MICROSTRUCTURE OF THE PULSED MIG / MAG WELDED JOINTS FROM DUPLEX STAINLESS STEEL X2CrNiMoN 22-5-3

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Abstract

The paper analyses the structural modifications occurred in the welded joints from a Duplex stainless steel, delivered in solution annealed state in form of sheet with 12 mm thickness. As filler material it has been selected an electrode wire E 2209-16 with a diameter of 1.2 mm, which has a higher Ni content (8-10 %) compared to the base material (4.5-6.5 %) in order to promote the formation of austenite and to induce in the weld approximately equal proportions of ferrite and austenite.

Also are capitalized the benefits of the pulsed current arc-welding regarding the precipitation reactions limitation of the intermetallic phase σ and of the nitrides in weld and heat affected zone (HAZ) which can affect both corrosion resistance and toughness.

Keywords: Duplex stainless steel, welding, microstructure

1. INTRODUCTION

Duplex stainless steels have excellent resistance to inter-crystallization and stress corrosion as well as mechanical strength characteristics higher than of the austenitic stainless steels [1-3]. The base metal is delivered in form of sheets, bars, wires, pipes longitudinally welded or seamless, castings (eg. houses and internal components of pump), forgings (eg. flanges and fittings), etc. which are either in solution annealed state or work hardened state. Most of industrial buildings use the welding techniques [2]. From technological and economic reasons, one of welding methods recommended in this paper in order to join these steels is the pulsed current MIG/MAG procedure. The experimental researches performed are for avoiding or minimizing the unfavourable structural changes which can cause selective cracking and corrosion phenomena.

2. EXPERIMENTAL PROCEDURE. RESULTS EVALUATION AND DISCUSSIONS

The chemical composition of the steel sheets used to make the penetrated butt welds is (in wt. %): 0.026 C; 0.74 Si; 1.86 Mn; 22.2; 5.1 Ni; 2.94 Mo; 0.16 Mo; 0.021 P; 0.014 S. The selected filler material was a E 2209-16 wire (according to AWS A5.4) with a diameter of 1.2 mm, which led to the following chemical composition for the deposited metal (in wt. %): 0.03 C; 0.45Si; 0.95 Mn; 22.6 Cr; 9.70 Ni; 3.0 Mo; 0.18 N; 0.014 P; 0.017 S. The shielding gas was Cronigon 2 (97.5% Ar + 2.5% CO_2) from Linde with a flow rate Q = 18 liters/min. The welding process was performed in horizontal position, PA/SRENISO 6943/2000 position, the welding sense being to the left, the wire electrode inclination was 85°. The preparation and positioning of the components for joining is shown in **Fig. 1**.

The welded joints were obtained by two welding technologies namely, one for the root layer and other for the filling layers. The root layer was realized at a low heat input value (6.9 kJ/cm), to avoid the breakthrough and leakage of the molten metal. For the filling layers the heat input value was 10 kJ/cm. The welding was done in 4 passes, 1 pass for the root layer and 3 passes for filling layers, with the following technological welding parameters:

a - root layer: wire feed speed, 5 m/min; average welding current; 116 A, electrical arc voltage, 20 V; welding speed, 20 cm/min; linear energy, 6.9 kJ/cm;

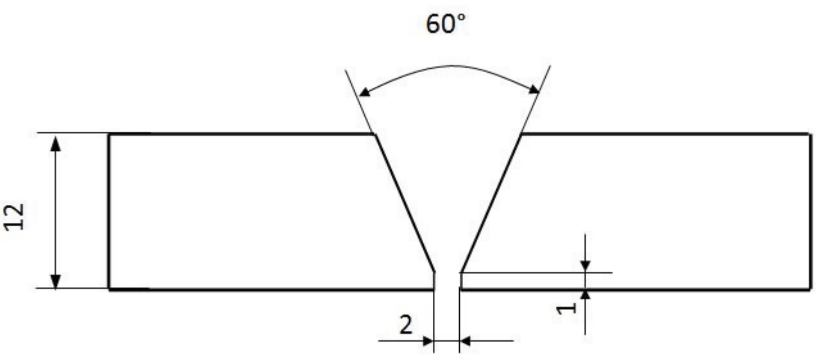

Fig. 1 The design and dimensions of the welding joint

The contact nozzle was positioned with 2-3 mm inside the gas nozzle so that a free length of 18-19 mm has resulted. The used welding equipment (type ARISTO 500) allows the synergistic control of process parameters. Their setting was made by a suitable selection of the electrode wire feed speed, v_{as} = 5m/min. Due to this welding speed the other welding parameters have resulted (**Fig. 2**).

