

EFFECTS OF DILUTION ON WELD OVERLAYS REALIZED WITH FLUX-CORED ARC WELDING (FCAW) PROCESS USING 309LV FILLER METAL ON THE S235JR STEEL

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The paper presents the dilution effects that appear in the weld overlays realized in horizontal and vertical uphill position, using flux-cored arc welding (FCAW) process. Two shielding gases (99,95% pure argon and 100% carbon dioxide) were used for welding and their influence on the microstructure has been studied. In order to evaluate the dilution effects the welded overlays were successively removed, each removed layer having 1 mm thickness, and then the chemical composition of the subsequent surfaces has been analyzed by spectrometry. Optical metalography was performed to reveal the microstructural features and imperfections generated by the shielding gases. One can conclude that the use as shielding gas of 100% CO₂ is not beneficial for 309LV stainless steel cladding on structural S235JR steel backing material.

Keywords: FCAW process, cladding, dilution, shielding gas, welding positions

1. Introduction

Cladding process aims to create a composite product consisting of a layer of stainless steel integrally bonded to the surfaces of substrate. The objective of such a technology is to combine, at low cost, the required properties of the stainless steel and the backing material, for applications where stainless steel full-wall construction is not necessarily. Nowadays overlaying is directly applied to the completed vessel shell, or to vessel dished ends, vessel cylinders or individual stakes. Stainless steel clad plates are widely used in chemical and nuclear industries in order to take advantage of the corrosion resistance and reduce the cost.

The various applications of weld cladding include the internal surfaces of carbon and low alloy steel pressure vessels, paper digesters, urea reactors, tube sheets, nuclear reactor containment vessels, and hydro-crackers [1-5].

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While the stainless cladding furnishes the resistance to corrosion, abrasion, or oxidation, the backing material contributes to the structural strength and improves the workability and thermal conductivity of the composite. For several decades, it has been known that nickel-based alloys suffer from stress corrosion cracking (SCC) in the primary water of pressurized water reactors (PWRs), while austenitic stainless steels have proven almost immune, with the exception of irradiated or oxygenated conditions [2, 3].

The interface between the austenitic deposit and the low carbon steel is complex. Depending upon the exact composition of the joined materials, a range of microstructures can be formed in the diluted zone and often there is potential to form a martensite phase, whose hardness, to a large extent, will be dictated by the carbon content diffusing from the base steel. These high hardness zones may evidently be present in the heat affected zone (HAZ) of most weld overlays and also in the HAZ of austenitic weld deposits on low carbon steels such as welds in clad and lined pipelines. [4-9].

A major concern in an arc welding based overlay is dilution or the extent of change in the chemistry of the deposited metal by mixing with the base metal. Even though some generic information concerning the extent of dilution associated with common arc welding processes is available, the actual dilution with a particular process itself can vary over a wide range, based on the welding parameters employed. In most cases of overlaying, it is necessary to control the dilution within close limits as an inhomogeneous chemical composition can reduce the service life of the part [5-8].

There are a number of variables which affect dilution such as the welding current, the arc voltage, current polarity, electrode diameter, electrode extension, weld-bead separation, welding speed, electrode grinding angle, welding position, shielding gas composition, etc. O-1 shielding gas (99% argon/1% oxygen) is often used for stainless steels welding, due the oxygen action to stabilize the electric arc. CO₂ shielding gas is common used for carbon and low alloy steels, providing a good weld penetration. It is necessary to control each of these variables within limits to get the desired properties on the overlay, for which it is necessary to have a clear understanding of the influence of each of these variables on dilution [6-16].

In this paper are presented some investigations related to the changes in chemical composition and microstructure in overlay welds realized with FCAW process using 309LV filler metal on the mild steel S235JR backing material. In order to study the evolution of chemical composition at different distance from the welding line, the clad material was successively removed by grinding. Five different layers were removed, having 1 mm thickness each, and then chemical composition has been measured. The microstructure has revealed influence of shielding gas on integrity of the welding zone and compounds formation.

2. Experimental details

2.1. Materials

A INOXCORED 309LV stainless steel was used as a filler material because this material has a good corrosion resistance and a very low carbon content. The structural S235JR steel was used as a base material because it is widely used in industries. The chemical composition of S335JR (EN 10025-2:2004) base material according to the material certificate was [6] as follows, (wt%): C=0.125; Si=0.195; Mn=0.67; P=0.011; S=0.013; N=0.0052; Al=0.039; Cr=0.0183; Ni=0.0153; Cu=0.0155; Ti=0.001; Mo=0.005; Nb=0.001; V=0.001; As=0.003.

