FABRICATED ROTORS FOR ADVANCED STEAM TURBINES

Development of Weld Procedure

PROJECT SUMMARY 285

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

The aims of this project were:

- To reduce the capital and through life cost of steam turbines generating with clean coal technologies at steam temperatures above 570°C.
- To develop the materials and welding technology necessary to provide a fabricated steam turbine rotor to operate with elevated steam temperatures in the high temperature part and long, high strength, turbine blades in the low temperature part of the rotor.
- To fully characterise the microstructures and properties of such steam turbine rotors to enable the development of lifeing methodologies.

SUMMARY

An investigation has been made into the possibility of welding together 10%Cr and 3.5%NiCrMoV rotor steels, a combination which would allow manufacture of large turbine rotors with inlet steam temperatures in excess of 570°C.

Following a comprehensive modelling programme by the University of Cambridge and complementary testing and examination by Siemens Power Generation (SPG), a welding procedure was developed and successful narrow gap TIG welds were made between 380mm diameter, 50mm thick material. This was accomplished using the established Tungsten Inert Gas (TIG) filler wire.

Mechanical and metallurgical assessment of these welds showed that the weldment properties matched the requirements of the original parent materials.

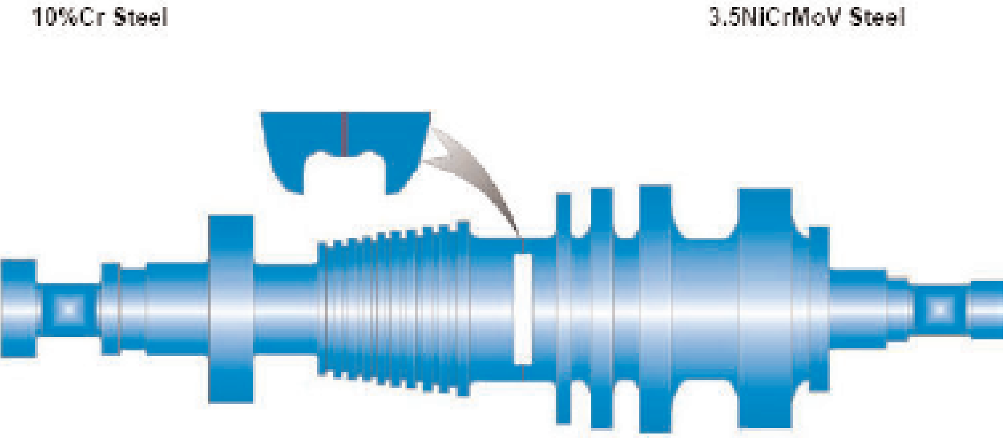

Figure 1. Steam turbine rotor for application above 570°C

Following the success of the 380mm diameter welds, a large-scale weld was manufactured using the established filler material and procedures to fully validate the developed welding procedure.

This weld has been subjected to Non-Destructive Examination (NDE) followed by extensive mechanical and metallurgical testing. The results confirm that the large scale weldment properties matched the requirements of the original parent materials and thereby satisfy the objectives of the project.

BACKGROUND

An increase in turbine efficiency can be made if the inlet temperature is increased for certain possible configurations. This requires a rotor made by welding together 10%Cr and 3.5%NiCrMoV rotor materials. The resultant composite rotor should possess the high-strength and toughness properties required to withstand the operational blade loads at the 3.5%NiCrMoV end, as well as having the creep resistance needed at the 10%Cr end (as illustrated in Figure 1).

A team was set up consisting of members from Siemens Power Generation (SPG) Newcastle, Mülheim and Charlotte supported by the department of Materials Science and Metallurgy, University of Cambridge.

Technical Challenges

The welding of the 10%Cr to 3.5%NiCrMoV rotor steel presented several potential challenges, namely:

- The large difference in tempering temperature of the two rotor materials.
- The difference in chemical composition and properties of the two rotor materials.
- The need for a high strength weld metal to match the strength of the parent materials (Yield strength >700MPa).
- The possibility of carbon migration and segregation due to the large difference in chromium levels.

Two solutions were proposed to address these issues.

Proposed Solution 1:
The first proposed solution was to clad the 10%Cr material with a suitable weld metal and subsequently heat-treat the clad layer at a sufficient temperature to adequately temper the Heat Affected Zone (HAZ) of the 10%Cr material. A butt-weld would then be made between the clad material and the 3.5%NiCrMoV steel using a suitable weld metal and finally the composite weldment would be heat treated. This was described as the 'two-shot' process.

