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Analyzing Defects with Failure Assessment Diagrams of Gas Pipelines

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***Abstract*—**The approach in analyzing defects on different pipe lines is conducted through Failure Assessment Diagram (FAD). These methods of analyses have further extended in recent years. This approach is used to identify and stress out a solution for the defects which randomly occur with gas pipes such are corrosion defects, gauge defects, and combination of defects where gauge and dents are included. Few of the defects are to be analyzed in this paper where our main focus will be the fracture of cast Iron pipes, elastic-plastic failure and plastic collapse of X52 steel pipes for gas transport. We need to conduct a calculation of probability of the defects in order to predict and avoid such costly defects.

***Keywords*—**Defects, Failure Assessment Diagrams, Safety Factor Steel Pipes.

I. Introduction

ENERGY is a key factor to economic development where gas mounts up large portion of world energy sources. However, gas fields are located in long distances from the industrialized zones. In order to feed these industries with gas, pipeline transmission systems are needed.

Gas is a product which can cause security problems for environment, people, and industry. To keep our environment safe, we must analyze any pipeline defects, in order to avoid, or at least to minimize the danger that may occur. In order to avoid the danger which occurs due to external factors, we need to analyze the defects through Failure Assessment Diagram (FAD), based on three domains: brittle fracture, elastic-plastic fracture, and plastic collapse [1].

The defects can occur in different stages of its operation, as result we have to use several forms for repairing them. In a particular situation, it can happen that a defect is a small one and it can be repaired while the pipes are still conducting their function of transmissions, others can be more problematic where we have to shut down the transmissions and the others can be even more problematic where we have to change parts or the entire section of the pipeline.

II. Failure Assessment Diagram

Through this diagram we can conduct the calculation of two parameters brittle fracture risk K_r and the plastic ruin S_r for each of the defects occurring. We can calculate parameters by using the following expressions:

Brittle fracture: $K_r = \frac{K_I}{K_{Ic}}$

Plastic ruin: $S_r = \frac{\sigma_n}{\sigma_f}$

where, σ_f is equivalent to $\frac{\sigma_y+\sigma_u}{2}$ for $\sigma_f < 1.2\sigma_y$ and identical to $1.2\sigma_y$.

As result we define the boundary envelope in relation of the form $K_r = f(S_r)$ presenting these graphically for the relation among (K_r, S_r) composes the (FAD) [2]. A defect is accepted if the calculation of these two points (K_r, S_r) is found under the curve $K_r = f(S_r)$ in the FAD

We further propose three levels of investigations as shown in Fig. 1.

Level 1 is the basic which is applied in the brittle fractures.

In this case we have limited date on properties of material and the investigation occurred instantly.

Level 2 requires the safety factor which is considering for maximization of the stress and dimensions of defects and minimizing mechanical properties.

Level 3 is applied when the failure has occurred due to prior plastic deformation.

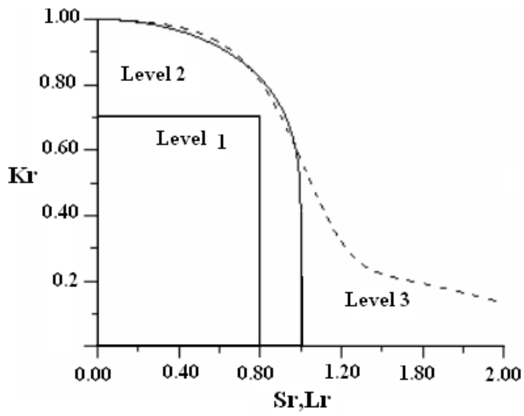

Fig. 1 FAD three levels of investigation

The equations for each level are given as for following expressions:

Level 1: $K_r < 0.707$ for $S_r < 0.8$ and $K_r = 0$ for $S_r > 0.8$

Level 2: $K_r = S_r\left(\frac{8}{\pi^2}\cdot\ln\left(\frac{1}{\cos\left(\frac{\pi}{2}\cdot S_r\right)}\right)\right)^{-0.5}$

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Level 3: $K_r = \left[\frac{(E\cdot\ln(1+\varepsilon))}{\sigma\cdot(1+\varepsilon)} + \frac{\sigma^3\cdot(1+\varepsilon)^3}{2\cdot\sigma_y{}^2\cdot E\cdot\ln(1+\varepsilon)}\right]^{-0.5}$

The ratio of the tensile curve of the material where the defect occurs is important to be identified. This curve establishes a relation among the $\sigma = f(\varepsilon)$.

