RELIABLE FORECASTING OF REMAINING STRENGTH OF PETROLEUM PIPELINES BASED ON LG-18 CRITERION

A. Chennakesava Reddy

Professor, Department of Mechanical Engineering, JNT University, Hyderabad-500 085, India
chennakesava@jntuh.ac.in

Abstract

The intention of the present work was to forecast the hoop stress and the remaining strength of carbon steel pipes using LG-18 criterion. The importance of crack dimensions was recognized using Taguchi techniques. The highly influencing crack dimension was crack depth. The hoop stress induced, in AISI 1039 carbon steel was high and it was low in AISI 1030 carbon steel. The results achieved by the LG-18 criterion have been acceptable with those of experimentation.

Keywords: *carbon steel, crack depth, crack length, pipe thickness, LG-18, hoop stress, remaining strength.*

*****

1. INTRODUCTION

Pipeline corrosion represents the most serious threat and monetary loss to any commercial or industrial building, or plant operation. In its less severe variety, corrosion can create problems ranging from lost heat transfer efficiency and constricted pipes to pinhole leaks and temporary shutdowns. More severe failures are often in the form of operating failures, lost production, productivity interruption, and personal injury. The corrosion takes in many forms. A few of them are presented in this paper. Every pipe thread is an inbuilt point of weakness, with approximately 50% of the pipe wall cut away. Galvanic corrosion can occur when different metals are joined together, and is significantly dependent on previously existing corrosion conditions and the piping system involved. Internal rust deposits (figure 1), commonly termed tuberculation, are an unavoidable death sentence for most piping systems. They are the lighter and less dense end product of steel pipe corrosion. Once established by high and uncontrolled corrosion conditions, internal deposits initiate much greater deep pitting. The highest corrosion loss is more likely at horizontal lines and in low flow or dead end areas where rust and other deposits will settle.

Figure 1: Internal rust collection.

Of all the forms of corrosion caused to piping systems, weathering damage due to rain, snow, atmospheric conditions, or cooling tower overspray is the easiest to prevent. Most weathering damage (figure 2) requires decades to produce a failure, and is simply due to a lack of maintenance. Smaller diameter piping is always most vulnerable due to its inherently lesser wall thickness. Microbiologically influenced corrosion (figure 3) produces large and deep pits due to its utilization of the steel pipe itself as an energy source (often as an alternative to oxygen), as well as through the production of strongly corrosive metabolic by-products, such as sulfuric acid, which further assist the microorganism in dissolving pipe metal.

Figure 2: Weathering damage.

Figure 3: Microbiologically induced corrosion

Figure 4: Petroleum pipeline bursting.

The petroleum pipes burst due to internal or external corrosion cracks is shown in figure 4. With respect to integrity and safety of a pipe system, it is necessary to know the maximum pressure load it can withstand without leakage and catastrophic fracture. Most popular failure pressure methods for pressurized pipes with active corrosion defects are ASME B31G [1], DNV-RP-F101 [2], SHELL-92 [3], RSTRENG [4]. These methods were applied for the assessment of 302, 304, 305 and 316 stainless pipes [5-8].

The present work was provoked to optimize safety criteria for petroleum pipes made of carbon steels having 150 mm diameter. The present study was to forecast the failure stress of the petroleum pipes with different crack dimensions using LG-18 criterion. The failure stress was optimized using Taguchi techniques.

2. MATERIAL AND METHODS

The material of pipes was carbon steels. The chosen control parameters are summarized in table 1. The control factors were assigned to the various columns of orthogonal array (OA), L9 is given in table 2. The dimensions of notch are given in figure 5.

Table 1: Control factors and their levels

Factor	Symbol	Level–1	Level–2	Level–3
Thickness, mm	A	2	3	4
Length of crack, mm	B	125	175	225
Depth of crack	C	40%t	50%t	60%t
Medium carbon steel	D	AISI 1030	AISI 1035	AISI 1039

where t is pipe thickness

Table 2: Orthogonal Array (L9) and control factors

Treat No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

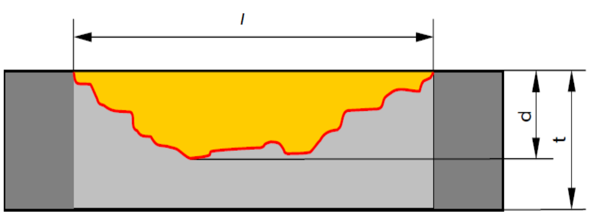

Figure 5: The Crack dimensions.

