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Analysis of the Effect of Corrosion-Induced Wall Thickness Reduction on the Stress Distribution of a Geothermal Steam Pipeline Using the Finite Element Method

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***Abstract* - The steam pipeline is a main component of the steam gathering system of a geothermal power plant, conveying steam from the separator to the turbine. During continuous operation at elevated pressure and temperature, the pipe is exposed to corrosion driven by the geothermal fluid and its non-condensable gases such as CO2 and H2S, which gradually reduces the wall thickness. This study examines the effect of corrosion-induced wall thickness reduction on the stress distribution of a straight steam pipeline segment at a geothermal power plant in Indonesia using the Finite Element Method (FEM). The pipe is a 12 inch SCH 80 seamless pipe made of ASTM A106 Grade B with an outside diameter of 323.9 mm and a modeled length of 7,000 mm. Two three-dimensional models were built: a design model with a wall thickness of 17.48 mm and an actual model with a wall thickness of 15.42 mm obtained from Ultrasonic Thickness (UT) inspection. Both models were simulated in ANSYS Mechanical (Static Structural) under an internal pressure of 14 barg, a temperature of 125 °C, and identical anchor and sliding supports. The maximum von Mises stress was 439.07 MPa for the design model and 498.75 MPa for the actual model and the maximum equivalent elastic strain was 0.0021954 and 0.0024938. The maximum total deformation was almost identical, 8.4159 mm and 8.4146 mm. Wall thinning therefore increases the stress and strain in the pipe wall, so periodic thickness monitoring is required.**

Keywords: Corrosion, finite element method, geothermal power plant, steam pipeline, stress distribution, ultrasonic thickness, von Mises stress, wall thinning.

I. INTRODUCTION

Indonesia holds one of the largest geothermal energy potentials in the world, and geothermal power is being developed as a renewable source to meet national energy demand and to reduce dependence on fossil fuels [1]. In a geothermal power plant, the geothermal fluid is produced from production wells and separated into steam and brine; the steam is then delivered through the steam gathering system to the turbine. The steam pipeline is one of the most important components of this system, so its reliability directly affects the continuity and efficiency of power generation.

A steam pipeline operates continuously at elevated pressure and temperature and must therefore retain adequate mechanical strength. During service, the pipe material degrades through corrosion, which is governed by the characteristics of the geothermal fluid, by non-condensable gases such as CO_2 and H_2S, and by the operating environment. Sustained corrosion reduces the wall thickness and with it the capacity of the pipe to withstand the operating pressure. If this condition is not monitored periodically, the risk of leakage, structural failure and interruption of electricity production increases [2]. The corrosiveness of geothermal steam has been related to its CO_2 and H_2S content and temperature [3], and carbon steel has been shown to corrode in CO_2-containing geothermal brine [4].

The actual wall thickness of a pipe is commonly measured by Ultrasonic Thickness (UT) inspection, a non-destructive method that determines thickness from the travel time of an ultrasonic wave reflected from the back surface of the material and that requires access to one side only [5], [6]. Thickness data alone, however, do not directly describe how wall thinning changes the mechanical behavior of the pipe. The Finite Element Method (FEM) divides a structure into small elements so that stress, strain and deformation under load can be computed, and it has been applied to corroded pipelines subjected to internal pressure [7]. It allows the stress distribution and deformation to be evaluated without disturbing plant operation.

This study therefore analyzes the effect of corrosion-induced wall thickness reduction on a geothermal steam pipeline using FEM. The objectives are (i) to model the pipe at its design thickness and at its actual thickness measured by UT inspection, and (ii) to compare the von Mises stress, total

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deformation and equivalent elastic strain of the two models under the same operating load. The study is limited to one straight steam pipeline segment at a geothermal power plant in Indonesia; corrosion rate and remaining life are not addressed.