The filler metal used in the experimental research has the average chemical composition (%wt) in accordance with the filler metal certificate, that contains the minimal values guaranteed for the weld metal [6]: C=0.04; Si=0.65; Mn=0.6; P=0.019; S=0.009; N=0.0266; Cr=22.85; Ni=12.54; Cu=0.133; Mo=0.162; Nb=0.025 and ferrite number FN=11.2. Schaeffler/DeLong is a constitutional diagram that shows the different microstructures in welds [20]. According this diagram, Cr_{equiv} value in welding consumable is 24% and Ni_{equiv} value is 14.04%. Considering a dilution value of 30% with base material, the values for Cr_{equiv} and Ni_{equiv} result to be respectively, 16.85% Cr_e and 10.44% Ni_e . This composition corresponds to austenitic microstructure and 1.92% Ferrite content.

2.2. Welding procedure

MIG/MAG welding machine was used to conduct the experiments and two type of shielding gases: 99.95% pure Argon and 100% Carbon dioxide have been tested, in order to establish the compatibility with the stainless steel overlays. The welding process has been conducted manually, in two different welding positions: PA – horizontal and PF – vertical uphill. The dimensions of cladded sample were: thickness of 15mm, length of 60mm and width of 60mm (Fig. 1).



Fig. 1. Samples welded using FCAW process: a) Horizontal (PA) / Sample A1-PA; b) Uphill (PF) / Sample A1-PF; c) (PA) / Sample AC-PA; d) (PF) / Sample AC-PF.

The welding parameters values are shown in Table 1, for the two different welding positions (horizontal and vertical uphill) and for the two different shielding gases. For the horizontal position 2 successive layers have been deposited and for vertical uphill one layer has been deposited. Heat input during welding was calculated using the relation:

$$Hi = \eta \frac{IsUa}{V_w}, \text{ J/s} \quad (1)$$

where η is the electric arc efficiency for FCAW process (0.8), Is the welding current, in A, Ua is the voltage during welding, in V and V_w is the welding speed in mm/min.

Table 1

FCAW welding parameters for each position and gas

Welding parameters values	Samples overlays using 99,95% pure Ar		Samples overlays using 100% carbon dioxide	
	Horizontal (PA) / Sample A1-PA	Vertical Uphill (PF) / Sample A1-PF	Horizontal (PA) / Sample AC-PA	Vertical Uphill (PF) / Sample AC-PF
Rows no.	1-20	1-8	1-26	1-8
Is (A)	180	160	180	160
Ua (V)	33	27	33	27
Gas type	Argon 99.95%	Argon 99.95%	CO ₂ 100%	CO ₂ 100%
Gas flow (l/min)	18	18	18	18
T_{initial} (°C)	75	75	75	75
Heat input (kJ/mm)	0.91	0,95	0.91	0,95
Velocity V_w (mm/min)	310	230	310	230

3. Result and discussion

3.1. Chemical composition analysis

The chemical composition was established using a Foundry-Master high-performing optical emission spectrometer. For each sample 4 layers successively were removed by machining (Fig. 2) and then the chemical composition was measured in three different points.

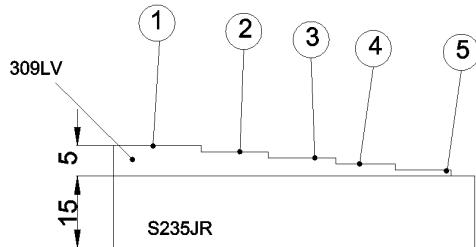


Fig. 2. The surfaces and layers prepared by grinding for chemical analysis and micro-hardness. Points 1, 2, 3, 4 and 5 represent levels of the surfaces on which chemical analysis and micro-hardness measurement have been carried out.

Analyzing the evolution of the chemical composition was found, as expected, that the most important alloying elements Cr and Ni, show an obvious tendency to decrease as approaching the fusion line. The amplitude of content decrease for Cr and Ni in clad, for each sample, is represented in Fig. 3.

