NEAR-NEUTRAL STRESS CORROSION CRACKING OF BURIED PIPELINES: FIELD EXPERIENCE AND RESEARCH RESULTS

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Using the example of the research on near-neutral stress corrosion cracking, a comparison of field experience and laboratory research methodologies is made.

The review is certainly not complete, but sufficient to highlight the limitation of laboratory research activities and the sometimes conflicting results.

In order to improve the relationship between industry and research laboratories, the importance of stress corrosion cracking to the integrity of existing lines is outlined together with items still not solved for the design of new lines.

Making use of the wide experience of the Canadian companies, an overview of the achievements of the current research is presented and the areas for further research discussed.

INTRODUCTION

The task of the research department within a gas company is to find answers to the needs of the industry, in many instances with the contribution of research laboratories. The relationship between industry and external research centres is not always as good as it should be, and a good amount of time and money is wasted because of different mind sets.

Gas companies have funded a large amount of research in the field of stress corrosion cracking (SCC) of buried pipelines, however they appear to be normally unaware of research carried out by Universities, or State Research Centres, as conferences attended by technical people involved in pipeline research are rather specific, and so is the literature.

The goal of the paper is to make an overview of the near-neutral SCC activities, as understood from a gas company point of view, outlining the research requirements coming from the needs and the experience of the users.

FIELD EXPERIENCE

The near-neutral stress corrosion cracking (SCC) entered the history of gas transmission with three pipeline failures, between March 1985 and March 1986, and is now considered a significant threat to the integrity of pipelines. Most of the failures attributed to near

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neutral stress corrosion cracking occurred in Canada and in Russia, and some occurred in the United States, but until now no significant failure has occurred in Europe.

The environment responsible for the occurrence of stress corrosion cracking is groundwater with pH from 5.5 to 7 at free corrosion potentials. Pipelines are protected against corrosion by cathodic protection that moves the potential at coating fault locations to levels where there is no risk of stress corrosion cracking. Experience has however shown that some kind of coating, namely polyethylene tapes, are prone to a specific phenomenon called disbonding, that can lead to SCC occurrence.

When the tapes are applied in the field, if the pipe surface has been poorly prepared, a lack of adhesion between the metal surface and the tape can occur, while good bonding between overlapping tapes is obtained. The result is the formation of a ridge where the external environment penetrates, but due to the long and very narrow channel between the disbonded area and the outside, the electric current cannot enter. In most cases the areas of disbonded coating develop corrosion, sometimes cracking. In terms of danger the difference lies in a faster growth rate and in the difficulty of detecting the occurrence of the cracking at an initial stage. While corroded areas can be reliably found using in line inspection tools, their ability to detect longitudinal cracks is still uncertain.

The material is not a distinctive characteristic, as linepipe steels commonly used showed the same susceptibility. Pipe failures occurred on API grades B to X65 with a minimum specified yield strength (SMYS) between 241 MPa to 448 MPa.

There is instead an effect of the applied stress. Failures from longitudinal defects in gas pipelines occurred in Canada at a minimum applied hoop stress of 65% SMYS, while most of the failures occurred at hoop stresses ranging from 70% to 77% SMYS, as reported in the National Energy Board publication (1). Oil lines had failures down to 46% SMYS, possibly because of the higher cycling associated with oil transportation.

When the hoop stress falls below 60% SMYS and longitudinal stress becomes important then circumferential cracking can occur. Circumferential cracking however is not seen as a significant problem, as it affects mainly small diameter lines (the low stiffness of such pipes makes them more susceptible to longitudinal stresses) and it will result in a gas leak, not in a rupture.

Near-neutral SCC has not been a significant problem in Europe, probably because the applied stress is mostly near or below 65% SMYS. Lower stresses are applied to pipelines near urban areas that are operated at very low design factors and in all the transmission pipelines of some countries, as Germany, where a minimum safety factor of 1.6 (hoop stress equal to 62.5% SMYS) is required.