The NG-18 surface flaw equation [9] is given by:

$$S_f = \bar{S}\left[\frac{1-\frac{A}{A_0}}{1-\left(\frac{A}{A_0}\right)\frac{1}{M_f}}\right] \qquad (1)$$

$$\text{Folias factor, } M_f = \sqrt{1 + 0.6275\left(\frac{L^2}{Dt}\right) - 0.00375\left(\frac{L^2}{Dt}\right)^2}$$

$$A_0 = Lt$$

$$\bar{S} = \text{SMYS} + 68.95$$

where, A and A_0 are the area of crack in the longitudinal plane through the wall thickness. L and t are, respectively, the axial extent of the crack and thickness of the pipe. S_f and $\bar{S}$ are, respectively, the hoop stress level at failure and the flow stress of the material, a material property related to its yield strength. D is the pipe diameter.

The remaining strength of the pipe material is given by:

$$S_r = \left(\frac{UTS - S_f}{UTS}\right) \times 100 \qquad (2)$$

Where, UTS is the ultimate tensile strength of the pipe material.

3. RESULTS AND DISCUSSION

The petroleum pipe materials were AISI 1030, AISI 1034 and AISI 1039 carbon steels (cold drawn).

3.1 Influence of crack dimensions and pipe material on hoop stress

Table 3 gives the ANOVA (analysis of variation) summary of hoop stress. Even if all the process parameters could convince the Fisher's test at 90% confidence level, crack depth and grade of carbon steel had major role in the total variation of hoop stress. The crack depth (C) and grade of carbon steel (D) had given, respectively, 78.49% and 21.31% in the total variation of the hoop stress. The pipe thickness (A) and crack length (B) were insignificant.

Table 3: ANOVA summary of the hoop stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	906.66	899.77	908.45	14.01	1	14.01	40763.92	0.08
B	909.79	898.77	906.33	21.17	1	21.17	61596.87	0.12
C	1053.2	898.48	763.22	14034.18	1	14034.18	40834274	78.49
D	841.86	260649.6	2714.88	3809.96	1	3809.96	11085575	21.31
e				0.001375	4	0.000344	1.00	0
T	3711.5	263346.6	5292.88	17879.32	8			100

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, F is the Fisher's ratio, P is the percentage of contribution and T is the sum squares due to total variation.

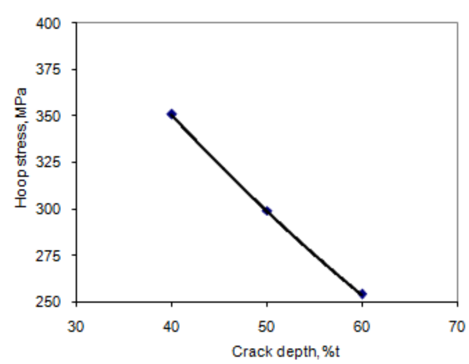

Figure 6: Effect of crack depth on hoop stress.

Figure 6 shows the dependence of hoop stress on the crack depth. As the crack depth increased the hoop stress induced in the pipe decreased. The developed hoop stress was high for the AISI 1039 carbon steel grade 80-55-06 as compared to the other two carbon steels (AISI 1034 and AISI 1030).

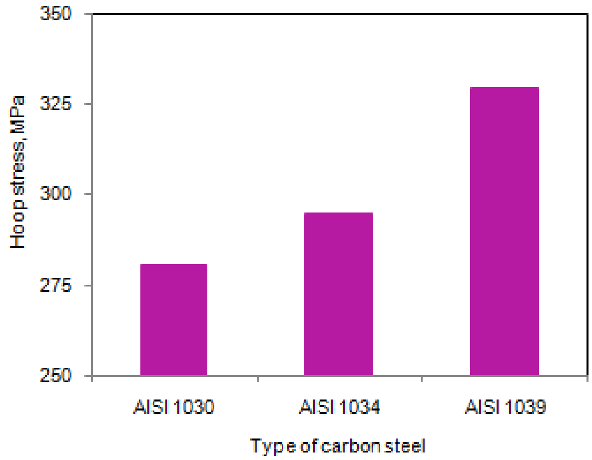

Figure 7: Effect of ductile iron grade on hoop stress.

