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INTEGRITY MANAGEMENT OF STRESS-CORROSION CRACKING IN PIPELINES

A CASE STUDY

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Background

Pipeline failures due to Stress Corrosion Cracking (SCC) have been well documented and although the types of SCC and associated risk factors are generally understood, managing SCC remains one of the major challenges for operators in the pipeline industry. As the Electro- Magnetic Acoustic Transducer (EMAT) technology emits ultrasound waves without the need for a coupling medium between the sensors and the pipe wall, it constitutes a key part of an integrated integrity approach to SCC management for both liquid and gas pipelines.

This case study describes the approach and subsequent steps taken by a pipeline operator following an in-service failure and hydro-test, to assess the Fitness-for-Service of the pipeline and ensure future safe operation. The activities included in chronological order:

• Pre-qualification of both EMAT and circumferential field MFL technologies

• In-line Inspection (using both EMAT and circumferential field MFL technologies)

• In-field verification work and correlation with ILI findings

• Fitness-for-Service assessment of the ILI findings, including comparison of methodologies

• Estimation of SCC growth rates

• ILI re-inspection after 3 year

• Run comparison and crack growth assessment

• In-field verification work and correlation with ILI findings

• Fitness-for-Service re-assessment of the ILI findings

Aim

The in-service failure was the first time that the problem of high-pH SCC had been discovered on this pipeline. A series of actions followed to determine the scale of the threat, in order to prevent further failures. The primary stage was to hydro-test approximately 30 miles of the pipeline to 110% SMYS; a process which resulted in a further 3 failures. The operator also recognized the need to locate and detect the size of the SCC anomalies within the pipeline, to enable an appropriate and safe integrity management & repair plan to be defined. Following the hydro-test and a number of in-field investigations, it was therefore decided that an in-line inspection would provide an appropriate measure of the linear anomalies within the pipeline. Standard crack detection and ultrasonic inspection tools are costly to run in gas pipelines, due to the need for a liquid couplant. The operator therefore looked towards the recent development of the ROSEN EMAT (Electro-Magnetic Acoustic Transducer) tools. The eventual aim of the operator is to replace the hydro-test with in-line inspection.

EMAT tools can detect linear anomalies such as SCC related features. They also provide complementary information on external coating types and bonding conditions. The results of the inspection were combined with those from a circumferentially orientated MFL tool, in order to detect and determine the location of external corrosion. An engineering critical assessment (ECA) using the results of the inspections was then conducted by MACAW Engineering, to provide an account of the integrity of the pipeline.

Methods

Prior to the actual in-line inspection, a prequalification test following Section 9 of API 1163 (2005) was conducted at the ROSEN facility in Houston, USA. The EMAT inspection was conducted in October 2010 and the data were subsequently assessed by the ROSEN Data Analysis Group in Germany. First EMAT ILI was conducted in October 2010 and the pipeline has been re-inspected in June 2013. ILI data were subsequently assessed by the ROSEN Data Analysis Group in Germany.

The EMAT tool induces ultrasound waves into the pipe wall and as such it typically records several thousand indications of both linear and volumetric character during an inspection. In this project, 510 indications of isolated cracks, crack fields and anomalies with crack-like character were identified.

API 579 provides a procedure for assessing crack-like anomalies (Section 9) based on a failure assessment diagram (FAD). The FAD shows the relative susceptibility of a crack to fail either by fracture or plastic collapse. If the assessment point is on or inside the FAD then the flaw is acceptable. If the assessment point is outside the FAD then the flaw is unacceptable. Assessments were carried out at both the MAOP and the MOP at the request of the client. The fracture toughness was estimated from Charpy data, conservatively using a lower bound correlation.

Results

In accordance with API 579 Part 9, a reduction in residual stress is allowed if the weld has been subjected to post weld heat treatment (PWHT) and/or has been subject to a pressure test. It is understood that this pipeline had not undergone any form of post weld heat treatment, therefore only the effect of the pre-service pressure test upon weld residual stresses were considered within the assessment. The API 579 Level 2 FAD at the MOP of the 2010 inspection run is shown in Fig. 1, which was conducted with and without the inclusion of the specified ROSEN EMAT inspection tool tolerances.

As shown, at the maximum operating pressure a total of 16 anomalies (including the addition of sizing tolerances) were unacceptable for operation according to the API 579 Level 2 assessment. The level 2 assessment was also conducted at the pressure equivalent to the hydrotest at 110% SMYS. This resulted in all reported linear anomalies failing the assessment, both with and without the inclusion of inspection tool tolerances. As the reported linear anomalies were demonstrably shown to have passed the hydro-test, this illustrates the conservatism inherent within the level 2 assessment.

Growth rates for stress-corrosion cracks typically vary considerably over time, and as the pipeline ages the crack growth velocity is likely to increase due to mechanical growth and coalescence. This is shown in Figure 2.

In order to predict the time taken for a crack to grow to a critical size, some assumption must be made regarding the time dependence of the growth rate. In the absence of specific data, a constant growth rate is often assumed. Quoted growth rates from the industry vary around 8 – 12 mpy (0.2-0.3 mm/year), however these are typically average values and may not account for crack coalescence [1].

Crack growth rates of up to 30 mpy (0.76 mm/year) have been deduced from metallographic examinations of cracks which had survived a hydrostatic test several years earlier. Current industry guidance suggests that for a pipeline which has had a single hydro-test, a growth rate of 0.76 mm/year can conservatively be assumed to give a safe hydro-test / inspection interval of 3 years [2]. In contrast to other available sources of literature, this growth rate is considered to be the most conservative and allows for instances of crack coalescence. Consequently, a growth rate of 0.76 mm/year was conservatively applied in assessing the future integrity of this pipeline.