LABORATORY RESEARCH

The research on near-neutral SCC have been carried out by various laboratories and only a limited amount of activities is considered here, having given priority to the papers easily available within a gas company. The goal of the review is to examine the test methodologies used and how much they correctly simulate field behaviour.

A very severe test method that has gained some acceptance as a fast test for materials screening is the slow strain rate test. Parkins (2) applied this test methodology to the near-neutral SCC. The test results show a decrease in the reduction of area, indication of a higher susceptibility, with decreasing potential from the free corrosion to the cathodic protection potentials. A crude interpretation would be that coating fault under cathodic protection are a lot more affected by cracking than areas under disbonded coating, what is contrary to the common experience of pipeline operators.

Other researchers have applied the slow strain rate test, using as indication of SCC susceptibility different parameters: reduction of area, elongation at fracture, presence of cracks on the specimen in the area of necking or outside. The test appears always rather severe and has the strong disadvantage of not allowing any consideration about applied stress or crack growth rate.

Parkins (3) did a significant activity using tensile testing specimens with the outside surface of the pipe left not machined in order to facilitate crack growth from the original micro-pits. The tests were performed under cyclic loading for times as long as 6000 hours. Metallographic sections were used to detect and measure cracks, the majority of them measuring by the end of the test just tens of microns, very few reaching 0.1 mm crack depth. If we had not field experience of failures, we would probably predict, using the constant load test, that no failure should be expected.

The cyclic loading was applied with an R ratio (minimum divided by maximum stress) of 0.85 at very low frequencies between 7.4 10^{-2} Hz and 4.3 10^{-4} Hz. Pressure fluctuations recorded on a gas transmission pipeline (4) had R ratios between 0.95 and 0.85 and frequencies between 10^{-4} Hz to 10^{-3} Hz. The importance of cycling loading and the amount applied during the tests is controversial and is probably not a necessary condition for cracking. Circumferential cracks occurred in the field under the effect of static or slowly increasing load.

A large research effort has been devoted to crack growth rate measurement during propagation, using pre-cracked specimens under slowly increasing or cyclic load. Beavers (5) tested fracture mechanics specimens under continuously increasing load, at an applied displacement rate of 1.27 10^{-6} mm/s. It was found however that the applied J-integrals and the crack growth rates measured exceeded by at least one order of magnitude field data. The test duration was about one month and a significant decrease in displacement rate appears difficult to obtain.

In a following research program, Beavers (4) used the same test specimens under cyclic loading, at a frequency between 10^{-4} Hz to 10^{-5} Hz, the latter corresponding to a cycle period of 27.8 hours and with a test time of two to three months. In these tests crack growth rates of about 2 10^{-8} mm/s at an R ratio of 0.9 were measured, in better agreement with field data. Decreasing R ratio to 0.6 resulted in a crack velocity more than double.

Zheng (6) used full scale pipes with natural and artificial cracks in an environment closely simulating field conditions. The R ratio was between 0.5 and 0.6 with test frequency of about 10^{-3} Hz. Measured crack growth rates were around 10^{-6} mm/s at a maximum stress of 105% SMYS, then decreasing to 10^{-7} mm/s at a maximum stress of

90% SMYS and to 10^{-8} mm/s at 72% SMYS. During the following periods however no measurable crack growth was detected when the stress was raised again first at 80% SMYS and then at 90% SMYS.

The picture that arises from the research activities outlined above is not encouraging. A better knowledge of the environment responsible of SCC has been gained and crack growth rates comparable to the field have been measured, however most of the understanding of the phenomenon still comes from field experience. The study of near-neutral SCC requires long test times and is affected by an unfortunate high scatter of results. Significant problems are found in correctly simulating the field behaviour and hasty conclusion, sometimes full of consequences for pipeline operators, should be avoided.

