## Research Article

# Experimental Analysis of Crack Effect on Stresses in Pipes

**Sakhi Jan** [*]**, Rafiullah khan , Sajjad Ahmad, Muhammad Amjad, Saeed badshah**

Department of Mechanical Engineering, International Islamic University Islamabad, Pakistan

**\*Corresponding author**
Sakhi Jan
Email: sakhi.jan@iiu.edu.pk

**Abstract:** This paper experimentally investigates the effect of crack size on the stresses in pipes. Tensile test specimens with and without cracks were tested in universal testing machine. The load and the displacement were monitored during testing. The results show that the strength of the pipe was decreased w.r.t crack size with a power trend. The elongation until failure also shows a similar trend. The failure of the specimens with cracks occurs at the crack position.
**Keywords:** Pipe stresses, crack size, tensile test, thin walled cylinder, longitudinal stress.

## INTRODUCTION

Pipe is a tube or hollow cylinder, usually but not necessarily of circular cross-section, used to convey water, gas, oil or fluids (substances which can flow i.e. liquids and gases). Pipe can be used in plumbing, pipe lines and also for structural applications. Fluid flows in pipe due to pressure difference. The pressure gradient across pipe produces stresses in pipes. The pipes should be designed in such way that it withstand with these stresses. Poor design can lead the pipe to failure that can cost both human life and money.

Structure failure/fracture initiate from cracks. These cracks may be of micro level and macro level. The strength of structure reduces with the crack size. Thus pipe will fail at lower pressure in the presence of cracks. Three types of stresses are developed in pipes carrying fluids under pressure. These are tangential, longitudinal and radial stresses.

Brickstad and Josefson [1] numerically investigated multipass circumferential butt-welding of stainless steel pipes in a non-linear thermo-mechanical FE-analysis. Recommendations were given for the through thickness variation of the axial and hoop stresses to be used when assessing the growth of surface flaws at circumferential butt welds in nuclear piping systems. Yaghi et al. [2] investigated residual stresses in welded components and a brief review of weld simulation was presented. Residual axial and hoop stresses were plotted for the considered range of pipe diameters for the two simulated pipe wall thicknesses and the differences are discussed. Paul Franz Schoeffl et al. [3] investigated the crack growth mechanism and failure behavior of commercial pipe grade materials when exposed to deionized water or LHC (90/10 wt% i-octane/toluene) under the simultaneous application of cyclic loads. The results of the cyclic crack growth experiments with three PE 100 pipe grades, using cracked round bar (CRB) specimens and performed at two different temperatures (35 °C and 60 °C), were compared in terms of the specimen lifetimes, and the micro-modes and kinetics of failure by referring to concepts of fracture mechanics. It was observed that while crack advance was preceded by crack-tip crazing in water, shear yielding took place at crack-tips in the LHC environment. The literature reveals that the effect of crack on the stresses is least investigated using uniaxial tensile test specimens.

The objective of this paper is to investigate the effect of cracks on the stress distribution in pipes. The investigation is carried experimentally and using finite element methods. For experimental study, longitudinal pipe specimens with induced cracks are tested in universal testing machine. The results are compared with the finite element investigation.

## EXPERIMENTAL ANALYSIS
### Test Specimens

Test specimens were made of stainless steel. Specimens were cut from a long pipe section. Test specimens are shown in figure 1.

**Fig-1: Longitudinal test specimens**

Cracks were produced in the specimens using hand saw. A total of nine specimens were prepared for testing. The detailed specifications of the specimens are given in table 1.

**Table 1: Test matrix for longitudinal test specimen**

| Specimen # | Material | Original Length(mm) | Crack size(mm) |
|---|---|---|---|
| 01 | Stainless steel | 300 | 0 |
| 02 | Stainless steel | 300 | 0 |
| 03 | Stainless steel | 300 | 2 |
| 04 | Stainless steel | 300 | 2 |
| 05 | Stainless steel | 300 | 2.2 |
| 06 | Stainless steel | 300 | 2.4 |
| 07 | Stainless steel | 300 | 2.6 |
| 08 | Stainless steel | 300 | 2.8 |
| 09 | Stainless steel | 300 | 3 |

**Test procedure**

Specimens were tested in universal testing machine shown in figure 2. The specimen was placed in the machine between the grips. The specimen length was measured before testing. The load and displacement were continuously recorded during testing. The specimens were loaded until it breaks at maximum stress. A typical broken specimen is shown in figure 3.



**Fig-2: Universal testing machine**

**Fig- 3:  Broken pipe specimen**

**Data analysis**

The stresses in the pipe specimen without crack was calculated using the formula

$$\sigma = \frac{4F}{\pi(D_o - D_i)^2} \qquad (1)$$

Where F is the force, $D_o$ and $D_i$ are outer and inner pipe diameters

Stresses in pipe specimens with crack are given by the following equation

$$\sigma_c = \sigma\sqrt{\pi a} \qquad (2)$$

Where σ is the stress in crack free pipe and *a* is the crack length.