II. MATERIALS AND METHODS

2.1 Pipe Specification and Material

The object of the study is a seamless 12 inch NB SCH 80 pipe with beveled ends made of ASTM A106 Grade B, a seamless carbon steel pipe grade intended for high-temperature service and widely used in power generation, oil and gas, and geothermal piping [8]. The pipe specification is given in Table 1. The actual wall thickness obtained from UT inspection, 15.42 mm, is lower than the design thickness of 17.48 mm, and this value was used to represent the actual condition of the pipe. The material properties are listed in Table 2.

Table 1: Pipe specification and dimensions

Parameter	Data
Pipe type	Seamless pipe
Nominal size	12 inch NB
Schedule	SCH 80
Material	ASTM A106 Grade B
Pipe end	BE (beveled end)
Outside diameter	323.9 mm
Design thickness	17.48 mm
Actual thickness	15.42 mm
Model length	7,000 mm

Table 2: Material properties of ASTM A106 Grade B

Property	Value
Material category	Carbon steel
Yield strength (min.)	240 MPa
Tensile strength (min.)	415 MPa
Elastic modulus	200 GPa
Poisson's ratio	0.30

2.2 Operating Conditions

The operating data were recorded during a well test and are shown in Table 3. The operating pressure represents the internal pressure load acting on the pipe wall, and the operating temperature represents the thermal condition of the pipe.

Table 3: Operating conditions during the well test

Parameter	Data
Operating pressure	14 barg
Control valve opening	25%
Operating temperature	125 °C
Fluid flow rate	56.29 ton/h

2.3 Geometry Modeling

The numerical analysis was performed in ANSYS Mechanical 2026 R1 using the Static Structural analysis system. Two three-dimensional models of the straight pipe were built in CAD software and imported into ANSYS (Fig. 1). Model A represents the design pipe with a wall thickness of 17.48 mm, and Model B represents the actual pipe with a wall thickness of 15.42 mm. Both models have the same outside diameter, length and material, so the wall thickness is the only variable that differs.

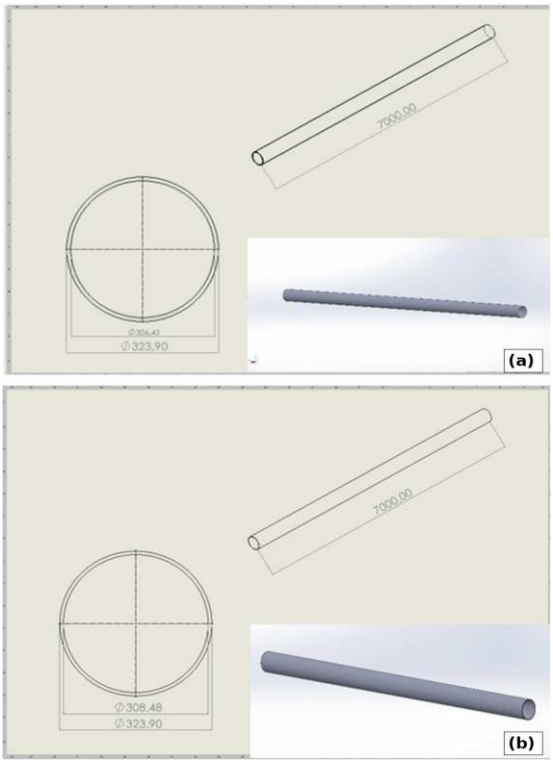


Figure 1: Pipe geometry: (a) design model and (b) actual model

2.4 Material Assignment and Meshing

ASTM A106 Grade B was defined in Engineering Data and assigned to both models. The geometry was then discretized into small elements connected at nodes (Fig. 2). The same meshing method and a comparable mesh density were applied to both models so that the results could be compared objectively.

