dti

THICK SECTION WELDED HCM2S (P23)

Advanced Modelling and Testing

PROJECT SUMMARY 299

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

The principal aim of the project was to use advanced modelling and testing to extend the size range for which the HCM2S (P23) steel can be fabricated both with and without Pre-Weld Heat Treatment (PWHT). The specific objectives were:

- To optimise the fabrication of thick section HCM2S utilising practical and efficient welding processes - Manual Metal Arc (MMA) and Flux Cored Arc Welding (FCAW).
- To thoroughly investigate the welding of HCM2S without PWHT.
- To model the weld and cross weld mechanical properties of HCM2S both with and without PWHT in order to define cross weld properties.
- To demonstrate acceptable weldment mechanical properties.
- Consequently to produce fabrication guidelines for thick section HCM2S both with and without PWHT.

SUMMARY

This project involved the manufacture of a number of pipe butt welds between HCM2S (P23) and itself - both with and without PWHT, and also dissimilar joints with BS 3064 660 (CMV) and ASTM A 335 P91 respectively, both these alloys representing materials with which there has been identified a potential desirability to join with thick section P23.

A commercial benefit is anticipated if P23 could be used to replace such martensitic steels as P91, with which it is on a par in respect to creep strength.

Figure 1. MMA welding in the 45° inclined position (courtesy of MBEL)

Obviously its use would necessitate the ability to produce dissimilar and similar welds in thick section and the potential to avoid PWHT would offer an even greater advantage.

The main infill procedure used on the weldments was either MMA or FCAW and, for some of the combinations, more than one filler metal chemistry was used. Routine mechanical testing, including Charpy impacts, were carried out to the requirements of BS EN288 part 3 and satisfactory weld procedures qualified for each of the combinations welded.

Samples were taken from the majority of the welds both as 'all weld' and 'cross weld' test pieces and creep rupture tests carried out. All of the tests were at 575°C conducted with a range of stresses with the intention of achieving durations up to 10,000 hours. In parallel, modelling was carried out using neural network technology to predict the creep rupture properties to be expected with both the PWHT and non-PWHT weldments in P23.

Subsequent to this, Finite Element (FE) modelling, using data both measured and estimated, was used to evaluate and compare the change in stress distribution with time for both as welded and stress relieved weldment. In addition, samples of P23 type weld metal were thermally aged to simulate 50,000hrs operation at 575°C. These were then stress rupture tested to evaluate any change in the creep properties due to this ageing.

BACKGROUND

HCM2S was developed some years ago as an improved version of the standard 2¼Cr 1Mo alloy, primarily through the addition of tungsten at around 1½% to improve creep strength and a reduction of carbon to less than 0.10% (compared with 0.15% maximum of T22) to improve weldability/ restrict HAZ hardness in the 'as welded' condition. The intended application was for water wall tube panels in super-critical power plant (Figure 2) where the ability to fabricate these large furnace panels complete, without the need for post weld heat treatment is of paramount importance. However it was soon recognised that the enhanced creep properties were nearly equal to those of the higher alloyed T91 and it was therefore a good candidate for other applications such as superheater tubes for metal temperatures possibly up to about 575°C. Note that the upper limit is related to problems with steam side (and flue gas) oxidation rather than creep strength. Apart from being potentially cheaper, its main advantages are that, in thin sections, it does not require either preheating or post weld heat treatment to produce acceptable microstructures and hardness. It has since obtained status in the ASME code through code case 2199-1, approved in 1999, which gave it the P number 5A (the same as standard 2¼Cr 1Mo - T22) and it was subsequently given the designation T23 in ASME IIA - SA213. Hence for manufacture to ASME I, as permitted by table PW 39, post weld heat treatment is not required up to a thickness of 16mm. When post weld heat treatment is unavoidable, it may be carried out at temperatures lower than that required for P91 thus ensuring minimal degradation of the adjoining materials in, for example, retrofit situations involving P22 or CMV.

