Microchemical and Microstructural Variations across Dissimilar Joints

EXECUTIVE SUMMARY

Ferritic steels are important structural materials in the steam generator circuits of LMFBRs. The weld joints between dissimilar ferritic steels of large components are the potential zones for failure during service exposure. The microstructural instability and elemental redistribution in dissimilar weldments between 9Cr-1Mo and 2.25Cr-1Mo ferritic steels during post weld heat treatment, which can lead to severe impairment of the mechanical properties has been studied using optical and electron microscopy techniques. Based on the investigations the micromechanism responsible for the microstructural degradation has been identified and methods to improve the service life of the weldments have been suggested.

OUTLINE

In the fabrication of steam generators for nuclear power plants, both high and low Cr steels are employed depending on the service temperature experienced by the components. This results in dissimilar welding in selected locations. It is known that when these dissimilar joints are exposed to elevated temperature a hard brittle layer forms at the interface which is the weak link in the structure. To investigate the cause for such a zone formation a dissimilar joint between two ferritic steels, 9Cr-1Mo and 2.25Cr-1Mo exposed to elevated temperature of 1023 K for various time durations was studied.

It was found that after heat treatment a hard brittle zone called as the 'hard zone' characterized by (1) high hardness of ~270 VHN (compared to the rest of the weldment) and (2) carbon enrichment forms on the high alloy side of the weldment. In addition a 'soft zone' characterized by (1) low hardness of ~120 VHN (2) ferritic structure almost free of carbides forms on the low alloy side of the weldment (Fig. 1). The width of these zones was found to increase with the time and temperature of exposure. Microchemical characterization gave evidence for the redistribution of carbon across the weld interface. Using numerical methods the carbon diffusion profile across the weld interface for various heat treatment conditions was simulated. Simultaneous enrichment for Cr and C was obtained on the hard zone suggesting that the precipitates present in the hard zone are chromium carbides. Detailed transmission electron microscopy on carbon extraction replicas was carried out to identify the carbides. The precipitation sequence in the hard zone is summarized as

$$\alpha' \rightarrow \alpha + M_{23}C_6$$

The soft zone was found to be almost devoid of carbides, containing only very few M_2C or M_6C type precipitates. Carbon content in the hard zone was estimated using an indirect method which depends on the type and volume fraction of the carbides. Diffusion of carbon against the activity gradient from low Cr to high Cr steel was identified as the mechanism responsible for the formation of the zones.

Based on the understanding of the atomic processes gained from the above studies further attempt was made to evolve a methodology to prevent the formation of hard and soft zones. The following three methods were suggested in this regard: (1) use of interlayers that act as diffusion barriers to carbon (2) welding ferritic steels with graded Cr concentration and (3) adjusting the chemistry of the base metal to reduce activity gradient. One of the three methods i.e. effectiveness of diffusion barriers in preventing carbon diffusion was demonstrated using Ni based interlayers. Ni was chosen mainly because of its repulsive interaction with carbon and also because of its compatibility with ferritic steels with respect to thermal properties and weldability.

Transition joints were fabricated between 9Cr-1Mo and 2.25Cr-1Mo ferritic steels using Inconel-182 interlayer. These joints were subjected to the same heat treatment conditions as that of direct dissimilar welds. No microstructural modification was noticed at the interface of dissimilar materials as shown in Fig. 2. Ni based interlayers were found to be effective in preventing the formation of hard and soft zones in ferritic steels.

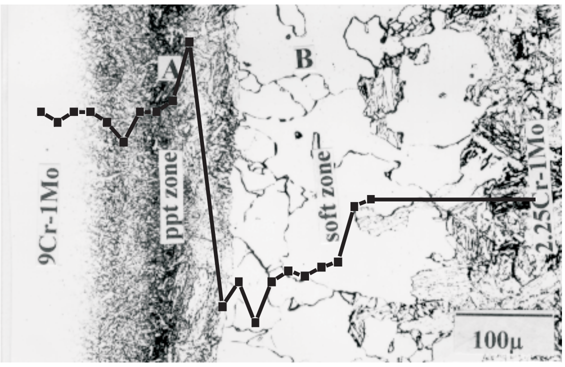

Fig. 1 : Optical micrograph and superimposed hardness profile showing the presence of hard zone 'A' and soft zone 'B'

