A Case Study on the Influence of Heat Treatment on Hydrogen Diffusion and Residual Stresses in Repair Welding of Clad Pipes

D. Lindholm
Institute for Energy Technology, 2007 Kjeller, Norway
E-mail: dag.lindholm@ife.no

INTRODUCTION

Utilization of clad and lined pipes, where a thin layer of corrosion resistant alloy provides interior corrosion resistance of a conventional carbon steel pipe, is with increasing frequency considered as an economically viable alternative for corrosion management in many new oil and gas developments. Detrimental hydrogen introduced by the weld metal or from cathodic protection reduces the ductility of the weld and increases the possibility of cold cracking. This type of failure has typically a delayed nature and crack initiation and especially crack propagation may occur several hours, or sometimes even days or weeks, after welding has been completed.

High-quality welds are essential as leakages are costly to repair, or even worse, a failure which may have serious environmental impact. It is not necessarily the hydrogen level alone that makes a potential risk, but a combination of hydrogen level, distribution of residual stresses and brittle microstructure in and adjacent to the weld. The objective of this study has been to use computer simulations to examine the influence of heat treatment (pre, interpass and post) on residual stresses, microstructure and decay of hydrogen in and adjacent to a multi-pass U-groove weld.

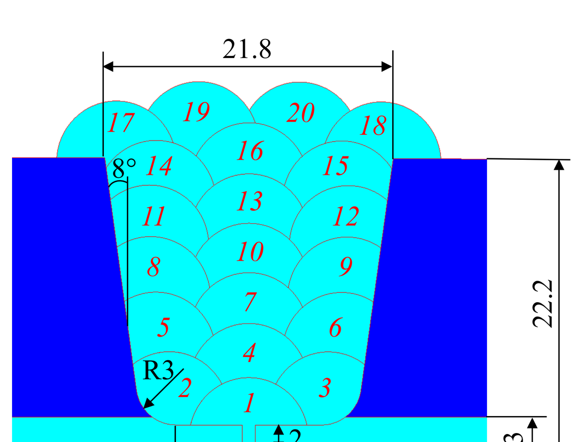
MATHEMATICAL MODEL

For two- and three-dimensional time-dependent problems WELDSIMS [1, 2], a software based on the Finite Element Method, solves

- The energy equation (temperatures/enthalpies)
- Thermo-elasto-viscoplastic models (stresses, strains and deformations)
- Microstructure evolution of carbon steel
- Advanced model for hydrogen diffusion (trapped and lattice hydrogen)

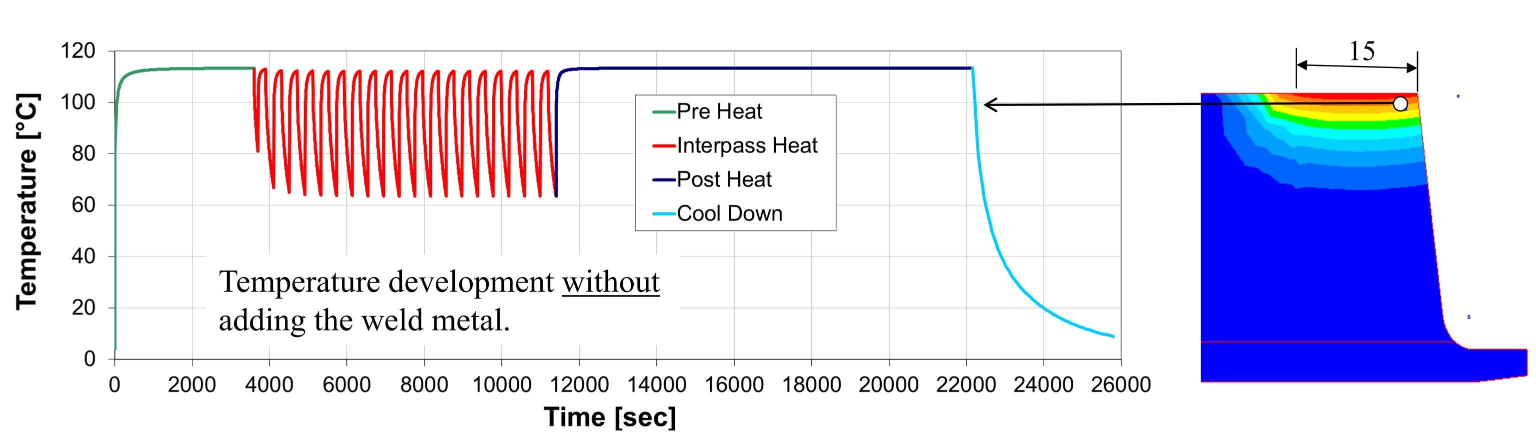
U-GROOVE WELD

Austenitic AISI 316L was used as clad material to protect the ferritic steel grade X70 base material. Similar material properties used for the clad was also assigned to the weld metal. Totally twenty weld passes were applied to complete the joint, and their sequence as well as geometrical weld details and weld parameters are shown in the figure below. A double ellipsoid distribution function, as proposed by Goldak [3], was used to represent the welding heat source. Material properties depend both on temperature and on microstructure.



