RELIABILITY ASSESSMENT OF CORROSION CRACKS IN COLD ROLLED 302 STAINLESS STEEL TUBES BASED ON SHELL-92 CRITERION

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Abstract

The present work was to assess the bursting pressure, longitudinal stress and hoop stress of cold rolled 302 stainless steel tubes using SHELL-92 criterion. The consequence of crack dimensions was optimized using Taguchi techniques. The highly influencing crack dimension was crack depth and pipe thickness. The bursting pressure decreased with the increase of crack depth. The hoop and longitudinal stresses were not influenced by the reduction percentage during cold rolling of the 302 stainless steel tubes.

Keywords: *302, cold rolling, crack depth, crack length, heat treatment, bursting pressure, SHELL-92.*

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1. INTRODUCTION

The remaining strength of pipes with corrosion defects has been studied for years using experimental, numerical, analytic and empirical methods. Pipeline flaws resulting from degradation of the protective coating or cathodic protection degradation, a corrosive environment, or third party damage may lead to corrosion, crack or hybrid crack-in-corrosion flaws (figure 1). Although literature on fracture mechanics of pipe lines is abundant, there is no estimation method that is accurate and broadly accepted. Using the von Mises yield criterion and the plastic instability theory, Cooper [1] and Svensson [2] presented a theoretical solution for the prediction of the burst pressure of cylindrical and spherical vessels. The SHELL92 method, which is a modified version of the ASME B31G method, conservatively predicts failure pressures for corrosion defects up to 80% deep in line pipe of strength [3]. The 302 stainless steel is a slightly higher carbon version of type 304 stainless steel. Stainless steel 302 is more corrosion resistant than 301 stainless steel due to higher nickel content.

Figure 1: Corrosion crack.

The present work was motivated to optimize safety criteria for pressurized thin 302 stainless steel tubes. The present study was concerned about the severity of crack dimensions in crack propagation.

2. MATERIAL AND METHODS

The material of pipes was 304 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.

Using SHELL-92 criterion, the bursting pressure can be estimated as follows:

$$P_b = \frac{1.8t}{D} SMTS \left[\frac{1-\frac{d}{t}}{1-\frac{d}{tM_f}} \right] \quad (1)$$

$$M_f = \sqrt{1 + 0.805 \left[\frac{L}{\sqrt{Dt}} \right]^2}$$

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. SMTS is the specific minimum tensile strength.

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	40%	50%	60%

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

When a thin walled cylinder is subjected to internal pressure, three mutually perpendicular principal stresses are developed in the cylinder materials, namely: hoop stress, radial stress, and longitudinal stress.

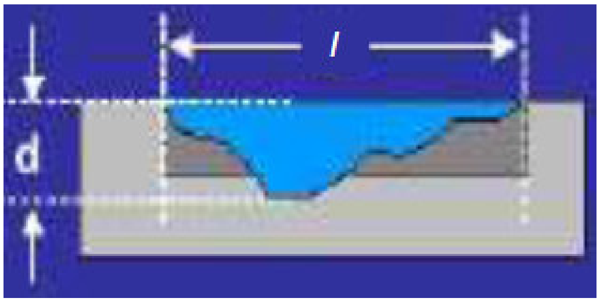

Figure 2: The Crack dimensions.

The hoop stress resists the bursting effect of the applied pressure, p.

Hoop stress, $\sigma_h = \frac{p \times d}{2t}$ (2)

Longitudinal stress, $\sigma_l = \frac{p \times d}{4t}$ (3)

Since the longitudinal stress is smaller than the hoop stress, for computing bursting pressure the hoop stress is only considered.

Theoretical bursting pressure, $p = \frac{\sigma_h \times 2t}{d}$ (4)

Theoretical bursting pressure is calculated by replacing the hoop stress with ultimate strength of the thin shell as follows:

$$p = \frac{\sigma_{us} \times 2t}{d} \quad (5)$$

3. RESULTS AND DISCUSSION

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, respectively, 55.81%, 40.05% and 39.53% in the total variation of the bursting pressure. The crack length (B) and % cold rolled reduction in stainless steel were insignificant.

Table 3: ANOVA summary of the bursting pressure

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	129.75	159.40	201.30	861.6	1	861.6	265514.9	55.81
B	152.74	165.07	172.65	67.3	1	67.3	20739.50	4.36
C	193.46	164.04	132.96	610.3	1	610.3	188073.1	39.53
D	161.32	8829.71	490.46	4.56	1	4.56	1405.23	0.3
e				0.01298	4	0.003245	1.00	0
T	637.27	9318.23	997.37	1543.747	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 2 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 3).