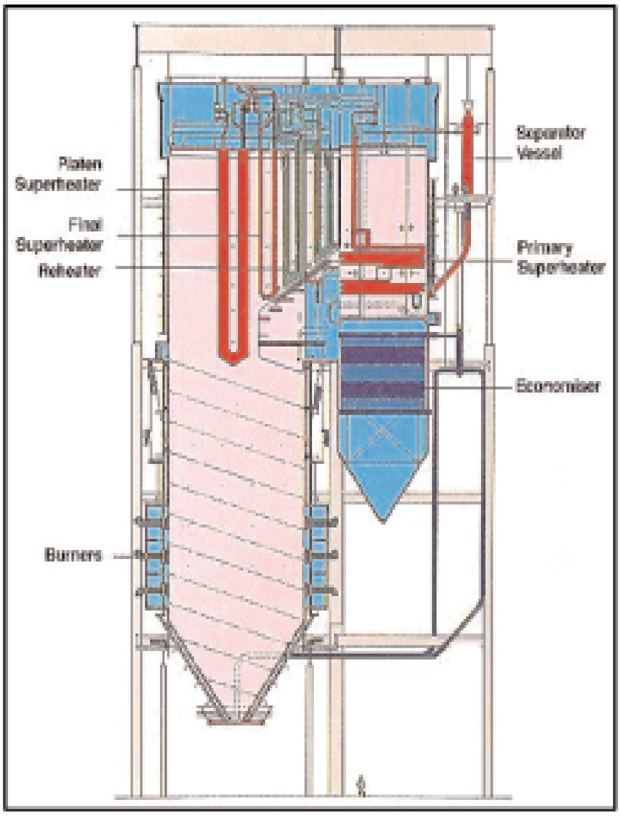

Figure 2. Modern supercritical boiler.

The heavier section pipe to SA 335 i.e. P23, although also included in the code case, is not currently included in ASME IIA although it was introduced to the ASTM series of material standards in the 2003 edition. Nevertheless, prior to this RWE-npower (formerly Innogy plc) obtained a pipe length from Sumitomo notionally to this specification and this report details welding and testing carried out on it. The material in this form has a potential for application in both headers and pipework with particular interest as a replacement for BS 3604 grade 660 (CMV) in repair and refurbishment of existing power plant. Of interest also was the possibility of avoiding post weld heat treatment in thicker sections.

EXPERIMENTAL WORK

The following scope of work was therefore established in order to better exploit the full potential of this alloy.

- Weldability of P23 to itself both as welded and stress relieved.
- Weldability of P23 to CMV - stress relieved.
- Weldability of P23 to P91 - stress relieved.

Welding was carried out with both the more traditional TIG/MMA combination and also the higher deposition FCAW welding process and testing carried out to the requirements of BS EN288 part 3. In addition all weld and cross weld stress rupture tests were conducted at 575°C over a range of stresses for target durations up to 10,000 hours.

Selected welds were also given an ageing treatment designed to simulate mid-service history and limited cross weld stress rupture tests again carried out. The ageing time and temperature was derived using the principles of Thermocalc. Neural network technology was used to predict the creep behaviour for the P23 material both as welded and post weld heat-treated. This data, together with additional information from various sources was used to model creep behaviour with time for both an as welded component and a stress relieved component to assess the viability of avoiding post weld heat treatment on thicker section fabrications.

RESULTS

The welding trials provided the following results:

Weldability: All welds were carried out satisfactorily in the inclined 45° position. The welder noted no specific difficulties and all the welds were found to be defect free by both magnetic particle inspection of the surface and volumetric examination using ultrasonic technique.

Strength: In every case, failure of the cross weld tensiles was located in the parent material at a stress exceeding the minimum for that material. In the case of dissimilar joints failure understandably occurred in the weaker material.

Ductillity: The side bends were bent over a former of diameter equal to four times the thickness of the bend specimen. In every case they were bent to 180° without any unacceptable defects being noted. Note that this is in excess of what is currently required by BS EN288 part 3, where an angle of 120° only is required.

