CONSISTENCY PREDICTION OF BURSTING STRENGTH OF 317 STAINLESS STEEL PIPES BASED ON PCORRC (BATELLE) CRITERION

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Abstract

The objective of the present work was to predict the bursting pressure of 317L, 317LM and 317LN stainless steels using PCORRC criterion. The failure of the pipes was evaluated based on the Tresca and von Mises criteria. The significance of crack dimensions was optimized using Taguchi techniques. The highly influencing crack dimensions were pipe thickness and crack depth. The results obtained by the PCORRC criterion have been matched with those of experimentation.

Keywords: *317 stainless steel, crack depth, crack length, bursting pressure, PCORRC, Tresca criterion, von Mises criterion.*

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1. INTRODUCTION

Pipelines are extensively used for the transportation of water, crude oil, and natural gas. 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. Accordingly, perfect calculation of the burst pressure is an essential concern in the design of pipelines. One of the most serious problems of pipes is corrosion. The gas pipes burst due to internal or external corrosion cracks (figure 1).

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Figure 1: Burst pipe

Although literature on fracture mechanics of pipe lines is copious, there is no assessment method that is accurate and largely accepted. 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 motivated to optimize safety criteria for pressurized 317L, 317LM and 317LN stainless steel pipes. The present study was to predict the bursting pressure of the pipes with different crack dimensions using PCORRC criterion. The bursting pressure was optimized using Taguchi techniques. The results were also cross-checked with those computed from ASME B31G, DNV-RP-F101, SHELL-92, and RSTRENG.

2. MATERIAL AND METHODS

The material of pipes was 317 stainless steel. 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 2.

Table 1: Control factors and their levels

Factor	Symbol	Level–1	Level–2	Level–3
Thickness, mm	A	1.0	1.2	1.5
Length of crack, mm	B	25	50	75
Depth of crack	C	30%t	40%t	50%t
Cold rolled reduction	D	317L	317LM	317LN

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

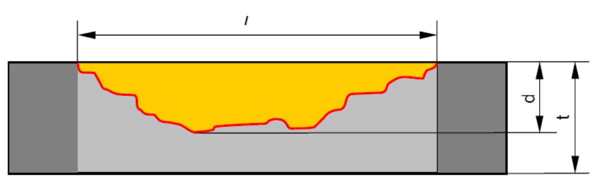


Figure 2: The Crack dimensions.

Using PCORRC criterion [9], the bursting pressure can be estimated as follows:

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

$$M_f = 1 - \exp\left(-0.157\frac{L}{\sqrt{0.5D(t-d)}}\right)$$

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. UTS is the ultimate tensile strength.

For PORRC 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

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

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

For PORRC 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:

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

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

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 3). Intersection of the von Mises yield criterion with the σ_1, σ_2 plane, where $\sigma_3 = 0$.

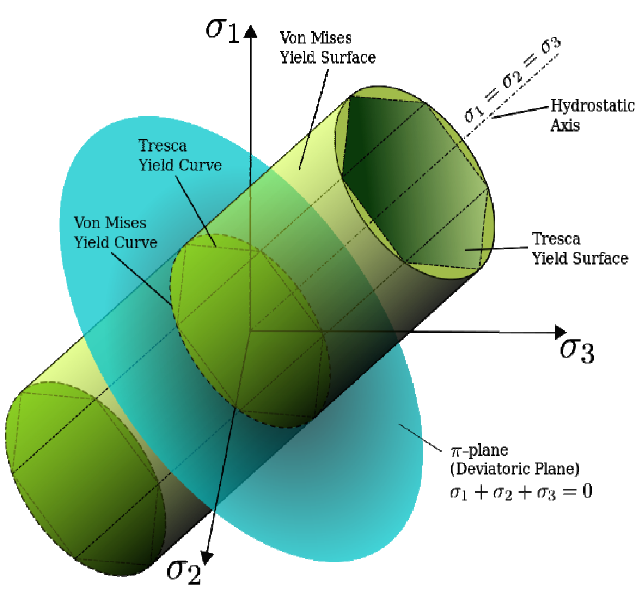


Figure 3: Illustration of Tresca and von Mises criteria.

3. RESULTS AND DISCUSSION

The bursting pressures computed from PCORRC, ASME B31G, DNV-RP-F101, SHELL-92, and RSTRENG criteria are given in figure 4. It is observed that the bursting pressures obtained through ASME B31G criterion form lower bound values whereas the bursting pressures attained through RSTRENG criterion form upper bound values. The pressure values computed using SHELL-92, DNV-RP F101 and PCORRC criteria are within these two limits. Therefore, the bursting pressures obtained through PCORRC criterion are acceptable.

