OPTIMISING QUALITY AND PRODUCTIVITY IN WELDING OF DUPLEX AND SUPERDUPLEX STAINLESS STEELS

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Abstract:
The aim of this work was to study the influence of shielding gases and welding positions on properties of duplex and superduplex stainless steel circumferential pipe welds. Corrosion resistance, microstructural features and weld defects were assessed and related to the welding procedures. Horizontal and vertical upward welding positions produced high quality welds. However, welding in the overhead position resulted in less good results in terms of porosity and corrosion resistance. Shielding gases containing 30% helium showed best results, whilst using a mixture Ar+2%CO_2 resulted in undercuts and porosity in all welding positions.

Keywords: duplex, superduplex, stainless steel, Gas Metal Arc Welding, shielding gas.

1. INTRODUCTION

The first batch of a duplex stainless steel was produced in Sweden in 1933 by Avesta Järnverk. However, it was not until the early 1980s when their evolution boosted with the development of new grades and new optimized compositions for more demanding applications (Cobb, 2010). Nowadays, duplex stainless steels are used in several industries and applications where their combination of high strength and superior corrosion resistance are required, for example in the oil and gas industry, transportation, construction and process industries.

A large scale application of duplex stainless steels is closely related to the use of welding for fabrication, and it is necessary to find the optimum way to weld these alloys without detriment to their properties. Therefore, the formation of deleterious phases needs to be avoided and a balanced ferrite/austenite microstructure needs to be achieved to meet the required mechanical properties and corrosion resistance (Karlsson, 2012).

Optimising quality and productivity in welding duplex and superduplex stainless steels is closely related to selecting the optimum shielding gases and welding positions to get the better properties with a minimum of defects. In GMAW (Gas Metal Arc Welding) there are currently two main groups of shielding gases recommended for welding duplex and superduplex stainless steels: on one hand, argon-based mixtures with small additions of CO_2 or O_2 to help in the arc stabilisation and on the other hand, multicomponent mixtures including argon as the main component and additions of around 30% helium to improve weld pool fluidity and to allow higher welding speeds and small additions of other gases like CO_2 (Karlsson, 2012; van Nassau, *et al*., 1993; Lu, *et al*., 2010). However, there is some concern about adding nitrogen to the above mentioned group of shielding gases for GMAW welding of duplex and superduplex stainless steels, as it is claimed to increase the risk of porosity [1], whilst nitrogen is commonly added in GTAW (Gas Tungsten Arc Welding) shielding gases to improve austenite formation and to compensate possible losses of nitrogen during welding (Pettersson, *et al*., 1995). However, the benefict of nitrogen in the backing gas has been accepted, as it known to improve the corrosion resistance of the root pass (Pettersson, *et al*., 1995; Westin, *et al*., 2013).

This research work aims at studying the relationship between shielding gases and welding positions on important properties of duplex and superduplex stainless steel welds. Circumferential pipe welds were prepared and results from different tests (corrosion, tensile, impact toughness, X-ray, chemical analysis, ferrite content, macro inspection and microstructure) were evaluated. Optimising quality and productivity in welding duplex and superduplex stainless steels is closely related to selecting the optimum shielding gases and welding positions to get the better properties with a minimum of defects.

2. WELDING AND TESTING

2.1. Welding details

Six pipes of duplex stainless steel (type 2205, 12 mm thickness, 114 mm OD) and nine pipes of superduplex stainless steel (type 2507, 12 mm thickness, 118 mm OD) with single-U groove joint preparation were multipass welded by GMAW (Gas Metal Arc Welding) in PA position (horizontal, ASME 1G pipe rotation), PF position (vertical upwards, ASME 3Gu plus pipe rotation) and PE position (overhead, ASME 4G plus pipe rotation).