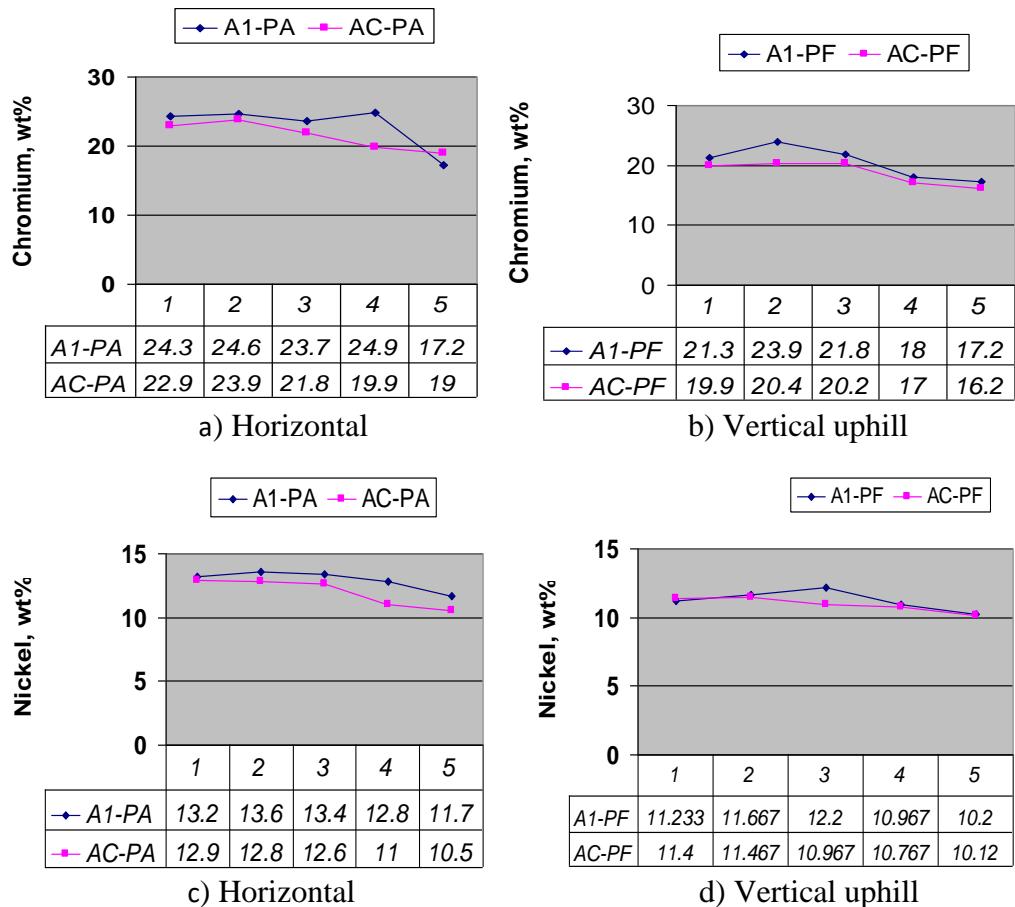


Fig. 3. Chromium and Nickel evolution as function of welding position and shielding gas: A1 – 99,95%Ar; AC – 100%CO₂.

As shown in Fig. 3 (a and b), for the uphill vertical welding position, the downward trend of the chromium content is most obvious comparative with the horizontal welding position. From the mean values expressed, it is found that in samples AC-PF, the chromium content decrease below the value prescribed by the filler material manufacturer ($\text{Cr} = 22.85\text{wt\%}$), at the distance of 5mm from the welding interface with the structural backing material. This situation represents a risk in terms of corrosion resistance, mainly in the first welding layer. For the horizontal position, the situation becomes critical at 3 mm from the base material interface.

In the case of nickel content, concentrations decrease below the amount prescribed by the manufacturer ($\text{Ni} = 12.54\text{wt\%}$) even more drastic for vertical uphill position, both for inert shielding gas (A1-PF) and for the active shielding gas (AC-BP) (Fig. 3d). This means that, for this welding position, at least 2 layers must be overlayed, required to avoid the risk of falling below the required Ni content. For the horizontal position, the situation is critical only at 3mm distance from the weld interface.

Dilution variation can be calculated, in relation to the minimal value predicted by the filler material manufacturer, with the simple relation:

$$Dv = \frac{(A - B) * 100}{A} \% \quad (3)$$

where: Dv is dilution variation for the main elements (Cr and Ni), A is the prescription value for element in weld metal and B is the value of element in clad layer. Using the relation 3, we can estimate the variation of Cr and Ni concentration in the critical zones, near the clad interface (at 1 mm from the welding line) (Fig. 4).

