Experimenting with welding superduplex without filler metal

Duplex and superduplex stainless steels are commonly welded with filler metals to obtain sound welds with good mechanical, metallurgical and corrosion resistance properties. Filler metal addition and heat input control are important factors to consider, but the diameter and thickness of the pipe must always been considered as main parameters. This study takes a closer look at the welding of small diameter and 'thin' wall thickness superduplex pipes with orbital GTAW, without filler metal, using an orbital closed head welding machine.

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When a pipe presents a thin wall thickness and small diameter, the heat diffusion during the welding process can be very weak. This weak diffusion leads to 'slow' cooling (regarding welding), and thus more austenite germination. If Ni-sur-allied filler metal is added on the welding pool, austenite germination can happen at a faster rate, thanks to the Ni gamma effect.
The combined effects of a weak diffusion and the Ni-sur-allied filler metal lead to easy austenite germination (i.e low ferrite content) in the weld metal after welding. In order to obtain an acceptable ferrite content (35% to 65%) in the weld metal, some welding joints can be performed without filler metal, using an orbital GTAW closed head welding machine.
In addition to diameter and thickness, some other parameters/welding difficulties must been taken into account:

- Edge preparation and fit-up;
- Welding position 5G (up and down) and welding pool with relatively low viscosity (gravity effect);
- Pitting Resistance Equivalent Nitrogen (PREN = Cr + 3.3Mo + 16N), mainly of root pass, limitation/absence of secondary austenite (corrosion resistance);
- Time elapsed within the range 600°C-1000°C (carbine, nitride, sigma phase);
- 'Low heat input' necessary due to thickness and diameter;
- Residual magnetism on the pipe (arc blow); and,
- Monitoring of welding parameters.

What is 'gamma effect'?

When an element helps the austenite (gamma phase) germination, we are talking about 'gamma effect'. When the element helps the ferrite (alpha phase) germination, we are talking about 'alpha effect'. For superduplex, the main elements are Ni, Cr, Mo and N. Elements Ni and N have gamma effect, whereas Cr and Mo have alpha effect.

The experimental setup

A full Welding Procedure Qualification Record (WPQR) was performed to qualify the welding of S32750 19.05/2.41mm pipe. 8 welds were performed using welding machine and instrumentation as follows:

- Polysoude PS164-2 orbital GTAW generator (figure 1);
- Polysoude MW40 orbital GTAW closed head (figure 2); and,
- Swagelok SWS internal purge pressure kit (figure 3).

The edge preparation and welding details included:

- BW square edge (by machining) without gap (figure 4);
- 5G (up and down) position (figure 5);
- No filler metal;
- GTAW orbital welding;
- 1 pass (figure 5);
- 98% Argon + 2% Nitrogen (shielding and backing gas); and,
- Tungsten electrode WTh20, 1.6mm, taper angle 60°, tip 0.5mm, arc gap 1.3mm (figure 6).

For each weld, full monitoring was completed. Important welding parameters to consider included:

- Pipe preparation (square edge, no gap, clean inner and outer surface);

Figure 1: PS164-2 Polysoude.

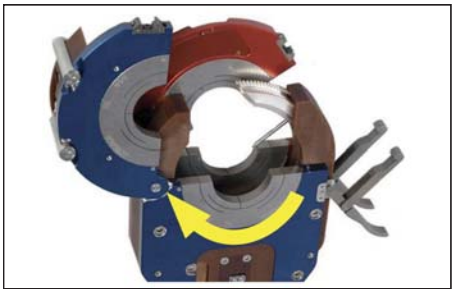

Figure 2: MW40 Polysoude.

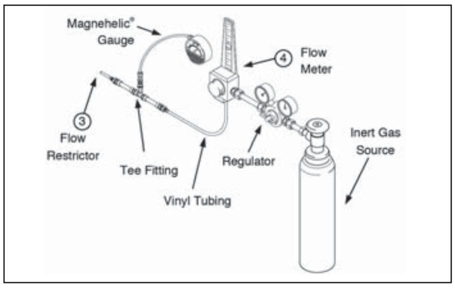

Figure 3: SWS internal purge pressure kit Swagelok.

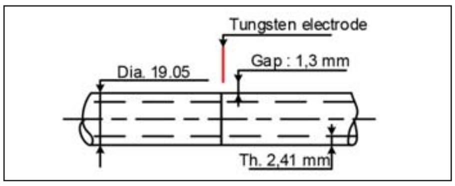

Figure 4: Welding preparation.

