# ABSTRACT

Quenched and tempered (Q&T) steels are a group of high strength low alloy steels (HSLA) in which strengthening is done by the formation of martensite phase. The steel taken up for the present study has a nominal composition of 0.3C, 0.9Cr, 0.3Mo, 0.1Zr, 0.6Si and 0.8Mn, and has a tensile strength of 1500 MPa in the Q&T condition. One important application of this steel is in armours for military hardware which require high strength and high hardness so as to offer good ballistic resistance.

Occurrence of hydrogen induced cracking (HIC) is the major metallurgical difficulty in welding of this steel. HIC occurs due to the combined effect of tensile residual stresses, diffusible hydrogen and certain susceptible microstructures. This study examines the effect of different welding variables with HIC performance.

Available literature on the welding of Q&T steels are mainly restricted to the low carbon types. Welding of medium carbon Q&T steels (like the one used in the present study) requires a totally different approach to get crack free joints. Also in the literature, quantitative data about the interactive effects of different welding variables like type of welding electrode, preheat temperature and post heating temperature are lacking. In this study therefore, detailed weldability tests using modified implant test (for heat affected zone) and Y-groove Tekken test (for the weld metal zone) are taken up. The objectives were to understand the individual and interactive influences of these welding variables on weld failures, which would result in evolving the conditions for crack free welds.

Y-groove Tekken test was used to determine the HIC resistance of the weld metal. Implant cracking test was used to determine the HIC resistance of heat affected zone (HAZ). The main welding variables investigated are the type of welding electrode, type of flux coating, preheating and post heating. A modified implant testing machine was

developed for this study and the welding and testing methods using this machine for testing the welded specimens were standardised.

The different electrodes used in this study were graded in terms of their tendency to produce diffusible hydrogen. Ferritic steel electrodes, austenitic steel electrodes and inconel (nickel base) electrodes were employed for welding. Diffusible hydrogen was analysed using an apparatus called "diffusible hydrogen determinator by mercury displacement method". These analyses show that the austenitic steel electrodes produced the least amount of diffusible hydrogen, among all the electrodes.

Implant tests indicated that HIC resistance can be improved by using appropriate austenitic steel electrodes. By preheating and also by post heating to appropriate temperatures, hydrogen embrittlement can be almost totally eliminated.

Residual stresses in the weldments were measured by using X-ray Diffraction. Susceptible microstructures were analysed using optical metallography and hardness survey.

When high preheating temperatures were used for austenitic stainless steel electrodes, weld metal deterioration occurred due to certain metallurgical transformations. When ferritic steel electrode, coated with basic flux, was used, this type of weld metal deterioration did not occur, but this electrode would require quite high preheat temperatures to avoid hydrogen embrittlement totally.

Influence of different welding variables on HAZ failure and weld metal failure is described by a map called "Weldability Map". "Safe" welding procedures can be evolved by knowing the interactive effects of the main welding variables from this map.