DECENT PROPHECY OF BURSTING STRENGTH OF NATURAL GAS PIPELINES BASED ON MODIFIED ASME B31G CRITERION

A. Chennakesava Reddy

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

Abstract

The objective of the present work was to envisage the bursting pressure of duplex stainless pipes using modified ASME B31G criterion. The failure of the pipes was evaluated based on the Tresca and von Mises criteria. The repercussion of crack dimensions was recognized using Taguchi techniques. The extremely influencing crack dimension was crack depth. The results obtained by the modified ASME B31G criterion were better than the ASME B31G old criterion.

Keywords: *Duplex steel, crack depth, crack length, bursting pressure, modified ASME B31G, Tresca criterion, von Mises criterion.*

*****

1. INTRODUCTION

Very often gas pipelines get damaged either due to corrosion or owing to high pressure flow. 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. One of the most serious problems of pipes is corrosion. The gas pipes burst due to internal or external corrosion cracks (figure 1).

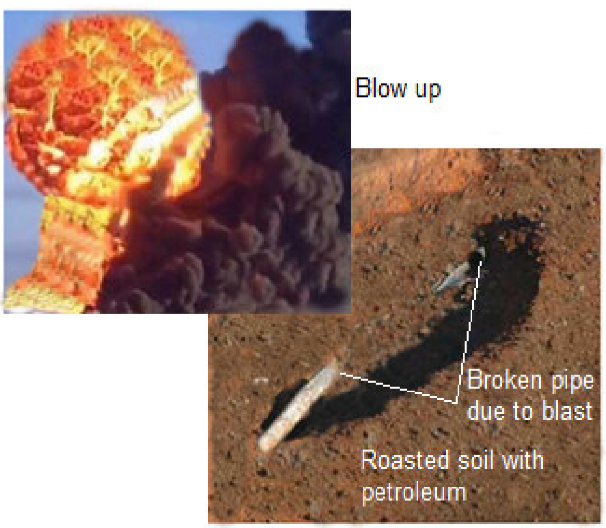

Figure 1: Burst of gas pipeline.

Although literature on fracture mechanics of the pipelines is abundant, there is no assessment method that is precise and largely acknowledged. 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 role of a material and corrosion engineer in selecting suitable material has become more complex, controversial and difficult. The process of selection includes identifying the most cost- effective material for the specified operating life, bearing in mind the health, safety and environmental aspects.

The present work was confident to optimize safety criteria for pressurized gas pipelines pipes having 200 mm diameter. The present study was to predict the bursting pressure of the pipes with different crack dimensions using modified ASME B31G criterion. The bursting pressure was optimized using Taguchi techniques. The results were also cross-checked with those computed from ASME B31G old criterion.

2. MATERIAL AND METHODS

The material of pipes was ductile iron. 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	3	4	5
Length of crack, mm	B	150	200	250
Depth of crack	C	40%t	50%t	60%t
Duplex steel	D	SAF 2304	SAF 2205	SAF 2507

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

Using modified ASME B31G criterion [4], the bursting pressure can be estimated as follows:

$$P_b = (YS + 68.95)\frac{2t}{D}\left[\frac{1-0.85\frac{d}{t}}{1-0.85\left(\frac{d}{t}\right)\frac{1}{M_f}}\right] \quad (1)$$

$$M_f = \sqrt{1 + 0.6275\frac{L^2}{Dt} - 0.003375\left(\frac{L^2}{Dt}\right)^2} \text{ for } L \ll \sqrt{50Dt}$$

$$M_f = 3.3 + 0.032\frac{L^2}{Dt} \quad \text{for } L > \sqrt{50Dt}$$

where, D and t are, respectively, the nominal outside diameter and thickness of the pipe. L and d are, respectively, crack length and crack depth. YS is the yield strength of the material.

