A STOCHASTIC CONTINUUM DAMAGE MECHANISM APPROACH TO STRESS CORROSION CRACKING (SCC) ASSESSMENTOF PIPELINES

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ABSTRACT

The increasing energy development activities in the world impose the viability of pipeline for the safe and economical working. Pipelines mainly transport chemicals and hazardous fluids hence need to have very good safe track record and proved to be a safe and economical mean of carrying them. To lay down this platform, extensive research and development program has lead to appropriate design, selection of suitable materials and good operational practices. The optimization of selecting and evaluating coatings for feasible use in northern pipelines is of great importance with respect to the extreme environments to which the coated pipe may be subjected. Still failure occurs in pipelines due to some instants. Major cause of this failure includes crack formation and it's propagation over the surface of the pipe. Key cause behind these unwanted cracks is induced due to stressed corrosion cracking (SCC). The reasons behind SSC include the crevice loads, hydrogen embrittlement, residual stresses and film induce cleavage. The main objective of this article is to explore mechanisms and morphology of cracks propagation due to stress corrosion cracking to the pipe wall and its effect over the pipe span.

Keywords: *Pipelines, Crack propagation, Stress corrosion cracking, Hydrogen embrittlement.*

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1. INTRODUCTION

Stress Corrosion Cracking (SCC) is a failure phenomenon which occurs in engineering metallic materials by slow environmentally induced crack propagation.SCC is a very insidious phenomenon since cracks can initiate and propagate with little outside evidence of corrosion.SCC is a complex phenomenon and in many cases its mechanisms have not been fully understood [1]. If a stress exists in a product exposed to a corrosive environment, the rate of corrosion can then increase and be extremely localized, such as at the tip of a growing crack. Furthermore, some specific chemicals are so aggressive that corrosion will occur at relatively low stress levels, such as those created during manufacture, for example. The residual stress in a component can then be enough to trigger crack growth and failure.. Therefore study of root causes of corrosion and cracks and their mitigation is vital. Stress corrosion cracking is cracking due to a process involving conjoint corrosion and straining of a metal due to residual or applied stresses [2]. The phenomenon is associated with combination of two types of stresses, applied and residual above the threshold values, soil properties, environmental conditions and metallurgical aspects of pipe material. The causes of stress corrosion cracking of API 5L X60 steel gas pipeline that was installed in the northern regions of Iran, has been studied. Chemical analysis of alloy steel pipeline above in comparison with the standard API SPEC 5L Grade X60 is given in Table 1

Table 1 [3]: Chemical composition of steel pipeline suffers stress corrosion cracking in comparison with API SPEC 5L Grade X60

	Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	V	Ti	Co	Al	Sn	As
Specimen	Base	0.12	0.3	1.2	0.029	0.016	0.01	0.01	0.01	0.03	0.061	0.002	0.007	0.017	0.002	0.005
API 5L X60	-	Max 0.22	-	Max 1.4	Max 0.03	Max 0.03	-	-	-	-	-	-	-	-	-	-

The SCC on the upper surface of pipelines has been seen occurred in many countries including Australia, Iran, Pakistan and united States [4,5]. The key thing is that SCC occurs with a static stress, while corrosion fatigue requires cyclic stress.

Example Many materials, particularly high strength materials, are susceptible to stress corrosion cracking when exposed to a specific environment. For example, cold worked brass, which is found in ammunition cartridges, is susceptible to stress corrosion cracking when exposed to an environment containing ammonia.Figure 1 shows a micrograph of cracks formed on steel plate due to SCC damage where the roots of cracks are initiated from pipe surface and moved down to cover the entire.

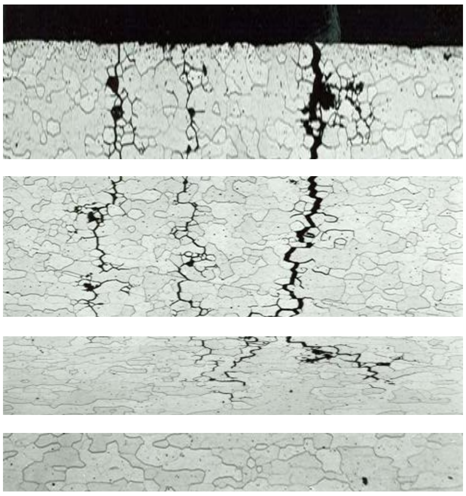

Figure 1. Cadmium plated steel plate with SCC damage [8]

