Applied Research and Smart Technology Vol. 1 No. 1 (2020) 11-15

ARS Tech

Applied Research and Smart Technology

Journal homepage: www.journals2.ums.ac.id/index.php/arstech

ISSN 2722-9645

Research Article

The effect of internal pressure and thickness on the creep strain of the superheater pipes

Tri Widodo Besar Riyadi[1,*], Sopyan Sahid Fatulloh[2]

[1,2] *Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani Tromol Pos I, Pabelan, Kartasura, Surakarta. 57102. Indonesia.*

[*]Corresponding author: Tri.Riyadi@ums.ac.id

Permalink (DOI): https://doi.org/10.23917/arstech.v1i1.21

ARTICLE INFO

Article history:

Received 06 April 2020
Revised 02 May 2020
Accepted 05 May 2020
Available online 05 June 2020
Published regularly 15 July 2020

Keywords:

Creep strain
Alloy 617
Superheater pipe
Internal pressure
Pipe thickness
Abaqus

ABSTRACT

Superheater pipes in turbines commonly is used to produce superheated steam. Internal pressure is critical for steam superheater elements. The pipes in such applications are vulnerable to temperature environments which can bring the component to enter the creep regime, creep deformation, or even creep fracture. In general, most of the failures in boilers are caused by creep. Creep-resistant materials used in facilities operated at high temperatures must, therefore, be able to withstand the highest possible temperature loads. This study aims to investigate the creep behaviour of a 617 alloys steel steam pipe, which operated within 100,000 hours. The temperature of steam was set at 700⁰C, and the pressure in the pipe was 35 MPa. Abaqus software based on the finite element method was used in the study. The effect of internal pressure and pipe thickness on the creep strains was observed. The variation of the internal pressure was 35, 37.5, 40, 42.5, and 45 MPa. Whereas, the thickness variations were 30, 35, 40, 45, and 50 mm. The simulation results revealed that an increase in the internal pressure and the decrease of the pipe thickness increase the creep strain. This study can be used to predict the possibility of creep damaged for the superheater pipes operated at high temperatures, which have different thicknesses.

1. INTRODUCTION

A boiler is one of a series of steam power plant systems that serves to convert water into hot steam. This process is done by heating the water in the steam pipe at a high temperature until the water turns into hot steam [1]. Advanced Ultra Supercritical (A-USC) boiler is a type of boiler that is currently being intensively developed because its work capability is estimated to have a theoretical efficiency value reaching 50% [2]. Not only does it produce the least amount of CO_2 gas pollution than other boiler types, but also the A-USC boiler works at the highest critical point of 700⁰C. This type of boiler is the development of an Ultra Supercritical (USC) boiler [3].

Until now, not many plants have used this A-USC technology since the used material must have excellent resistance at high temperatures.

In developing materials that can operate at high temperatures, several phenomena need to be considered; one of them is the creep phenomenon [4][5]. Creep is defined as a strain due to constant load at high temperatures. Creep occurs when the temperature exceeds 0.4 from the absolute melting temperature of the material. At high temperatures, creeps occur at all stress levels. The creep process can be divided into three stages, namely primary creep (transient creep)[6], secondary creep (stationary state creep), and tertiary creep (accelerated creep) [7][8]. The occurrence of creep can cause material damage even though it is burdened below its melting point. If creep continues, the material can break. In general, 30% of material failures are caused by creeps. So far, there has been much research on the damage caused by creeps in superheaters.

An evaluation of the creep lifetime of the pipe was carried out using computational methods with an emphasis on the creep lifetime reduction [9][10]. Afterward, a study on the wall thickness reduction of the boiler pipes under high temperature and pressure was reported [11]. The research results were to predict the mechanism of thickness reduction in order to make replacement before failure. A research was carried out on the development of materials used in steam turbines operating at temperatures reaching 700-800 ⁰C [12][13]. Knezevic et al. identified the creep characteristics of the 617 steam alloy pipe manufactured by Vallourec and Mannesmann (V&M) company, which was used in power generation technology with a temperature of 700⁰C [14]. The material was tested at 170 - 295 MPa. In all tests, it was concluded that the 617 alloy pipe has excellent resistance for the power generation industry with steam temperatures above 700⁰C [15].