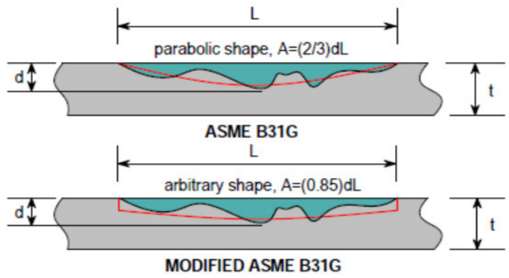

Figure 2: The Crack dimensions.

For the modified ASME B31G criterion, the Tresca criterion is the first classical yield criterion in the strength theory for isotropic ductile materials, often referred to as the maximum shear stress criterion. In principal stress space (σ_1, σ_2, σ_3), the Tresca criterion can be expressed as

$$\tau_{max} = \max\left(\frac{|\sigma_1-\sigma_2|}{2}, \frac{|\sigma_2-\sigma_3|}{2}, \frac{|\sigma_1-\sigma_3|}{2}\right) = \frac{\sigma_{YS}}{2} \qquad (2)$$

where τmax is the maximum shear stress and σ_{uts} is the ultimate tensile strength in tension.

For Fitnet FSS criterion, the von Mises criterion is the second classical yield criterion in strength theory, often referred to as the octahedral shear stress criterion. It can be expressed by the principal stresses in the form:

$$\tau_{vm} = \sqrt{\frac{1}{6}[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2]} = \frac{\sigma_{YS}}{\sqrt{3}} \quad (3)$$

where τ_{vm} is the von Mises effective shear stress.

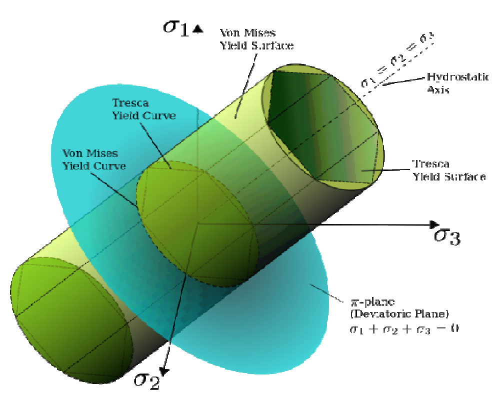

Figure 3: Illustration of Tresca and von Mises criteria.

The von Mises yield surfaces in principal stress coordinates circumscribes a cylinder with radius $\sqrt{2/3}\,\sigma$ around the hydrostatic axis. Also shown is Tresca's hexagonal yield surface (figure 6). Intersection of the von Mises yield criterion with the σ_1, σ_2 plane, where $\sigma_3 = 0$.

3. RESULTS AND DISCUSSION

The bursting pressures computed from ASME B31G, modified ASME B31G [5], DNV-RP-F101 [6], SHELL-92 [7] and RSTRENG [8] criteria are given in figure 4. It is observed that the bursting pressures obtained through modified ASME B31G criterion higher than those predicted using ASME B31G old criterion [5]. The bursting pressures attained through RSTRENG criterion [8] form upper bound values, where as pressures computed employing ASME B31G old criterion form lower bound values. The pressure values computed using SHELL-92 [7] and DNV-RP F101 [6] criteria are within these two limits. The results obtained using modified ASME B31G criterion were between ASME B31G old criterion 1 and SHELL-92 [7]. Therefore, the bursting pressures obtained through modified ASME B31G criterion are highly acceptable.

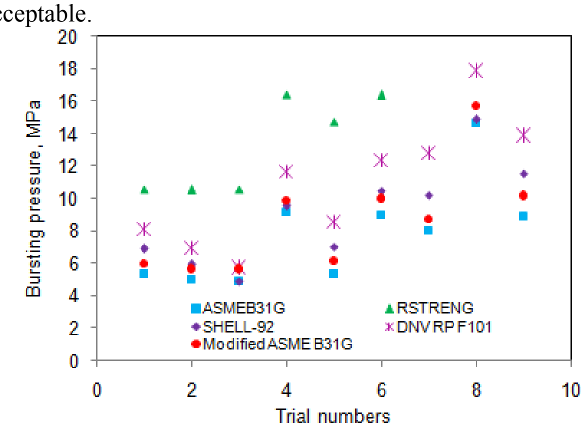

Figure 4: Bursting pressures computed from different methods.

