TRUSTWORTHINESS JUDGMENT OF CORROSION CRACKS IN COLD ROLLED 305 STAINLESS STEEL TUBES BASED ON RSTRENG CRITERION

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Abstract

The present work was to evaluate the bursting pressure, longitudinal stress and hoop stress of cold rolled 305 stainless steels using RESTRENG criterion. The magnitude of crack dimensions was optimized using Taguchi techniques. The highly influencing crack dimension were crack depth and pipe thickness. The hoop and longitudinal stresses were not influenced by the reduction during the cold rolling.

Keywords: *305, cold rolling, crack depth, crack length, bursting pressure, heat treatment, RESTRENG.*

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1. INTRODUCTION

Extensive research has been undertaken to develop methods for assessing the remaining load carrying capacity of corroded pressurized transmission pipelines. One of the most serious problems of pipes is corrosion. The pipes burst due to internal or external corrosion cracks (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 RSTRENG procedure [3], which is a further development of the ANSI/ASME B31G standard, is also used very often to assess the bursting strength of the pipes [3]. The 305 has the lowest work and strain hardening rate of all the austenitic stainless steels. It was designed for maximum formability. It combines good strength and corrosion resistance.

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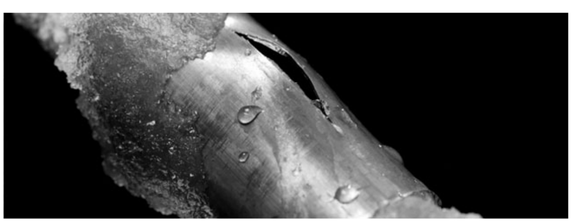

Figure 1: Burst pipe

The present work was motivated to optimize safety criteria for pressurized thin 305 cold rolled 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 RSTRENG criterion, the bursting pressure can be estimated as follows:

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

$$M_f = \sqrt{1 + 0.6275\left[\frac{L^2}{Dt}\right] - 0.003375\left[\frac{L^2}{Dt}\right]^2}$$

for $L^2/Dt \leq 50$

$$M_f = 0.032\frac{L^2}{Dt} + 3.3$$

for $L^2/Dt > 50$

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

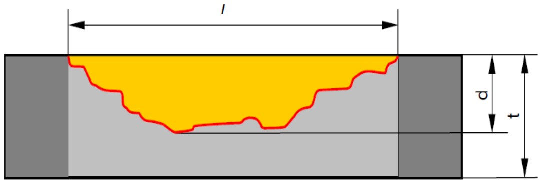

Figure 2: The Crack dimensions.

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) 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	2908	2847	2804.47	1794.7	1	1794.7	13213711	80.56
B	2619	2866	3074.68	34694.83	1	34694.83	2623773	16
C	2968	2840	2751.73	7865.33	1	7865.33	541379	3.3
D	2872	2702293	8559.09	192.43	1	192.43	23798	0.15
e				0.002037	4	0.000509	1.00	-0.01
T	11367	2710846	17189.96	44547.29	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.

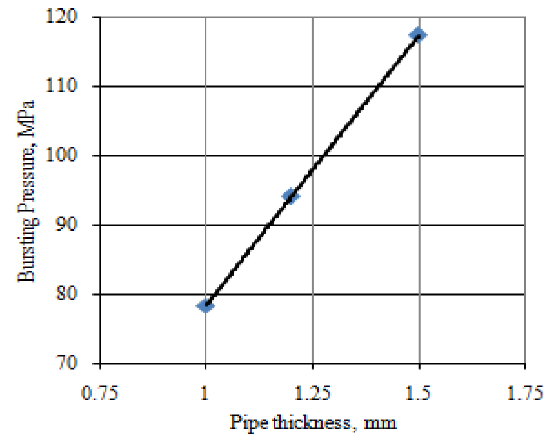

Figure 3: Effect of pipe thickness on bursting pressure.

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).

