Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 29, issue 3 / 2023, pp. 91-98

BEHAVIOR OF CORRODED ABOVEGROUND PIPES SUBJECTED TO INTERNAL PRESSURE

Ladislau RADERMACHER[1*], *Cristian RĂDEANU*[2], *Ludovic CĂLCÂI*[3]

[1]University of Petrosani, Romania, ladislauradermacher@upet.ro
[2]National Institute for Research and Development in Mine Safety and Protection to Explosion INSEMEX Petroșani, Romania, cristian.radeanu@insemex.ro
[3]'Gheorghe Asachi' Technical University Iași, Romania

DOI: 10.2478/minrv-2023-0027

Abstract: *Corrosion is accountable for numerous malfunctions and leakages in gas pipelines. In instances of external corrosion, due to the internal pressure within the pipes, stress concentrations can occur around the corroded areas. These, in the presence of cavities or cracks resulting from corrosion, may amplify the risk of pipeline failure. Consequently, as the wall thickness diminishes due to corrosion, the pipeline's ability to withstand internal pressure declines. In the case of corrosion, the pressure at which a corroded pipe might collapse is significantly lower than that of an uncorroded one. Finite element modeling of corroded pipes with a defect is conducted using the Abaqus software, taking into account the mechanical effects of internal pressure on the gas pipeline structure. Abaqus facilitates the simulation of internal pressure and predicts the behavior of the pipe under pressure conditions.*

Keywords: *corrosion defect, internal pressure, numerical analysis, Abaqus*

1. Introduction

Gases are valuable resources that currently drive over 50% of the world's energy [1, 2]. Natural gas is transported from one place to another through pipelines. Steel is the most commonly used material for pipelines that transport natural gas, and it is highly susceptible to corrosion [3].

When a pipeline is affected by corrosion, it loses its essential properties and mechanical strength [4]. This can lead to malfunctions, endangering lives and the environment, as well as incurring costly damages [5]. Corrosion poses a significant challenge to the integrity and safety of pipelines, especially aboveground ones exposed to environmental conditions. As pipelines corrode, they can weaken and become more susceptible to failure under internal pressure.

Corrosion is a natural chemical process as the surrounding environment causes the deterioration and destruction of pipe materials. Pipeline corrosion becomes a tangible problem as changes in the environment, climate, and aging infrastructure dramatically affect corrosion rates. Corrosion is undoubtedly a growing concern in the gas industry.

External corrosion [2] occurs due to environmental conditions on the outer surface of the steel pipe, which can cause an electrochemical interaction between the exterior of the pipe, and the surrounding air or water. Galvanic and atmospheric corrosion are common types of external corrosion. The corrosion cell is powered by the continuous supply of water and oxygen from external sources. The primary area where external corrosion is found is in places with paint application.

* Corresponding author: Radermacher Ladislau, lect. Ph.D. eng., University of Petrosani, Petrosani, Romania, Contact details: University of Petrosani, 20 University Street, ladislauradermacher@upet.ro

 vol. 29, issue 3 / 2023
pp. 91-98

Maintaining the integrity of aboveground pipelines is essential to prevent accidents and ensure the safe transport of gases or other substances [6, 7]. Regular monitoring and timely intervention can extend the lifespan of the pipeline and reduce risks.

Thus, significant effort has been made in recent years to study the behavior of metal loss defects in corroded pipelines under static internal pressure, using experimental, numerical, and theoretical methods. According to DNV RP F101[8], actual corrosion defects can be divided into three types, namely singular defect, interacting defect, and complex shape defect. A singular defect is one that does not interact with a neighboring defect; an interacting defect is one that interacts with neighboring defects in an axial or circumferential direction; a complex shape defect is a defect resulting from the combination of colonies of interacting defects, or a singular defect for which a profile is available. The failure behavior of a colony of spatially close defects is much more complex than the failure behavior of an isolated defect.

2. Finite element modeling of corroded pipes

2.1. Finite Element Model

The development and validation of new assessment methods for pipelines with corrosion defects have relied on both laboratory test results and FE analyses since the early 1990s [7]. Guidelines for the FE analysis of corroded pipelines are available in recognized standards such as BS 7910 (Annex G).

FE analyses are performed using the ABAQUS software [9]. A rate-independent plasticity model is adopted using the von Mises yield criterion [10]. Pressure is applied to the inner surfaces of the model. Since the finite element formulation used in this work is based on continuum mechanics, it is not possible to simulate the development of discontinuities in the material. For this reason, it is necessary to define a criterion for detecting the failure pressure level of the corroded pipeline. The failure criterion known as the "tensile stress criterion" is adopted [7, 11], according to which failure is attained when the von Mises stress around the defect exceeds the ultimate tensile strength of the pipeline steel.