**RESULTS AND DISCUSSION**

The stress strain diagram for a specimen is shown in figure 4. The stress decreased after yield point and the specimen get permanently elongated after yield point as seen in the figure. The test results for all specimens are summarized in table 2.  Figure 5 plots the breakage stress against crack length. The figure shows that the breaking stress decreases with the crack size. The specimen with no crack requires highest stress for breaking.  The maximum elongation of the specimens until failure is plotted against crack size in figure 6. The elongation is the highest for specimen with no crack. It decreases with the crack size as shown in the figure 6.
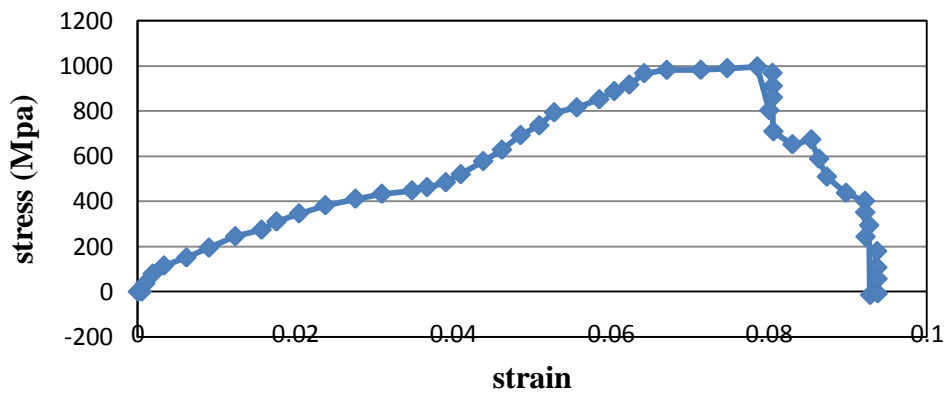


**Fig-4: Stress strain diagram for a typical tensile pipe specimen**
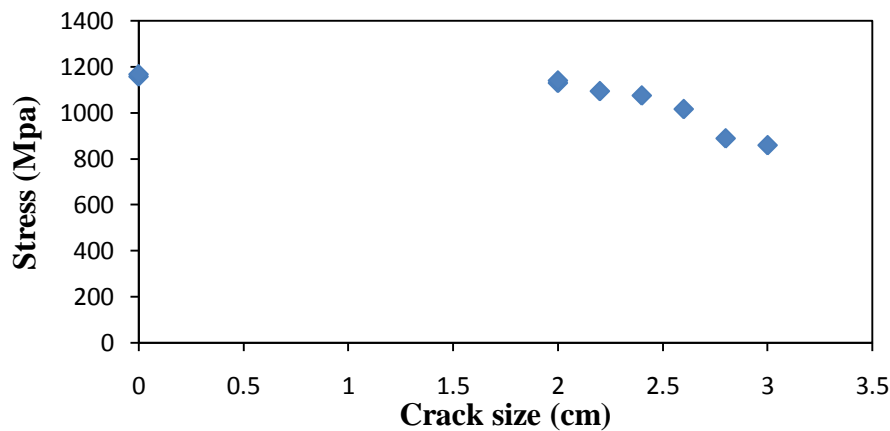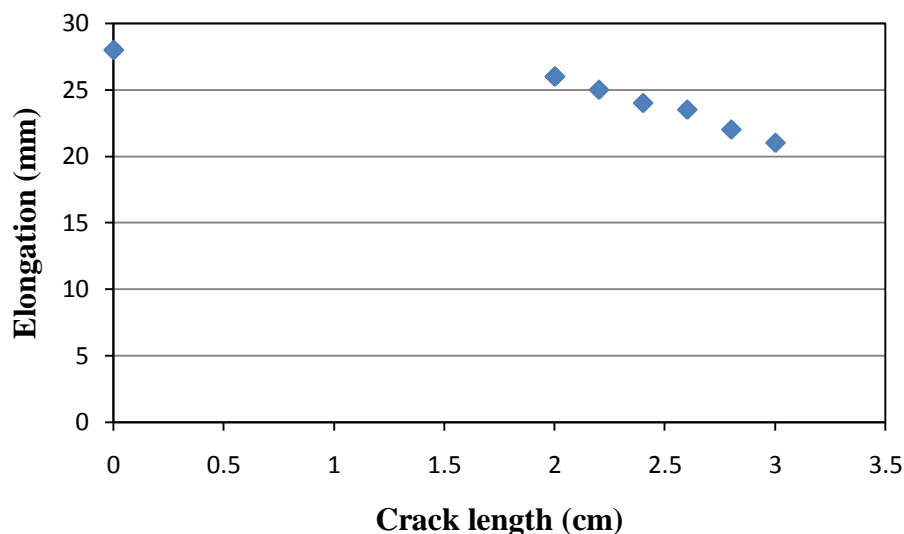