The root pass was performed in the same way for all duplex and superduplex stainless steel pipes: GTAW (Gas Tungsten Arc Welding) process in PA position, pure argon as shielding gas (15 l/min) and fixed arc energy 1.5 kJ/mm was employed, which is in the high range of arc energy recommended for duplex and superduplex stainless steel.

Filler materials employed for GTAW root pass and GMAW passes were OK Autrod 2209 Ø 1 mm for duplex and OK Autrod 2509 Ø 1 mm for superduplex.

Typical composition of duplex stainless steel type 2205 is: 22%Cr, 5.7%Ni, 3.1%Mo, 0.17%N and 0.02%C, whilst typical composition of superduplex stainless steel type 2507 is: 25%Cr, 7%Ni, 4%Mo, 0.27%N and 0.02%C.

From preliminary bead-on-plate tests, four shielding gases were selected: Ar+2%CO_2, Ar+30%He+2%CO_2, Ar+30%He+0.5%CO_2 and Ar+30%He+0.5%CO_2+1.8%N_2. Arc energy input was fixed at 1.1-1.2 kJ/mm in the 3 GMAW passes, which was 73%-80% of the arc energy used in the root pass. Interpass temperature was always lower than 50ºC and grinding between passes was performed to minimise the risk of lack of fusion of the following pass. Figure 1 shows the multi-pass layout, Table 1 shows the experimental shielding gas and welding position settings and Figure 2 illustrates the GMAW setup for the multi-pass welds. It included a rotating system for the pipes and a mechanised welding system with a robotic arm to ensure repeatability and control of the heat input.

2.2. Testing

The following tests were used for a comprehensive characterisation of the pipe welds: macroscopic examination, microstructural inspection, corrosion test (ASTM G48A), tensile test (ISO 6892-1), impact toughness test (EN148-1), radiographic test (EN 1435), chemical analysis and ferrite measurement (magnetic permeability technique).