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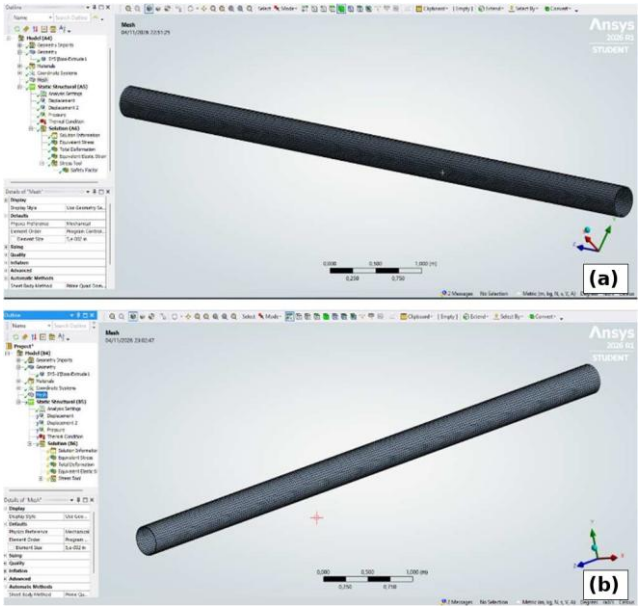


Figure 2: Meshed pipe model: (a) design model and (b) actual model

2.5 Boundary Conditions and Loading

Identical boundary conditions were applied to both models (Fig. 3). One end of the pipe was treated as an anchor, with displacement constrained in the X, Y and Z directions. The other end was treated as a sliding support, with displacement constrained in the X and Y directions and free along the pipe axis (Z).

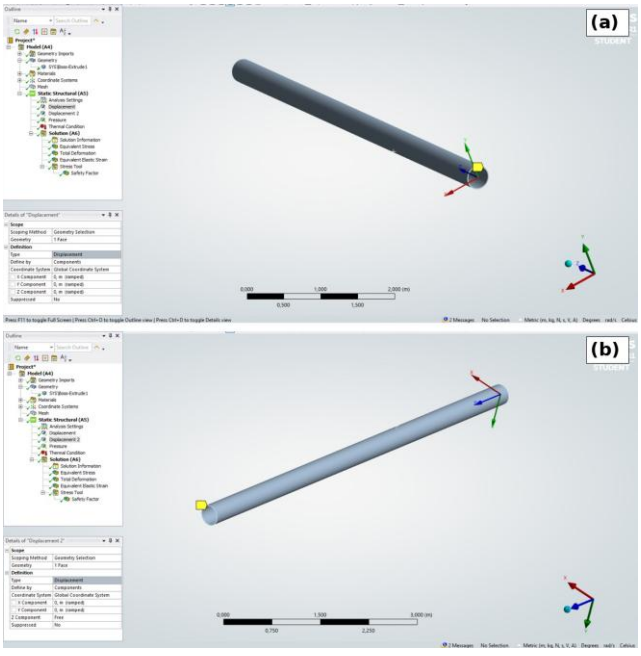


Figure 3: Support conditions: (a) anchor support and (b) sliding support

The loads were taken from the operating conditions in Table 3. An internal pressure of 14 barg (1.4 MPa) was applied to the inner surface of the pipe, and the operating temperature of 125 °C was applied as the thermal condition of the model (Fig. 4). The solution was then run to obtain the equivalent (von Mises) stress, total deformation and equivalent elastic strain of each model.

