTAW process. However, a large amount of the active element formed some oxides on the weld surface that will decrease the effects of the surface tension, reducing the D/W ratio.
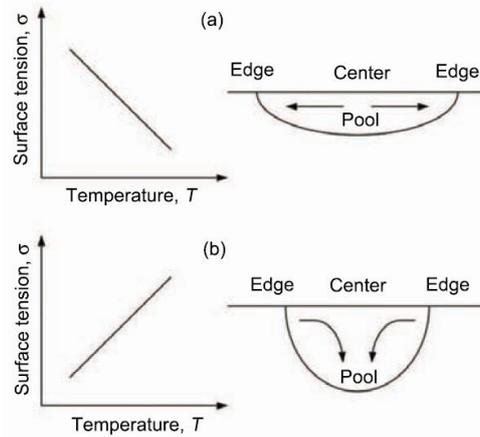
Figure 3. Marangoni convection mode in the weld pool: (a) $\partial\sigma/\partial T < 0$ (b) $\partial\sigma/\partial T > 0$ (Lu et al, 2010)

3.3. Electrode Morphology

The morphology of the electrode before and after the welding is shown in Table 5 for different concentrations of carbon dioxide in the outer layer of the double shielding GTAW process.
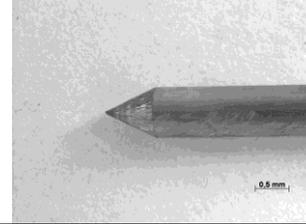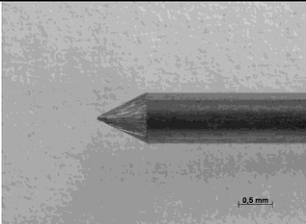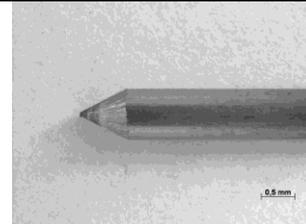
When the percentage of CO_2 used in the outer layer was lower than 25 (samples 1 to 6) the electrode was well protected. For percentages of CO_2 higher than 25 (samples 7 to 9) the electrode oxidized seriously during the process.

The electrode weight loss after the welding process was lower than 0,05% of its initial weight for all samples as shown in Table 4. The oxidized electrodes presented in average 4.27 times more weight loss than the protected ones.
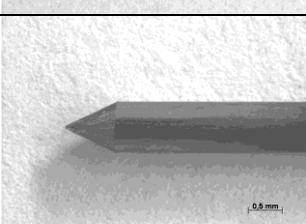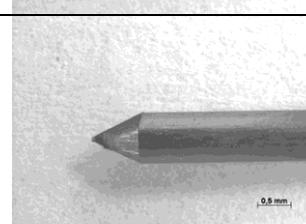
Table 4. Electrode weight before and after the experiments for different concentrations of active gas (CO_2) in the outer layer of the double shielding GTA welding process

Gas Composition	Initial Weight (g)	Final Weight (g)	Mass loss (g)	Mass loss (%)
100% Ar	10.7430	10.7430	0	0
100% Ar + 1% CO_2	10.9775	10.9775	0	0
100% Ar + 2,5% CO_2	11.5197	11.5185	0.0012	0.0104
100% Ar + 4% CO_2	10.5631	10.5624	0.0007	0.0066
100% Ar + 8% CO_2	11.5574	11.5569	0.0005	0.0043
100% Ar + 15% CO_2	10.9501	10.9493	0.0008	0.0073
100% Ar + 25% CO_2	11.7402	11.7373	0.0029	0.0247
100% Ar + 50% CO_2	11.5664	11.5634	0.003	0.0259
100% Ar + 100% CO_2	10.7727	10.7683	0.0044	0.0408

Table 5. Electrodes before and after the experiments for different concentrations of active gas (CO_2) in the outer layer of the double shielding GTA welding process