INDUSTRY NEEDS

The National Energy Board of Canada required each oil and gas company to have a management program to control the risk of failure by SCC. The program must contain three principal components: determination of pipeline susceptibility and active monitoring of pipelines believed to be susceptible to SCC, mitigation if significant SCC is found, recording and sharing of information on susceptible pipelines.

The key factor is of course the determination of susceptibility to SCC. Predictive models have been developed to identify and rank areas along a pipeline that most likely are affected by stress corrosion cracks. The available data comes from the construction records and the operational history: coatings applied, cathodic protection potentials, different soil types and geographical features crossed by the pipeline, stress profile and pressure fluctuations.

The lines with higher chances of SCC must then be inspected. Digging the most probable sites and verifying the presence of crack through magnetic particle inspection appears to be the best practice at the moment. Running an inspection with a tool specifically devoted to the detection of longitudinal cracks is very expensive and still at a research stage and would be motivated only by a very high probability of cracking.

Hydraulic tests at high hoop stress allow safe operation of the line in the time interval needed to grow the crack from the critical dimensions at the hydraulic test stress to the critical dimensions at the operating pressure. The knowledge of the crack growth rate is therefore crucial to the safe and economic operation of the line. The use of reliable in line inspection tools can substitute the hydraulic tests and allow larger safety margins by detecting cracks at an earlier stage, and repairing them. The determination of crack growth rate is however still important for the definition of inspection frequency.

Table 1 shows the complete list of items under consideration by Canadian companies with regards to SCC research items. The expected benefits of the research are divided among the increased ability to define the risk of having stress corrosion cracking on a line (Monitoring), to select the lines having higher chances in order to first devote resources to them (Prioritizing), and to detect and repair cracks (Mitigation).

Table 1. Current and future research items according to the Canadian Energy Pipeline Association (1).

				Management program benefit		
	Research subject	Current	Future	Monitoring	Prioritizing	Mitigation
1	Coating disbondment	X		X		
2	Behaviour of high performance coating		X	X		
3	Cracking environment - mechanistic studies	X		X	X	
4	Macroscopic behaviour of crack / colonies	X		X	X	
5	Effect of surface conditions		X	X	X	
6	Effect of periodic pressure variations	X		X	X	
7	Effect of realistic pressure variations		X	X	X	
8	Residual stress		X	X	X	
9	Effect of steel composition and microstructure on susceptibility	X	X	X		
10	Cyclic stress / strain behaviour		X	X	X	
11	In -line inspection	X		X		X
12	Hydrostatic testing	X				X

The National Energy Board (1) remarked that the items with greater impact on pipeline operations were:

- SCC detection through in-line inspection tools, to overcome the limited ability to detect cracks of hydrostatic re-testing and selective excavations based on predictive models;
- hydrostatic re-test frequency; being the only method to guarantee safe operation of a line, the re-test frequency must be calibrated on the knowledge of crack growth rates and critical defect dimensions at various pressure levels, and how hydrostatic testing affects them;
- monitoring the long term performance of pipe coatings;

- analysis of the SCC database of the Canadian companies to refine predictive models and point out future research areas.

For the European gas companies the safe operation of lines containing cracks is not a high priority, as no major failure occurred in Europe, consequently the interest concentrates on pipeline design and construction. For new constructions, mainly for long distance pipelines carrying gas from remote fields in Siberia or Central Asia to Europe, the use of high grade material is a way of achieving a significant reduction in construction costs. Pipeline of API steel grade X80 have already been laid in Germany and Canada, and X100 is under research. The behaviour of high grade materials with reference to SCC will be then a very important subject of research.

Pipelines for oil and gas transportation can be designed with a maximum applied stress of 77% SMYS, that can be increased to 83% for locations subject to infrequent human activity and without human habitation. As such stress levels appear associated with a significant risk of SCC, the only line of defence against cracking will be through the development of good coatings with excellent adhesion and low susceptibility to the surface preparation.

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