Proposed Solution 2:
The second proposed solution was to weld the 10%Cr direct to the 3.5%NiCrMoV material using an appropriate weld metal and Post-Weld Heat Treatment (PWHT). This solution, described as the 'single-shot' process would generate significant cost and lead time advantages over the previously described two-shot process.

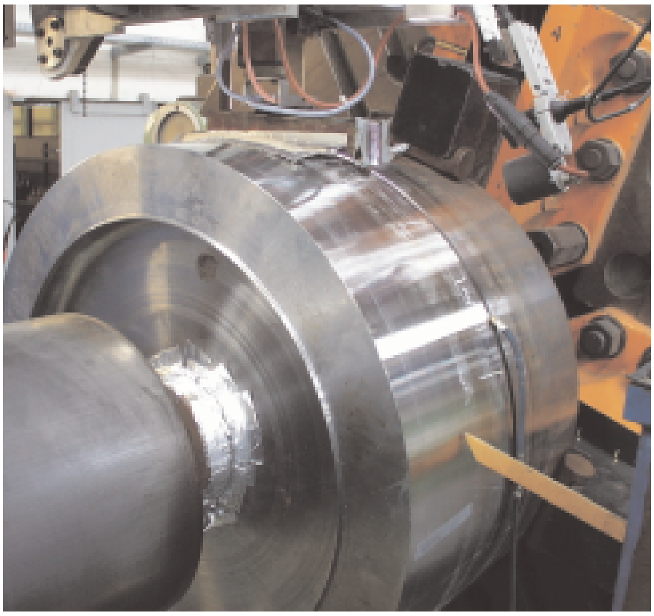

Figure 2. Narrow gap welding of 840mm diameter forgings

DEVELOPMENT PROCEDURES

The following constraints were agreed at a preliminary meeting of the team:

- The weld metal properties would have to at least meet the relevant design requirements for the weaker of the two parent materials.
- The weld metal should have a minimum 0.2% proof strength of 700MPa and a minimum impact energy of 30 Joules at 20°C.
- Only commercially available welding consumables would be investigated, including consumables developed by, and readily available from, SWPC.

Eight candidate weld metals were chosen for consideration within the programme.

The team also agreed the following weld procedure details:

- A narrow gap weld preparation would be adopted.
- The thickness of the buttering weld metal would be kept to the minimum required to retain a 6mm thick layer after machining.
- Only vertical buttering would be employed because of the difficulty of upending the rotors.

University of Cambridge Modelling

The University of Cambridge modelled the parent materials and the proposed weld metals for creep and tensile strength at different tempering temperatures and times for the same welding heat input. Additional parameters also used in the model were preheat temperature, post weld heat treatment temperature and post weld heat treatment time

A comprehensive HAZ simulation programme of the 10%Cr steel and the 3.5%NiCrMoV steel by the University of Cambridge indicated the potential for both single-shot and two-shot processes if a peak hardness of 350HV could be accepted.

As a result of the modelling four of the candidate welding consumable were eliminated from further investigation due to a combination of low predicted strength and poor weldability. It was decided to exclude a further consumable from the programme because, although the modelling indicated that it could produce acceptable strengths at the PWHT temperatures proposed for the weldment, the actual property data available at the time did not give enough confidence to justify further work using this consumable.

Development Welding Trials

To support the work at Cambridge in assessing HAZ microstructures, response to PWHT and the effects of carbon migration, a number of plate welding trials were made.

Following the results from the plate welds the team decided to manufacture three small-scale, 380mm diameter x 50mm thick, test welds using both the 'two shot' and 'single shot' procedures.

The metallography, hardness surveys and mechanical properties from these test plate and 380mm diameter welds in various heat-treated conditions showed good correlation with the Cambridge model predictions for the parent metals, HAZ's and the weld metals.

When further tensile data became available from Siemens Westinghouse on the weld metal that had initially been shown by Cambridge to be satisfactory, but which was rejected by contradictory data, it was seen that this further data was in good agreement with predictions from the initial modelling by the University of Cambridge. The team discussed this and concluded that this weld metal should meet the mechanical properties required.

Additionally it was considered that it could provide some control on the carbon migration as the vanadium in this weld metal might stabilise the carbon and thereby reduce the effect of the carbon gradient.

