Fatigue crack initiation from corrosion pits in sour fluid

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Abstract. Oil and gas pipelines are subjected to cyclic loading and corrosive sour environment. The sour fluid leads to corrosion pitting. Fatigue cracks may be promoted at these geometrical discontinuities. Understanding the corrosion fatigue behaviour of pipeline materials helps to improve the prediction of crack initiation from corrosion pits hence optimising the asset inspection and repair schedules. This works presents a new test protocol to simulate the field environment using a bespoke corrosion fatigue test vessel and monitoring fatigue crack initiation using X-ray tomography. Also, to better understand the fatigue behaviour of corrosion pits, Finite Element Analysis (FEA) of corrosion pits in API-5L X65 grade steel has been carried out.

Introduction

API-5L Grade X65 steel are used in oil and gas pipeline due to relatively low cost, resistance to general corrosion and its mechanical properties. But, in sour fluid including Hydrogen Sulphide (H_2S) this grade of steel is prone to localised corrosion, i.e. pitting. The pipelines are also subjected to cyclic loading from sea waves, seabed, and internal pressure variation. At this condition corrosion pits are considered as one of the main factors in fatigue failure in oil and gas industry. To lower the risk of fatigue failure, a more reliable fatigue prediction model is required. Previous models that predict fatigue from corrosion pits are in benign environment whereas the model presented herein uses data obtained from environmental fatigue testing that replicates in service sour conditions.

Crack initiation from corrosion pits in different alloys were studied by researchers using FEA, however all have been based on simulations of the static loading employing elastic material model. The current study considers the effect of cyclic loading and accounts for the plastic deformation by 3D elastic-plastic FEA.

Previous studies have investigated the transition of pit to crack using ex-situ surface methods such as light microscopy or Scanning Electron Microscope (SEM) to probe the exterior of the material intermittently during and after fatigue testing. However, observation and monitoring of cracks initiated within the pit wall or base of the pit are not possible using this approach. In present work, a laboratory-based X-ray tomography was used to characterize the cracks initiated from corrosion pits.

Finite Element Analysis

The local stress-strain hysteresis loop at the corrosion pits were obtained from FEA (Figure 1) [1]. Figure 2 shows that despite the applied cyclic stress being tensile-tensile, the local stress could be tensile-compressive depending on the size and level of applied stress. It is apparent from Figure 2 that more compressive stress is experienced for higher aspect ratios. Areas under compression are likely to act as cathode with respect to nearby areas that are under tensile stress. Also comparing analysis with the experiments showed that cracks were initiated at the pit shoulders where highest strain level was seen in FEA [2]. The local stress was also calculated using Glinka and Neuber's approaches that showed delivery of local stress and strain range within 20% of the values predicted using FEA [1].

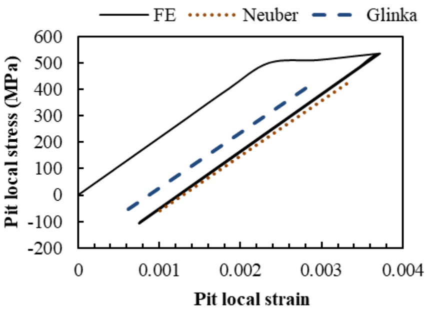

Figure 1. Local stress-strain hysteresis loop for pit aspect ratio of 0.54 under applied stress ratio of 0.1 [1]

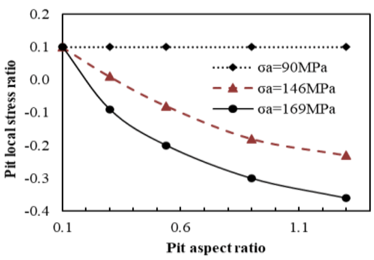

Figure 2. Relationship between local stress ratio and pit geometry with respect to applied stress amplitude [1]

Experiments

To establish the S-N data in air and real in-service environment fatigue tests were carried out on smooth samples. A bespoke environmental test vessel was designed and fabricated to undertake in-situ corrosive fatigue tests in 3.5% NaCl solution saturated with CO_2 and H_2S gas (Figure 3) [3]. 13 pre-pitted samples were tested in sour environment to study the transition to fatigue crack, from which three tests were interrupted at different cycles to take X-ray tomography images of the samples without the need to remove the specimen from the test cell. X-ray images resulted that 90% of the fatigue life belonged to transition of pit to crack. Figure 4 includes the result of 10 pre-pitted samples that were not interrupted [4]. A crack initiation model was proposed combining the local stress calculated by Glinka's approach and obtained material's S-N data. Figures 5 and 6 compare the experiments and prediction.