2.2. Validation of the Finite Element Model

The finite element method is a powerful numerical tool that can be used to study the failure behavior of corrosion defects. The ability to use FEM to perform parametric studies by varying geometric data also allows the development of new corrosion assessment guidelines. However, as [12, 13] have mentioned, due to the sheer complexity generated by real-life corrosion problems, the accuracy of the results obtained using FEM heavily depends on the model characteristics, material behavior, and boundary conditions of the model. Since simulating pitting can take hours or even days to yield results, an efficient FEM must be simulated to save time and increase research productivity [14, 15, 16].

There are numerous papers utilizing FEM to investigate the behavior of steel pipelines at corrosion defects. Despite this, only a few have considered combined loads. This paper describes a detailed FEM to simulate the failure behavior of a single corroded pipe subjected to internal pressure.

2.3. Model Data

A tubular pipeline of 2 m length made of API 5L X65 steel is considered. The material properties according to the Johnson-Cook criterion are A=500, B=927, n=0.34257, m=1, Mt=0 (Melting temperature), Tt=0 (Transition temperature), C=0.032604, $\dot{\varepsilon}$=0. An elasticity modulus E=210,000 MPa and Poisson's coefficient ν=0.3 are used. This specimen has an outer diameter D and the same wall thickness t, namely 168.3 mm and, respectively, 4.5 mm. The defect has dimensions where L, a, w represent the corrosion length, depth, and respectively, the width of a single defect according to figure 1.

The depth of the defect is 3.82 mm (considered 85% of the pipeline thickness).

vol. 29, issue 3 / 2023
pp. 91-98

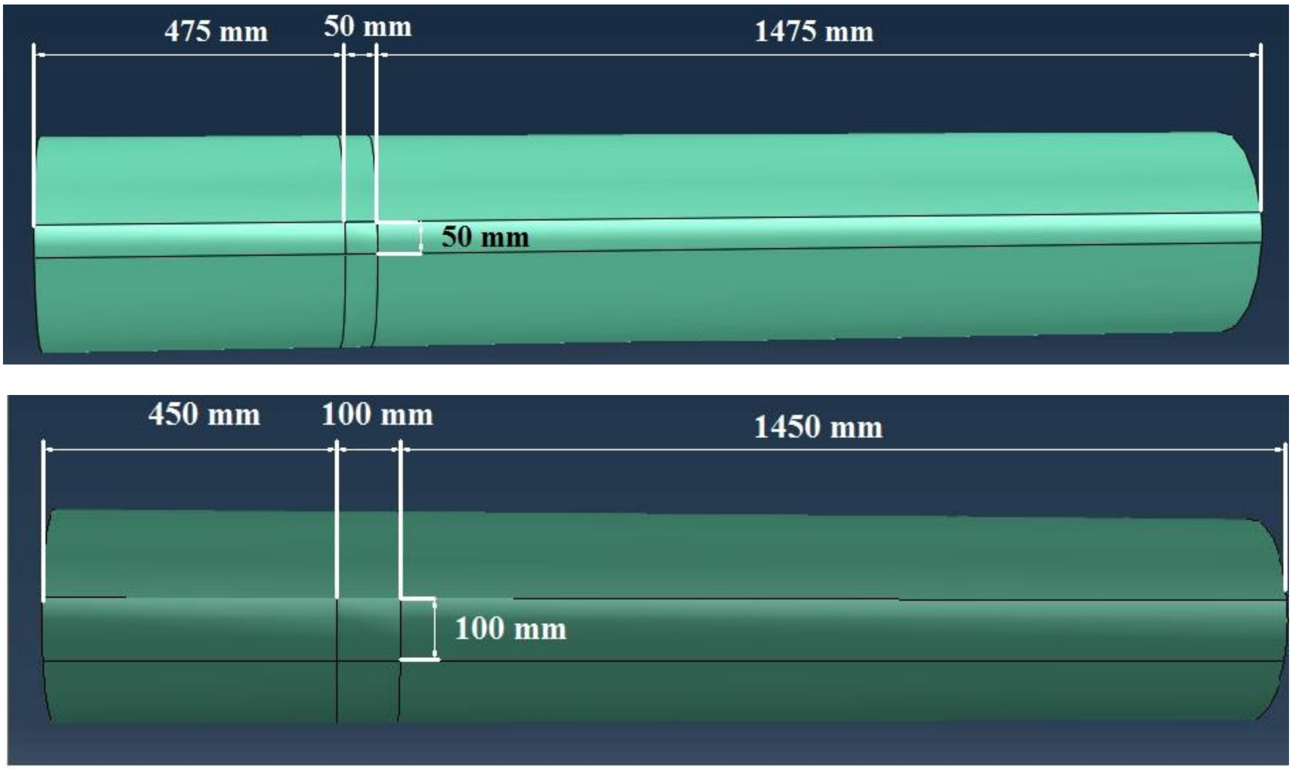


Figure 1. Dimensions of the Model

The internal pressure is 6 bars, as shown in Figure 2.

