Thermo-Mechanical Simulations of Residual Stresses and Hydrogen Diffusion in a Part-Size Sleeve-on-Pipe Mock-Up for Remote Pipeline Repair Welding

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ABSTRACT
Detrimental hydrogen in the weld reduces its ductility and increases the possibility of cold cracking. The objective of this study has been to use computer simulations to predict residual stresses and decay of hydrogen in and adjacent to a 10 cm test weld which closes the gap between the sleeve and the pipe in a part-size sleeve-on-pipe mock-up for subsea pipeline repair applications. Pre- and post-weld heat treatment was applied to the test geometry which was designed to replicate the highest restraint level of a remote pipeline repair scenario. Two cases from the experiments were chosen for modeling, one successful that produced a crack-free weld and another which was given a lower PWHT temperature that generated a level of hydrogen assisted cracking. With respect to the incidence of cracking and the position where the crack was initiated, the microstructure composition, the tensile stresses and the level of hydrogen predicted by the computer model is considered to support the experimental findings.

KEY WORDS: welding; hydrogen diffusion; trapping; residual stresses; pipeline repair.

INTRODUCTION
Deeper waters impose considerable technological challenges for eventual pipeline repair and hot-tapping as diver assisted operations are not normally permitted below 180 m sea depth in the North Sea (Woodward, 2006). A concept of high-priority for Statoil has been to develop remote hyperbaric welding technology for pipelines at large sea depths. In August 2012, Statoil became the first company in the world to remotely weld a hot-tap tee connection at 265 meters water depth on the Asgard field in the Norwegian Sea. Plans for upgrading the equipment to work for water depth down to 2500 m have been launched, with the ambition to go even deeper to 4000 m.

Repair of a pipeline implies replacement of a damaged part with a new pipe section to be joined at the seabed, and for deep water it has to be remotely controlled. High-quality welds are essential as leakages are costly to repair, or even worse, a failure which may have serious consequences for the environment. Hydrogen assisted cracking (HAC) is a serious detrimental problem in welding of offshore steel structures. This mechanism causes loss of ductility and decrease of fracture resistance. Hydrogen cold-cracking has typically a delayed nature in that crack initiation and especially propagation may occur several hours, or sometimes even days or weeks, after welding has been completed.

For offshore pipelines, the main hydrogen sources are cathodic protection and hydrogen in the weld metal. Most often it is the heat affected zone (HAZ) adjacent to the weld that constitutes the critical area. Hydrogen dissolves in the weld metal and diffuses slowly to the surrounding steel structure through the typical brittle HAZ. Post weld heat treatment (PWHT) is an efficient and well-known method to reduce the hydrogen content in the weld and in the HAZ.

Previous experimental investigations conducted in a high-pressure welding chamber at Cranfield, where a single test weld was added to close the gap between a sleeve and a pipe, has identified a required level of PWHT and duration for the specific geometry and steel type that prevent the weld and/or HAZ to crack. At 100 bar, which corresponds to a water depth of 1000 m, parameters such as pipe surface temperature and sleeve-pipe gap-size were methodically varied and their influence on the weld’s tendency to crack logged. Due to the limited size of the chamber and the requirement to use the true pipe size, the test geometry was reduced to a part-size sleeve-on-pipe mock-up. The experimental work confirmed that PWHT has significant effect for avoiding cracks.

Two cases from these experiments have been chosen for modeling, w304.4 and w304.11. The pair is of particular interest since the main difference between them was the PWHT temperature and the fact that w304.4 created a crack-free weld, while w304.11 was given a lower PWHT temperature that generated a level of HAC. The same two cases have been studied in a previous work (Lindholm et al., 2013) where the influence of stresses on diffusion of hydrogen was neglected. The thermal conditions for both cases were replicated well by the computer model and the level of hydrogen in and adjacent to the weld after completed PWHT was considered to be reasonable compared to a hydrogen concentration crack criterion of 1-2 wt ppm (Wongpaya et al., 2007).