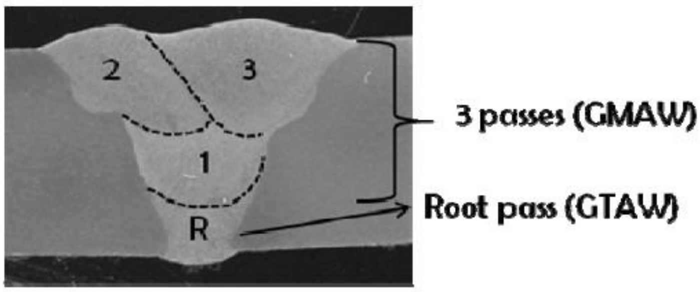

Fig. 1. Multi-pass layout

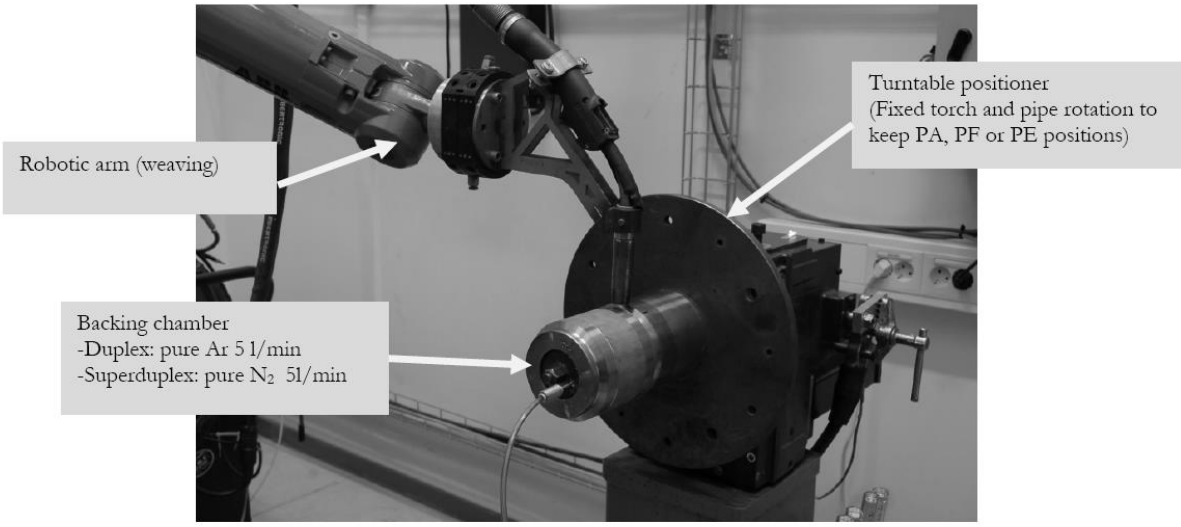

Fig. 2. GMAW setup for multipass welds.

Table 1. Pipe welds settings: shielding gases and welding positions.

Sample	Welding position	Shielding gas
D 1	PA	$Ar+2\%CO_2$
D 2	PA	$Ar+30\%He+2\%CO_2$
D 3	PF	$Ar+2\%CO_2$
D 4	PF	$Ar+30\%He+2\%CO_2$
D 5	PE	$Ar+2\%CO_2$
D 6	PE	$Ar+30\%He+2\%CO_2$
SD 7	PA	$Ar+2\%CO_2$
SD 8	PA	$Ar+30\%He+0.5\%CO_2$
SD 9	PA	$Ar+30\%He+0.5\%CO_2+1.8\%N_2$
SD 10B	PF	$Ar+2\%CO_2$
SD 10A	PF	$Ar+2\%CO_2$
SD 11	PF	$Ar+30\%He+0.5\%CO_2$
SD 12	PF	$Ar+30\%He+0.5\%CO_2+1.8\%N_2$
SD 13	PE	$Ar+2\%CO_2$
SD 14	PE	$Ar+30\%He+0.5\%CO_2$
SD 15	PE	$Ar+30\%He+0.5\%CO_2+1.8\%N_2$

3. RESULTS AND DISCUSSION

3.1. Mechanical testing

All the specimens passed the Charpy-V impact toughness testing in the weld metal and in the HAZ (heat affected zone) at -40ºC and exceeding significantly the requirements with absorbed energy values higher than 20 J (EN 10028, 2008). Regarding tensile test, all the specimens showed yield strength values and ultimate tensile strength values over the minimum values required for the base metals.

3.2. Ferrite content and chemical composition

The average ferrite content for each weld pass as well as the average content for the whole weld metal were in accordance with a balanced ferrite/austenite microstructure in all the samples. Chemical analysis for the welds showed that values are within the standard range for duplex and superduplex stainless steel weld metals.

3.3. Implications of welding procedure and microstructure on corrosion results.

There was a significant difference in corrosion resistance between on the one hand the 2205 duplex stainless steel welds and on the other hand the 2507 superduplex welds. All the duplex samples passed the corrosion test (ASTM G48A) at +20ºC. However, from the 20 superduplex specimens evaluated, 13 failed the corrosion test at +40ºC. Ten out of these 13 specimens also presented discontinuities in the root (SD 7, SD 8, SD 10B, SD 11, SD 12, SD 13, SD 14, SD 15). These discontinuities are mainly related to stop-start points in the root run and also in the top run. From these results it is clear that defects or irregularities in the root pass and failure in corrosion testing are directly correlated for the superduplex welds. To illustrate this phenomenon, Figure 3 contrasts the appearance of the root of two different specimens.

Transverse cross sections of corrosion test samples were microstructurally inspected. Only two superduplex samples (SD 14 and SD 15) showed evidences of pitting corrosion at the surface of the root. These samples also showed the highest weight loss values in the corrosion test (20 and 60 g/m^2). From microstructural inspection it is possible to confirm that pitting corrosion initiated at the secondary austenite formed in the root pass (Figure 4). These samples were also the ones showing great amounts of secondary austenite spread in the whole first pass. This evidence is supported by the literature, as it is known that secondary austenite is depleted in nitrogen and consequently pitting corrosion resistance is lower in these regions (Nilsson, *et al*., 1995).