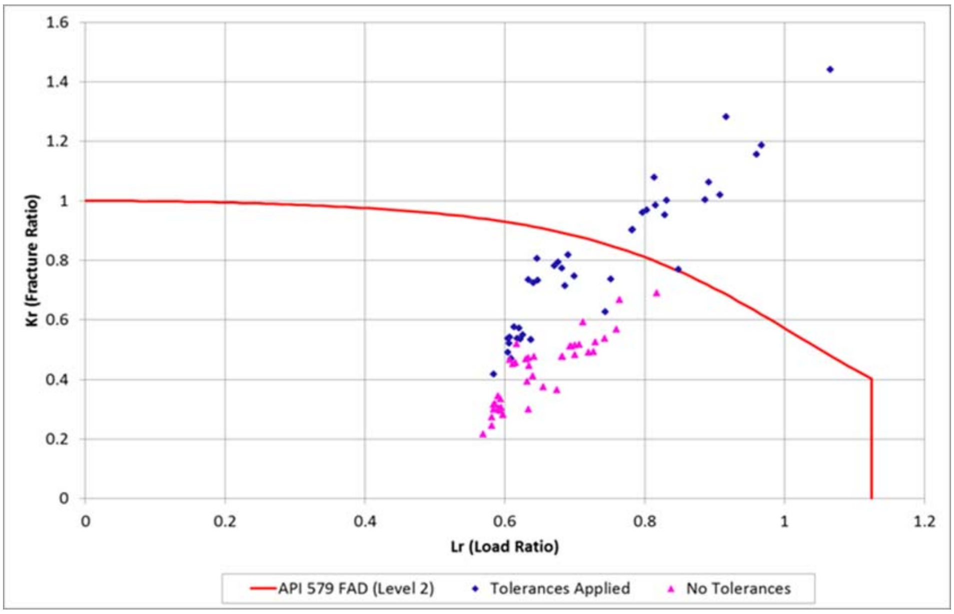

Figure 1: API 579 Level 2 FAD Curve Assessment, Linear Anomalies and Groups

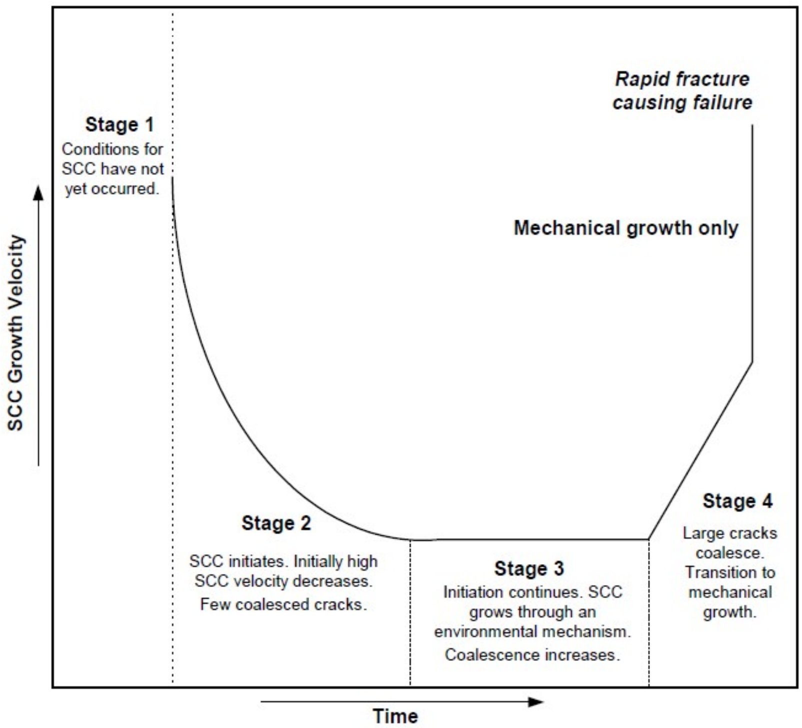

Figure 2: Bathtub Model: Life-Cycle of SCC Growth in Pipelines, Parkins (1987) cited by CEPA

Conclusions

The EMAT technology is an effective means for the in-line inspection of gas and liquid pipelines. It is a sensitive and accurate crack detection tool with high Probability of Identification (POI). The combination of EMAT and CMFL increases the inspection scope and POI for cracks. An accurate continuous depth sizing with EMAT is prerequisite for FFS, e.g. according to API 579.

The API 579 level 2 FAD based assessment was conservative in the Assessment of SDD for this line. However, the results were useful in prioritising features for in-field verification. A more detailed and representative analysis could be obtained through an API 579 Level 3 ductile tearing analysis. Estimates of SCC growth rates can be obtained from industry wide practice.

The EMAT and in-filed verification results in the segment known to have suffered failures, demonstrated that SCC of subcritical dimensions could be identified, it also showed that there were few SCC colonies outside of the area.

References

[1] Banff Pipeline Workshop Proceedings, Managing Pipeline Integrity, The 11th Workshop, Questions and Answers, Working Group 5 – Management of Stress Corrosion Cracking, April 4-7 2011.

[2] FESSLER, R.R., BATTE, A.D., HERETH, M., Integrity Management of Stress Corrosion Cracking in Gas Pipeline High Consequence Areas, STP-PT-011, ASME Standards Technology, LLC, 2008