A study was conducted on the behaviour of Alloy 617 material at a temperature of 700⁰C [16][17]. Experiments were carried out to obtain the tensile properties, creep properties, and creep strain properties. A model on the creep characteristics of a superheater with a T91 steel material has been fabricated [18][19]. The mechanical load used in this study was 100-200 MPa. Creep modelling was done using Abaqus software. Superheater temperature was inputted as a predefined field. The modelling was successful by calibrating with experimental and literature data.

In our previous study, an investigation has been carried out to study the effect of temperature on creep in the modelling of 11.3 MPa pressurized steel pipes with temperature variations of 30-750 °C [20]. The simulation was performed by Abaqus software. It was found that the simulation results were well matched with those obtained by the experimental methods. The results indicated that the higher the temperature, the greater the creep that occurs. The load condition on the pipe, however, was uniformly distributed across the pipe, which was not real. The objective of the study is to investigate the creep behaviour of a steam pipe operated in a real condition. The study was carried out using a simulation package software called as Abaqus.

2. NUMERICAL SIMULATION

2.1. Physical problem and geometry

The simulation in this study was carried out to model a steam pipe as the specimen. The dimension of the pipe geometry was taken by referring to the steam pipe produced by the V&M Pipe tube Company, with an outer diameter of 420 mm, a thickness of 35 mm, and a length of 1000 mm, as shown in Figure 1.

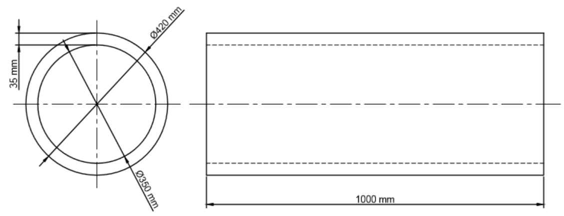

Figure 1. Schematic model of pipe.

Table 1. Elasticity and thermal conductivity.

T (⁰C)	Ex10³ (MPa)	δ
25	211	13.4
100	206	14.7
200	201	16.3
300	194	17.7
400	188	19.3
500	181	20.9
600	173	22.5
700	166	23.9
800	157	25.5
900	149	27.1
1000	139	28.7
1100	129	

The pipe material was Alloy steel 617, with a thermal load of 700⁰C on the inner and 40⁰C on the surface of the outer pipe. The creep strain of the steam pipe was studied using the estimated working time of 100,000 hours. The creep behaviour was observed by pressure variations of 35, 37.5, 40, 42.5 and 45 MPa, and thickness variations of 30, 35, 40, 45 and 50 mm. All the simulation was conducted using Abaqus software. The pipe material was modelled as deformable. The elastic properties of the material are given in Table 1.

2.2. Simulation

The first study of the simulation was performed to determine the mesh convergence. The element type used in this work was standard, quadratic, with reduced integration. The element was seeded using different approximate global size, with a variation of 6, 3, 1, 0.75, 0.5, 0.25, and 0.1. Figure 2 shows the curve of von Misses stress with a different mesh size observed in an element of the tube wall. The curve indicates that a decrease in the element size increases the stress. The stress curve starts to converge at the element size of 0.25. The use of smaller mesh size produces a flat curve. Therefore, the adequate size of the element number of the part structure used throughout the simulation was 0.25.

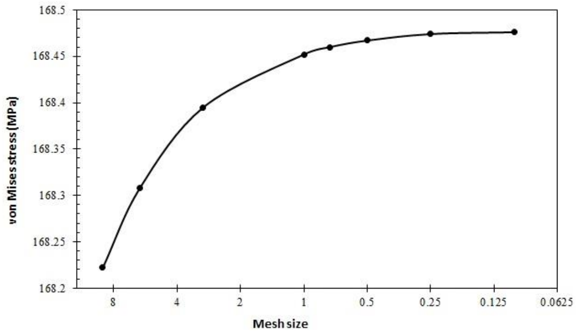

Figure 2. Convergence studies in different mesh sizes.

