International Conference on Mechanical Engineering Research (ICMER2013), 1-3 July 2013
Bukit Gambang Resort City, Kuantan, Pahang, Malaysia
Organized by Faculty of Mechanical Engineering, Universiti Malaysia Pahang
Paper ID: P104

THE INFLUENCE OF GOUGE DEFECTS ON FAILURE PRESSURE OF STEEL PIPES

N. A. Alang[1*], N. A. Razak[1] and M. R. Zulfadli[2]

[1]Corrosion and Fracture Focus Group
Faculty of Mechanical Engineering, University Malaysia Pahang
26600 Pekan, Pahang, Malaysia
[*]Email: azuan@ump.edu.my
Phone: +6094246266; Fax: +6094246222
[2]Faculty of Mechanical Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia

ABSTRACT

Failure pressure of API X42 steel pipes with gouge defects was estimated through a nonlinear finite element (FE) analysis. The effect of gouge length on failure pressure of different pipe diameters was investigated. Stress modified critical strain (SMCS) model was applied as in predicting the failure of the pipe. The model uses strain based criteria to predict the failure. For validation of the model, the FE results were compared to experimental data in literature showing overall good agreement. The results show that the gouge length has significant influence on failure pressure. A smaller pipe diameter gives highest value of failure pressure.

***Keywords*:** Failure Pressure; Gouge; Stress Modified Critical Strain; Stress Triaxiality

INTRODUCTION

Since few years ago, pipelines become the most preferred medium for oil and gas transportation. After period of time in services, number of cases of pipe failure has been reported (MacDonald et al., 2008; Liu et al., 2010 and Hossam. et al., 2010). The failure of the pipes is due to the reduction of wall thickness that may cause by corrosion phenomenon and gouge defect. The gouge on pipe surface normally occurred during installation of the pipes in which the collision between the pipes was occurred. Study by Netto et al. (2005) has shown that the defect on the pipes give significant effect on the failure pressure. In this respect, huge number of mathematical models has been developed to assess the remaining strength of pipelines containing defect (DNV-RP-F101, 2010 and API579, 2000). Most of the models use stress based failure criterion to predict the failure of the pipes. However, these models sometimes were underestimate or too conservative (Alang et al., 2012). Another models use in predicting the failure is based on local strain criterion. Oh et al. (2007) uses strain based criterion which is SMCS model to predict the failure pressure of API X65 steel pipes. The results published by Oh et al. (2007) show that the SMCS model is capable to predict the failure pressure for both pipes with corrosion and gouge defects. Oh et al. (2007) has determined the failure pressure of API X65 steel pipes with constant diameter. Mathematically, the SMCS model is evaluated by Eq. (1) that is express by:

$$\varepsilon_f = A\ exp\left(-\frac{3}{2}\frac{\sigma_m}{\sigma_e}\right) \quad (1)$$

where ε_f is fracture strain, σ_m/σ_e is stress triaxiality and A is the material constant that can be found through experiment.

In this work, the effects of gouge length on failure pressure of API X42 steel pipes with different pipe diameters were investigated. The pipe with gouge defect was modeled and analyzed using MSC PATRAN/MARC 2008r1 software. The SMCS model was applied to estimate the failure pressure of the steel pipes.

MATERIAL

The material used in this study was API X42 steel. The chemical compositions of the material have been identified using spectrometer machine. The uniaxial tensile test was performed according to ASTM E08-2008. The chemical compositions and mechanical properties of the material are tabulated in Table 1 and Table 2, respectively. Figure 1 shows the true plastic stress-strain curve obtained from tensile test.

Table 1. Chemical composition of API X42 steel (%wt)

C	P	Mn	S	Si	Fe	Ceq
0.03	0.01	0.98	0.003	0.19	98.6	0.21

Table 2. Mechanical properties of API X42 steel at room temperature

Young Modulus, E (GPa)	Poisson Ratio, v	Yield Strength, σ_y (MPa)	Tensile Strength, σ_u (MPa)
207	0.3	284.7	464.4

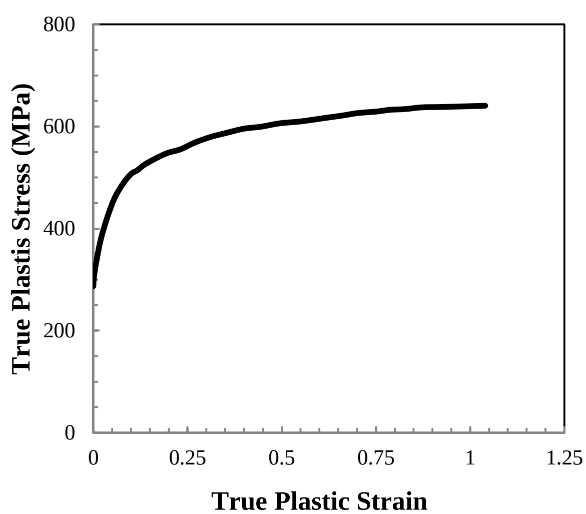

Figure 1. True plastic stress-strain data employed in FE analysis.