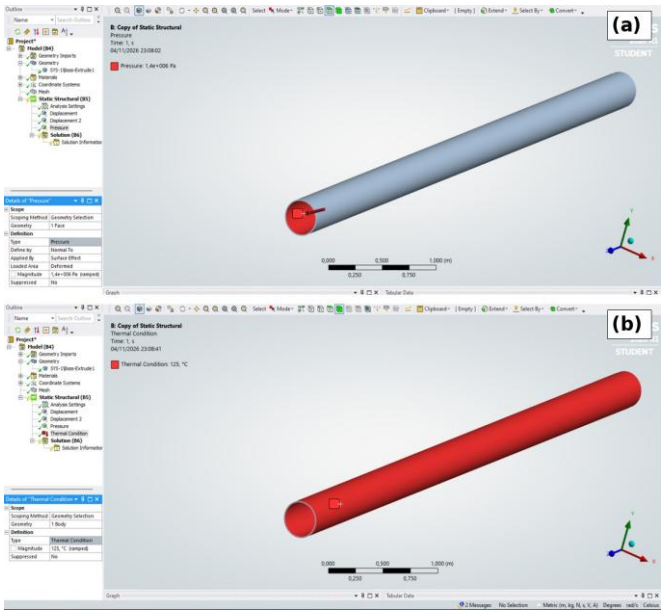


Figure 4: Applied loads: (a) internal pressure of 1.4 MPa and (b) temperature of 125 °C

III. RESULTS AND DISCUSSIONS

The finite element results of the two models are summarized in Table 4, and the corresponding contours are shown in Figs. 5 to 7.

Table 4: Finite element results of the two models

Parameter	Model A (design)	Model B (actual)
Wall thickness	17.48 mm	15.42 mm
Max. von Mises stress	439.07 MPa	498.75 MPa
Max. total deformation	8.4159 mm	8.4146 mm
Max. equivalent elastic strain	0.0021954	0.0024938

3.1 Equivalent von Mises Stress

The maximum von Mises stress is 439.07 MPa in Model A and 498.75 MPa in Model B (Fig. 5). Under the same load, a thinner wall provides a smaller cross-section to carry the internal pressure, so the stress in the material rises. The result shows that the reduction in wall thickness affects the capacity of the pipe to withstand internal pressure.

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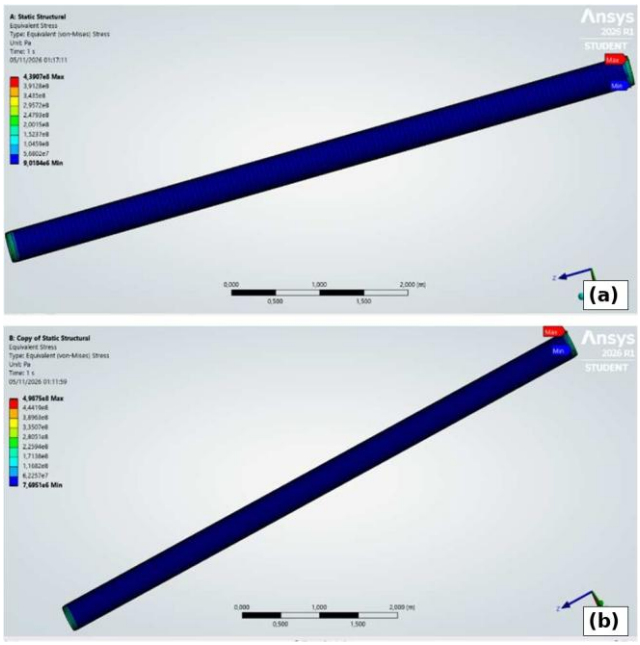


Figure 5: Equivalent (von Mises) stress: (a) design model and (b) actual model

3.2 Total Deformation

The maximum total deformation is 8.4159 mm in Model A and 8.4146 mm in Model B (Fig. 6). The two values are almost identical, which indicates that the change in wall thickness does not produce a meaningful change in the maximum displacement under the applied loads and boundary conditions. A change in thickness therefore does not affect all mechanical response parameters to the same degree.