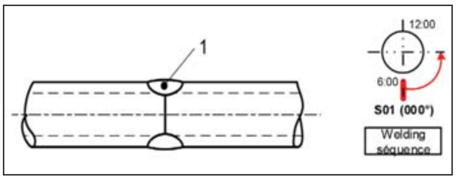

Figure 5: Welding sequence.

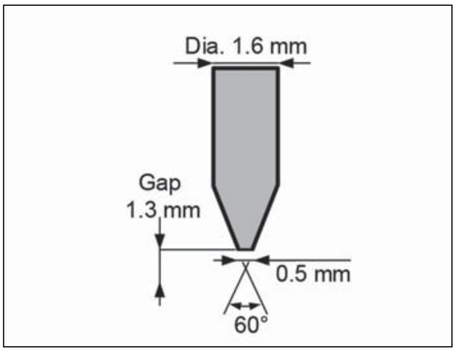

Figure 6: Tungsten electrode preparation.

- Tungsten electrode geometry (type, diameter, angle, tip);
- Internal pressure;
- Shielding and backing gas;
- Gas composition and flow rate;
- Oxygen content (<30ppm inside the pipe);
- Preheat time (welding pool germination) and current;
- Pulsed current (peak and background current and time);
- Travel speeds (peak and background);
- Voltage (arc gap);
- Down slope time; and,
- Heat input.

Non-destructive and destructive (mechanical, corrosion, metallurgical) tests were performed on the welds to meet industry standards. On each weld, the following NDT was performed: visual testing VT with control of maximum underfill at 12h; penetrant testing PT; radiographic testing RT (X-rays); and, ferrite content on weld metal and base metal (with feritscope), each 90° around the pipe.

On the whole welding package, destructive testing was performed as well, such as: tensile testing (x2 whole pipe section); bend testing (x2 root and x2 face at 1h30, 4h30, 7h30 and 10h30); hardness testing HV10 located at root, middle and capping in base metal, HAZ (heat affected zone) and weld metal (x2 at 6h and 12h); ferrite content testing located at root, middle and capping in HAZ and weld metal (x2 at 6h and 12h); macrographic testing (x2 at 6h and 12h); micrographic testing (x2 at 6h and 12h); and, corrosion testing (x1).

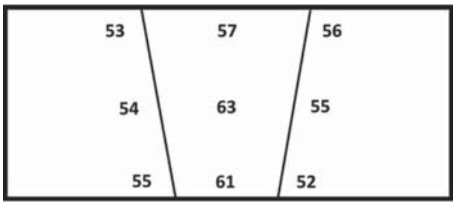

Figure 7: Ferrite content ASTM E562 at 12h.

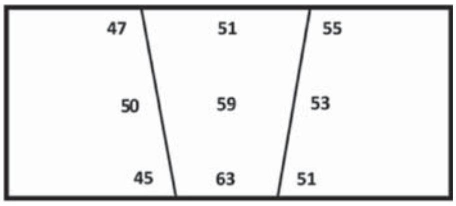

Figure 8: Ferrite content ASTM E562 at 6h.

The experimental results

The NDT and destructive testing results are presented hereafter.

Visual testing results: no indication found by visual testing, the maximum underfill at 12h is less than 0.2mm.

Penetrant testing results: no indication found by penetrant testing.

X-rays radiographic testing results: no indication found by radiographic testing.

Ferrite content (with feritscope) testing results: all ferrite contents on base metal and weld metal are within the range 35% - 65%.

Tensile testing results: tensile strength values of 1052 and 1142 MPa, fracture location on weld metal (acceptance criterion: 750 MPa).

Bend testing results: no indication found both on face and root bend testing.

Hardness testing results: the maximum value of hardness testing in base metal, HAZ and weld metal is 280 HV10 (acceptance criterion: 350 HV10).

Ferrite content testing results: all ferrite content on HAZ and weld metal are within the range 35-65% (figures 7 and 8).

Macrographic testing results: no indication found by macrographic testing. There is no underfill at 6h and the maximum underfill at 12h is 0.16mm (WT is kept thanks to root penetration – figure 9).

Micrographic testing results: no indication found by micrographic testing (absence of nitride, carbide and intermetallic phase - figure 10).

