Development and control of welding procedures for duplex stainless steels

by R Bradshaw and R A Cottis*

The authors describe the development of welding procedures for the GTA welding of duplex stainless steel pipe using mechanised orbital welding equipment. The superduplex stainless steel Zeron 100 is welded using argon shielding gas with nitrogen addition. A method of avoiding tungsten contamination is introduced and consideration is given to the monitoring of thermal cycles to provide Quality Assurance data.

The ever increasing demand for corrosion resistant alloys with good mechanical properties and reasonable cost has resulted in ferritic-austenitic duplex stainless steels becoming an important alternative to austenitic stainless steels. Thus, the application of duplex stainless steel has widened to include the oil-gas, petro-chemical, paper, nuclear, food and shipbuilding industries1,2.

Zeron 100 is a super duplex stainless steel having a high resistance to pitting and crevice corrosion and outstanding mechanical properties. It has been successfully welded with care by GTAW, SMAW, GMAW, SAW and PAW; and it is recommended that consideration be given to the importance of limiting weld zone temperatures by the imposition run-out-lengths of ~90mm and the incorporation of stringer bead techniques3. Manual GTAW is very popular and is used on the vast majority of pipework welded, especially the root pass. However, both welding efficiency and metallurgical control can be improved significantly by the use of mechanised orbital GTAW techniques. Further benefit can be derived from the high first time acceptance levels influencing both productivity and cost. The repair of a defective weld can take longer to complete than the original weld. In addition, welds can be produced with surface profiles that require little or no dressing prior to NDT4. To date very little orbital GTA welding on duplex stainless steels appears to have been carried out. However, since this work was completed, the state of the art in mechanised orbital welding techniques has been reviewed5,6.

Gas mixtures are being developed

Fig 1. Experimental welding set up showing welding head, monitor-ring and multiple pipe attached thermocouples.

which not only shield the weld pool from the atmosphere but also enhance the as-welded properties7. Nitrogen is known to have a beneficial effect on duplex stainless steels8 and recent work at BOC9 has quantified the effect of nitrogen additions to argon in both shielding and backing gases for manual GTA welding of duplex and superduplex stainless steels. Additions to the shielding gas are considerably more potent in doping the weld metal with additional nitrogen compared to backing gas additions thereby increasing the austenite phase and improving corrosion performance7,10. However, levels of nitrogen above 3% in argon can lead to detrimental effects on weldability, particularly reflected in tungsten electrode contamination, unstable arc conditions, weld pool turbulence, spatter and weld metal porosity11,12. If nitrogen additions are to be used beneficially it is vital that such weldability difficulties are overcome. The correct choice of shielding gas by a contractor can then lead to both improved weld quality and higher productivity.

The initial findings of a current PhD research programme sponsored by BOC Limited at UMIST are described in this paper. This programme required a series of high quality butt weld specimens in Zeron 100 pipe (168.27mm OD by 7.11mm wall thickness). A welding procedure using pure argon as the torch shielding and purge gas was established. This welding procedure was then repeated using a series of argon and nitrogen combinations in order to obtain the experimental butt welds required.

WELDING PROCEDURE DEVELOPMENT

It was beyond the scope of this investigation to develop orbital welding procedures. Instead, the pipes were rotated beneath the welding head and the experimental welds completed in the 1G rotated position.

The Dimetrics Inc Gold Track II automatic gas tungsten arc pipe welding system and an accurate rotator system were used, fig 1. The use of

Fig 2. Weld preparation showing extent of machining required to remove all ovality and thickness variation.
this equipment guaranteed welding procedure reproducibility to the highest levels possible, that is repeatable to within 1% of preset values.

To further ensure total repeatability, the pipes were machined internally and externally to remove all traces of ovality and variation in thickness, followed by the machining of the weld preparation, fig 2. The set-up, not having a root gap, allowed for very low levels of oxygen contamination of the purge gas. This was continuously monitored using a PBI Dansensor Model 2 GI-2 oxygen indicator capable of measuring down to 1 ppm. The OIS portable arc monitoring system PAMS IV was used to provide a measurement and logging facility.

A number of K-type thermocouples were attached either directly to the pipe, or remotely via a stainless steel band, in order to measure the thermal cycling of the welding process, fig 1. Attachment was made using a Cooperheat (UK) Ltd thermocouple attachment unit (TAU). A Hewlett Packard HP 3497A data acquisition unit connected to an Amstrad PC 1512 and using proprietary software was used to store the data.