FINITE ELEMENT ANALYSIS

A 3-D nonlinear FE analysis was performed. The pipe with gouge length, *l* and outer diameter, *D* was modeled using eight node solid elements, isotropic elastic-plastic material with large deformation using MSC PATRAN/MARC 2008r1 software. Reduced integration scheme is applied in all simulation works. The simulation was performed with fully utilized the symmetrical condition for computational efficiency. Therefore, only a quarter of the pipe was simulated. The internal pressure was applied at the inner surface of the pipe. The schematic illustration of the pipe with gouge is shown in Figure 2. The total lengths of the pipe, *L* gouge depth, *d* and wall thickness, *t* were kept constant to be 2300 mm, 8.75 mm and 17.5 mm, respectively. The gouge is characterized by the 45 degree V-notch with the radius of 2 mm. Figure 3 shows the detail FE mesh applied on the gouge defect. Since the failure is assumed will be occurred at gouge defect, the FE mesh is applied sufficiently small at that particular region.

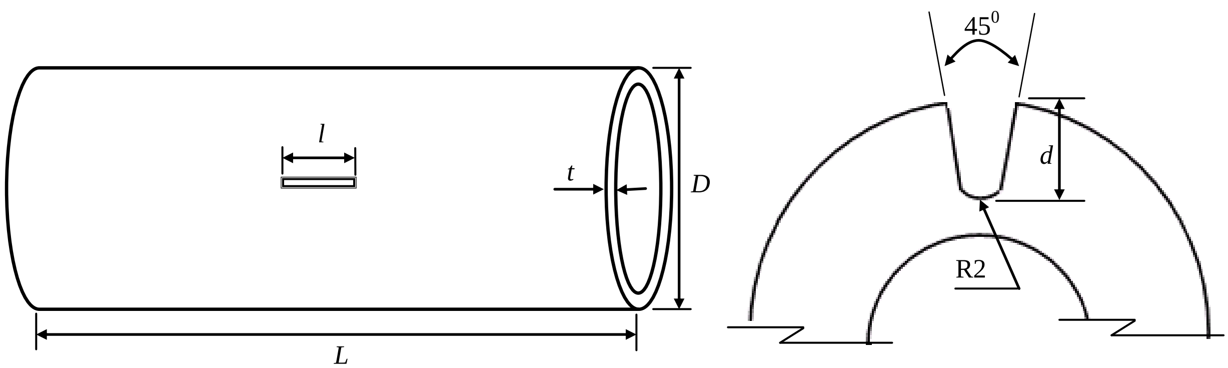

Figure 2. Schematic of pipe with gouge.

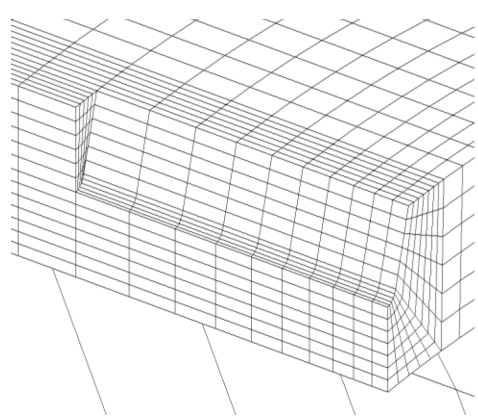

Figure 3. Detail FE mesh on gouge defect.

In order to determine the failure pressure of the defective pipe, the local stress strain results was collected. The stress triaxiality and equivalent strain were calculated for the entire loading history. The failure is assumed to occur when the equivalent strain is equal or greater than fracture strain of the pipe material. Recently, the author (Alang et al., 2012) has developed the SMCS model for API X42 steel pipes. In mathematics, the model can be written as:

$$\varepsilon_f = 1.732\ exp\left(-1.5\frac{\sigma_m}{\sigma_e}\right) \tag{2}$$

VALIDATION OF THE MODEL PARAMETER

The model has been validated by comparing the FE results coupled with SMCS model with experimental data from literature. The small scale burst pressure test had been performed on pipes with rectangular artificial defect and been summarized in Table 3. The pipes were pressurized by hydraulic oil and failure pressures were experimentally determined. Detail on the experimental works can be found in literature (Alang et al., 2013). Figure 4 shows the failure pipe after the test. The maximum error between these two methods is 9%.

