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Reliability of the High Strength Pipeline Steel under Corrosion Defect

O. Ghelloudj[a,b,*], D. Zelmati[b], A. Gharbi[a], D. Berdjane[a], C.D. Ramoul[a] and T. Chouchane[a]

[a]Research Center in Industrial Technologies (CRTI), P.O. Box 64, Cheraga 16014 Algérie, Algeria

[b]Research Laboratory Advanced Technology in Mechanical Production LRTAP, Mechanical Engineering Department, Badji Mokhtar University, B.P. 12-23000, Annaba, Algeria

The demand of energy based on hydrocarbons, such as gas and oil, requires construction of more and more new pipelines. Therefore, the assessment of the remaining life of these pipeline structures became increasingly important to ensure the continuity of production and distribution operations. The reliability of these industrial facilities is largely conditioned by specific characteristics of each system, by its conditions of use and its environment. Generally, the causes of deterioration of hydrocarbon transportation pipelines are related to the presence of apparent defects (pinholes, cracks, corrosion, etc). This study is aimed to estimate the reliability of pipeline structures. The B31G mechanical model of degradation was used to assess the probability of failure through dimensions of defects.

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1. Introduction

Pipelines are considered as the best way for transportation of oil and hydrocarbons, especially when distances are very long. During hydrocarbon transporting, the pipelines are subjected to different stresses, the most important being the hoop stress and the corrosion phenomenon, considered as the main reason of decrease of the remaining life of all steel pipelines and structures [1–5]. Hence, the assessment of the reliability of a pipeline under influence of a corrosion pit and subjected to hoop stress should be evaluated. Taking in consideration all uncertainties of the pipe geometry, mechanical properties and applied stress, it is very interesting to give the best approach in order to determine the remaining life of steel pipelines [3–5]. In first step we have developed the engineering model, then each parameter within the mechanical model has been represented by a mean value and standard deviation.

In this paper, we assume that the B31G code is the mechanical model in order to determine the reliability of the control of the burst pressure of a pipeline [1].

2. Experimental work

Table I illustrates random variables within the engineering model.

3. Limit state function

The limit state function $G(x)$ is attributed to the difference between the burst pressure and the operating hydrocarbon pressure inside the pipelines as expressed in Eq. (1)

*corresponding author; e-mail: o.ghelloudj@crti.dz

TABLE I

Random variables and coefficient of variation.

Description	Mean value	Standard deviation
Yield stress, σ_y	486 MPa	10%
Operating pressure, P_{op}	7 MPa	10%
External diameter, D	400 mm	1%
Thickness, t	6 mm	10%
Defect depth, d	1.2 mm	10%
Defect length, L	12 mm	10%

$$G(x) = P - P_{op}. \quad (1)$$

The safety margin domain is defined by $G(X_j) > 0$ and the failure domain is attributed to $G(X_j) < 0$, where X_j are the random variables in the system [3–10]. The assessment of the reliability of the pipeline is summarized to evaluation of the reliability index β.

In this paper, we have used the FORM/SORM analyses to estimate the reliability index via Rackwitz-Fissler algorithm [2–6]. Reliability index results have been obtained by means of PHIMECA Software [11].

4. Results and discussion

Deterministic approaches are based on the safety factor concept and are unable to predict the remaining life of corroded pipelines because the uncertainties are not taken in consideration [3–7]. Figure 1 illustrates the effect of the defect dimension on the security factor. Independently from the depth-to-wall-thickness ratio of the defect, the security factor has a limit value of 2, which is the conventional value in mechanical engineering. For the greatest defect depth the security factor is equal to 1.5. For longest defect, the safety factor is converging to the highest value of about 2.1, for all defect depth-to-wall-thickness ratios. In order to predict the remaining life of the pipeline, the probabilistic approach must be evaluated. Figure 2 illustrates the evolution of the reliability index versus the defect geometry. The reliability index decreases when the defect depth to defect length ratio increases, independently from the defect depth-to-wall-thickness ratio. Also, for the same defect depth, when the crack length increases, the reliability index decreases for all assessment points.

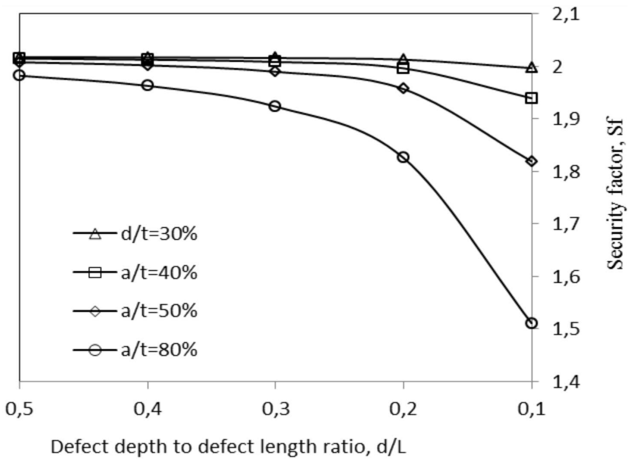

Fig. 1. The effect of defect depth to defect length ratio on the security factor.