3.1 Influence of crack dimensions and pipe material on bursting strength

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

Table 3: ANOVA summary of the bursting pressure

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	3711.5	263346.6	5292.88	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 5 shows the dependence of bursting pressure on the crack depth. As the crack depth increased the pressure required to burst the pipe would decrease. The required bursting pressure was high for the SAF 2507 duplex steel as compared to the other two grades (duplex steels ASF 2205 and ASF

2304). The carbon steel ASF 2034 failed at low bursting pressure.

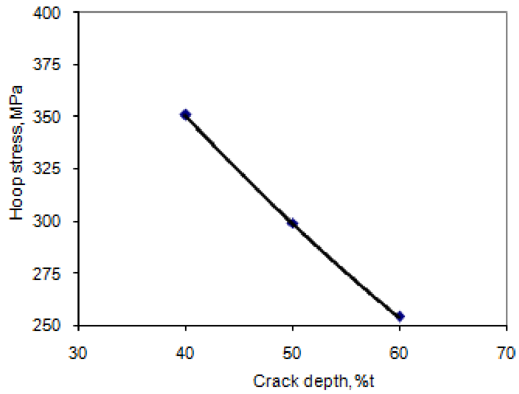

Figure 5: Effect of crack depth on bursting pressure.

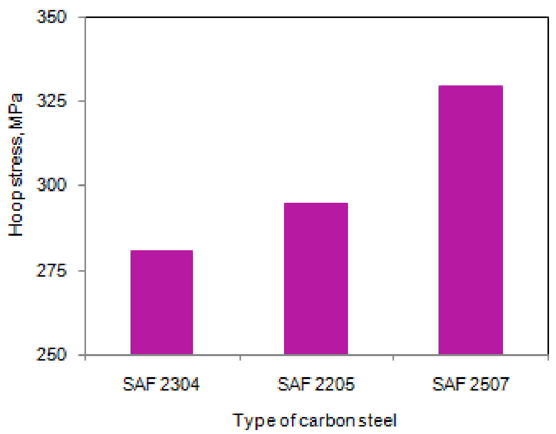

Figure 6: Effect of duplex steel grade on bursting pressure.

3.2 Failure criteria

Table 4 and 5 give the ANOVA (analysis of variation) summary of Tresca criterion and von Mises criterion respectively. Even though all the process parameters could assure the Fisher's test at 90% confidence level, only crack depth and grade of carbon steel had foremost contribution in the total variation of Tresca and von Mises criteria. The crack depth (C) contributed nearly 60.90% of the total variation in the Tresca and von Mises criteria. The duplex steel (D) put in 38.25% of the total variation in the Tresca and von Mises criteria. The pipe thickness and the crack length were insignificant in the variation of Tresca and von Mises criteria.

Table 4: ANOVA summary of the Tresca criterion

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	427.53	426.72	423.56	2.95	1	2.95	708.37	0.04
B	416.01	433.52	428.29	53.84	1	53.84	12928.32	0.8
C	504.04	426.24	347.54	4081.99	1	4081.99	980187.38	60.9
D	372.94	56234.22	1277.82	2563.94	1	2563.94	615665.80	38.25
e				0.016658	4	0.004164	1.00	0.01
T	1720.5	57520.70	2477.21	6702.703	8			100

Table 5: ANOVA summary of the von Mises criterion

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	740.51	739.11	733.63	8.82	1	8.82	1766.30	0.04
B	720.55	750.87	741.82	161.51	1	161.51	32344.05	0.8
C	873.02	738.27	601.96	12245.96	1	12245.96	2452380.6	60.9
D	645.95	168702.6	2213.25	7691.83	1	7691.83	1540368.8	38.25
e	2980.0	170930.9	4290.66	0.019974	4	0.004993	1.00	0.01
T	3058.9	177500.5	4315.56	20108.1	8			100