While investigating in levels 1 and 2 we must posses data such are$\sigma_y$and σ_u .In this case Parameter S_r is replaced by:

$$L_r = \frac{\sigma(1+\varepsilon)}{\sigma_y}$$

In the same line we have the relationship as for expression below: K_r is calculated based on level 3 as below expressed:

$$K_r = \left(1 - 0.14L_r{}^2\right)\cdot\left(0.3\cdot 0.7\cdot \exp\cdot\left(-65\cdot L_r{}^6\right)\right)$$

An example of Domain Failure Assessment Diagram DFAD is given in Fig. 2 where the assessment point A gives the referring point for coordinates ($l^*_{r,}$ k^*_r) In this case the FAD is limited by the failure assessment curve which shows us the safe and unsafe pipes [3].

The safe zone is divided in three conventional zones.

If we have the assessment point to be found in this zone than the increase of the pressure can cause brittle fracture.

In the zone 2 increased applied pressures than the elastic-plastic fracture can occur. According to Zone 3 plastic collapse occurs due to increased service pressure.

As for the Feddersen Diagram, limits of these two zones are defined conventionally as expressed below:

Zone 1: $0 < L_r < 0.62L_{r,y}$
Zone 2: $0.62L_{r,y} < L_r < 0.95\ L_{rL}$
Zone 3: $0.95L_{r,max} < L_r < L_{r,max}$

where $L_{r,y}$ is associated with the manufactured pressure and $L_{r,max}$ is the value of $L_{r.}$

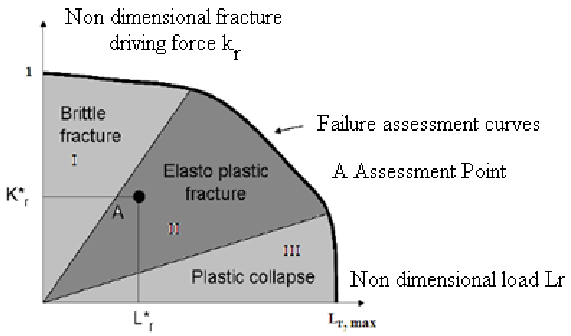

Fig. 2 Domain failure assessment diagram

The combination between k_r and L_r is a curve which is gained due to a generation and calculation of an experimental data. This failure curve is a product which derives as cross cut of brittle fracture with the assessment point (k_r=1, L_r=0) with the plastic collapse point which is gained from the following formula (k_r=0, L_r= $L_{r,\ max}$).

III. Elastic-Plastic Failure of the Steel Pipes Made of Material API X52

X52 Steel is an material which has been used in the past and it is a considered a very problematic material with the occurrence of many defects. Some companies are replacing these materials but still there are hounded of thousands of kilometers pipe lengths still operating in the world. For these reasons studding this material is still an appropriate issue until all of them are replaced. However replacing gas pipes is a very complex task to fulfill, as result those remain a topic for analyses.

TABLE I
Chemical Composition of API X52 (WEIGHT %)

C	Mn	Si	Cr	Ni	Mo	S	Cu	Ti	Nb	Al
0.22	1.22	0.24	0.16	0.14	0.06	0.036	0.19	0.04	< 0.05	0.032

TABLE II
Mechanical Properties of the API X52 Are Given

E (Gpa)	Y	Σ_y(Mpa)	Σ_u	A %	N	K	K^*_C
203	0.30	410	528	32	0.164	876	116.6

E is Young's module, ν Poisson's ratio, $\sigma_Y$yield stress, $\sigma_U$ultimate stress, A% relative elongation, n -hardening exponent, K hardening coefficient and Kc^* fracture toughness.

