The presence of a Ni interlayer reduces the fracture initiation toughness with 44% for testing in CP.

Material

Two different clad steel pipes are investigated in this study, presented in Table 1 as Sample A and Sample B.

The interface microstructure of both samples is presented in Figure 1. A continuous area of carbide precipitation is visible on the clad side of Sample B, attributed to carbon diffusion across the interface.

Microhardness measurements across the interface confirmed carbon diffusion, with an average clad value of 210 HV for Sample A and 350 HV for Sample B.

A versatile cohesive zone element with the capability to handle solute mass diffusion.

Prior to testing under CP, the specimens were pre-charged for 24 hours at -1050 mV

A finite element formulation for bulk mass diffusion which assumes that hydrogen resides either

2. A versatile cohesive zone element with the capability to handle solute mass diffusion.

The constitutive response of the cohesive elements is given by the traction separation law (TSL), a relationship between the crack separation, cohesive stress and cohesive energy.

Hydrogen diffusion influence is built into the TSL by a reduction of the cohesive energy at total failure (3).

The fracture initiation toughness is assessed using CT numerical modelling of Sample B.

Fracture toughness testing

Method

• CT specimens were machined with the notch at the dissimilar interface using EDM.
• Fracture mechanical testing was performed in air and under CP, with a constant loading rate of 0.74 N/min.
• Prior to testing under CP, the specimens were pre-charged for 24 hours at -1050 mV.
• A multiple specimen procedure was applied to establish CTOD-R curves and fracture initiation values following standard 73448-4 [1].

Results

• Figure 2 compares the linear best fit crack growth resistance curves, illustrating a significant influence of hydrogen on Sample B, while little to no influence of hydrogen on Sample A.
• Figure 3 presents the fracture surface profiles of Sample A and B tested under CP.
• Hydrogen reduced the CTOD fracture initiation toughness with 20% for Sample A and 85% for Sample B.
• The presence of a Ni-interlayer reduced the fracture initiation toughness with 44% for testing in air, while it raised the fracture initiation toughness with 216% for testing under CP.
• Fractographic investigations confirmed hydrogen influence, with a change in fracture surface appearance from dimpled ductile to cleavage morphology.

For Sample A, fracture occurred mainly in the Ni-interlayer, with initiation in the BM for testing under CP. Sample B revealed an alternating crack path, shifting between the cohesive interface and the BM, and with initiation in the BM for all samples.

Conclusions and further work

• The presence of a Ni-interlayer between clad and pipeline steel was found to reduce the fracture initiation toughness with 44% for testing in air, while it raised the fracture initiation toughness with 216% for testing under CP.
• Fracture mechanical testing of the weld heat-affected zone clad interface is currently being conducted in air and under CP.
• A coupled mass diffusion and cohesive analysis framework has been developed for numerically assessing the effect of hydrogen on the fracture toughness. Initial results were presented and compared with experiments.
• Nanomechanical testing is being considered as an option for establishing the mechanical properties at the Bi-bismutite interface, for input to the numerical model.
• A procedure for importing hydrogen concentration fields and residual stresses from WeldSim into Abaqus as initial boundary conditions has been developed, and will be applied in cohesive zone modelling of hydrogen induced fracture of repair welded clad pipes.

References


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