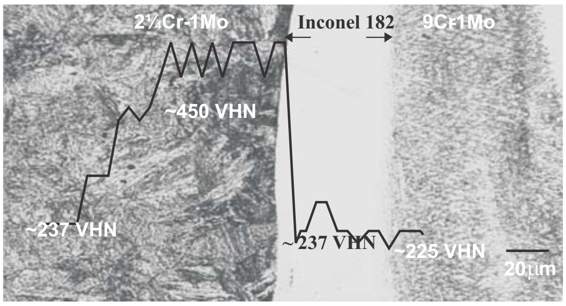

Fig. 2 : Optical micrograph showing the absence of hard and soft zones in a transition joint of ferritic steels with a Ni based interlayer

ORIGIN OF THE HARD AND SOFT ZONES

When dissimilar Cr-Mo steels are welded together and subjected to high temperature exposure carbon diffuses from low Cr to high Cr side. The following equation relates the activity of carbon a_c to concentration of C_r, C_{Cr} and interaction parameter between Cr and C, ε_C^{Cr} :

$$a_C = C_C\left(\exp\left(C_C\varepsilon_C^{C} + C_{Cr}\varepsilon_C^{Cr}\right)\right)$$

According to this equation since chromium has a negative interaction parameter with carbon ($\varepsilon_C^{Cr} = -72$), an increase in Cr content means a decrease in carbon activity. This activity gradient between the high and low Cr sides acts as the driving force for the diffusion of carbon.

MECHANISTIC CONSIDERATIONS OF THE AUSTENITE FORMATION

An activity gradient in carbon from the low Cr to high Cr steel results in diffusion of carbon across the interface. The transport of carbon into 9Cr-1Mo steel far exceeding the solubility leads to formation of chromium rich carbides, which manifest as a hard and brittle zone. To maintain the equilibrium, carbides in the 2.25Cr -1Mo steel dissolve leading to the transformation of bainite to ferrite. This results in the formation of a soft zone near the low Cr side of the dissimilar weldment. As the temperature or time of heat treatment is increased diffusion of carbon, dissolution/precipitation of carbides proceeds leading to an increase in the width of the zones. Due to the various constraints on the diffusion of carbon like (1) decrease in the activity difference between the two sides (2) depletion of Cr in the weld metal and (3) low C level in transformed ferrite the width of the zones do not show an increase beyond a specific time duration and temperature.

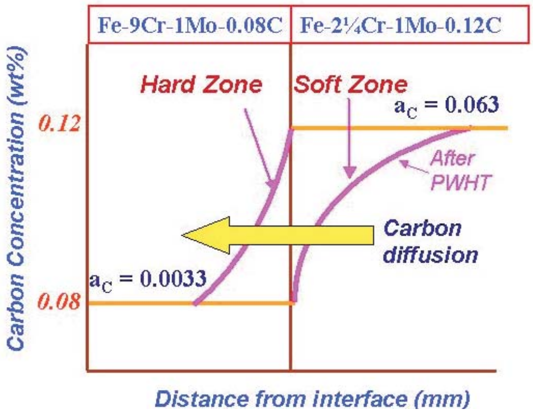

Fig. 3 : Schematic illustrating the formation of hard and soft zones

BRIEF DESCRIPTION OF THEORETICAL BACKGROUND

Using Finite difference method the carbon diffusion profiles and width of the zones have been predicted for various post weld heat treatment conditions.

ACHIEVEMENT

This work demonstrates that using a Ni based interlayer in transition joints of dissimilar ferritic steel improves their service life. The paper titled “Microstructure and microchemistry of hard zone in dissimilar weldments of Cr-Mo steels” has been awarded the Mc Kay Helm Award from the American Welding Society for the best research paper in 2006.

PUBLICATIONS ARISING OUT OF THIS STUDY AND RELATED WORK

1. C.Sudha, V.Thomas Paul, A.L.E.Terrance, S. Saroja and M.Vijayalakshmi, *Welding Journal*, **85** (2006) 71.
2. R. Anand, C. Sudha , T. Karthikeyan , S. Saroja , A. L. E. Terrance and M. Vijayalakshmi, Proc. Welding in South-East Asia – A challenge for the future – IIW Congress, 21st – 22nd November 2006, Bangkok, Thailand.
3. R. Anand, C. Sudha, T Karthikeyan, A.L.E Terrance, S.Saroja and M. Vijayalakshmi, Proc. Int. Symposium for research scholars on Metallurgy, Materials Science and Engineering, December 18th – 20th, 2006, IIT, Chennai, India.

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