Notch toughness: The absorbed energy measured in the Charpy test for the stress relieved manual metal arc weld metal of the P23 type all gave values in excess of 100J at room temperature. Note that similar test welds made with both the Metrode Chromet 23L and BWP type J electrode gave essentially identical.results. However in the 'as welded' condition poor results, an average of 12J, were obtained in test reference PQT3. This utilised 4mm diameter electrodes for the infill and low toughness was attributed to the large areas of unrefined weld metal developed at this stage. The weld procedure was therefore revised to limit the electrode to 3.2mm maximum. This resulted in a noteable improvement in absorbed energy to an average of 22J. Although still relatively low, this compares favourably with manual metal arc 9% Cr weld metal Other notable, though not too surprising results were the lower toughness exhibited by the comparable FCAW weld metals.

Neural Network Analysis: For the present work, three developed neural network programmes were used to predict the properties of the P23 type manual metal arc and flux cored weld metals.

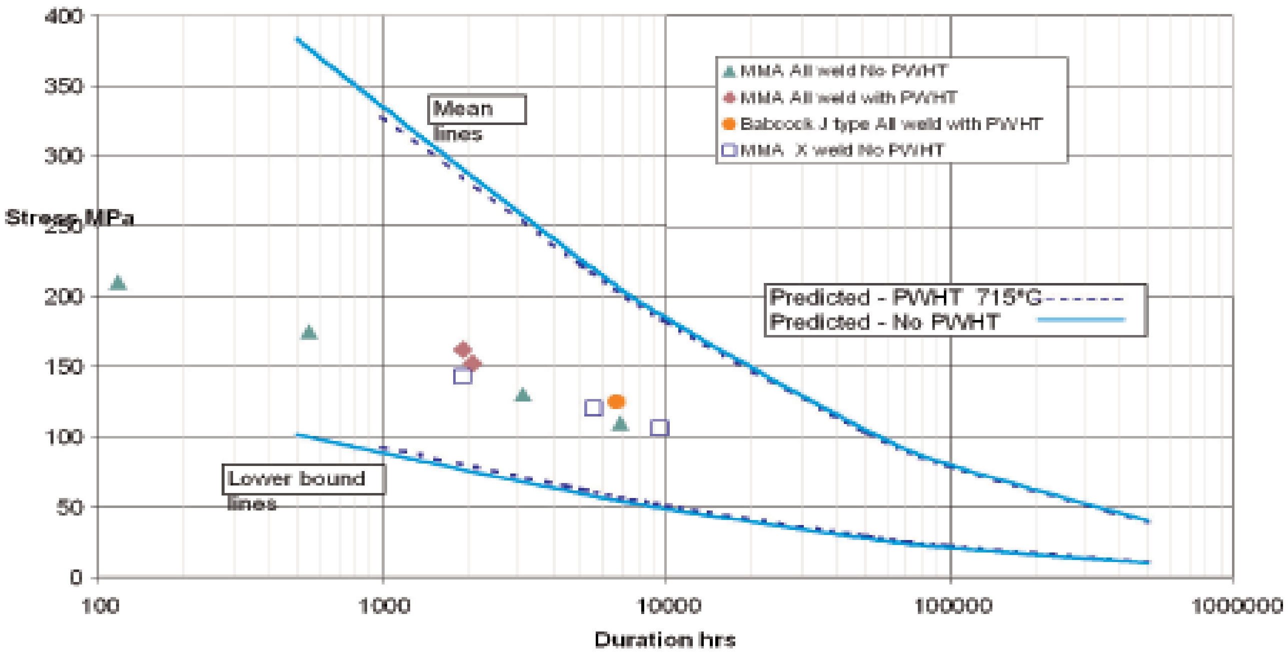

Figure 3. Comparison of measured stress rupture values with mean and lower bound predictions.

The results from the yield stress and ultimate tensile stress analysis were considered to be in good agreement with the observed values. The mean of the stress rupture estimates were quite close to the measured values when it is considered that ± 20% is typical scatter.

However the upper and lower bound values showed a high level of uncertainty and it is felt that further refinement of the model may be necessary to improve this.