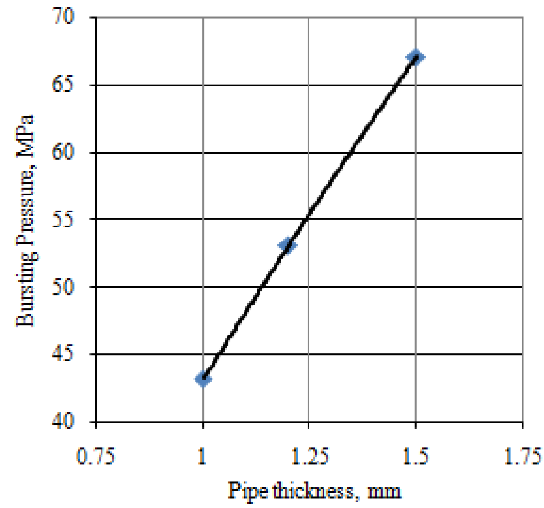

Figure 2: Effect of pipe thickness on bursting pressure.

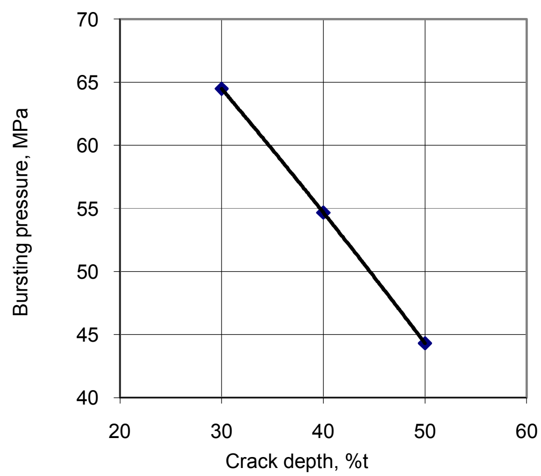

Figure 3: Effect of crack depth on bursting pressure.

Table 4: ANOVA summary of the longitudinal stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	803.72	803.66	801.86	0.75	1	0.75	556.91	0
B	777.90	795.33	836.02	593.04	1	593.04	440359.11	3.72
C	956.22	799.64	653.38	15290.79	1	15290.79	11354105.42	96.01
D	803.65	219040.1	2409.24	41.07	1	41.07	30496.34	0.26
e				0.00539	4	0.001347	1.00	0.01
T	3341.5	221438.8	4700.50	15925.66	8			100

Table 4 gives the ANOVA summary of longitudinal stress. Even if all the process parameters could satisfy the Fisher's test at 90% confidence level, only crack depth had major role in the total variation of longitudinal stress. The crack depth

(C) put in 96.01% in the total variation of the longitudinal stress. The pipe thickness, crack length (B) and type of steel (D) were insignificant. Table 5 gives the ANOVA summary of hoop stress. Incidentally, the crack depth (C) and type of material (D) contributed the same values of the total variation in the hoop stress.

Table 5: ANOVA summary of the hoop stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	1607.5	1607.32	1603.72	2.98	1	2.98	1410.23	0
B	1555.8	1590.65	1672.03	2372.16	1	2372.16	1122584.63	3.72
C	1912.4	1599.27	1306.77	61163.18	1	61163.18	28944441	96.01
D	1607.3	876160.58	4818.48	164.32	1	164.32	77761.66	0.26
e				0.00845	4	0.002113	1.00	0.01
T	6683	880958	9400.99	63702.63	8			100

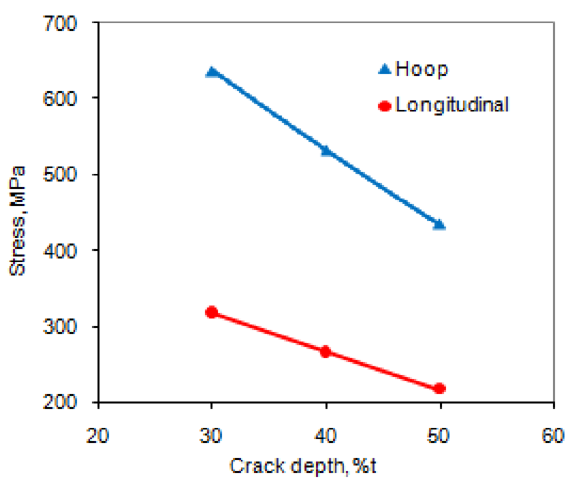

Figure 4: Effect of crack depth on longitudinal and hoop stresses.

The effect of crack depth on the longitudinal and hoop stresses is shown in figure 4. Both the longitudinal and hoop stresses decreased with the increase of crack depth.

5. CONCLUSIONS

The bursting pressure is highly dependent on the pipe thickness and crack depth for cold rolled 302 stainless steels. The bursting pressure increases with the increase of pipe thickness. Also, the bursting pressure decreases with the increase of crack depth. There was no influence of cold rolling on the longitudinal and hoop stresses.

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