Abstract

Various aspects related to weldability of Cr-Mo steels have been investigated in the present study. These include hydrogen assisted cracking susceptibility (HAC), variation in weld metal hardness with cooling rate and Cr content, tempering behaviour of weld metal during post weld heat treatment (PWHT) and carbon migration and soft zone formation during PWHT of dissimilar welds.

Measurement of diffusible hydrogen content ($H_D$) and HAC susceptibility studies were carried out on three different Cr-Mo steels namely; 0.5Cr-0.5Mo, 2.25Cr-1Mo and 9Cr-1Mo steels using samples prepared under identical conditions. $H_D$ content was measured using a gas chromatograph and a newly developed polymer electrolyte-based sensor. The results showed that under identical conditions of welding, $H_D$ content is maximum in 0.5Cr-0.5Mo steel and minimum in 9Cr-1Mo steels. This is attributed to decrease in the diffusivity and increase in the trapping of hydrogen with increase in alloy content. HAC susceptibility was studied using the University of Tennessee-Modified hydrogen sensitivity test (UT-Modified HST). Studies showed that the susceptibility is maximum in 9Cr-1Mo steel and a preheat of 225°C is required to prevent cracking at the maximum strain level of 4% employed in this study with 5 vol.% $H_2$ in the shielding gas. However, it was found that in this steel cracking was confined to weld metal while both weld metal and HAZ cracked during straining in the other two steels. The results were further analysed to propose an equation that can predict safe preheat temperature for Cr-Mo steels from composition and $H_D$ content in the welds.

Variation in the weld metal hardness with cooling rate and Cr content was studied using bead-on-plate welds prepared at different heat inputs and stationary arc weld puddles of 2.25Cr-1Mo steels in which Cr was added to obtain weld metals differing in Cr-content. Hardness of the weld metal decreased with increase in cooling time from 800 to 500°C ($t_{85}$) for weld metal containing up to a maximum of 5 wt.% of Cr, with corresponding changes in the microstructure. For weld metals with higher Cr content, no significant change in hardness with $t_{85}$ was observed. It was found that Yurioka’s formula can be used to predict the weld metal hardness with a reasonable accuracy for 2.25Cr-1Mo and 9Cr-1Mo steels.

The tempering behaviour of weld metals of 2.25Cr-1Mo and 9Cr-1Mo steels, during PWHT was studied by measuring hardness and studying variations in the microstructure at different stages of tempering. It was found that the tempering behaviour is similar to that of the normalised steel. However, in the initial stages of tempering, kinetics have been found to be faster in weld metal than in the normalised steels. Further, in the case of 2.25Cr-1Mo steel, it was observed that initial microstructure had a definite but minor influence on the tempering kinetics.

In order to study the carbon migration and the soft zone formation during PWHT of dissimilar welds between 2.25Cr-1Mo and 9Cr-1Mo steels, hardness measurements, optical
microscopy and secondary ion mass spectroscopy (SIMS) were carried out on these welds. The results confirm the migration of carbon from low-Cr side to high-Cr side during PWHT and the formation of a soft zone at the low-Cr side and an associated carbide-rich hard zone at the high Cr side. Presence of unmixed zones in the weld metal caused the formation of additional bands of soft and hard zones in the weld metal. Based on the carbon activity data, a carbon activity diagram, to choose suitable welding consumables that would prevent or reduce soft zone formation in the dissimilar welds, is proposed.

**Key words:** Cr-Mo Steels, Hydrogen Assisted Cracking, Diffusible Hydrogen, Post Weld Heat Treatment, Tempering, Carbon Migration, Dissimilar Welding, Soft Zone Formation.