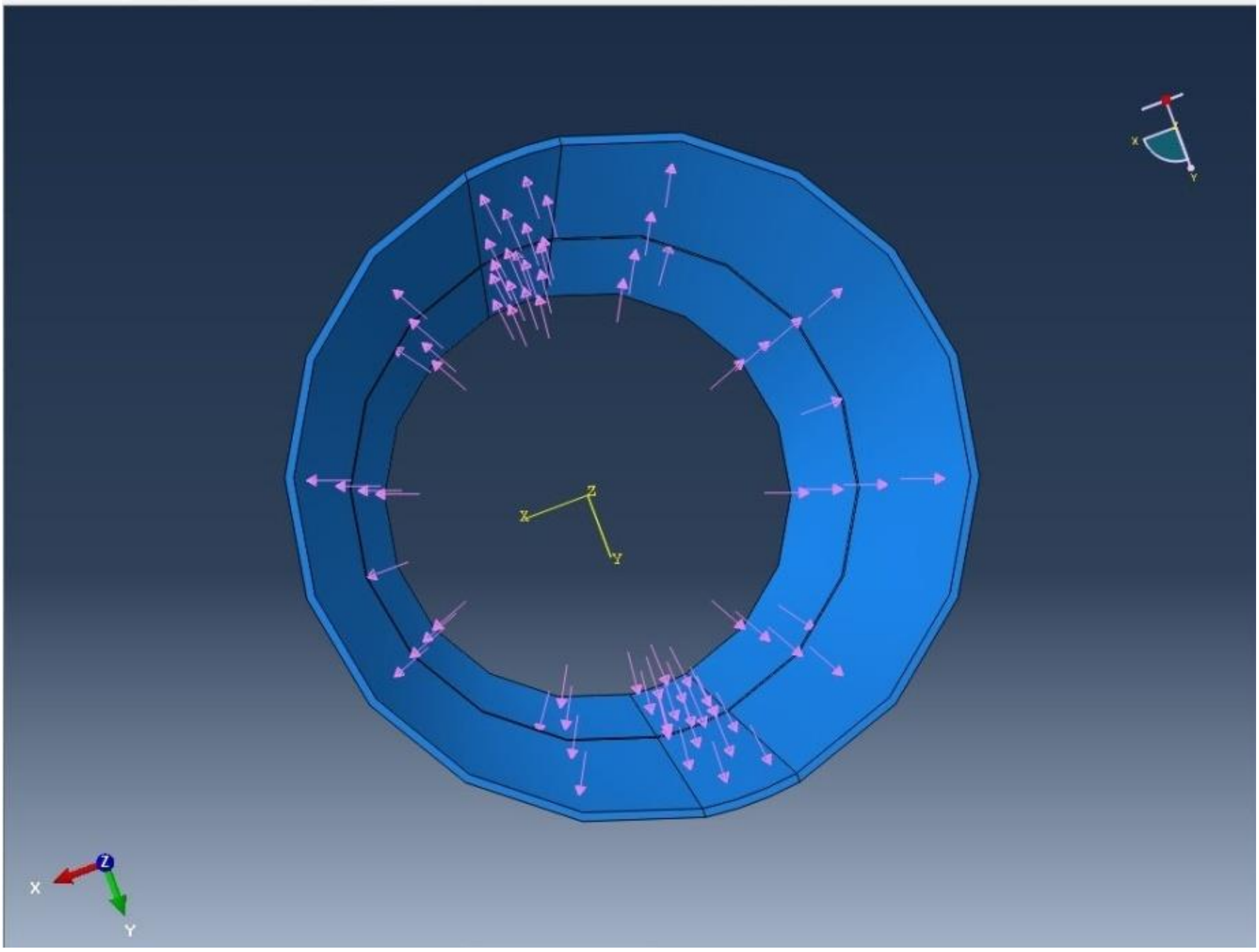
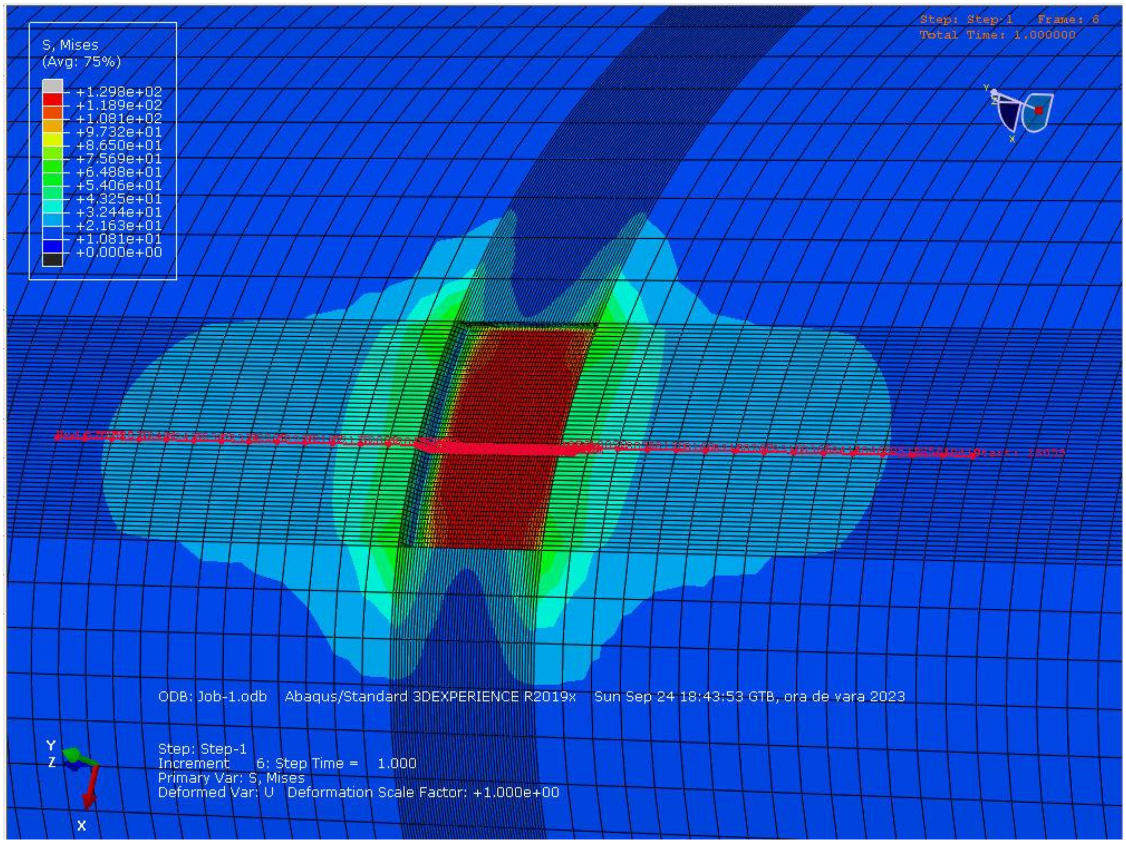