Table 3. Comparison of failure pressure between FE and experiment.

Pipe No.	Defect Length, *l* (mm)	Experiment (MPa)	FEA (MPa)	Deviation (%)
A1	50	54	57.62	6.7%
A2	70	46	50	8.7%

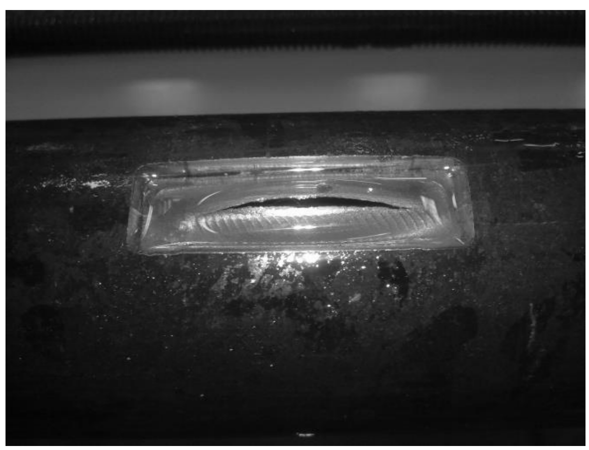

Figure 4. Failure pipe after the test.

RESULT AND DISCUSSION

A total 9 cases of pipe parameters were simulated that represent by PN1 to PN9. Three different gouge lengths were analyzed for each pipe outer diameter. The outer diameter, *D* that has been selected in this study is 508 mm, 762 mm and 1016 mm. Table 4 summarizes the parameters for each case including the predicted failure pressure results. Figure 5a presents the effect of gouge length on failure pressure of the API X42 steel pipes. Figure 5a clearly shows that the failure pressure decreases as the gouge length increases. There is no significant change on failure pressure value for the pipe with outer diameter of 762 mm and 1016 mm. However, when the diameter of the pipe changes from 508 mm to 762 mm, the failure pressure significantly decreases. It is due to the ratio of wall thickness to the pipe diameter. For the pipe with outer diameter of 508 mm and 762 mm, the ratio of wall thickness to diameter is 3.44% and 2.29%, respectively. Meanwhile, for pipe with outer diameter of 1016 mm, the wall thickness to pipe diameter ratio is 1.72%. The graph of failure pressure as a function of this ratio was plotted and shown in Figure 3b. The relationship between these two parameters can be represented by linear regression demonstrate a strong correlation. Figure 6 shows the von Mises stress distribution on gouge defect area for pipe PN4. This figure also shows that the bulging phenomenon was occurred at the onset of pipe bursting.

Table 4. Summary of the failure pressure results.

Case	**Pipe Diameter, (mm)**	***t/D (%)***	**Defect Dimension, (mm)**		**Failure Pressure (MPa)**
			Length, *l*	**Depth, *d***	
PN1	508	3.44	100	8.75	28.8
PN2			200		25.2
PN3			300		23.6
PN4	762	2.29	100		19.2
PN5			200		18.0
PN6			300		17.0
PN7	1016	1.72	100		16.8
PN8			200		15.0
PN9			300		14.2

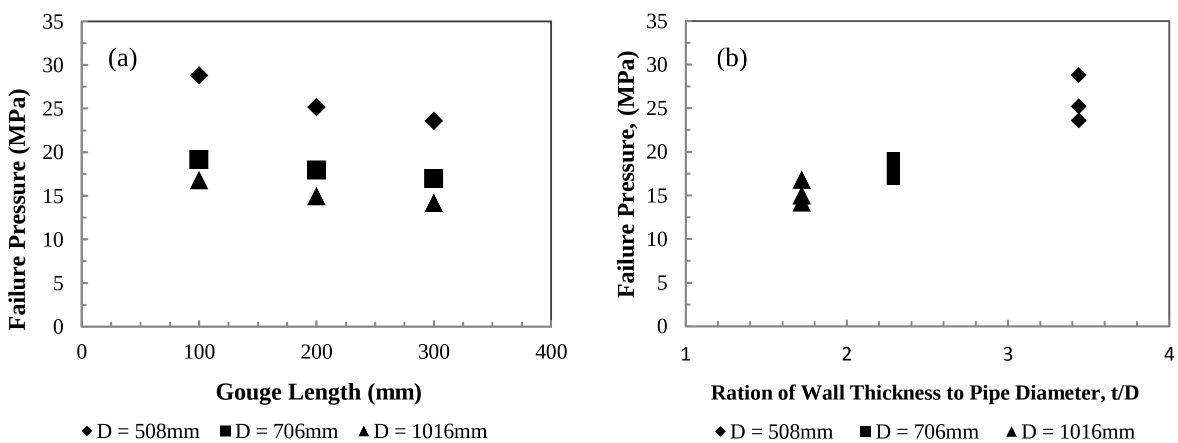

Figure 5. Failure pressure for different pipe diameter: (a) effect of gouge length, (b) effect of wall thickness to pipe diameter ratio.