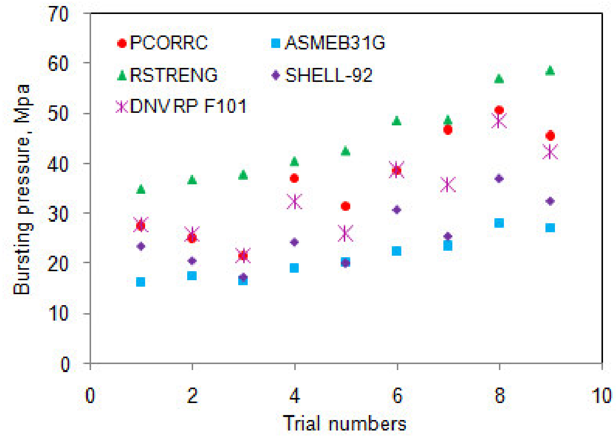


Figure 4: Bursting pressures computed from different methods.

3.1 Influence of crack dimensions and tube 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, only pipe thickness and crack depth had major role in the total variation of bursting pressure. The pipe thickness (A) and crack depth (C) had contributed, respectively, 92.90% and 5.66% in the total variation of the bursting pressure. The crack length (B) and type of stainless steel (among 317L, 317 LM and 317LN) were insignificant.

Table 3: ANOVA summary of the bursting pressure

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	74.63	107.11	142.79	774.81	1	774.81	107994.13	92.9
B	111.45	107.32	105.77	5.77	1	5.77	804.23	0.69
C	116.82	107.71	100.01	47.2	1	47.2	6578.80	5.66
D	104.72	4076.83	324.53	6.31	1	6.31	879.50	0.76
e				0.028698	4	0.007175	1.00	-0.01
T	407.62	4398.96	673.10	834.0613	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.

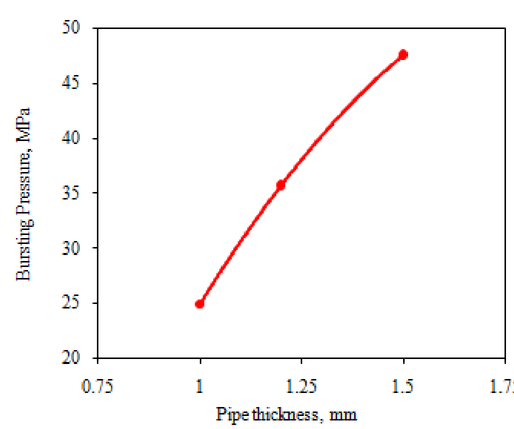


Figure 5: Effect of pipe thickness on bursting pressure.

Figure 5 shows the dependence of bursting pressure on the pie thickness. As the pipe thickness increased the pressure required to burst the pipe would increase. The bursting pressure decreased with the increase of crack depth (figure 6).

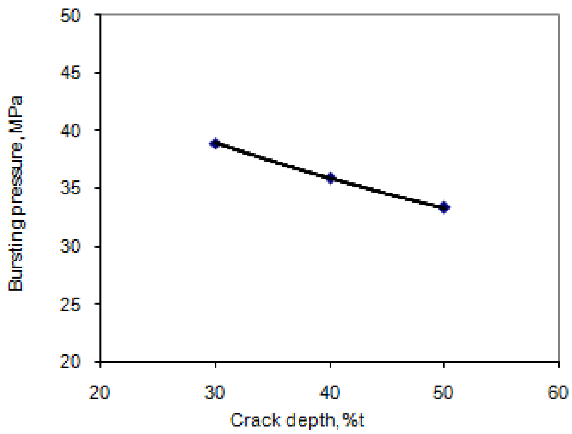


Figure 6: Effect of crack depth on bursting pressure.

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 pipe thickness, crack length and crack depth had key roles in the total variation of Tresca and von Mises criteria. The pipe thickness (A) contributed nearly half of the total variation in the Tresca and von Mises criteria. The crack length (B) put in one-third of the total variation in the Tresca and von Mises criteria. The crack length gave 8.20% of the total variation. Type of stainless steel (among 317L, 317 LM and 317LN) was 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	462.19	540.01	568.78	2027.3	1	2027.3	431322.43	52.17
B	548.65	514.27	508.07	318.51	1	318.51	67765.26	8.2
C	571.70	521.60	477.68	1475.4	1	1475.4	313901.80	37.97
D	516.05	95328.93	1570.99	64.59	1	64.59	13741.98	1.66
e				0.01880	4	0.00470	1.00	0
T	2098.6	96904.82	3125.52	3885.82	8			100

Table 5: ANOVA summary of the von Mises criterion

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	800.54	935.33	985.16	6081.93	1	6081.93	3799808.9	52.17
B	950.28	890.75	880.00	955.55	1	955.55	596999.21	8.2
C	990.22	903.44	827.37	4426.21	1	4426.21	2765364.3	37.97
D	893.82	285986.8	2721.03	193.77	1	193.77	121061.73	1.66
e				0.006402	4	0.001600	1.00	0
T	3634.9	288716.3	5413.56	11657.47	8			100

As the pipe thickness increased the level of failure shear stress also increased (figure 7). The level of maximum shear stress got reduced for the pipe failure with the increased crack length and crack depth (figure 8 and 9).