Figure 2. The internal pressure

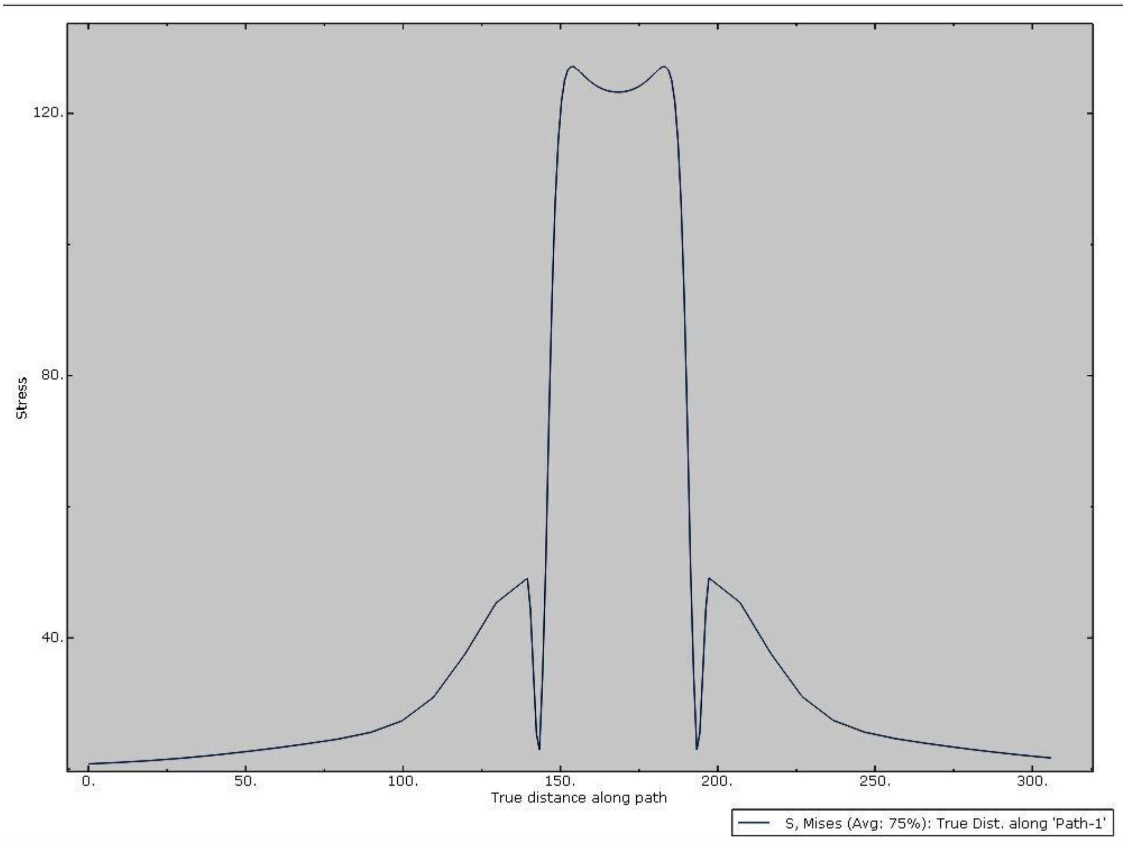
Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590