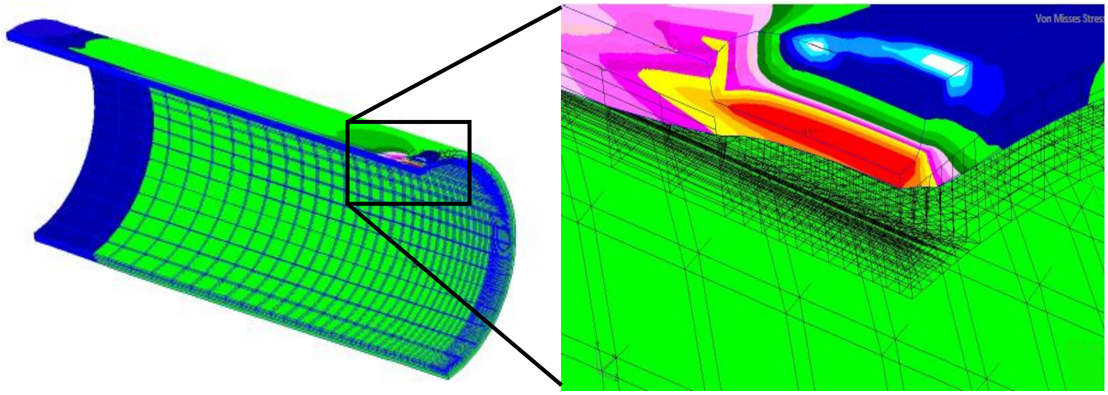

Figure 6. Von Mises stress distribution and enlargement on gouge defect.

CONCLUSION

This paper has presented the effect of gouge length on failure pressure of API X42 steel pipes. The conclusions of the study are as follow:

1) The failure pressure of API X42 pipe was influenced by the length of the gouge defects.
2) The failure pressure dropped significantly when the pipe diameter reduced from 508 mm to 762 mm. However, predicted failure pressure for pipe diameter of 762 mm and 1016 mm is slightly different. It is due to highest deviation of wall thickness to pipe diameter ratio between pipe diameter 508 mm and 762 mm.

ACKNOWLEDGEMENTS

The authors would like to express appreciation to all members of Corrosion and Fracture Focus Group (CFRAC) for technical support. Not forgotten to the sponsors of the research, University Malaysia Pahang, Malaysia (RDU100312).

REFERENCES

Alang, N.A., Razak, N.A., Safie, K.A. and Sulaiman, A. 2012. Finite element analysis on burst pressure of defective steel pipes. European Conference on Fracture, Kazan, Russia.

Alang, N.A., Razak, N.A., Safie, K.A. and Sulaiman, A. 2013. Finite element analysis on burst pressure of steel pipes with corrosion defects. International Conference on Fracture, Beijing, China.

American Petroleum Institute. 2000. API RP579—Recommended practice for fitness-for-service. American Petroleum Institute.1

ASTM Standard E8-08. 2008. Standard test method for tension testing of metallic material. American and Society for Testing and Materials.

DNV Recommended Practice RP-F101. 2010. Corroded pipelines, Det Norske Veritas.

Hossam, A. and Kishawy. 2010. Review of pipeline integrity management practices. International Journal of Pressure Vessels and Piping, 87: 373 – 380.

Liu, P.F., Zheng, J.Y., Zhang, B.J. and Shi, P. 2010. Failure analysis of natural gas buried X65 steel pipeline under deflection load using finite element method. Materials and Design, 31: 1384–1391.

MacDonald, K.A., Cosham, A., Alexander, C.R. and Hopkins, P. 2007. Assessing mechanical damage in offshore pipelines – Two case studies. Engineering Failure Analysis, 14: 1667–1679.

Netto, T.A., Ferraz, U.S. and Estefen, S.F. 2005. The effect of corrosion defects on the burst pressure of pipelines. Journal of Constructional Steel Research, 61: 1185–1204.

Oh, C.K., Kim, Y.J., Baek, J.H. and Kim, W.S. 2007. Ductile failure analysis of API X65 pipes with notch-type defects using a local fracture criterion, International Journal of Pressure Vessels and Piping, 84: 512–525.