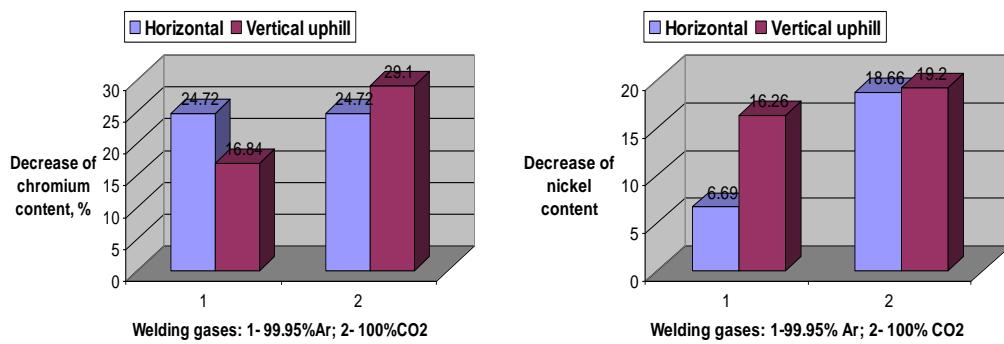


Fig. 4. Level of chromium and nickel at 1 mm from the welding interface

By analyzing the effects of the two protective gases it become obvious that, for using of 100% CO_2 as shielding gas, the decreasing concentration of the alloying elements is more pronounced, as a result of the heat developed by the

electric arc in the active medium and by the effect of oxidation in the melting zone.

3.2. Microstructure

For microstructural analysis, the base material (S 235JR) samples were etched using a 2% Nital reagent, while the weld deposit 309LV was electrolytically etched in 10% $H_2C_2O_4$ + 90% H_2O . Then specimens were observed by optical microscopy, using an Olympus GX51 microscope equipped with software for image processing (AnalySIS) (Fig. 5 and 6). As result from optical microstructures, when 100% CO_2 is used as shielding gas, the risk to form cracks appears, especially in the heat affected zones of S235JR structural steel (Fig. 5b and Fig. 6).

