A MODEL OF INTERNAL CRACK EXTENSION DUE TO A CONTINUOUS BUILD-UP OF HYDROGEN PRESSURE : APPLICATION TO A PRESSURE VESSEL COMPONENT

Jean-Gabriel Sezgin, Mines Saint-Etienne, Univ Lyon, CNRS, UMR 5307 LGF, Centre SMS, F - 42023 Saint-Etienne, France, currently Framatome, Paris, France
jean-gabriel.sezgin@framatome.com
Cédric Bosch, Mines Saint-Etienne, Univ Lyon, CNRS, UMR 5307 LGF, F - 42023 Saint-Etienne, France
Aurore Montouchet, Framatome, Site du Creusot, 71200 Le Creusot, France
Gilles Perrin, Framatome, Paris, 92400 Courbevoie, France
Andrej Atrens, The University of Queensland, School of Mechanical and Mining Engineering, St Lucia, Australia
Krzysztof Wolski, Mines Saint-Etienne, Univ Lyon, CNRS, UMR 5307 LGF, F - 42023 Saint-Etienne, France

The present work was motivated by the occurrence of penny-shaped cavities within the thickness of massive shells used for manufacturing of pressure vessels. Such shells are produced from hollow ingots that contain some hydrogen, typically 1 ppm, coming from interaction between liquid steel and the environment. This hydrogen, if not properly desorbed, can lead to the formation of cavities, usually at MnS / steel interfaces. Such cavities can be formed by nucleation of sub-millimetre penny-shaped thin cracks in the vicinity of ghost lines and their extension due to the hydrogen uptake and pressure increase. Metallurgical aspects of 18MnNiMo5 steel [1], the use of a refined Abel-Noble Equation of State [2] and a scenario of crack initiation have already been published [3].

The present paper proposes a model for a discontinuous cavity extension and its application to support our interpretation that such an extension cannot be unlimited because of a fixed hydrogen content at the end of manufacturing and its progressive outgassing.

In the present crack propagation model, a heterogeneous material with sub-milimeter crack initiation sites continuously filled with hydrogen is considered as a starting point. For a given initial crack size and local fracture toughness, there is a critical hydrogen pressure that will results in the first crack propagation event. A discontinuous crack extension is assumed. In each event the crack restarts once the pressure due to hydrogen desorption exceeds the critical pressure and propagates over a fixed microstructural distance with a concomitant pressure decrease due to the volume increase. The 1D approach illustrates all assumptions based on metallurgical and thermodynamical approaches and provides a detailed algorithm for the calculation of crack propagation in a simplified 1D geometry. A more realistic 3D model additionally takes into account elastic deformation of the crack due to internal hydrogen pressure as well as a significantly increased hydrogen flux to the cavity. Quantitative evaluation of crack propagation rates as a function of the initial crack size and materials toughness is provided. This model is applied to the analysis of cracks recently observed in a pressure vessel shell at the end of the manufacturing process.

References :

[1] J.-G. Sezgin, C.Bosch, A. Montouchet, G. Perrin, K. Wolski, “Modelling of hydrogen induced pressurization of internal cavities”, Int. J. of Hydrogen, 42 [22] 15403-15414 (2017), DOI : 10.1016/j.ijhydene.2017.04.106

[2] J.-G. Sezgin, C.Bosch, A. Montouchet, G. Perrin, K. Wolski, “Modelling and simulation of hydrogen redistribution in a heterogeneous alloy during the cooling down to 200 degrees C”, Int. J. of Hydrogen, 42 [30] 19346-19358 (2017), DOI : 10.1016/j.ijhydene.2017.03.095

[3] J.-G. Sezgin, C.Bosch, A. Montouchet, G. Perrin, A. Atrens, K. Wolski, “Coupled hydrogen and phosphorous induced initiation of internal cracks in a large 18MnNiMo5 component”, Engineering Failure Analysis, Vol 104, pp 422-438 (2019), DOI : 10.1016/j.engfailanal.2019.06.014