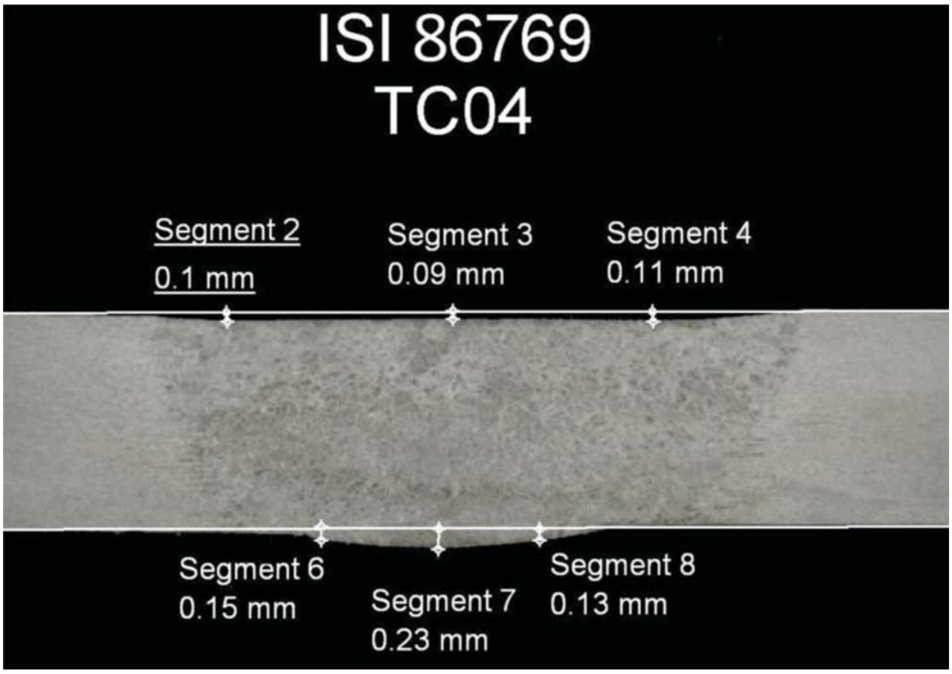

Figure 9: Macrography at 12h.

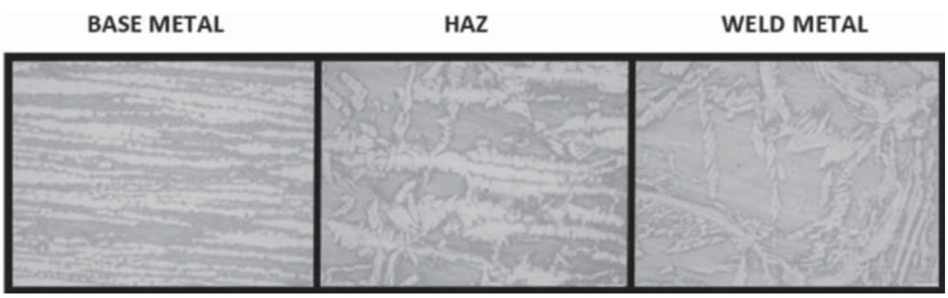

Figure 10: Micrography of base metal, HAZ, weld metal at 12h.

Corrosion testing results: test conditions included pickling 5min HF 5% + HNO_3 20%, 60°C, air passivation 96 hours, and ASTM G48 method A corrosion test 24h, 40°C. There was no pitting and no weight loss.

Conclusions

All non-destructive, mechanical, metallurgical and corrosion testing were satisfactory. A maximum underfill less than 0.2mm is located at 12h, but the root penetration compensates this underfill.
A lot of welding parameters (pulsed current, arc voltage, welding speed, sectors, downslope) and welding difficulties (edge preparation, fit up, pressure purge, welding position, underfill) can be managed to obtain a sound weld. Therefore, a lot of preliminary welding trials must been done before the beginning of the WPQR.
The main challenges of the welding without filler metals are the limitations of underfill at 12h, and obtaining a ferrite content within the range 35%-65%, both in weld metal and HAZ. The use of internal purge pressure kits helps to manage both root penetration and underfill. The cooling rate and heat input must be under control to manage ferrite content, nitride, carbide, and sigma phase.
Welding with only one pass leads to the absence of secondary austenite, limitation of time elapsed within the range 600°C-1000°C, and optimization of corrosion resistance. The use of an orbital welding machine with closed head leads to good monitoring, control of welding parameters, and good shielding gas protection. The edge preparation and fit-up without gap leads to an optimized backing gas protection with very low oxygen content (nearly 0ppm). Residual magnetism shall be verified before welding to prevent arc blow. If the residual magnetism is above 2-3 Gauss, the magnetism shall be removed.
Welding superduplex without filler metal is possible, particularly on thin WT and small pipe diameter, but must been used with care.

Acknowledgements

The author wishes to express his appreciation to Mr. Jean-Christophe Langan, (jean-christophe.langan@ortec.fr), Welding Engineer, Friedlander Ortec Group, and Mr. Pascal Pattyn, (pascal.pattyn@ortec.fr), Welding Engineer, Friedlander Ortec Group, for their help on this study.

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