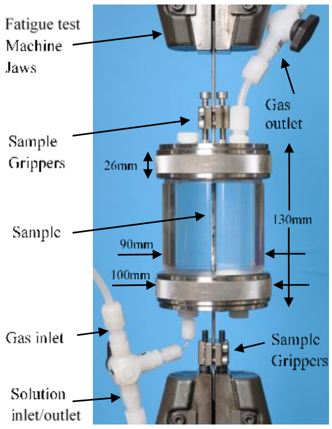

Figure 3. The bespoke corrosion fatigue test apparatus mounted in the fatigue test machine [3].

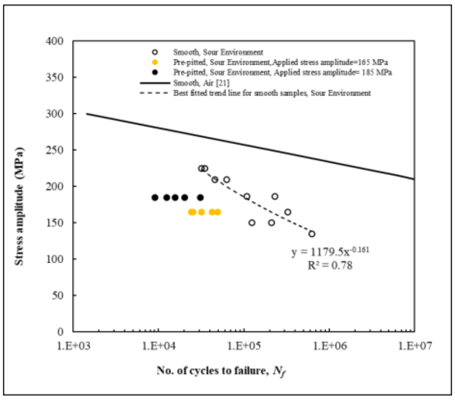

Figure 4. Stress vs. Number of load cycles to failure for X65 steel tested at *R*= 0.1 in the air and sour environment (smooth and pre-pitted specimens) [4]

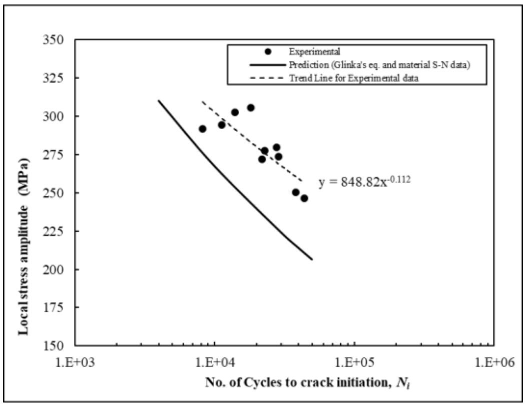

Figure 5. Comparison of predicted crack initiation life with the experimental test in the sour environment (pre-pitted specimens) [4]

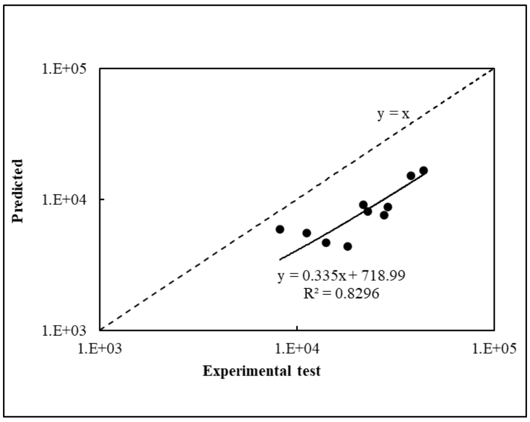

Figure 6. Comparison of experiment with prediction in terms of the number of cycles to crack initiation [4]

Conclusion

a)The local hysteresis loops revealed that at the applied stress ratio of 0.1, the pit local stress ratio varies from 0.1 to -0.2. b)The Glinka and Neuber's approaches are alternatives to computationally expensive FEA. c)The safe and reproducible performance of the apparatus and test methodology in sour saline solutions has been demonstrated. d)The average difference between the predicted life and experimental test result was about 16% and the prediction was on the conservative side.

References

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