ESTIMATION OF BURSTING PRESSURE OF THIN WALLED 304 STAINLESS STEEL TUBES BASED ON DNV RP F101CRITERION

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Abstract

The aim of the present work was to evaluate the bursting pressure, longitudinal stress and hoop stress of 304L, 304N and 304HN stainless steels using DNV RP F101criterion. 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 bursting pressure was not influenced by the heat treatment 304 stainless steel.

Keywords: *304L, 304N, 304HN, crack depth, crack length, heat treatment, bursting pressure, DNV RP F101.*

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1. INTRODUCTION

An accurate defect assessment procedure is needed to ensure integrity steel pipelines while avoiding unnecessary repairs. The pipes burst due to corrosion defect (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 DNV-RP-F101 defines simple approximations to the exact corroded area, based on the maximum length and the maximum depth of the defect. Corrosion typically has an irregular profile. The most conservative idealization is a rectangular profile as in DNV-RP-F101 [3]. The steel contains both chromium (18%) and nickel (8%) metals as the main non-iron constituents. It is an austenite steel. It is not very electrically or thermally conductive, and is non-magnetic. It has a higher corrosion resistance than regular steel.

Figure 1: Burst pipe.

The present work was motivated to optimize safety criteria for pressurized thin 304 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.

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
Type of stainless steel	D	304L	304N	304HN

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

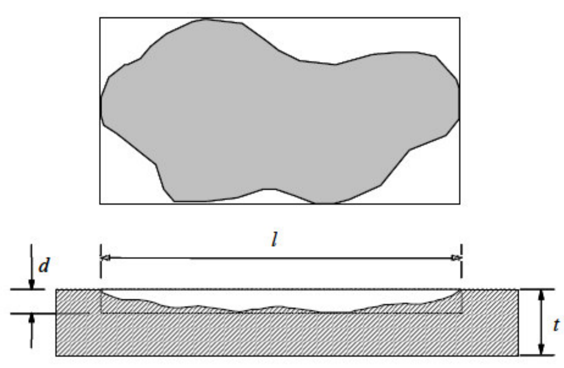

Figure 2: The crack dimensions.

Using DNV-RP-F101 criterion, the bursting pressure can be estimated as follows:

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

$$M_f = \sqrt{1+0.31\left[\frac{L}{\sqrt{Dt}}\right]^2}$$

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.

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.

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) contributed, respectively, 71.41%, 40.05% and 26.09% in the total variation of the bursting pressure. The crack length (B) and type of 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	82.77	106.34	139.26	536.73	1	536.73	706108.8	71.41
B	106.85	112.93	108.60	6.54	1	6.54	8603.86	0.87
C	126.36	109.96	92.06	196.14	1	196.14	258037	26.09
D	104.94	4031.62	328.37	12.24	1	12.24	16102.64	1.63
e				0.00304	4	0.00076	1.00	0
T	420.91	4360.84	668.29	751.647	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 3 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 4).

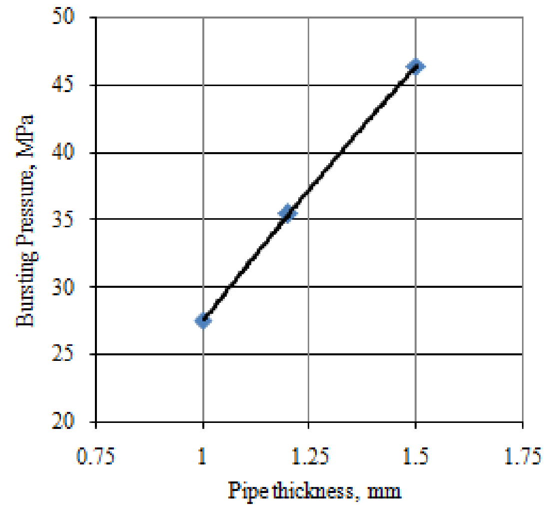

Figure 3: Effect of pipe thickness on bursting pressure.

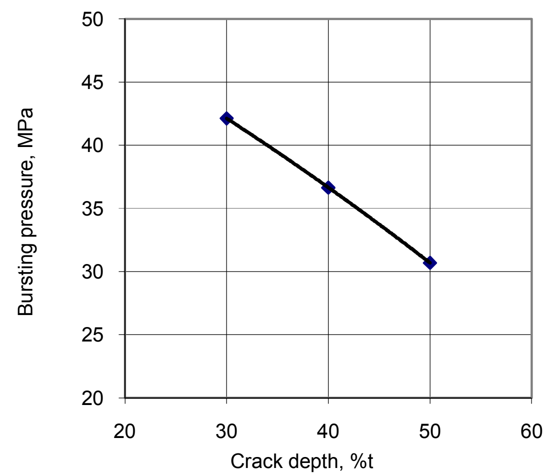

Figure 4: Effect of crack depth on bursting pressure.

Table 4: ANOVA summary of the longitudinal stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	512.62	536.13	554.73	296.91	1	296.91	331937.11	5.43
B	536.79	542.40	524.27	57.45	1	57.45	64227.50	1.05
C	619.67	537.74	446.06	5028.92	1	5028.92	5622193	92.03
D	522.01	98281.16	1603.47	81.32	1	81.32	90913.49	1.49
e				0.00358	4	0.000895	1.00	0
T	2191.1	99897.43	3128.53	5464.604	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) tendered 92.33% 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	1025.2	1072.26	1109.46	1187.62	1	1187.62	1101784	5.43
B	1073.6	1084.81	1048.54	229.83	1	229.83	213219	1.05
C	1239.4	1075.48	892.12	20115.7	1	20115.7	18661819	92.03
D	1044.0	393124.6	3206.94	325.28	1	325.28	301770	1.49
e				0.004312	4	0.00108	1.00	0
T	4382.2	396357.2	6257.06	21858.43	8			100

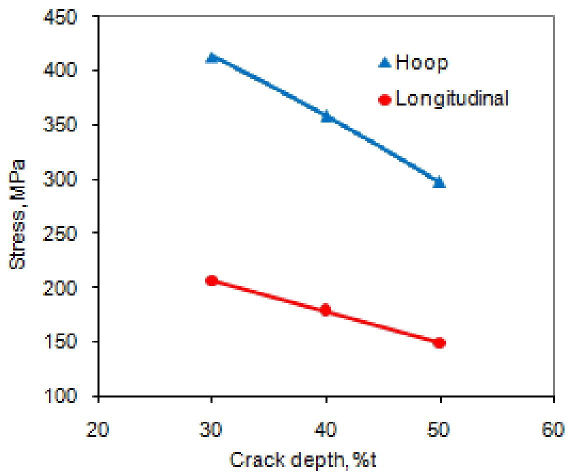

Figure 5: Effect of crack depth on longitudinal and hoop stresses.

The effect of crack depth on the longitudinal and hoop stresses is shown in figure 5. 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 304 stainless steels. The bursting pressure increases with the increase of pipe thickness. Also, the bursting pressure decreases with the increase of crack depth. The longitudinal and hoop stresses are nearly equal for 304L, 304N and 304HN stainless steels.

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