**Fig-5: Maximum stress versus crack size for the test specimens**

**Table 2: Results summary of the tested specimens**

| Specimen # | Original Length (mm) | Change in length (mm) | Elongation (l2-l1) | strain | Crack size (cm) | Load (kgf) | Stress (Mpa) |
|---|---|---|---|---|---|---|---|
| 01 | 300 | 328 | 28 | 0.093 | 0 | 6680 | 1155.83 |
| 02 | 300 | 328 | 28 | 0.093 | 0 | 6690 | 1165.62 |
| 03 | 300 | 326 | 26 | 0.086 | 2 | 6570 | 1128.08 |
| 04 | 300 | 326 | 26 | 0.086 | 2 | 6580 | 1138.57 |
| 05 | 300 | 325 | 25 | 0.083 | 2.2 | 6315 | 1092.68 |
| 06 | 300 | 324 | 24 | 0.080 | 2.4 | 6205 | 1073.65 |
| 07 | 300 | 323.5 | 23.5 | 0.076 | 2.6 | 5870 | 1014.92 |
| 08 | 300 | 322 | 22 | 0.073 | 2.8 | 5130 | 887.83 |
| 09 | 300 | 321 | 21 | 0.070 | 3 | 4960 | 858.22 |



**Fig-6: Maximum elongation versus crack size for the test specimens**

**CONCLUSIONS AND RECOMMENDATION**

In this study the effect of crack on the stresses in pipes was experimentally investigated. Following conclusions are drawn from the investigation.
1. The failure stress decrease with the crack size.
2. The elongation of the specimens until failure decreases with the crack size.
3. The specimen fails always at cracks making it critical location for stress concentration.
4. It is recommended that such tests should be compared with hydrostatic burst tests for pipes. The tests presented in the current paper are extremely simpler than burst tests and requires minimum safety and equipment costs.

**REFERENCES**
1. Brickstad B, Josefson BL; A parametric study of residual stresses in multi-pass butt-welded stainless steel pipes. International Journal of Pressure Vessels and Piping, 1998; 75(1):11-25.
2. Yaghi A, Hyde TH, Becker AA, Sun W, Williams JA; Residual stress simulation in thin and thick-walled stainless steel pipe welds including pipe diameter effects. International Journal of Pressure Vessels and Piping, 2006; 83(11–12): 864–874
3. Schoeffl PF, Lang RW; Effect of liquid oilfield-related media on slow crack growth behavior in polyethylene pipe grade materials. International Journal of Fatigue, 2015; 72: 90-101.
4. Richard K, Gaube E, Diedrich G; Drinking Water Pipes of Low Pressure Polyethylene. Kunststoffe/German Plastics Digest, 1959; 49(10): 516-525.
5. Gaube E, Gebler H, Muller W, Gondro C; Creep rupture strength and aging of HDPE pipes: 30 years experience in testing of pipes. German Plastics, 1985;75(7): 412-415.
6. Pinter G, Lang RW; Effect of stabilization on creep crack growth in high-density polyethylene. Journal of Applied Polymer Science, 2003;90(12):3191-3207.
7. ASTM D2837: standard test method for obtaining hydrostatic design basis for thermoplastic pipe materials or pressure design basis for thermoplastic pipe products.
8. ISO 4437: plastics piping systems for the supply of gaseous fuels – polyethylene (PE).
9. ASTM D2513: standard specification for polyethylene (PE) gas pressure pipe, tubing, and fitting.

10. ISO 4433: thermoplastic pipes. Resistance to liquid chemicals.
11. Kempe B;  Hazardous *materials* exposure: Emergency response and patient. Materialwiss Werkst, 1984;15:157.
12. Andersson U, Ifwarson M. Proceedings of the Plastic Pipes X Conference, Göteborg; 1998.
13. Hoàng EM, Lowe D.  Lifetime prediction of a blue PE 100 water pipe. Polym Degrad Stabil, 2008;93:1496.
14. Chudnovsky A, Zhou Z, Zhang H, Sehanobish K; The effect of microstructure on the slow crack growth resistance in polyethylene resins.  Int J Eng Sci, 2012;59:108.
15. Pinter G, Haager M, Balika W,  Lang RW; Fatigue crack growth in PE-HD pipe grades. Plastics, rubber and composites,  2005;34(1): 25-33.
16. ISO 9080: plastics piping and ducting systems – determination of the longterm hydrostatic strength of thermoplastics materials in pipe form by extrapolation.
17. EN ISO 1167: Thermoplastics pipes, fittings and assemblies for the conveyance of fluids – determination of the resistance to internal pressure.