The welding procedure details are given in table 1. It will be noted that a cold pass technique has been used on top of a thick ligament root, fig 3. This technique helps keep any precipitation caused by what is generally known as the hot pass away from the inner surface of the pipe. The wire was continually fed into the molten pool at the maximum rate allowable to ensure good fusion, thus further assisting in keeping heat input to a minimum.

The monitor-ring

Temperature monitoring practice in industry relies on the diligence of inspection personnel using hand held digital thermometers or Tempilstik crayons that melt at a known temperature, measuring single points or lines at random. Individual inspectors may well have a large work area with many welding stations and will also have numerous other duties to perform. Thus monitoring may not occur and even if it did no record would be made.

The monitor-ring allows a hard copy to be produced of the thermal cycling of the welded joint. It consists of a thin stainless steel band with a number of thermocouples welded to its outside diameter which are connected to a data logging system, fig 4. The thermocouples measure temperature over a short time interval (typically less than 5 seconds) at a set distance from the edge of the weld preparation remote from the fusion zone. The data recorded include:

- Start temperature,
- Interpass temperature,
- Peak temperature reached,
- Cooling rates,
- Time held in various temperature envelopes,
- Prediction of precipitation from manufacturers’ Time-Temperature-Precipitation curves,
- Time of welding operation.

The data obtained can be used for direct comparison with the procedure weld data or related by mathematical modelling to the actual thermal cycling of any area of the weld zone, thus providing for the assessment of:

☐ Procedure adherence (for certain parameters),
☐ Detection of malpractice,
☐ Prediction of deleterious precipitation which can effect mechanical and corrosion properties.

The system involves no damage to the pipe and can be attached and removed quickly. Direct attachment to the pipe has been deliberately avoided to prevent the possible contamination of the parent material, undesirable HAZ effects and a reduction in corrosion resistance and also to avoid the necessity for the careful removal of thermocouple weld and heat affected zone and any additional heat.
NDT requirement. Significant benefits for quality assurance purposes may be achieved.

**Weldability assessment**
The only procedural welding problem was that of tungsten electrode contamination and associated effects, as described earlier. When nitrogen was added to the argon shielding gas, the amount of tungsten electrode contamination appeared to increase as nitrogen content was increased, fig 5.

In fact, after only 3 minutes of welding Zeron 100 with argon + 10% nitrogen the ground end of the tungsten electrode was completely obliterated. It was observed that rapid contamination seemed to occur whilst the weld pool was being established, prior to filler wire being added, and that further contamination seemed to take longer.

It is suggested that tungsten electrode contamination and its associated effects can be avoided completely or effectively controlled if at no time is the parent metal molten without filler wire being added. The method evolved which appeared to give the best results is:

- Initiate the arc.
- Feed in a small amount of wire on to the parent metal.
- Melt this small amount of wire and the parent metal to form the weld pool.
- Add further small amounts of wire as necessary, denoted by any signs of weld pool disturbance or spatter, until the weld pool is fully established and full fusion and penetration has been obtained.
- Commence welding with constant wire feed into the weld pool.

### Table 1. Outline Welding Procedure details. Parent metal: Zeron 100, consumable: Zeron 100X SW, 0.8mm diameter, electrode: 2% thoriated tungsten, 3.2mm diameter, shielding gas (torches and purge): Argon and argon + nitrogen with 2%, 3%, 5%, 7% and 10% nitrogen, purge purity: <1.5ppm oxygen on weld start up. (Also reported is work done on Avesta SAF 2205 stainless steel, with regard to the avoidance of tungsten electrode contamination).

<table>
<thead>
<tr>
<th>Process</th>
<th>Cold pass</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root</td>
<td>GTAW</td>
<td>GTAW</td>
</tr>
<tr>
<td>Mode</td>
<td>Pulsed</td>
<td>SynPulsed</td>
</tr>
<tr>
<td>Interpass temp</td>
<td>&lt;60°C</td>
<td>&lt;60°C</td>
</tr>
<tr>
<td>Heat input</td>
<td>1.2kJ/mm</td>
<td>0.8kJ/mm</td>
</tr>
</tbody>
</table>

- At no point allow the arc to melt parent material without filler wire being fed into the molten pool.

