Burst capacity due to corrosion acting at radial orientation of pipeline

N N Idris, Z Mustaffa and N N A Ismil

Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Malaysia.

Abstract. Carbon steel pipeline is known as the safest method to transfer a large volume of oil and gas from sources to the consumers. Carbon steel has higher tendency to fail after long time because of major hazard such as corrosion. Corrosion develops at both sides of pipeline wall; internally and externally thus the strength and integrity are affected caused by such metal deterioration. This paper emphasizes on defects interaction between external and internal walls in the radial orientation towards failure burst pressure. To date, there are no standards, codes or guidelines on radial corrosion defect to explain such behaviour. Seven types of corrosion arrangement retrieved from literature were modelled in finite element software for a pipeline in the grade API 5L X42. Von Mises distribution curve was plotted to determine the pipeline pressure limit at different corrosion arrangement. The maximum radial interaction with the lowest failure pressure was determined from the values obtained.

Keywords – corrosion, radial interactions, burst capacity, failure pressure, finite element analysis

1. Introduction

Oil and gas are the main sources of energy production in the world. Pipeline is one of the major transportation used in oil and gas industry. It is mostly used in transporting crude oil and natural gas from the areas of production to the refineries. The importance of oil and gas industry cannot be underestimated because it delivers major values towards economy. However, there are many pipeline incidents every year around the world.

One of the reasons of pipeline failure is metal deterioration or corrosion. It has been identified as the main challenge affecting the productivity of oil and gas pipelines as it produces a reduction in the pipe wall thickness. Furthermore, corrosion can be divided into two categories, namely external and internal corrosion. Typically, wall thickness will have an irregular depth profile and extend in irregular pattern in both longitudinal and circumferential directions. There are three categories for corrosion known as single defect, interacting (multiple) defect and complex shaped defect. Single defect is a type of corrosion which does not interact with surrounding and is isolated. On the other hand, interacting defect is a type of corrosion that interacts with surrounding corrosion defect. It is interacting with neighbouring corrosion in an axial and circumferential direction. The most severe one is complex defect as it will cause a lower failure pressure to the pipeline compared to isolated corrosion effect [2].
Thus, codes and guidelines were developed to evaluate the residual strength of the corroded pipeline. It is mostly empirical formula based on the results from experiments and numerical analyses conducted [16]. Failure pressure of pipeline with corrosion defects can be determined by classifying whether interaction between defects occurs by using an interaction rule. Numerous studies conducted on interaction rules include DNV RP F101, API 759, BS 7910, Kiefner and Vieth and Pipeline Operator Forum (POF) [7].

In the past of 40 years, the development of a number of study for assessing the defects had been conducted and some of them had been incorporated into industry guidance and recommended practices [4]. Though their contributions are significant, but less attention is paid on radial interacting corrosion defect which important to engineering practice particularly on assessment of residual strength of corroded pipe. Radial interaction defect can be defined when corrosion occurs at external and internal wall of pipeline, simultaneously.

Therefore, the modelling of the problem using finite element software was conducted to assess the failure pressure of pipeline with radial interacting defects. The objective of this paper is to determine the failure pressure of corroded pipeline with radial interacting corrosion defects. The effect of different radial interaction arrangement to their failure pressure have been studied after the modelling is validated.

2. Numerical Simulation

A. Material properties and Sampling

The material properties for API 5L X42 was shown in Table 1.

| Material Properties                  | Value  |
|--------------------------------------|--------|
| Yield Strength (MPa)                 | 290    |
| Ultimate Tensile Strength (MPa)      | 414    |

The simulations were performed with different corrosion arrangement. The pipeline was loaded with internal pressure with different external defect arrangement using Solidworks for modelling and Ansys software for analysis. The corrosion was specified into seven arrangement with elliptical shape developed from literature with 40% corrosion at internal walls, another 40% corrosion at external walls with total 80% of corrosion, leaving around 20% remaining strength of the pipeline. The length of corrosion (L) is 57.15mm, 0.3D and width (w) is 35.4mm, 0.15D [1]. Figure 1 shows corrosion interaction arrangement of seven cases.
Validation of Finite Element Modelling

To ensure its accuracy the numerical simulation was validated. For validation purpose, pipe API 5L X80 was used to compare from past research [7]. There were two simulated defects; IDTS 2 and IDTS 3 configurations. In order to validate the simulated model, the percentage error should be less than 10% for each configuration based on all two corroded defects pipe models.