Sample #	Electrode Morphology Before	Electrode Morphology After
1 (100% Ar)		
2 (100% Ar + Ar-1% CO_2)		
3 (100% Ar + Ar-2,5% CO_2)		
4 (100% Ar + Ar-4% CO_2)		
5 (100% Ar + Ar-8% CO_2)		
6 (100% Ar + Ar-15% CO_2)		
7 (100% Ar + Ar-25% CO_2)		
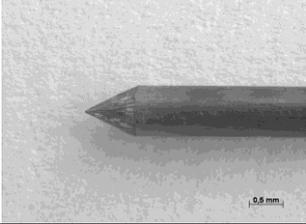
8 (100% Ar + Ar-50% CO_2)	 0,5 mm	 0,5 mm
9 (100% Ar + 100% CO_2)	 0,5 mm	 0,5 mm
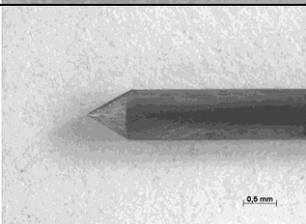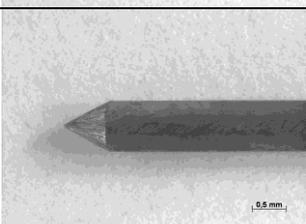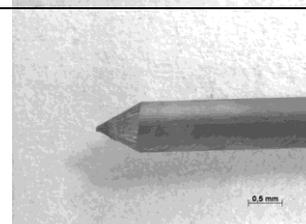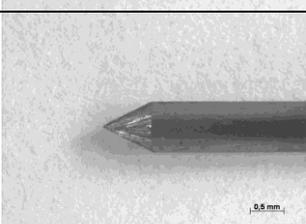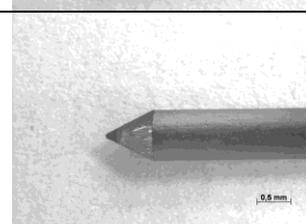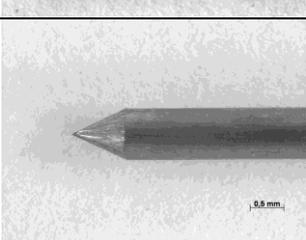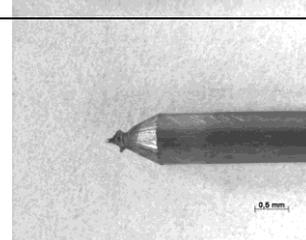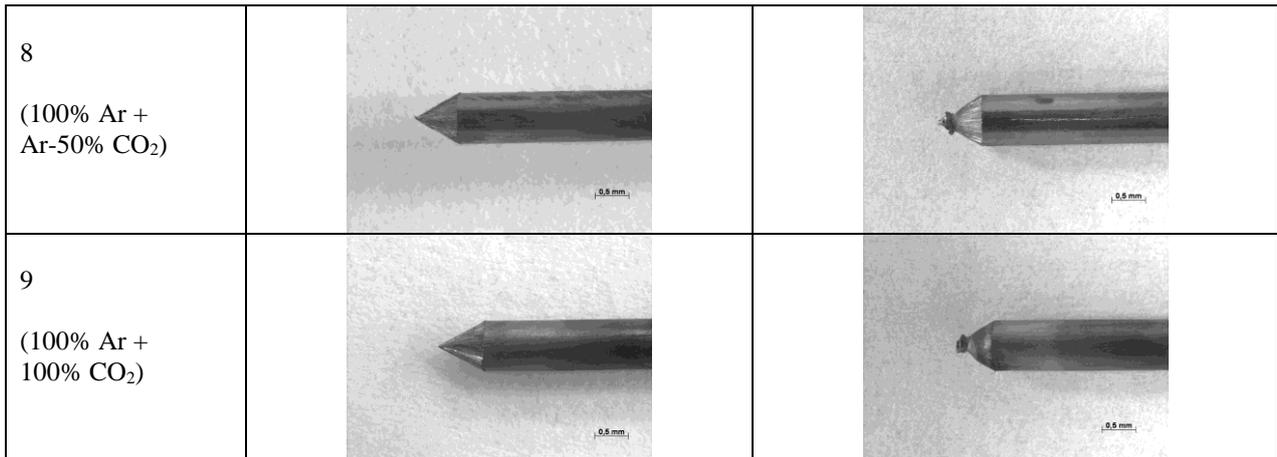
4. CONCLUSION

When CO_2 was used in the outer layer in the double shielding GTAW process on AISI 316L the weld shape changed significantly. Small additions of the active element (O) in the weld pool promoted the direction reverse of the Marangoni convection from outward to inward leading to an increase of the D/W ratio. Weld bead shape changed from wide and shallow to a narrow and deep one. The higher value of D/W ratio (0,37) was found for the Ar-2.5% CO_2 configuration. The penetration found for this configuration was 1.79 mm, 2.5 times larger than the penetration achieved using the process without the active gas.

The double shielding GTA welding process well protected the electrode from oxidation when using concentrations of CO_2 equal or smaller than 15% CO_2 in the outer layer. When 25% CO_2, 50% CO_2 and 100%CO_2 were used in the outer layer the electrode was oxidized.

5. ACKNOWLEDGEMENTS

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