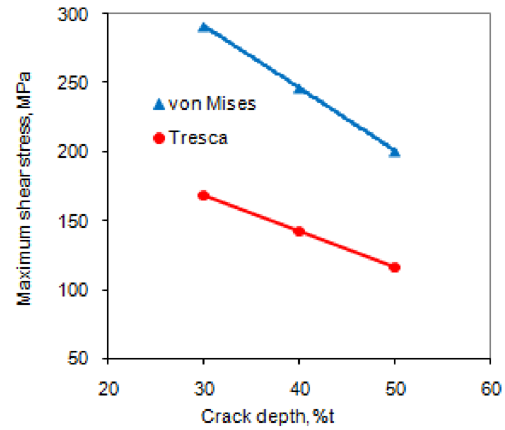

Figure 7: Effect of crack depth on failure criteria.

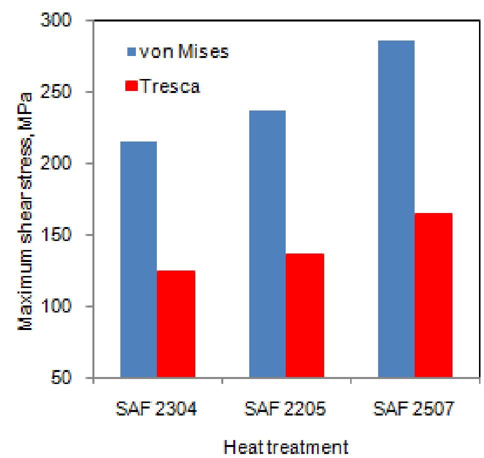

Figure 8: Effect of grade of ductile iron on failure criteria.

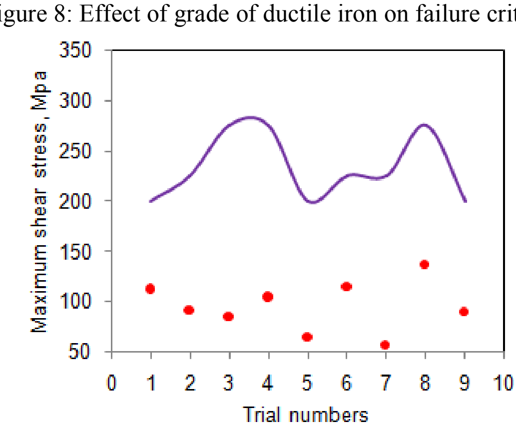

Figure 9: Tresca failure criterion of all pipes.

As the crack depth increased the level of failure shear stress decreased (figure 7). The level of maximum shear stress was low for SAF 2304 duplex steel and it was high for SAF 2507 duplex steel (figure 8). As observed from figure 9 & 10, all the pipes were safe under Tresca and von Mises failure criteria.

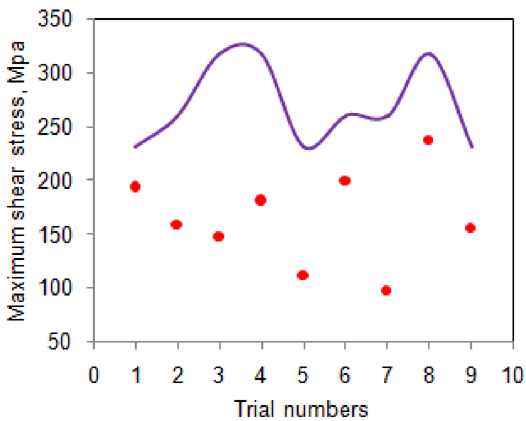

Figure 10: von Mises failure criterion of all pipes.

5. CONCLUSIONS

The bursting pressure is highly dependent on crack depth and grade of duplex steel. The bursting pressure decreases with the increase of crack depth. The von Mises criterion is very near the failure pattern of the pipes. The ASME B31G criterion could predict the bursting pressure of the duplex steel pipes better than ASME B31G old criterion.

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.