Therefore, welding procedures need to be optimised to avoid discontinuities caused by stop-start. Also special care needs to be taken to avoid high cooling rates which result in high ferritic regions, as secondary austenite can be formed when reheating those overly ferritic areas during the following passes.

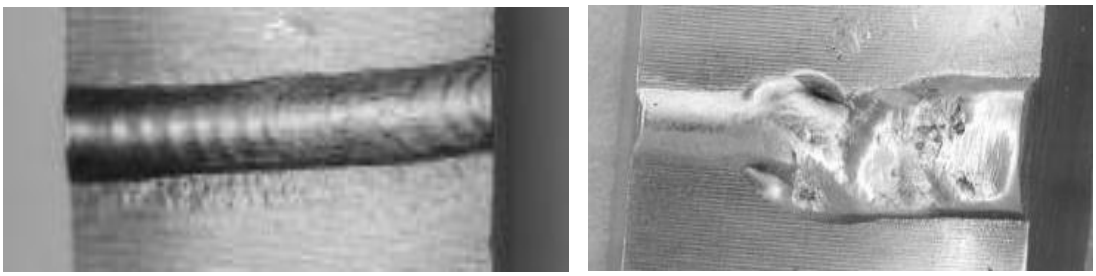

Fig. 3. To the left, root of specimen SD 9, free of defects and passing corrosion test. To the right, root of specimen SD 15, showing defects and not passing corrosion test.

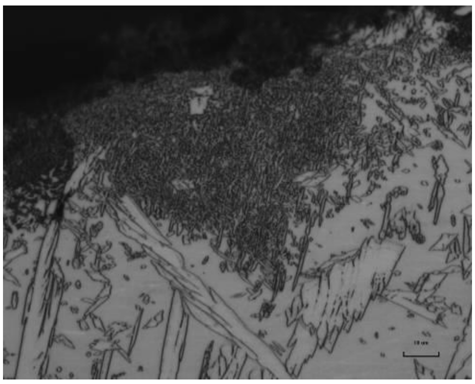

Fig. 4. Pitting corrosion at the surface of the root, starting at secondary austenite.

3.4. Other welding defects: undercuts and porosity

Macroscopic examination was also used to inspect the transverse cross section of the specimens. It was found that samples shielded by Ar+2%CO_2 presented undercuts for the majority of the welds (5 out of 7), as shown in Figure 5.

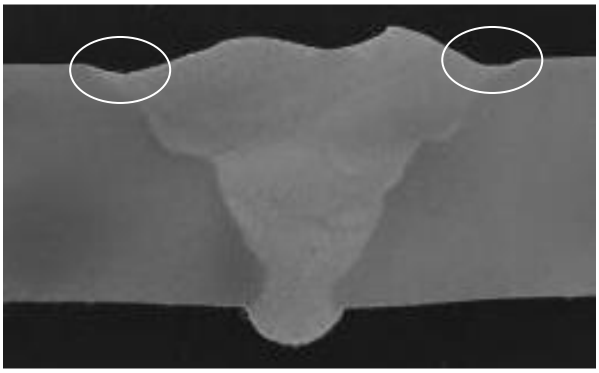

Fig. 5. Macrograph of sample SD 10B (shielded by Ar+2CO_2) showing undercuts.

Porosity was checked by radiographic testing in 4 specimens per sample according to EN 1435. Evidences of porosity found by X-ray were also confirmed during microstructural inspection of transverse cross sections of the welds (Figure 6).

Porosity was also confirmed when inspecting the fracture surface of tensile test specimens D 3 and SD 10B by stereomacroscopy (Figure 7). These specimens presented problems with low elongation values and they were the only ones failing the tensile test in the weld metal. This failure can be associated with the presence of porosity in both samples.