Residual Stress Modelling: Both the PWHT and non-PWHT FE analyses were run for a 40mm thick weld under service conditions for 140,000 hours. At the end of this period the axial stresses in both the PWHT and non-PWHT welds had relaxed to the same level with the stresses at mid thickness being greater than those on the inner and outer surfaces but still only of the order of 20MPa. In a third model, a 16mm thick non-PWHT FE analysis was run under the similar service conditions for 140,000 hours. This is the current maximum limit on thickness for which ASME code does not require PWHT. At the end of the service period the axial stress in the 16 mm wall thickness pipe model had relaxed to a slightly higher level compared to the corresponding results for the 40mm wall thickness pipe weldment model, with the stresses at the mid and outer thickness being greater than those in the inner surface (of the order of 40 MPa)

At the end of the service period the creep strains in the 40mm thick non-PWHT weld were greater than those of the PWHT weld. The maximum creep strains were approximately 0.3% (at the inner surface) and 0.4% (at the outer surface). In the 16mm thick model the creep strains at the end of the service period in the non-PWHT weld were greater than those of the non-PWHT 40mm weld on the inner and outer surfaces of the pipe but lower at the mid thickness of the pipe.

The maximum creep strains in this case were approximately 0.2% (at the inside surface) and 0.4% (at the outer surface). There is therefore little difference between the responses of the 16mm (model 3) and 40mm (model 2) weldments without PWHT. Currently, P23 weldments are limited by code requirements to sections of up to 16mm without PWHT. The comparative exercise presented in this report has indicated that the service performance is similar for a 16mm and 40mm thick pipe. P23 welds may therefore be acceptable for service up to thicknesses of 40mm.

CONCLUSIONS

The project was successful in achieving the following deliverables:

- Qualified welding procedures using both manual metal arc and flux cored arc welding techniques for joining thick section P23 to itself, CMV and P91 - all with PWHT.
- A qualified weld procedure for P23 at 40mm thick in the 'as welded' condition utilising the temper bead technique to improve properties.
- Prediction of short term mechanical properties and long term stress rupture values in P23 weld metal using neural network analyses techniques
- Verification by comparison that the tensile predictions and measured values were in good agreement.
- Verification that the measured stress rupture values were within an acceptable scatter from the mean of the derived values.
- Confirmation that the long term stress rupture values in the non post weld heat treated and post weld heat treated condition were similar as predicted by the neural network analysis.

- Developing a methodology to simulate accelerated long term ageing of test material using kinetic and thermodynamic models
- Estimating that the remaining life of the aged material was, by extrapolation, consistent with the design allowable stress.
- Thick section P23 was modelled by finite element analysis (FEA) to estimate residual stress and stress relaxation in creep across a weld in both the as welded and post weld heat treated condition.
- The model was used to compare the difference in effect between the code limit of 16mm and the likely practicable upper limit of 40mm.

It was concluded that acceptable strains were developed during the life of the thick P23 weld for the non-PWHT'd condition to make it a viable option

POTENTIAL FOR FUTURE DEVELOPMENT

It is recommended that further investigation be carried out on the creep behaviour of P23/P91 weldments to confirm the suggestion that improved performance is obtained with the higher alloy filler metal. The influence of, for example, carbon migration may play a significant role.

It would be beneficial to incorporate the current data into the creep based neural network analysis to further refine and improve its capabilities.

Consideration should be given to the use of full scale feature tests (pressure bottle) or 'in plant' demonstration to underwrite the derived acceptability of 40mm thick as welded P23 joints.

COST

The total cost of this project is £217,068 with the Department of Trade and Industry (DTI) contributing £104,363 The balance of funding was provided by the participants.

DURATION

39 months - January 2001 to March 2004

CONTRACTOR

Mitsui Babcock
Porterfield Road
Renfrew
PA4 8DJ
Tel: +44 (0) 141 885 3856
Email: mbarrie
@mitsuibabcock.com

COLLABORATORS

RWe-npower plc &
Cambridge University

Further information on the Cleaner Fossil Fuels Programme, and copies of publications, can be obtained from:
Cleaner Fossil Fuels Programme Helpline, Building 329,
Harwell International Business Centre, Didcot, Oxfordshire OX11 0QJ
Tel: +44 (0)870 190 6343 Fax: +44 (0)870 190 6713
E-mail: helpline@cleanercoal.org.uk
Web: www.dti.gov.uk/cct/

DTI/Pub FES 05/1688