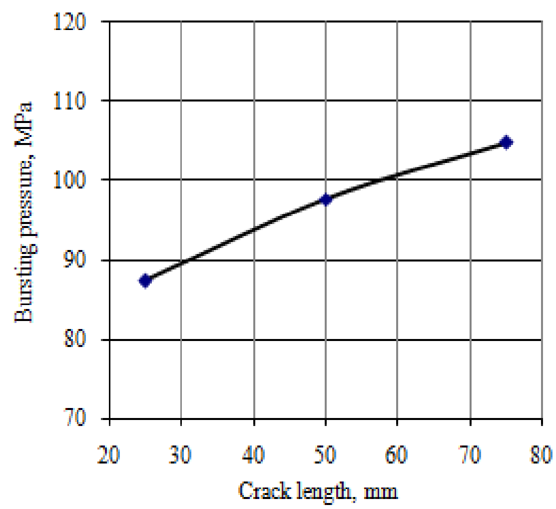

Figure 4: Effect of crack length on bursting pressure.

Table 4: ANOVA summary of the longitudinal stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	1453.9	1423.46	1402.23	448.68	1	448.68	189100.2	4.03
B	1309.5	1432.74	1537.34	8673.7	1	8673.7	3655609	77.88
C	1483.9	1419.82	1375.87	1966.33	1	1966.33	828727.5	17.66
D	1436.1	675573.4	4279.54	48.1	1	48.1	20272.18	0.43
e				0.009491	4	0.002373	1.00	0
T	5683.3	679849.4	8594.98	11136.82	8			100

Table 5: ANOVA summary of the hoop stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	2907.7	2846.92	2804.47	1794.7	1	1794.7	3524821	4.03
B	2618.9	2865.48	3074.68	34694.83	1	34694.83	68141235	77.88
C	2967.7	2839.63	2751.73	7865.33	1	7865.33	15447642	17.66

D	2872.2	2702293	8559.09	192.43	1	192.43	377935.78	0.43
e				0.002037	4	0.000509	1.00	0
T	11367	2710846	17189.96	44547.29	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.

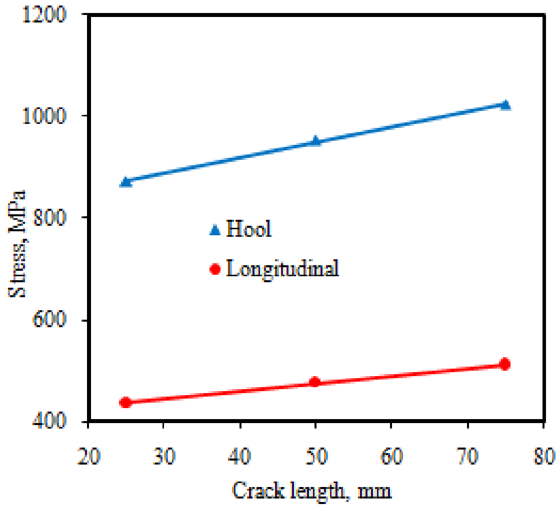

Figure 5: Effect of crack length on longitudinal and hoop stresses.

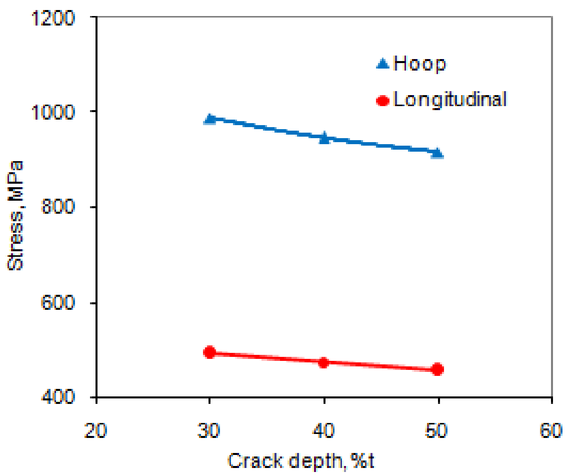

Figure 6: Effect of crack depth on longitudinal and hoop stresses.

The effect of crack length on the longitudinal and hoop stresses is shown in figure 5. The effect of crack depth on the longitudinal and hoop stresses is shown in figure 6. Both the longitudinal and hoop stresses decreased with the increase of crack depth.

5. CONCLUSIONS

The bursting pressure is highly dependent on the crack depth and pipe thickness for 305 stainless steels. The reduction during cold rolling is not influential on the longitudinal and hoop stresses.

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