2. MECHANISMS OF SCC

The Stressed Corrosion Cracking mainly depends on both an aggressive environment and a tensile stress. Main role of tensile stress is to open up cracks in the material. It can be either directly applied or residual in form. An example of residual stress resulting in stress corrosion cracking of brass is after deep drawing. Large hoop residual tensile stresses are present after the deep drawing process. If an aggressive environment is placed on the brass, cracks will appear due to the conjoint action of the stress and the environment. In its early days this was called "season cracking" as it occurred during the monsoon season in India on brass bullets and cartridge shells due to ammonia from rotting vegetation rendering them useless as they stress corrosion cracked. Similarly "caustic embrittlement" is due to sodium hydroxide in combination with residual stresses on steels.

Stress corrosion cracking can be separated into two distinct regions, crack initiation and crack propagation.

2.1 Crack Initiation

Cracks can be initiated by following mechanisms:-

2.1.1 Mechanical Features

Cracks will often initiate at features such as scratches, nicks or dents on the surface of the metal. In this case the local environment or local stress conditions favor enhanced dissolution, poor formation of a passive film or in-situ damage to a protective film.

2.1.2 Local galvanic cells initiating dissolution

Local corrosive effects dominate the process where the local galvanic cell locally dissolves one phase of the material. This will also localize the stress on the material. The crack in this case may initiate in a transgranular mode or an intergranular mode. One example of the latter would be intergranular cracks during SCC of sensitized stainless steels.

2.1.3 Pitting type crack initiation

The pitting potential is related to formation of its and there is some correlation between the pitting potential and the potential for stress corrosion cracking. A 10:1 ratio of pit depth to width was suggested to be needed for a pit to initiate a crack. The local environment in a pit may also be important in the crack growth process. For example, the environment in a pit mat favor crack growth by intergranular crack growth. Several studies were made employing a pit as an effective crack in the surface to be used in linear elastic fracture mechanics approach. These have met with some success. However electrochemical effects can nullify this approach.

2.1.4 Initiation at stress induced phenomena

Thus phenomenon is due to the slip lines which can have a double effect when they intersect the surface. One is to provide local anodes as the site is very active. The second is to rupture passive films on the surface and locally form dissolving regions. Once a crack has initiated, then it will grow. As pointed out above the growth mechanism may not be the same as the initiation process. Several mechanisms were proposed to explain the observed features of SCC crack growth.

2.2 Crack Growth Mechanisms

One important feature for SCC cracks is that some show clear evidence of stopping and starting. The cracks do not continually grow to failure. The mechanisms proposed try and take this factor into account.

2.2.1 Film Rupture Mechanism

The tensile stress ruptures films at the crack tip and the crack grows rapidly from the bare metal exposed until the crack tip can repassivate in some cases or grow slowly to failure in other cases. Unfortunately, SCC cracks often have significant features on their faces which should be removed by local dissolution effects. In addition the crack plane in transgranular failure is often not the active slip system in the metal [6]. Others have suggested a similar model in which the film is formed by a tarnish process. Intergranular corrosion is proposed to occur by preferential oxidation of the grain boundaries.

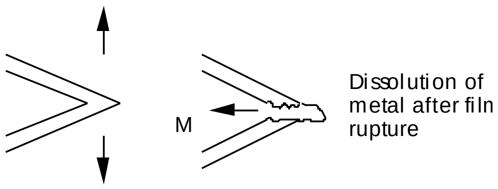

Figure 2 metallic dislocation after film breakage

2.2.2 Film Cleavage Mechanism

In this mechanism, the surface film grows and may increase in internal stress with thickness. This combined with the applied tensile stress induces brittle failure in the film which propagates across into the metal and provides a period of crack growth. The loss of the film stress and plasticity in the metal than blunts the crack and stops it growing to give periods of crack growth followed by rest while the film grows back to the conditions for cleavage. The film induced cleavage Cracks initiated in a brittle surface film may move(over a microscopic distance) into underlying more ductile material, before being arrested by the blunts of ductile materials at the tip of cracks as appropriately seen if the film of brittle material reforms over neck tip of blunted crack, such a process could be repeated [7].