Fig. 2 Recording of the main welding parameters, I_s, U_a

The voltage value indicated on the equipment screen, 28 V, corresponds to the pulse arc voltage and not to the average arc voltage of 20V.

Based on these values were defined the following pulsed current parameters:

- impulse current, I_p = 328 A;
- impulse time,t_p = 2 ms;
- base current, I_b = 56 A;
- impulse frequencies, f = 146 Hz.

b - filler layers

The filling of the welding joint was made in a number of 3 passes with a linear energy of 10kJ/cm. The welding was done mechanized, the welding direction was to the left, or by "pushing" and the torch was inclined with α = 5°. Between two successive depositions, the temperature was limited to 140-150 °C. The arrangement of the metal depositions in the welding joint is shown in **Fig. 3**.

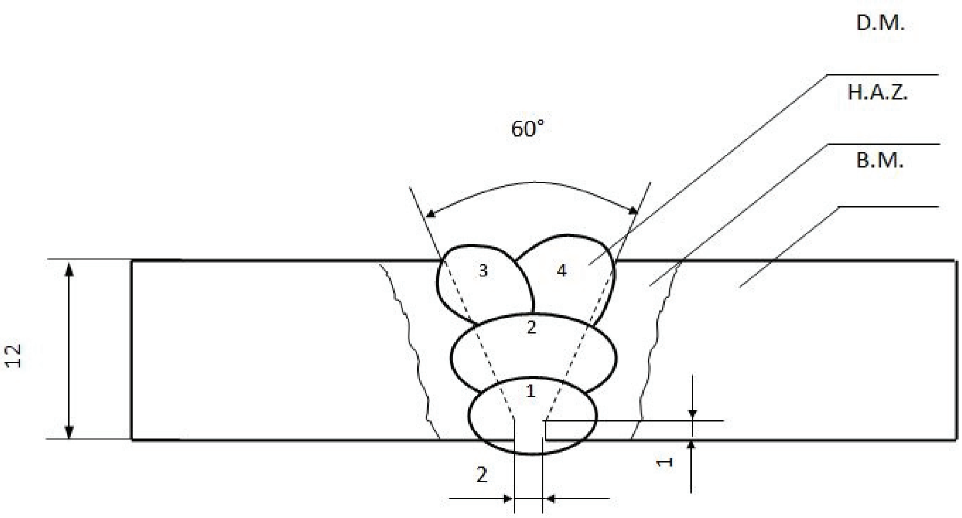

Fig. 3 The arrangement of the deposited metal in the welding joint (D.M. - deposited metal, H.A.Z. - Heat affected zone, B.M. - base metal)

The average values of the technological welding process parameters used for the filler layers are:

- wire feed speed, 8 m/min;
- welding current, 180 A;
- arc voltage, 28 V;
- voltage correction, +3V;
- welding speed, 30 cm/min.
- linear energy, 10 kJ/cm

The setting of the technological welding process parameters was done by choosing an electrode wire feed speeds of 8 m/min (**Fig. 4**).

From this figure one can observed that it is applied a correction voltage of +3V in comparison with the one prescribed by the arc welding power source. This is determined by the splashes reducing when is performed the filling layers deposition by properly increasing of the arc length which reduces the risk of its short circuits during welding.

The measured values of the welding parameters are presented in **Fig. 5**.

Also in this case the voltage value from the equipment screen is the measured value of the pulse voltage, 32.5 V and not of arc voltage, 28 V. It is noted that the difference between the pulse voltage and the arc voltage is smaller than in case of the root layer welding; the phenomenon is explained by the pulses frequency increasing. The parameters values of the impulse current for 8m/min wire feed speed are:

- impulse current, Ip=328 A;
- impulse time, tp =2 ms;
- base current, Ib =96 A;
- frequency, fp=236 Hz.

The aspect of the weld outer surface is shown in **Fig. 6**.

It is noted that there are no surface defects such cracks, pores and marginal notches respectively there is a good wetting of depositions to the base metal. The right positioning of the wire electrode into the joint by execution of the two deposition layers is evidenced by a proper weld overlap, the absence of marginal notches respectively the uniformity of the two welding passes without the appearance of a surface with notches in the bounding zone between them.

Fig. 4 Setting of the wire feed speed

Fig. 5 Measured values of the welding parameters

Also, it can be seen that the last layer was obtained in 2 welding passes because of the high welding speed which makes difficult the joint filling into a single pass; keeping constant the linear energy for all layers deposition.