It was therefore decided to manufacture a 380mm diameter one-shot weld between a 3.5%NiCrMoV forging and a 10%Cr forging (weld No. W5510) using this welding consumable. Welding was completed successfully. The subsequent metallography, hardness surveys and mechanical properties from this weld in the heat-treated condition met the required properties.

The team concluded that the overall results from weld W5510 using the selected weld metal were satisfactory. It was also agreed that another weld (W5513) would be completed to determine whether consistent results could be achieved using the same weld metal in conjunction with the same welding procedure.

The test results for the narrow-gap butt weld W5513 were in close agreement with those previously obtained for the weld W5510 in the same PWHT condition, confirming the reproducibility of weld quality and mechanical properties.

Figure 3 Macrosection through full-scale weld

A large-scale weld (W5522) with a diameter of 840mm and a thickness of 100mm was manufactured using the selected weld metal and the developed parameters to fully validate the welding procedure.

The weld was given the selected stress relief and then subjected to extensive mechanical and metallurgical testing to compare the properties with those of the previous smaller-scale weld W5513. There was good correlation of the properties between the these welds.

A transverse macro section through the full thickness of the narrow gap TIG weld (Figure 3) revealed a very regular bead pattern with smooth sidewall profiles in both parent materials. The weld also had good root fusion and capping bead profile. There were no visible defects in the weld metal. The welding parameters and bead sequence used for the weld had produced a high degree of refinement both in the weld metal and the heat affected zones.

Some carbon migration was evident at both sidewalls. At the 3.5%NiCrMoV side, the weld metal showed a carbon enriched zone resulting from the migration of carbon across the fusion line from the lower chromium parent material. Carbon depletion of the 3.5%NiCrMoV had not resulted in the formation of any ferrite grains at the parent material side of the fusion line. At the 10Cr side, the direction of carbon migration was reversed with a carbon enriched zone in the higher alloy 10%Cr parent material and carbon depleted zone in the weld metal but again there had been no ferrite formation as a result of the carbon diffusion.

CONCLUSIONS

1. The modelling and heat affected zone simulations undertaken by the University of Cambridge provided accurate predictions of the parent steels and weldment properties. It confirmed the suitability of the selected welding parameters, enabled the short-listing of suitable weld metals, established the effects of post weld heat treatment parameters on the weld metals and parent steels.
2. The information generated allowed the University of Cambridge models to be enhanced to provide better prediction data for the range of alloys under investigation.
3. The plate welding trials determined the welding procedures for cladding and butt-welding of the selected materials and the testing of these confirmed the modelling results.
4. The single-shot butt weld made using the selected weld metal (W5413) reported in the interim report, gave adequate strength and toughness and had a satisfactory microstructure.
5. Residual stress measurements after post weld stress relief heat treatment determined that the levels and patterns of stress were acceptable.
6. The welding procedure developed using the selected weld metal has now been successfully used to manufacture the full-scale weld W5522 (840mm diameter and 100mm thick) and has been shown to be of good quality and has demonstrated that the process can be successfully applied to production-size rotor welds between 3.5%NiCrMoV and 10%Cr meterials.
7. The hardness profile of the completed weldment after the selected PWHT was satisfactory with no excessive heat affected zone hardness levels and no unacceptable softening at the weld fusion lines.

FUTURE WORK

Based on the success of the current programme, Siemens Power Generation is taking advantage of the results in product design. As expected, the developed welding strategy has enabled a type of combined welded rotor to be specified for fossil fired and combined cycle applications with main steam temperatures up to 600°C inlet.

The extended knowledge which has been generated in the project serves also as the basis for further rotor designs with different construction using the investigated filler material.

The current market situation clearly indicates that new turbo-set types are required with welded rotors. The ability to use the optimal material combination results in improved material exploitation and enables design solutions which would not otherwise be possible. Internal R&D activities are ongoing.

COST

The total cost of this project is £355,696 with the Department of Trade and Industry (DTI) contributing £164,687 and Siemens Power Generation the balance.

DURATION

43 months – February 2000 to September 2003

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FURTHER INFORMATION

For further information about this project see project report R265 URN 04/1798 'Fabricated Turbine Rotors – Advanced Steam Turbines' available from the Helpline.

Further information on the Cleaner Fossil Fuels Programme, and copies of publications, can be obtained from:
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