This method allowed for 360° welding of the experimental butts without serious tungsten electrode contamination, fig 6. It was possible using this method to weld Zeron 100 material with up to 7% nitrogen addition to the argon shielding gas. In the case of Avesta SAF 2205 it was possible to weld with up to 10% nitrogen addition with no significant tungsten electrode contamination.

**WELD TESTING AND RESULTS**
All welds were radiographed before destructive examination to detect any defects which might have been caused by the addition of nitrogen to the argon shielding gases.

No defects were detected for welds made with 3% or less nitrogen addition to the argon shielding gas. For welds made with greater than 3% nitrogen additions, isolated micro pores were detected (<6 in 520mm of weld).

**Charpy impact tests**
Charpy impact specimens were extracted transverse to the weld length and notched in the through thickness direction in the weld centre line. Two sets of three specimens were taken and tested at −46°C, in accordance with BS EN 10.045 1990. Subsize specimens of 5 by 10mm were used. The results obtained from all Charpy impact testing exceeded 50 joules at −46°C for 5 by 10mm specimens.

**Corrosion testing**
Pitting corrosion tests were performed in accordance with ASTM G48 Method A. The test solution was 10% FeCl₃ x H₂O and the immersion time was 24 hours at 45°C. No specimens showed any evidence of pitting corrosion.

**Monitor-ring**
To demonstrate the effectiveness of the system a thermal cycle obtained from thermocouples directly attached to the inner diameter of the root pass and monitoring the fillet and cap passes is shown in fig 7.

The typical relationship between Monitor-Ring attached thermocouples and corresponding thermocouples attached directly to the pipe can be seen in fig 8.

The data generated are mathematically modelled and therefore computer processing would rapidly provide valuable information for quality assurance purposes.

**DISCUSSION**
The welding procedures developed have been successful in the production of weldments using up to 7% nitrogen addition to the argon shielding gases on Zeron 100 material and up to 10% nitrogen with Avesta SAF 2205. It has been shown that 360° welding can be achieved without the need to impose run-out-length restrictions or stringer bead techniques for the pipe size used. Micro-porosity, evident in welds produced with more than 3% nitrogen addition was, due to its size and distribution, considered to be an insignificant defect to all but the most stringent of nuclear specifications.

The proposed method of avoiding tungsten electrode contamination...
might appear difficult to reproduce, especially the start of the weld. However, in practice it was not found to be difficult and the welding operator quickly adapted to the technique. The situation may be likened to the welding of low carbon steel with a triple deoxidised welding rod whereby the consumable is kept in the weld pool virtually all the time to prevent porosity and weld pool disturbance. The method involves manual override at the start of a weld. The advantages gained in maintaining tungsten electrode vertex angle and cleanliness far outweigh any inconvenience. Obviously the method proposed would not be appropriate in autogenous welding.

The weld microstructures have not been reported as a detailed examination relating them to electron microscopy/analysis is to be presented in a later paper.

The Charpy impact and pitting corrosion test results are also the subject of a later paper so a detailed analysis has not been reported. However, the results obtained from all the experimental welds far exceeded the minimum requirements of International construction codes and more stringent clients’ requirements.

The monitor-rung system and numerous combinations of direct thermocouple attachment to the pipe have provided a wealth of data for mathematical modelling and computer processing. These results, once related to the material manufacturers Temperature-Time-Precipitation curves, will also be presented in a paper to be published at a later date.

The repeatability of these results, provided by mechanised orbital welding equipment, should lead to an increased acceptance of duplex stainless steels as confidence in their reliability grows.

CONCLUSIONS

- A method of avoiding tungsten electrode contamination in the presence of high nitrogen containing shielding gases has been established.
- Welding capability with nitrogen addition to the argon shielding gases has been extended to 7% for Zeron 100 and 10% for Avesta SAF 2205.
- Welding procedures avoiding run-out-length restriction and using weave techniques have been successfully developed.
- A deep root ligament followed by a cold pass technique has been successfully employed.
- A system for monitoring weld thermal cycles and relating them to weld zone properties has been established.
- The mechanical and corrosion resistance properties of all the experimental welds produced far exceeded the most stringent oil-gas industry requirements.

FURTHER WORK

The work reported here represents the initial findings of a current PhD research programme. Further work is obviously needed to extend the scope of the project and expand the supporting discussion.

REFERENCES

WELDING & METAL FABRICATION

The following features are scheduled to appear in our June Issue.

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★ Brazing parameters

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