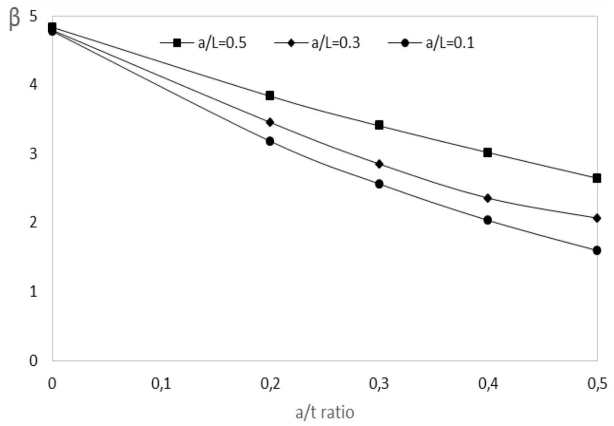

Fig. 2. Effect of defect depth-to-wall-thickness ratio on the reliability index.

In industrial structures we assume that the pipelines are reliable if the reliability index is above the value of 3.72. Hence, if the reliability index is less than this value, the pipelines are not reliable.

When the defect length increases, the effect of corrosion is accentuated and affects the remaining life of the pipeline. Figure 3 illustrates the remaining life of the pipelines under localized corrosion defect.

The pipe is still safe and may be in service without risk for a period of 60 years, after that, a maintenance program must be evaluated.

The performed sensitivity analysis is of a great interest in the developed maintenance program. Therefore,

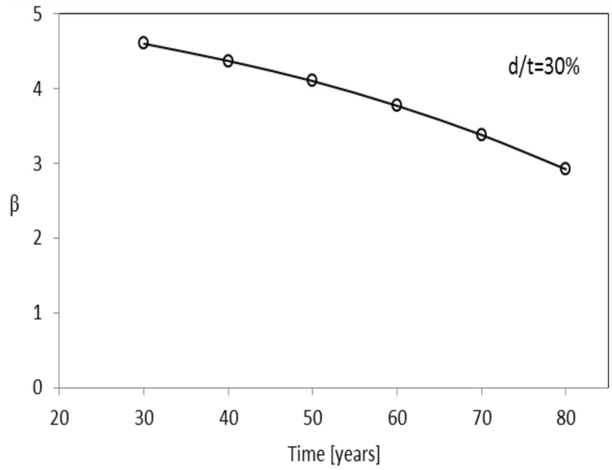

Fig. 3. Degradation of the reliability index with time.

a search of the main random variables, having a significant contribution to the probability of failure of pipelines, must be conducted. To evaluate the weight of a variable is to identify the influence of its variation on the condition of pipes. The aim is to select the most significant variables, allowing better control according to their role in relation to the mechanical behavior or reliability. Figure 4 illustrates the sensitivity parameters of the random variables within the mechanical model.

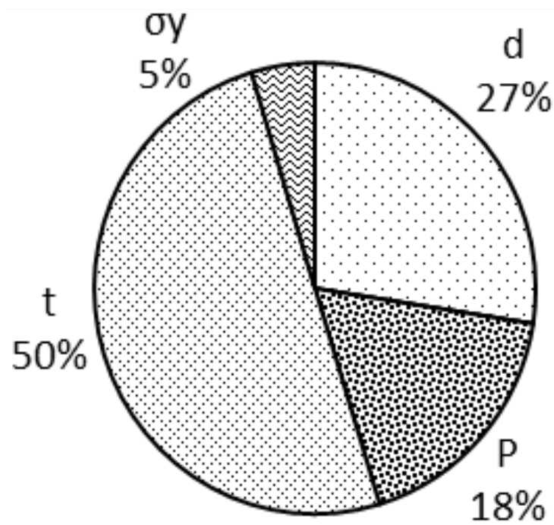

Fig. 4. Sensitivity of the variables of the pipe having the defect depth-to-wall-thickness ratio of $d/t = 30\%$.

5. Conclusions

The analysis of variables sensitivity shows that the most dominant variable is the trio of defect depth, operating pressure and the thickness. The reliability index must be evaluated to estimate the remaining life of the corroded pipeline. The program of maintenance is developed by predicting the remaining life of pipeline.

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