vol. 29, issue 3 / 2023
pp. 91-98

It is assumed that the pipeline is fixed at both ends, resulting in the stress states depicted in Figures 3 and 4.



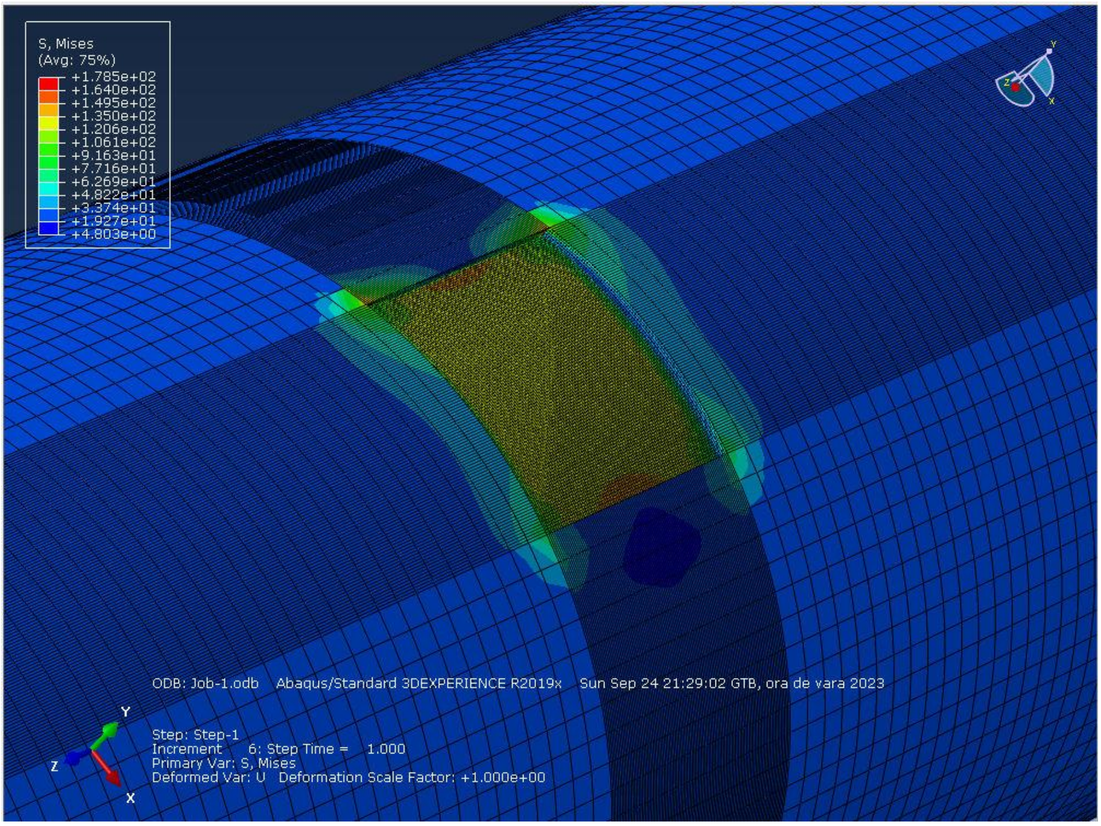
a



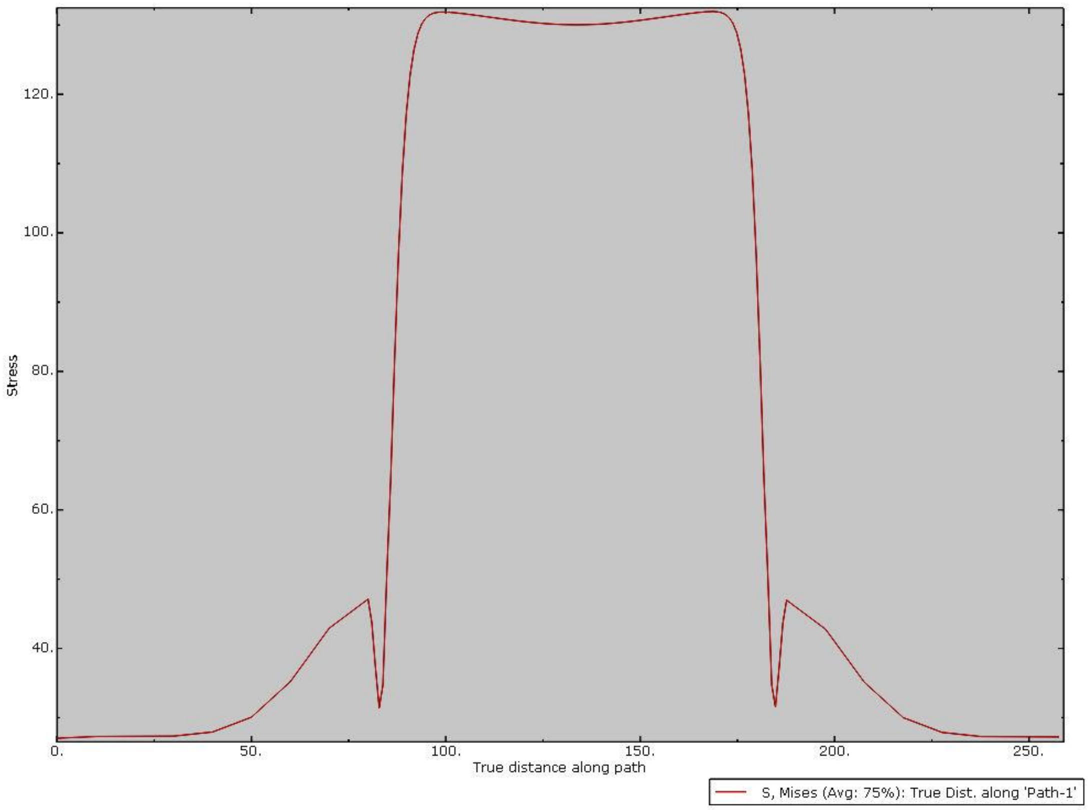
b

Figure 3. Von Mises Stress State for the 50x50x3.82mm Defect (MPa/mm)

vol. 29, issue 3 / 2023
pp. 91-98



a



b

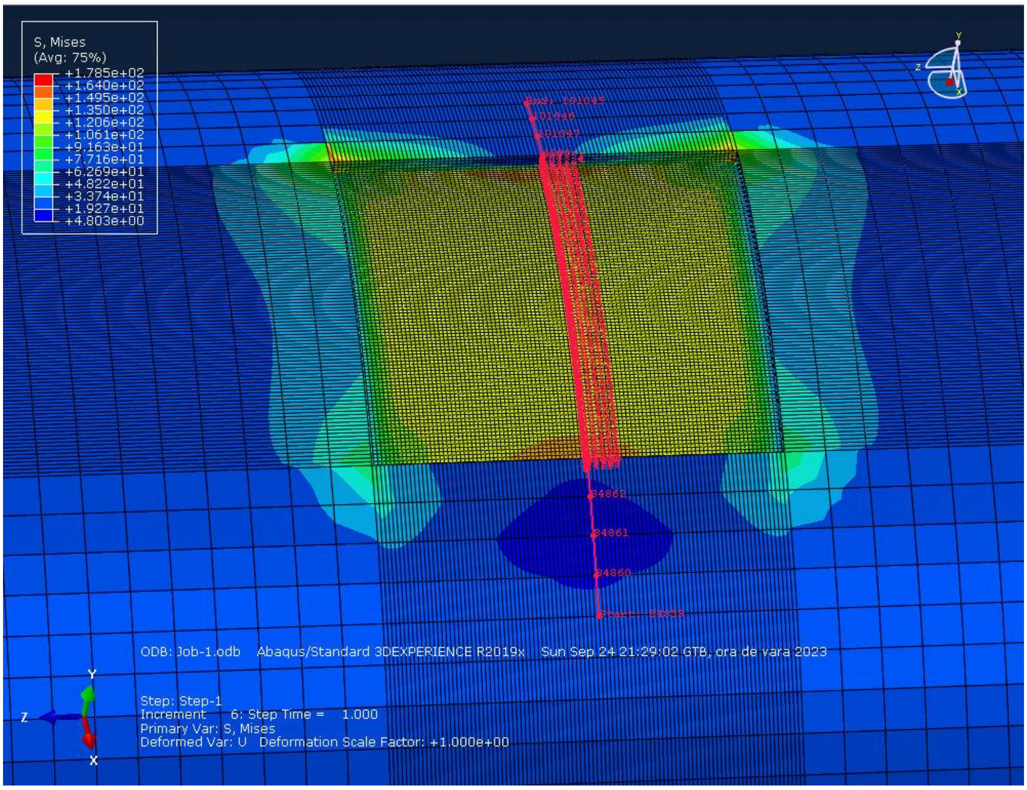
Figure 4 Von Mises Stress State for the 100x100x3.82mm Defect, transverse (MPa/mm)

Both models, sharing the same parameters and boundary conditions, were developed to determine the von Mises stress in a pipe with a single corrosion defect under internal pressure. The similarity in results validates the consistency and reliability of the finite element method (FEM) in modeling such problems.