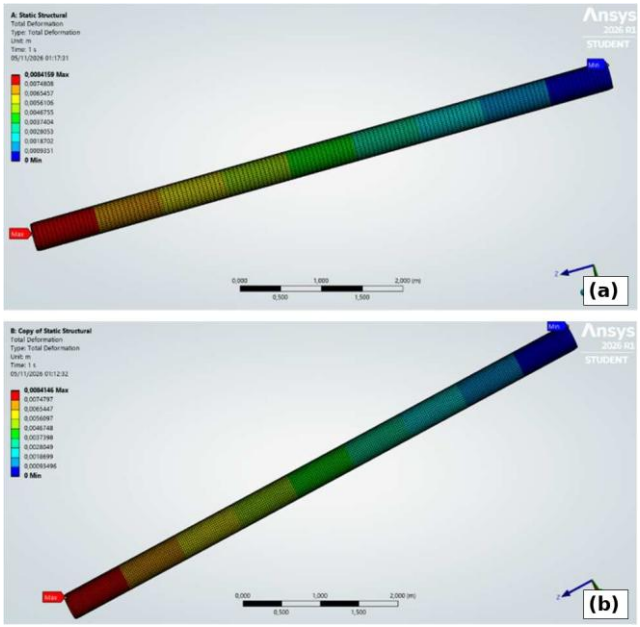


Figure 6: Total deformation: (a) design model and (b) actual model

3.3 Equivalent Elastic Strain

The maximum equivalent elastic strain is 0.0021954 in Model A and 0.0024938 in Model B (Fig. 7). The actual pipe, with its thinner wall, experiences a larger elastic strain under the same load, which is consistent with the higher von Mises stress obtained for this model.

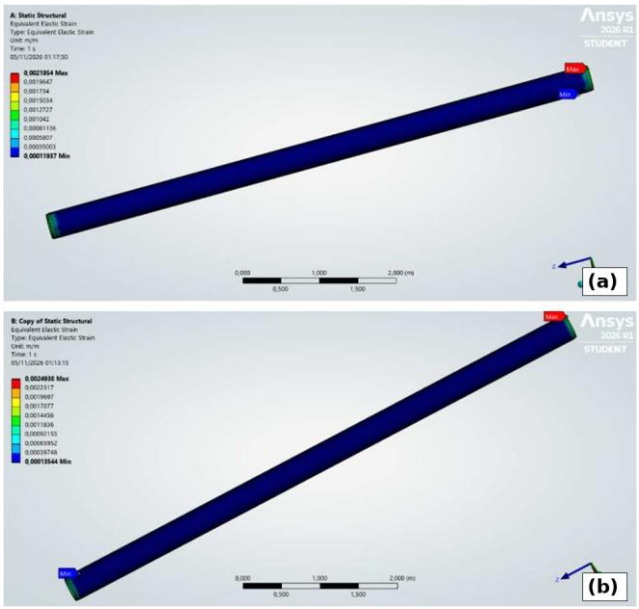


Figure 7: Equivalent elastic strain: (a) design model and (b) actual model

3.4 Effect of Wall Thickness Reduction

Overall, the reduction in wall thickness from 17.48 mm to 15.42 mm changes the mechanical response of the pipe. The effect is most visible in the von Mises stress and the equivalent elastic strain, which both increase. The maximum total deformation, in contrast, is practically unchanged. The simulations thus show a relationship between wall thinning and higher stress and strain in the pipe wall, which is in line with the concern that corrosion of geothermal steam pipelines must be managed through periodic inspection [2].

IV. CONCLUSION

The effect of corrosion-induced wall thickness reduction on a 12 inch SCH 80 ASTM A106 Grade B geothermal steam pipeline was investigated by finite element simulation in ANSYS Mechanical. Reducing the wall thickness from the design value of 17.48 mm to the actual value of 15.42 mm increased the maximum von Mises stress from 439.07 MPa to 498.75 MPa and the maximum equivalent elastic strain from 0.0021954 to 0.0024938. The maximum total deformation was almost the same in both models, 8.4159 mm and 8.4146 mm. The actual pipe is therefore in a more critical condition than the design pipe. The wall thickness of the pipeline should

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therefore be monitored and documented periodically, particularly where thinning is indicated, and the simulation results can support the prioritization of inspection and maintenance of the piping system.

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