For samples welded in PA and PF positions, porosity was only found in those shielded by Ar+2%CO_2 gas. All the samples welded in PE position presented porosity regardless of which shielding gas that was used. Therefore, in the latter case the reason for porosity cannot be associated with the shielding gas type, but with the welding procedure and the welding position.

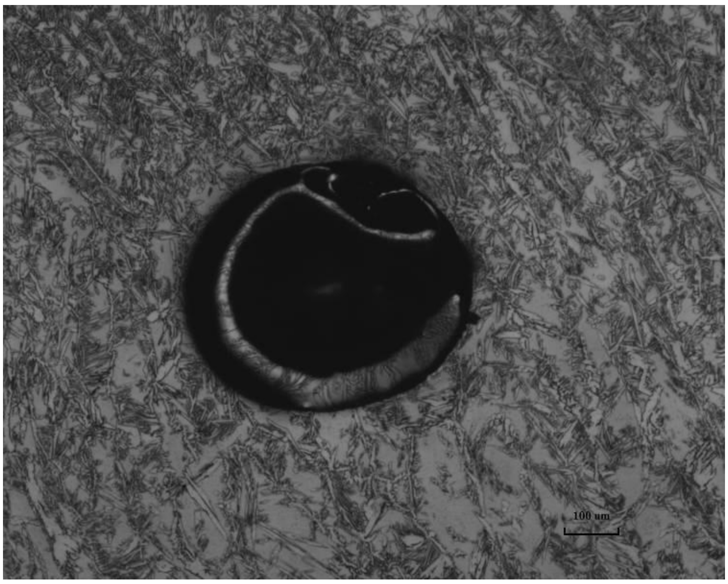

Fig. 6. Micrograph of sample SD 7 showing a pore of around 0.5 mm diameter.

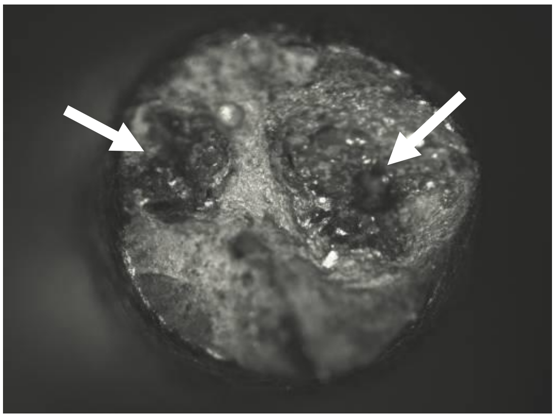

Fig. 7. Image of the fracture surface in specimen SD 10B showing porosity in the weld metal

4. CONCLUSIONS

High quality welds showing excellent mechanical properties and good corrosion resistance could be produced in duplex and superduplex stainless steel pipes.

1- Excellent results were achieved using shielding gases with 30% He. However, samples shielded by Argon+2%CO_2 presented porosity in all welding positions and also showed undercuts in the majority of the welds.

2- Horizontal and vertical upward welding positions produced high quality welds. Samples welded in overhead position presented the highest content of porosity, the lowest corrosion resistance and also higher amounts of secondary austenite.

3- Only two superduplex specimens presented pitting corrosion. In both cases pitting was initiated in secondary austenite at the surface of the root run. These specimens were welded in overhead position.

4- To decrease pitting corrosion susceptibility, welding procedures need to be optimised to minimise the number of stop-start points and also to minimise the formation of secondary austenite. The importance of a high quality root pass should also be underlined.

ACKNOWLEDGEMENTS

The Knowledge Foundation is gratefully acknowledged for the economic funding. It is also acknowledged the great support received from the business partners involved: AGA Gas AB, ESAB AB and Sandvik Materials Technology and the involvement and contribution of their representatives.

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