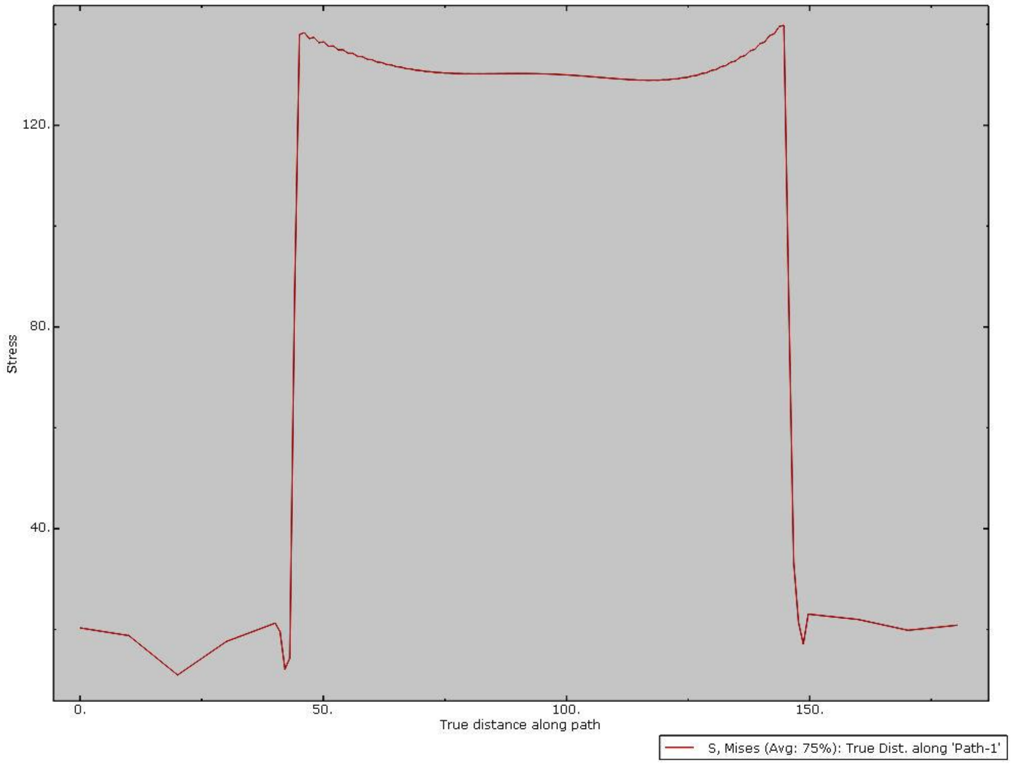
vol. 29, issue 3 / 2023
pp. 91-98

The failure criterion, based on the von Mises stress exceeding the actual tensile strength, has been validated through comparative analysis. In both cases, the von Mises stress state was found to be below the fracture limit of X65 steel (σr=537.4 MPa), indicating that the model aligns with theoretical and experimental expectations.

A detailed analysis of figure 5. reveals the presence of stress concentration zones, a phenomenon that can contribute to the initiation and propagation of cracks, potentially leading to pipe failure. The increased surface area of the corrosion defect is a significant contributing factor to this stress concentration.



a



b

Figure 5. Von Mises Stress State for the 100x100x3.82mm Defect, longitudinal (MPa/mm)

 vol. 29, issue 3 / 2023
pp. 91-98

A more extensive corrosion, even with the same depth, can lead to a more unfavorable stress distribution around the defect's perimeter. This can increase the risk of crack initiation and reduce the pipe's resistance to internal pressure.

The size of the corrosion can influence the Stress Concentration Factor (SCF). A larger corroded area may generate a higher SCF, thereby increasing local stresses and facilitating crack propagation.

According to fracture mechanics theory, once a crack has initiated, its size can influence the rate of propagation and the risk of rupture. More extensive corrosion can thus facilitate faster crack propagation and reduce the time to failure.

Pipes with larger corrosion defects will have a more significant reduction in the effective cross-sectional area, leading to a decrease in residual strength and the ability to withstand external loads and internal pressure.

In practice, these considerations suggest that assessing both the size and depth of corrosion is essential for determining the degree of pipe degradation and the need for intervention or replacement.

3. Conclusions

The conclusions drawn from this study underscore the importance of monitoring and assessing the integrity of pipes, especially in the presence of corrosion defects. However, it is essential to acknowledge and further explore the inherent limitations of modeling and to consider the variability of real conditions and the complexity of the involved phenomena.

Based on the obtained results and identified limitations, it is recommended to develop more advanced and diversified models, explore different types of defects and loading conditions, and conduct complementary experimental studies for the continuous validation and improvement of pipe integrity analysis methodologies.

