In-Situ Study of Ductility Dip Cracking in Nickel Alloys

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Nuclear power plant systems comprise hundreds of kilometres of pipework joined by thousands of welds. For efficient harnessing of nuclear energy, dissimilar metals have to be joined by welding, that is mainly austenitic stainless steel to ferritic-martensitic steels which have significantly different thermo-physical properties. A Nickel based weld filler, Alloy 52, is increasingly being used to construct such dissimilar metal welds (DMWs) in water cooled nuclear power plants across the globe to mitigate historic susceptibility of DMWs to stress corrosion cracking (which has compromised plant safety). In addition, this is a promising weld filler material for sodium cooled nuclear power plants currently under construction (e.g. in India) and for next generation nuclear power plants. However, Alloy 52 is prone to the occurrence of ductility-dip cracking (DDC) during welding (in the temperature range 750 to 1000 °C). DDC is a type of hot cracking, which differs from solidification cracking and liquation cracking, in the sense that no liquid phase is involved. Fine cracks occur at the grain boundaries which are nearly impossible to detect using conventional post-weld non-destructive evaluation methods (Fig. 1).

Control and prevention of DDC is highly desirable, but this requires a better understanding of the mechanisms and the conditions leading to the cracking. DDC is believed to occur by intergranular embrittlement, resulting from segregation of impurity elements such as sulphur and phosphorus (and micro-constituents forming because of this segregation) and the triaxial state of stress introduced by the welding thermo-mechanical cycle. However, the detailed mechanism of DDC is still under discussion and remains inconclusive.

The innovative idea behind this project is to study the development of DDC “in-situ” during a “Programmed Deformation Test” and elucidate the fundamental mechanisms and controlling conditions. A range of complementary state-of-the-art measurement techniques will be applied, for the first time, to study the phenomena, in both time and space, including neutron diffraction for bulk elastic strains, digital image correlation (DIC) for surface inelastic strains, neutron tomographic imaging for volumetric hot cracking and 3D DIC for quantifying the onset and propagation of surface cracking. The rich data obtained will be fully analysed to understand and quantify the state of stress and deformation (including cumulative history effects) which drive the initiation and propagation of DDC.