3. RESULTS AND DISCUSSION

Having loaded by the internal pressure of 35 MPa and temperature of 700⁰C, the steam pipe has experienced a creep strain. The occurrence of creep strain indicates that the steam pipe was operated at a high temperature at approximately 0.4. It was above the absolute point of the material. The observation of the creep that occurred in the inner and outer surface of the steam pipe can be seen in Figure 3. The simulation results described in Figure 4 depict that the steam pipe experiences a maximum creep strain on the inner surface of 4.922 x $10^{-3,}$ and it decreases towards the outer surface of the steam pipe at the value of 3.28 x 10^{-3}. The creep strains on the inner surface of the pipe occur quickly and then slow down. The faster rate of the creep strain during the initial period may be caused by the effect of the material's strain hardening. After a while, the creep strain was slowing down and tended to constant, as indicated by a linear curve. At this time, the object was experiencing a recovery and strain hardening. Compared to the outer surface of the pipe, the development of creep strain in the inner surface is higher. It is due to the temperature load was applied at the inner surface only. The outer surface receives the heat from the heat conduction. Therefore, the creep strain at the outer surface is not as enormous as that occurring at the inner surface.

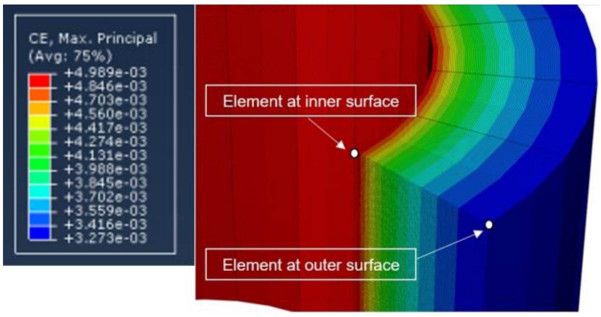

Figure 3. Location of elements at the inner and outer pipe surface.

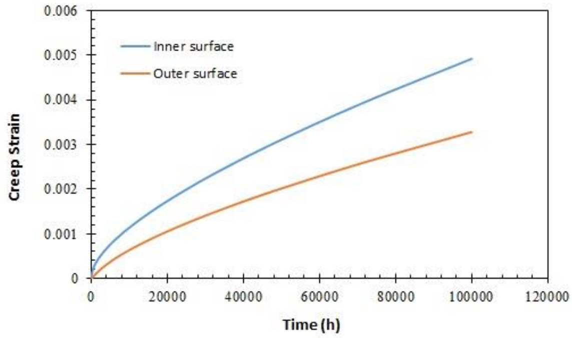

Figure 4. Development of creep strain.

Figure 5 gives the effect of internal pressure on the creep strain of the steam pipe, observed using a variation of 35, 37.5, 40, 42.5, and 45 MPa. The geometry dimension and a load of steam pipes for all variations were kept the same at 420 mm in diameter and 35 mm in thickness, with an internal temperature of 700⁰C and an outside temperature of 40⁰C.

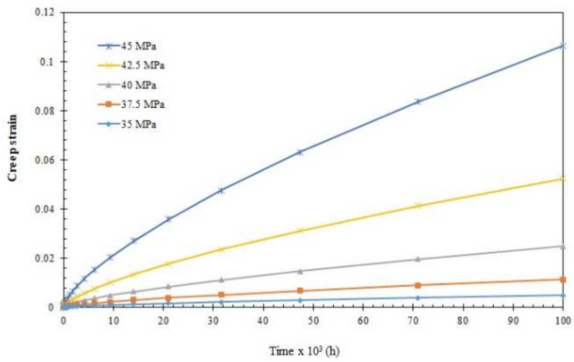

Figure 5. The creep strain with different internal pressures.

From the simulation results, it can be obtained that an increase of the internal pressure increases the creep strain of the steam pipe. After 100.000 hours, the internal pressure in the pipe of 35, 37.5, 40, 42.5, and 45 MPa results in the maximum creep strain at the inner surface by 4.922 x 10^{-3}, 1.13 x 10^{-2}, 2.49 x 10^{-2}, 5.252 x 10^{-2}, and 1.064 x 10^{-1}.