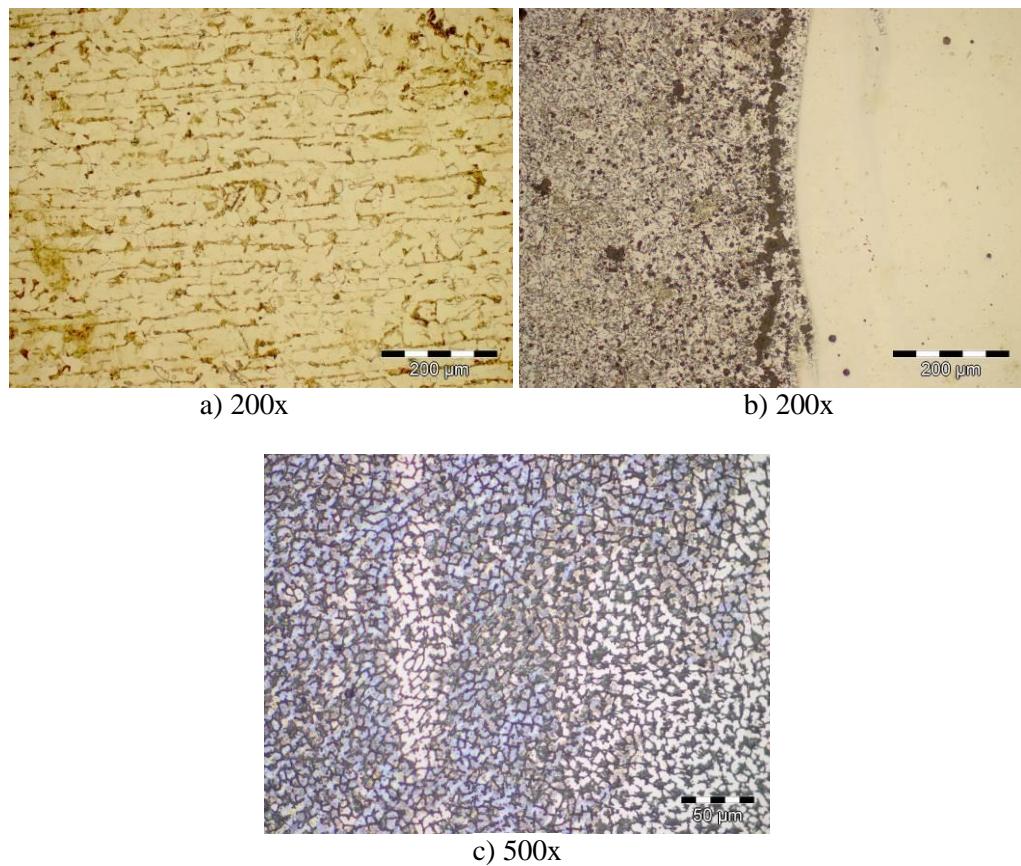


Fig. 5. The aspect of cladding zone of AC-PA sample: a) Base material (S235JR) – ferrite and pearlite; b) Heat affected zone - Widmanstätten structure with discontinuous fracture line located near the welding zone, that follows the fusion line; c) Welding zone (stainless steel 309LV) with fine biphasic microstructure: ferrite (white grains) and austenite (black dendritic grains).

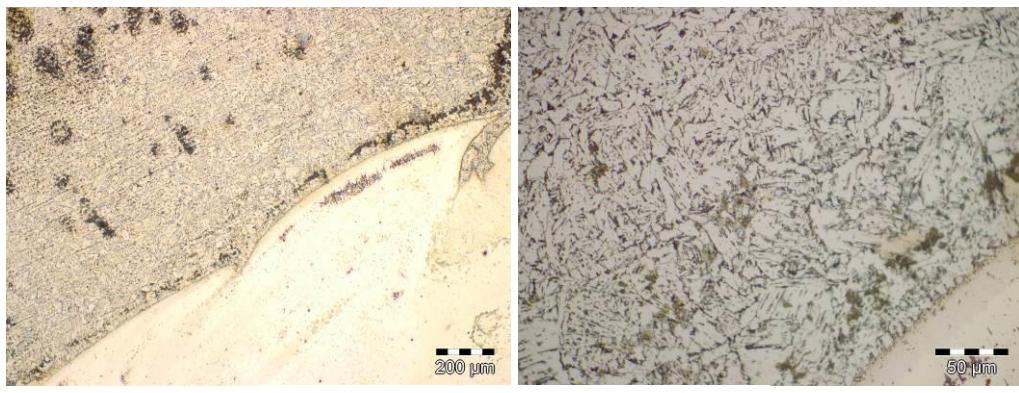


Fig. 6. Heat affected zone for sample AC-PF: micro-crack developed near the welding line, into 235JR steel.

Near the welding line the microstructure of HAZ has changed from ferrite and pearlite to Widmanstätten structure composed of acicular and allotriomorphic ferrite and fine pearlite, leaving the large inclusions of oxides inside the grains and accumulating the structural stress that can stimulate the nucleation of acicular ferrite [17-19]. Moreover, some mixing zones containing ferrite amounts less alloyed with Cr and Ni are visible in the cladding layer, which is emphasized by the chemical attack like islands located near the fusion line (Fig. 6b).

3. Conclusions

- Although the wire producer allows the use of CO₂ as shielding gas, in the case of the uphill cladding it was observed that there is a tendency of a higher quantitative loss of the alloying elements Ni and Cr in comparison with the horizontal welding position, because of a more powerful oxidation effect and lack of protection with shielding gas.
- The aspect of the welding beams is better when 100% CO₂ is used as shielding gas, the welding pool is hotter and more fluid (Fig. 1c). Using 99.95% Ar as shielding gas, the contraction effects of the welding pool appears and the viscosity of the melted metal is higher, as a characteristic of rutile wires (Fig. 1a). Therefore, for stainless steel welding or overlapping the best option is the use of 99% argon/1% oxygen as shielding gas.
- Using 100% CO₂ as shielding gas promote the risk to form cracks and overheating, especially in the heat affected zones of S235JR structural steel. For 100% CO₂ shielding gas, the decreasing concentration of the

main alloying elements (Cr and Ni) is more pronounced, as a result of the heat developed by the electric arc in the active medium and by the effect of oxidation in the melting zone. This situation represents a risk in terms of corrosion resistance, mainly in the first welding layer. For the horizontal position, the situation becomes critical at 3 mm from the base material interface.

Acknowledgement

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/159/1.5/S/132397.

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