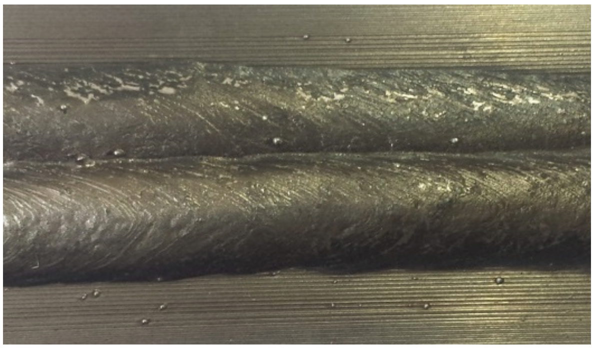

Fig. 6 The aspect of the outer weld surface

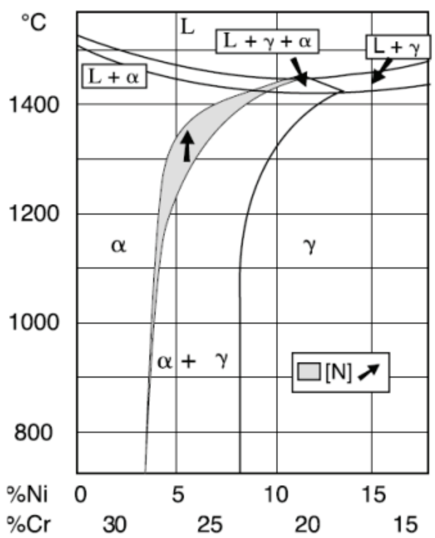

Fig. 7 Cross-section through the ternary diagram Fe-Cr-Ni [3]

In accordance with the pseudo-binary diagram Fe-Cr-Ni shown in **Fig. 7**, the solidification microstructure of the molten metal bath is almost completely ferritic. The further cooling initiates the austenite formation on the ferritic grain boundaries. The austenite amount depends significantly on the chemical composition and cooling rate.

By welding, the cooling rate is relatively high and therefore there is a short time to form austenite. Therefore, the selected filler material has a higher content of Ni, element which stabilizes austenite phase, compared with the base metal. A similar effect is given by N, which has a great importance in reforming austenite. Normally, the ferrite content of the deposited metal must correspond to the ferrite index NF 30-100 (22-70 %) [3, 4]. Transposing on the diagram WRC - 92 [4] from **Fig. 8** the values $Cr_{ech.}$ and $Ni_{ech.}$ specific to the base metal and filler material and taking into account the dilution value, the index of the deposited metal ferrite was estimated, as FN 32-38 (24-28 %).