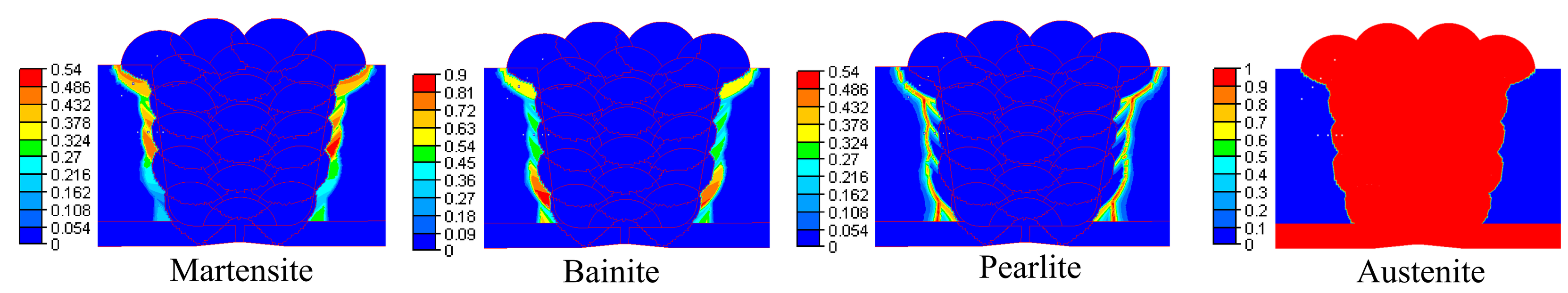
- Pipe inner diameter: 704 mm
- Number of weld passes: 20
- Weld pass time interval: 405 sec
- Weld source speed: 5.8 mm/s
- Weld heat input: 1.0 kJ/mm

Three cases with different use of heat treatment were compared in the study; full heat treatment (pre, interpass and post), partial heat treatment (post) and no heat treatment. For a location positioned just below the pipe outer surface where the heat is provided, the figure below shows the development of the local temperature (full heat treatment) when no weld metal is added. It also identifies the extent of the heated area (15 mm on each side) and the duration of the various heating periods.



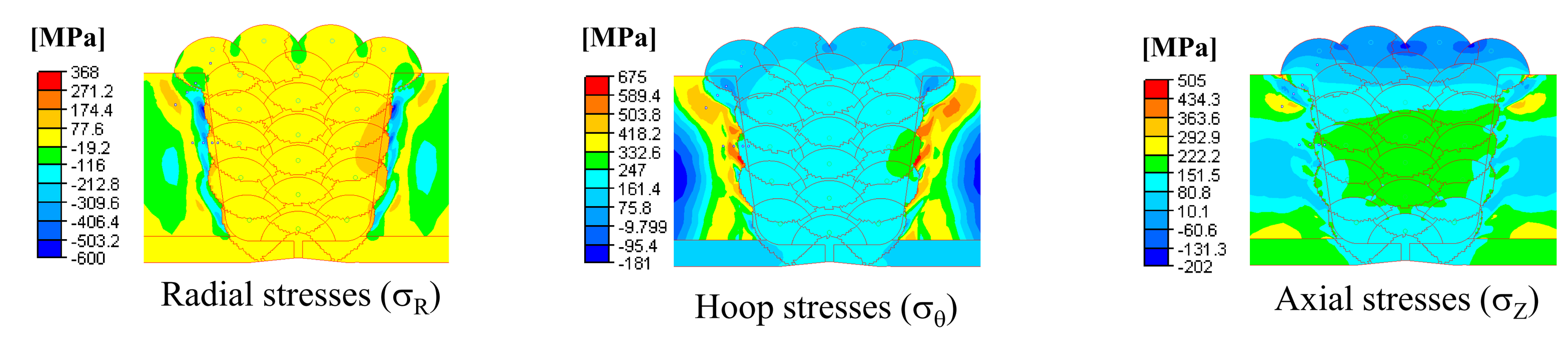
MICROSTRUCTURE

Based on the continuous cooling transformation phase diagram of API X70 [4] and a methodology for calculation of phase transformation [1], the computed microstructure in the fused (FZ) and the heat affected zone (HAZ) was found to consist of a mixture of martensite (far left in the figure below), bainite (middle left), pearlite (middle right) and austenite (far right). These plots represent full heat treatment. A comparable microstructure with slightly more martensite present in the HAZ was obtained for the case without heat treatment. The resulting microstructure has strong influence on the time for hydrogen to escape from the weld metal and from the HAZ.