The material properties for the pipe; yielding strength $\sigma_y = 534.10$ MPa, and the ultimate tensile strength $\sigma_u = 661.40$ MPa. Table 2 shows the parameters of the corrosion defects for model validation. The percentage error for each corrosion arrangement was computed to be less than 10% based on both samples. For IDTS 2, the error percentage calculated was 3.9% and 2.5% error for IDTS 3. Therefore it was concluded that the simulation model developed was valid for conducting to the next stage.

### Table 2. Parameters of corroded pipeline specimens

| Case    | Defect Depth (mm) | Corrosion Profile | | |
|---------|------------------|------------------|---|---|
|         | Corrosion View   | Length, L (mm)   | Width, w (mm) | Longitudinal spacing, $S_L$ (mm) | Circumferential spacing, $S_C$ (mm) |
| IDTS 2  | 5.39             | 39.60            | 31.90         | 0.00                        | 0.00                       |
| IDTS 3  | 5.32             | 39.60            | 31.90         | 20.50                      | -31.90                     |

Meshing

The model was meshed using tetrahedrons solid elements with 0.005 element size. Figure 2 shows the meshed model.
Figure 2. Meshed model

D. Static structural
The internal pressure was defined as 20 Mpa with two fixed support at the end of the pipe as it assemble clamped setup in physical experiment.

E. Solutions
The result of interest was the failure pressure of the pipe. Therefore, failure pressure was assumed when the von Mises stress was equal to the ultimate tensile strength on any point on the pipe, although it was expected to occur at corrosion defect area or location.

3. Results and Discussion

A. Maximum von Mises Stress Distribution
The operating pressure was varied to understand its influence on interaction arrangement defect located on external and internal sides of pipeline wall. It was simulated to perceive its corresponding to the maximum von Mises stress distribution. In addition, Figure 3 shows von Mises stress distribution when corrosion arrangement for sample no 6 was modelled. At different corrosion interaction arrangement, results were plotted as shown in Figures 4 and 5.

Figure 4 represents equivalent von Mises stress while Figure 5 represents max equivalent elastic strain for seven cases of interaction corrosion arrangement. Failure with cumulative wall losses of 80% for all the specimens were determined based on two criteria. The first criteria where the material true ultimate tensile strength value was projected from the von Mises stress axis to the internal pressure axis in order to identify the limit of the applied load. The second criterion where material yield strength value was projected from the von Mises stress axis to internal pressure in order to identify the safe value before it burst. From the figures, it can be seen that when operating pressure increased, the values increased to 1600 MPa.
Figure 3. Equivalent von Mises stress distribution for sample no 6

Figure 4. Equivalent von Mises stress distribution for seven cases

Figure 5. Maximum elastic strain for seven cases
B. Failure Pressure

Figure 6 shows the von Mises stress increase with respect to the pipeline walls internal pressure. For each specimen, failure pressure of different defect orientation was determined. Maximum failure region was developed where pressure limit was derived from the projection of true ultimate tensile strength which was 414 MPa. Minimum failure region is the second criteria under ASME requirement, where it stated that minimum failure is 90% developed stress on yield stress 290 MPa. Minimum failure region is where the pipe still can be used but the steel is yielding and on plastic deformation stage.

For intact pipe, the allowable ASME combined stress was 12.29 Mpa, whereas when corrosion was applied, pipe case number 3 obtained the lowest value 3.88 Mpa. This could be because of the corrosion arrangement aligned circumferentially compared to others arrangement. [14] stated that failure pressure of corroded pipeline decreases with increasing interaction effect between multiple corrosion.

CONCLUSIONS

Based on the discussion, it was concluded that stress increases as the internal pressure on the pipeline increase. The lowest possible failure pressure for each pipe sample depends on the multiple interaction defects arrangement. Results have shown that radial interaction corrosion affects the integrity of the pipeline and the failure pressure. Therefore, radial interacting corrosion does affect the failure pressure more severely up to 10.77 MPa compared to external and internal interacting corrosion acting alone.

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