The strain experienced by the pipe during creep deformation makes the inner and outer diameter of the pipe was changed. As a result, the thickness of the pipe changes. The actual strain and the thickness change of the pipe can be calculated by the equation (1) and (2), respectively.

$$d_1 = d_0(1+\varepsilon), \quad (1)$$

$$Thickness = \frac{d_1 - d_0}{2}, \quad (2)$$

The change in the pipe thickness occurred during the creep deformation can be seen in Figure 6. At the time, t = 100,000 hours, the outside diameter of the pipe has changed to 421.37 mm, while the inner diameter of the pipe has changed to 351.72 mm. Therefore, the thickness of the pipe was 34.83 mm. From figure 6, it can be seen that the thickness of the pipe is dropped very fast, but then it continually decreases. If the pipe continues to be burdened, the pipe can be got thinner and might be damaged.

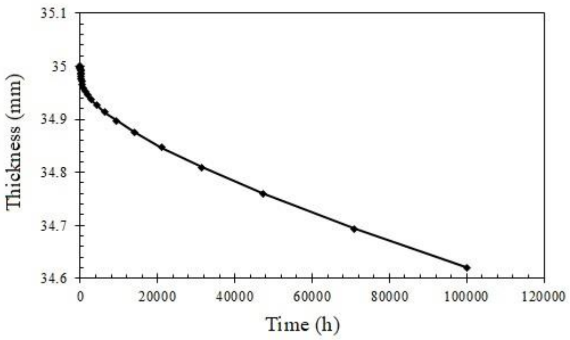

Figure 6. Thickness change of the pipe, using an internal pressure of 35 MPa and temperature of 700⁰C.

The effect of the thickness of the pipe on the creep strain was conducted using thickness variations of 30, 35, 40, 45 and 50 mm, with the same Output Diameter (OD) of 420 mm. The internal pressure was 35 MPa with a temperature of 700⁰C. The logarithmic creep strain observed at the inner pipe, and the outer surface of the pipe is shown in Figure 7 (a) and (b). The result provides that the highest creep strain occurs at the 30 mm pipe thickness both at the inner surface and the outer pipe surface that is at 3.69 x 10^{-2} and 2.7 x 10^{-2}, respectively. On the contrary, the lowest creep strain occurs at the 50 mm pipe thickness of both the inner surface and the outer surface of the pipe by 1.38 x 10^{-4} and 3.18 x 10^{-6}. Therefore, an increase in the pipe thickness has reduced the creep strain.

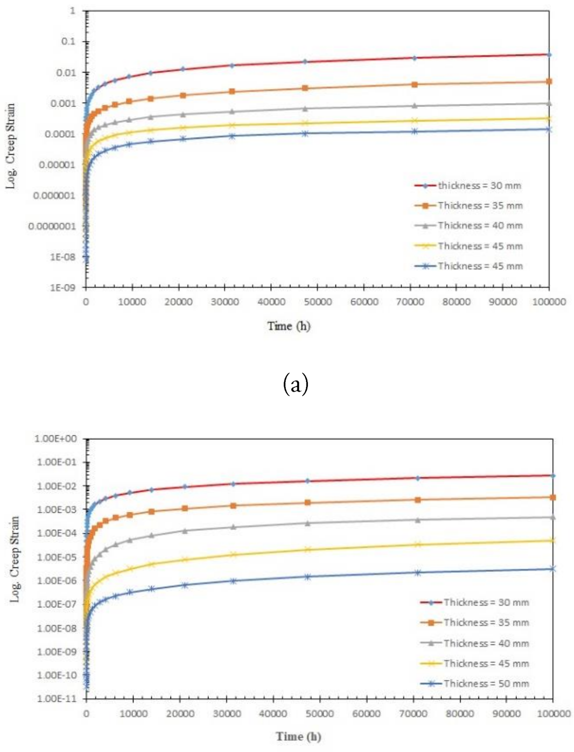

Figure 7. The logarithmic creep strain with a variation of pipe thickness at (a) inner surface, and (b) outer surface, with an internal pressure of 35 MPa and temperature of 700⁰C.