The current study provides a solid foundation for understanding the behavior of pipes with corrosion defects under internal pressure, validating the applicability of the finite element method (FEM) and identifying risk zones for crack initiation. Nonetheless, it is imperative for future research to address the limitations and continue the development of strategies for monitoring and preventing failures in pipeline systems.

References

[1] **Overholt M.,** 2019
The importance of oil and gas in today's economy. Available from: https://www.tigergeneral.com/the-importance-of-oil-and-gas-in-today-s-economy/.

[2] **Wasim M., Djukic M.B.,** 2022
External corrosion of oil and gas pipelines: A review of failure mechanisms and predictive preventions, Journal of Natural Gas Science and Engineering, Volume 100, 104467, ISSN 1875-5100, https://doi.org/10.1016/j.jngse.2022.104467

[3] **Sharma S.K., Maheshwari S.,** 2017
A review on welding of high strength oil and gas pipeline steels, Journal of Natural Gas Science and Engineering, Volume 38, Pages 203-217, ISSN 1875-5100, https://doi.org/10.1016/j.jngse.2016.12.039.

[4] **Netto T.A., Ferraz U.S., Botto A.,** 2007
On the effect of corrosion defects on the collapse pressure of pipelines, International Journal of Solids and Structures, Volume 44, Issues 22–23, Pages 7597-7614, ISSN 0020-7683, https://doi.org/10.1016/j.ijsolstr.2007.04.028

[5] **Sherar B.,** 2011
T*he Effect of the Environment on the Corrosion Products and Corrosion Rates on Gas Transmission Pipelines*, Electronic Thesis and Dissertation Repository. 162. https://ir.lib.uwo.ca/etd/162

[6] **Chegeni B., Jayasuriya S., Das S.,** 2019
Effect of corrosion on thin-walled pipes under combined internal pressure and bending, Thin-Walled Structures, Volume 143, 106218,ISSN 0263-8231, https://doi.org/10.1016/j.tws.2019.106218.

[7] **Xin L., Yu B., Chenliang S., Mingshu L.,** 2016
Effect of interaction between corrosion defects on failure pressure of thin wall steel pipeline, International Journal of Pressure Vessels and Piping, Volume 138,, Pages 8-18, ISSN 0308-0161, https://doi.org/10.1016/j.ijpvp.2016.01.002

[8] **DNV RP F101,** 2004
Recommended Practice of Corroded Pipelines

[9] *****,** 2023
ABAQUS / CAE User Manual, Simulia , Providence, RI, USA

[10] **Soliman A.A., Megahed M.M., Saleh Ch.A.R., Shazly M.,** 2021
Assessment of Interacting Corrosion Defects in Thin-Walled Pipes, Journal of Pressure Vessel Technology-transactions of The Asme, volume 143, https://api.semanticscholar.org/CorpusID:229412665

[11] **Batte D., Fu B., Kirkwood M.G. Thai Vu D.T.,** 1997
Advanced methods for integrity assessment of corroded pipelines, Pipes & pipelines international, volume 42, pp 5-11, https://api.semanticscholar.org/CorpusID:114280666.

[12] **Arumugam T., Karuppanan S., Ovinis M.,** 2020
Finite element analyses of corroded pipeline with single defect subjected to internal pressure and axial compressive stress, Marine Structures, Volume 72, 102746, ISSN 0951-8339, https://doi.org/10.1016/j.marstruc.2020.102746.

[13] **Andrade E.Q., Benjamin A.C., Machado P.R.S.jr., Pereira L.C., Breno J.P., Carneiro E.G., Guerreiro J.N.C., Silva R.C.C., Noronha D.B.jr.,** 2006
Finite Element Modeling of the Failure Behavior of Pipelines Containing Interacting Corrosion Defects, Volume 4, Terry Jones Pipeline Technology; Ocean Space Utilization; CFD and VIV Symposium, 25th International Conference on Offshore Mechanics and Arctic Engineering, OMAE2006, International Conference on Offshore Mechanics and Arctic Engineering, https://doi.org/10.1115/OMAE2006-92600.

[14] **Dick I., Inegiyemiema M.,** 2014
Predicting the structural response of a corroded pipeline using finite element (FE) analysis. International Journal of Scientific & Engineering Research 5.11 pp 194-207.

[15] **Mocanu F., Istudor I.I.,** 2016
Study on the Performance and Risk of the Companies Selling Construction Materials at Exercise Price, Valahian Journal of Economic Studies; Targoviste Vol. 7, Iss. 4, pp. 77-84.

[16] **De Keyser K., Van Acker F., Hertelé S., Verstraete M., De Waele W., Denys R.,** 2011
Validation of a Wide Plate Finite Element Model Using Digital Image Correlation, Sustainable Construction and Design