The possibility for the failure of pipe which is made in API X52 steel is studied when it is found under the service pressure of 80 bars. The pipe diameter was 218.1 and the thickness of the wall t=6mm.

We have studied three types of defects which are semi-elliptical (SE), semi-spherical (SS) and the long notch defect (N). Each of the defect depth a is equal to the half of the thickness and it is considered with length 2c, with a longitude direction L.As result we have (t= 6mm, a= t/2, a/c = 0.2. In order to define the assessment points volumetric methods are used where those are reported in DFAD [4].

As result we have gained the safety factor values which are given in Table III below.

TABLE III
Values Obtained from DFAD FOR the Safety Factor

DEFECT TYPE	LONGITUDINAL	CIRCUMFERENTIAL
SEMI-SPHERICAL	3.91	3.84
SEMI-ELLIPTICAL	3.97	3.47
BLUNT NOTCH	3.61	2.6

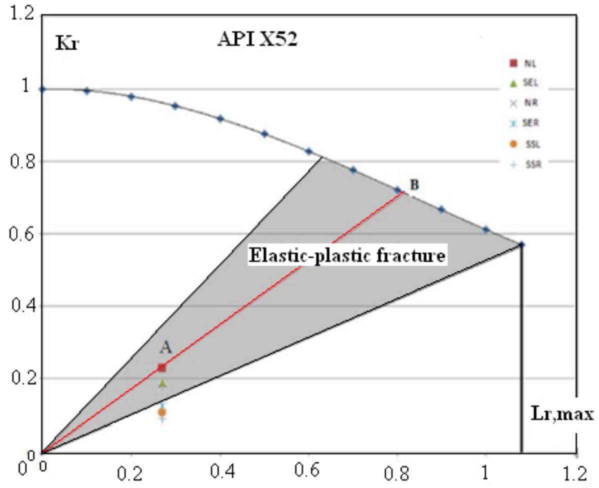

Fig. 3 Semi elliptical, Semi Spherical and notch diagram based on DFAD

IV. Calculation of the Safety Factor in FAD

A calculation of safety factor of FAD is presented in Fig. 4 and it is expressed as for the equation as follows:

$$F_s = OB/OC,$$

where F_s are safety factors. One of the advantages of F_s is that it serves as a unique tool for the defining the safe zone. Another advantage is to use the F_s for any solution of non-critical zones [5].

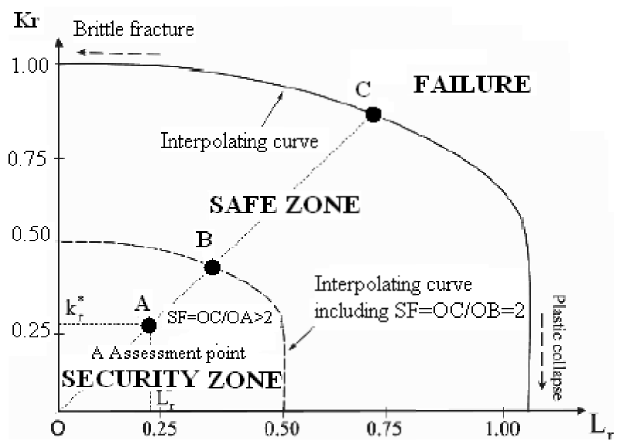

Fig. 4 Calculation of the safety factor

V. Conclusion

By analyzing FAD we have classified three levels of failure occurrence of pipes where the diagram defines intervention on the fractures which can occur while the gas pipes are in operation. FAD defines the distance of security from a given point and defines three main zones based on the level of security. We obtain three different security zones: brittle fracture, elastic-plastic fracture and collapse plastic zones. Also we have defined the elastic-plasticity of the steel material API X52. The result gained was the calculation of the safety factor F_s.

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