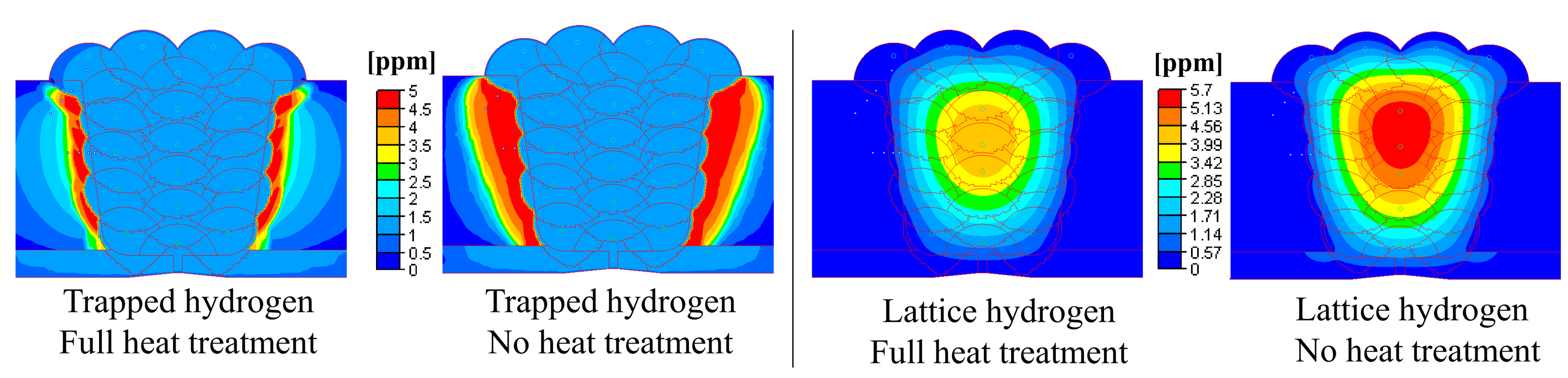
STRESS FIELDS (RESIDUAL STRESSES)

Compared to a case without heat treatment, full heat treatment did not make any significant change of the residual stress fields. Predicted radial (left), hoop (middle) and axial (right) stresses are shown below. Positive values are tensile, while negative are compressive. At the HAZ-FZ interface, stresses equal to yield stress are achieved.



HYDROGEN (TRAPPED AND LATTICE)

For removal of hydrogen from the weld metal and the brittle crack susceptible HAZ, heat treatment proved to have large influence. Because of low diffusivity of hydrogen in austenite, as well as high solubility, the hydrogen content (10 wt% ppm) introduced in the weld metal decreases slowly. Hydrogen is stored in the weld metal and feeds the HAZ with hydrogen long after the welding has been completed. Because of strong coupling of the diffusivity to temperature, post-heat treatment has significant effect on transporting hydrogen out from the weld metal and through the base metal HAZ. As shown below, trapped hydrogen accumulates in the brittle HAZ, where the residual stresses are significant, and makes the zone prone to hydrogen embrittlement.



CONCLUSIONS

- A brittle, crack susceptible microstructure was obtained in the HAZ.
- At the HAZ-FZ interface, stresses equal to the yield stress are achieved.
- The residual stresses were insignificantly influenced by the applied heat treatment.
- Because of the microstructure, the hydrogen content in the weld metal decreases very slowly.
- Post-heat treatment has significant effect on removal of hydrogen from the weld metal and from the base metal HAZ.
- Use of an austenitic weld metal only for the first three weld passes, then completing the other passes with a ferritic weld metal, will enhance removal of hydrogen.

REFERENCES

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[3] J Goldak, A Chakravarti and M Bibby (1984). Metallurgical Transactions B, Volume 15, pp 299-303.
[4] M Onsøien, M M'Hamdi and A Mo (2009). Welding Journal, Volume 88, pp 1s-6s.

ACKNOWLEDGEMENTS

The present work was financially supported by the Research Council of Norway (Petromaks 2 Programme, project No. 234110/E30), Statoil Petroleum AS, Gassco AS, Technip Norge AS, Pohang Iron and Steel Company (POSCO) and EFD Induction. Research partners are SINTEF, The Norwegian University of Science and Technology (NTNU) and Institute for Energy Technology (IFE).