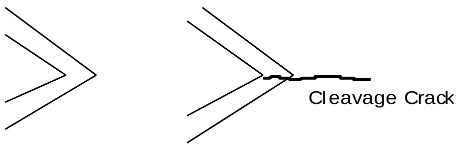

Figure 3 Film Cleavage crack

2.2.3 Adsorption Induced Cleavage

During the electrochemical process atoms are absorbed on the surface that weakens the bonds. The stress to initiate a crack then decreases and a crack grows until it is blunted by plastic deformation or grows out of the adsorbed region.

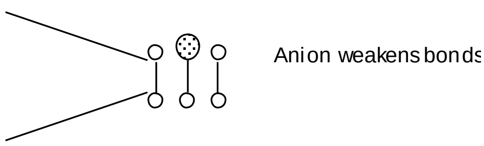

Figure 4 anionic bond formation

2.2.4 Adsorption Induced Plasticity (AIP)

The adsorption of specific ions in this cases reduces the critical resolved shear stress for dislocation mobility. Dislocations can then move locally under the influence of the tensile stress. This is different from the above model where the cohesive strength was decreased but not the resolved shear stress as in this case.

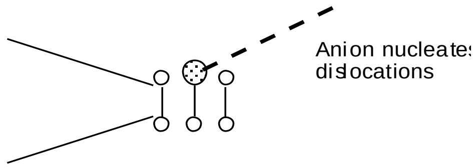

Figure 5 Dislocality due to AIP

2.2.5 Atomic Surface Mobility

At the crack tip atoms move away from the tip and vacancies move in by a surface diffusion process coupled with electrochemical activity. There is not a lot of support for this mechanism at present.

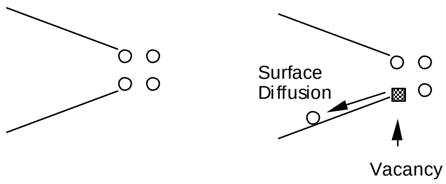

Figure 6 Vacancy Creation Due To Mobility

2.2.6 Corrosion Tunnel Model

In this case, corrosion tunnels are formed by active corrosion alone emerging slip lines. When sufficient metal is removed in the tunnels, then the undissolved regions between them fracture by ductile overload and some crack growth occurs until it is plastically blunted and the process starts again. A later modification suggested the tunnels were slots on an atomic scale which can only be formed in stainless steels by SCC conditions.

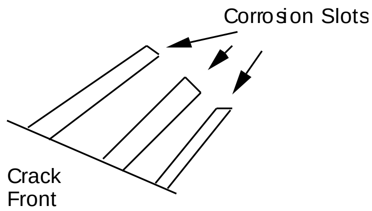

Figure 7 Corrosion Slotting

3. HYDROGEN EMBRITTLEMENT

Hydrogen dissolves in all metals to a moderate extent. It is a very small atom, and fits in between the metal atoms in the crystals of the metal.3 consequently it can diffuse much more rapidly than larger atoms. For example, the diffusion coefficient for hydrogen in ferrites steel at room temperature is similar to the diffusion coefficient for salt in water. Hydrogen tends to be attracted to regions of high triaxial tensile stress where the metal structure is dilated. Thus, it is drawn to the regions ahead of cracks or notches that are under stress. The dissolved hydrogen then assists in the fracture of the metal, possibly by making cleavage easier or possibly by assisting in the development of intense local plastic deformation. These effects lead to embrittlement of the metal; cracking may be either inter- or transgranular. Crack growth rates are typically relatively rapid, up to 1 mm/s in the most extreme cases. Macro hardness Vickers tests of base metals show low hardness in base material that allows one to discard susceptibility to hydrogen embrittlement, possibly generated by cathodic overprotection [8].

CONCLUSION

The formation and propagation of active defects on external surface steel pipeline immersed in corrosive environments shows its possible susceptibility to SCC failures in such aggressive media. In this study, different mechanism views above showed the combination of micro cleavage, intergranular and branched stress corrosion cracks with high-pH. In view of the above, the following recommendations are made to prevent the recurrence of similar failures caused by stress corrosion cracking of the pipelines.

(1) Diagnosis the place of the cracks by destructive and non-destructive tests, to prevent them from growing up.

(2) The prevention or reduction of the growth of stress corrosion cracks, to prevent them from reaching the critical size.

In general, prevention of SCC requires elimination of one of the three conditions – tensile stress, a critical environment or a susceptible alloy. Also changing the environment, electrochemical potential, level of stress and temperature, using inhibitors (organic or inorganic inhibitors) and new coatings are considered as other ways of preventing stress corrosion cracking.

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