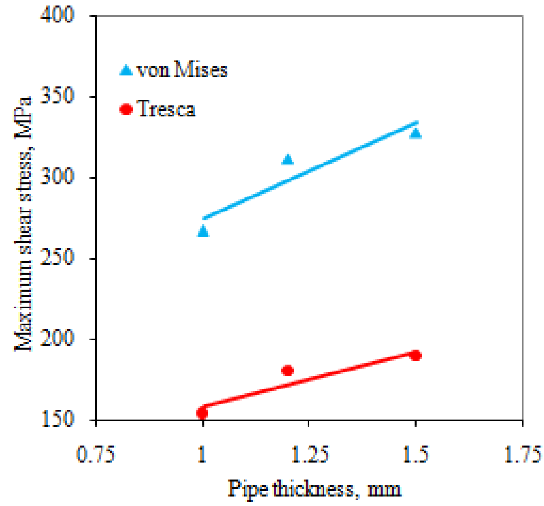


Figure 7: Effect of pipe thickness on failure criteria.

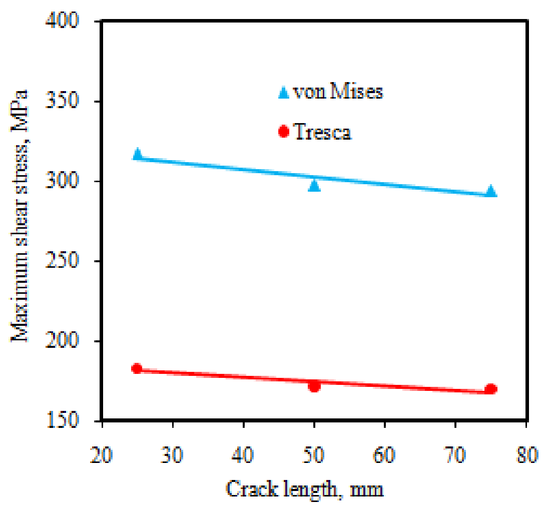


Figure 8: Effect of crack length on failure criteria.

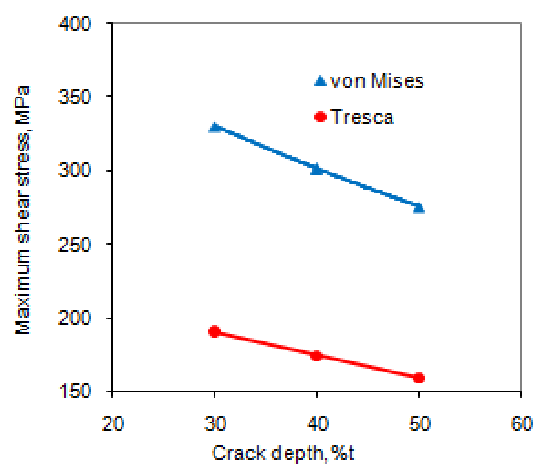
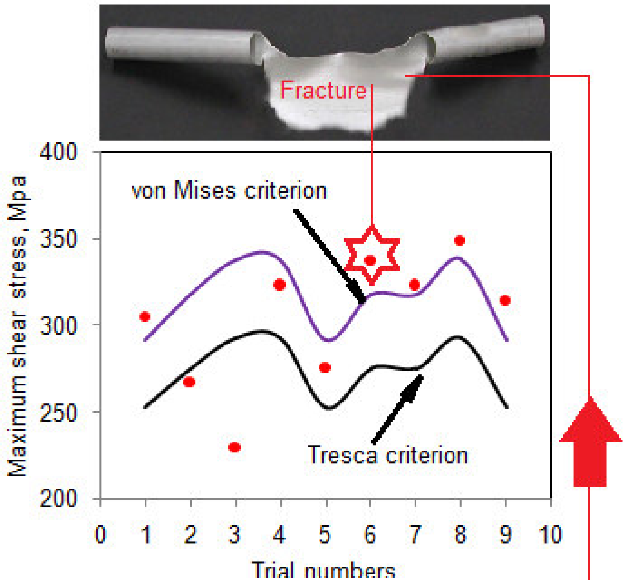


Figure 9: Effect of crack depth on failure criteria.

As observed from figure 10, the pipes 2, 3, 4 and 5 were safe, whereas the pipes 1, 6, 7, 8 and 9 were likely to fracture with the conditions prevailed with them.



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
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6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Dangerous   Safe

Figure 10: Fracture behavior of 317 stainless steel pipes.

5. CONCLUSIONS

The bursting pressure is highly dependent on the pipe thickness and crack depth for 317 stainless steels. The bursting pressure increases with the increase of pipe thickness. Also, the bursting pressure decreases with the increase of crack depth. The von Mises criterion is very near the failure pattern of the pipes. The PRORRC criterion could predict the bursting pressure of the 317 stainless steel pipes accurately matching the experimental results.

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