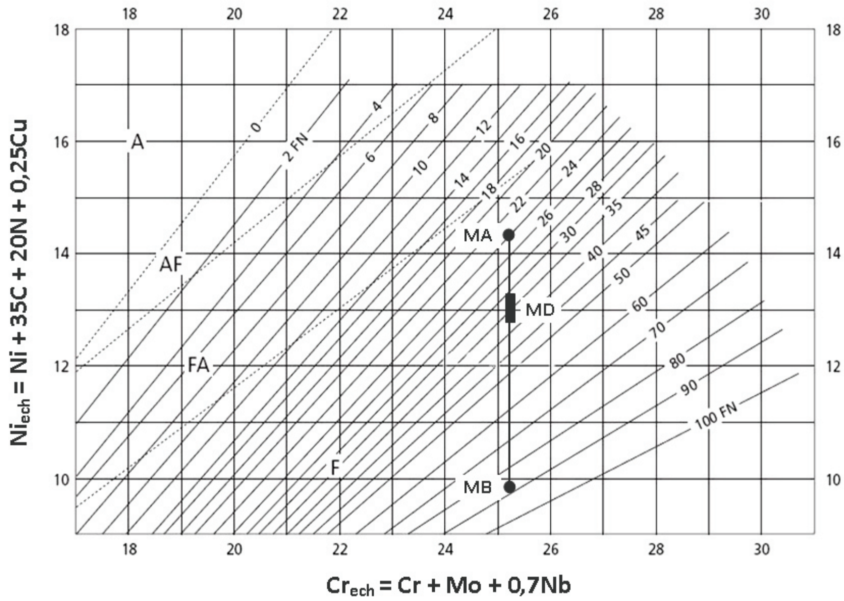

Fig. 8 Prediction of the ferrite index

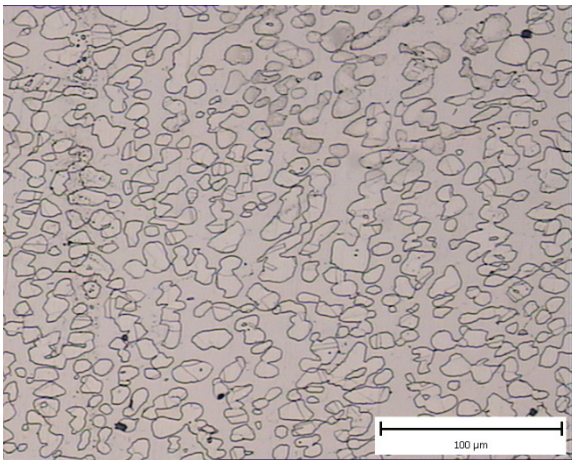

Fig. 9 Microstructure of the base metal

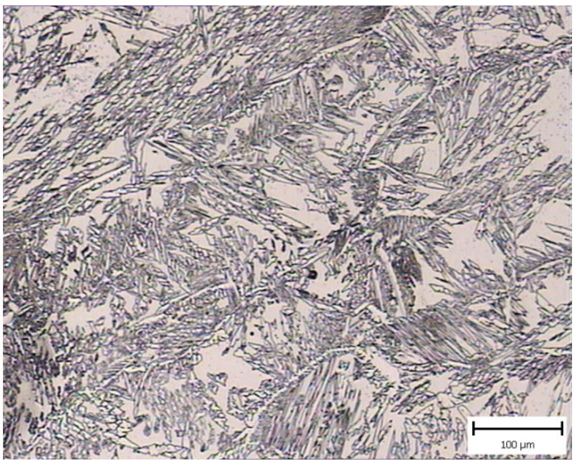

Fig. 10 Microstructure of the weld

The representative microstructures of the welded joint areas are shown in **Figs. 9-11**. It is noted that the base metal has a structure (**Fig. 9**) consisting of approx. 52 % austenite and 48 % ferrite (determined with a Fischer ferrit scope), the deposited metal has a dendritic structure (**Fig. 10**), and in the area from the heat affected zone adjacent to the fusion line occurs a predominantly ferritic structure (**Fig. 11**). A structure with a high ferrite proportion may decrease the toughness at low-temperatures, while a structure with a too high amount of austenite affects both the mechanical strength characteristics and stress corrosion resistance in chloride environments.

The hot cracking sensitivity is reduced by the very highest concentrations in Ni and N. At the same time, the resistance to cold cracking of the austenitic-ferritic weld and of the high ferritized area from HAZ is high, although in the austenitic zones adjacent to the ferritic areas it can be stored appreciable quantities of hydrogen. To eliminate the risk of cold cracking is recommended the selection of welding materials with low hydrogen content and applying of a preheating at approx. 150 ˚C.

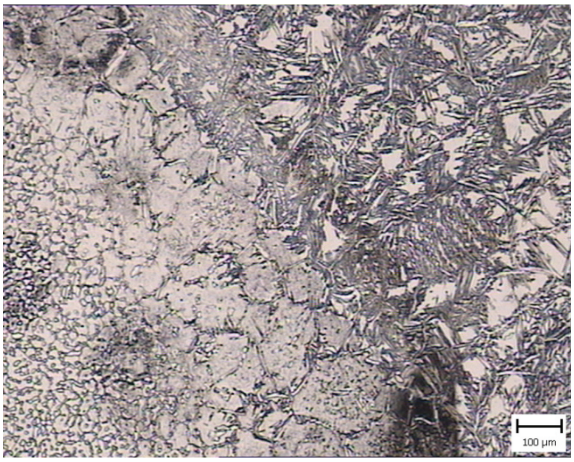

Fig. 11 Microstructure of the transition zone B.M - D.M

3. CONCLUSIONS

The selection of a filler material having a similar content in Cr, Mo and N with the base metal, but a higher Ni content, has a favourable effect on the structure of the deposited metal meaning that the ferritic structure resulted from the solidification process is partially converted in austenite without to be necessary a subsequent heat treatment.

The area from HAZ, adjacent to the fusion line, has a predominantly ferritic structure, even when filler was applied.

The limitation in both directions of linear energy and temperature between 2 successive layers deposition allows on the one hand the austenite formation in weld and HAZ and, on the other hand prevents the precipitation of intermetallic phases intense (σ) and nitrides ($Cr2N$, CrN), which decrease the toughness and corrosion resistance.

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