3.2 Remaining strength of pipe materials

The remaining strength of the pipe materials is shown in figure 8. It is observed that the remaining strength was higher than the induced hoop stress in the trail pipes numbered 3, 5 and 7. The predicted values were matched with the experimental values.

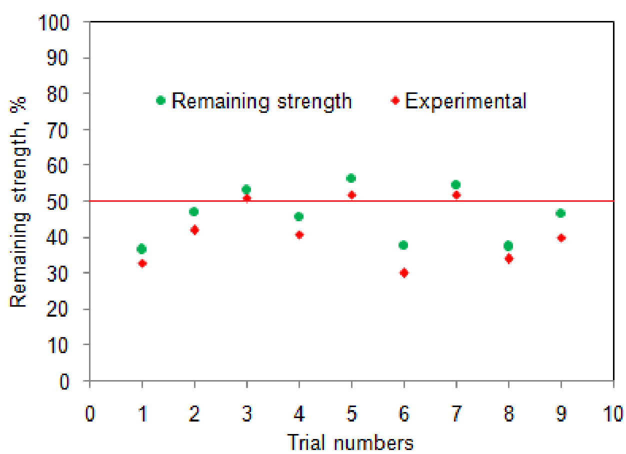

Figure 8: Remaining strength of all pipes.

4. CONCLUSIONS

Hoop stress is highly dependent on the crack depth and grade of carbon steel. The induced hoop stress decreases with the increase of crack depth. The pipe materials with trail conditions 3, 5 and 7 have the remaining strength greater than the hoop stress developed in them. The LG-18 criterion could predict the hoop stress of the carbon steel pipes accurately harmonizing the experimental results.

REFERENCES

[1] American National Standards Institute (ANSI) / American Society of Mechanical Engineers (ASME): Manual for determining the remaining strength of corroded pipelines, ASME B31G, 1991.

[2] Anon, DNV-RP-F101, Corroded Pipelines, Det Norske Veritas, 1999.

[3] D. Ritchie and S. Last, Burst Criteria of Corroded Pipelines - Defect Acceptance Criteria, Paper 32, Proceedings of the EPRG/PRC 10th Biennial Joint Technical Meeting on Line Pipe Research, Cambridge, UK, 18-21 April 1995, pp. 32-1 - 32-11.

[4] J. F. Kiefner and P. H. Vieth, A Modified Criterion for Evaluating the Strength of Corroded Pipe, Final Report for Project PR 3-805 to the Pipeline Supervisory Committee of the American Gas Association, Battelle, Ohio, 1989.

[5] A. C. Reddy, Prediction of bursting pressure of thin walled 316 stainless steel tubes based on ASME B31G criterion, National Conference on Advances in Design Approaches and Production Technologies (ADAPT-2005), Hyderabad, 22-23rd August 2005, pp. 225-228.

[6] A. C. Reddy, Estimation of bursting pressure of thin walled 304 stainless steel tubes based on DNV RP F101criterion, National Conference on Advances in Design Approaches and Production Technologies (ADAPT-2005), Hyderabad, 22-23rd August 2005, pp. 229-231.

[7] A. C. Reddy, Reliability assessment of corrosion cracks in cold rolled 302 stainless steel tubes based on SHELL-92 criterion, National Conference on Advances in Design Approaches and Production Technologies (ADAPT-2005), Hyderabad, 22-23rd August 2005, pp. 232-234.

[8] A. C. Reddy, Trustworthiness judgment of corrosion cracks in cold rolled 305 stainless steel tubes based on RSTRENG criterion, National Conference on Advances in Design Approaches and Production Technologies (ADAPT-2005), Hyderabad, 22-23rd August 2005, pp. 235-237.

[9] A. Cosham, P. Hopkins, P. and K. A. Macdonald, Best Practice for the Assessment of Defects in Pipelines-Corrosions, Engineering Failure Analysis, no. 14, pp. 1245-1265, 2007.