4. CONCLUSION

A creep phenomenon of steam pipe has been successfully simulated with different internal pressures and pipe thicknesses within 100.000 hours. The relationship between creep strain and time concerning internal pressure and pipe thickness was observed. From the results, it can be concluded that the creep strain occurred in the inner surface of the pipe was higher than that in the outer surface. The maximum creep strain in the pipe with an internal pressure of 35 MPa was 4.922 x 10^{-3} and 3.273 x 10^{-3} in the inner and outer surface of the pipe, respectively. However, the greater the internal pressure, the higher the creep strain that occurs. In the different pipe thickness, it was observed that the highest creep strain occurs at a pipe thickness of 30 mm, and the lowest creep strain occurs at a pipe thickness of 50 mm. Further work can be carried out to validate using an experimental work.

5. ACKNOWLEDGEMENT

The authors would like to thank Universitas Muhammadiyah Surakarta and the Ministry of Research and Technology of the Republic of Indonesia.

REFERENCES

[1] L. Felkowski and J. Mędrala, "Analysis of superheater tubes failure," *E3S Web Conf.*, vol. 82, pp. 1–8, 2019, doi: 10.1051/e3sconf/20198201002.

[2] K. C. Sahoo, S. Goyal, and K. Laha, "2nd International conference on structural integrity and exhibition 2018 assessment of creep deformation and rupture behaviour of 304HCu austenitic stainless steel," *Procedia Struct. Integr.*, vol. 14, pp. 60–67, 2019, doi: 10.1016/j.prostr.2019.05.009.

[3] Z. Kuboň, "New austenitic creep resistant steels for superheaters of USC boilers," *Key Eng. Mater.*, vol. 635, pp. 75–80, 2015, doi: 10.4028/www.scientific.net/KEM.635.75.

[4] W. Xia, X. Zhao, L. Yue, and Z. Zhang, "Microstructural evolution and creep mechanisms in Ni-based single crystal superalloys: A review," *J. Alloys Compd.*, vol. 819, p. 152954, 2020, doi: 10.1016/j.jallcom.2019.152954.

[5] A. Al Mamun *et al.*, "A novel insight into the primary creep regeneration behaviour of a polycrystalline material at high-temperature using in-situ neutron diffraction," *Mater. Sci. Eng. A*, vol. 786, no. March, p. 139374, 2020, doi: 10.1016/j.msea.2020.139374.

[6] P. Bérest, M. Karimi-Jafari, and B. Brouard, "Geometrical versus rheological transient creep closure in a salt cavern," *Comptes Rendus - Mec.*, vol. 345, no. 11, pp. 735–741, 2017, doi: 10.1016/j.crme.2017.09.002.

[7] L. W. Morland and R. Staroszczyk, "A constitutive law for the viscous and tertiary creep responses of ice to applied stress," *Cold Reg. Sci. Technol.*, vol. 174, no. March, p. 103034, 2020, doi: 10.1016/j.coldregions.2020.103034.

[8] K. Chen, Y. Xu, and S. Song, "Effect of impurity antimony on the creep behaviour of 2.25Cr-1Mo heat-resistant steel," *Results Phys.*, vol. 13, no. January, p. 102208, 2019, doi: 10.1016/j.rinp.2019.102208.

[9] S. Linn and A. Scholz, "Creep-fatigue lifetime assessment with phenomenological and constitutive material laws," *Procedia Eng.*, vol. 55, pp. 607–611, 2013, doi: 10.1016/j.proeng.2013.03.302.

[10] R. Bakhtiari, M. Ahmadian, A. Olfati, and M. Derhambakhsh, "Failure Analysis of A Superheater Pipe Based on Microstructure/Mechanical Properties Study," pp. 29–34, 1943.

[11] A. Smith, M. Asadikiya, M. Yang, J. Chen, and Y. Zhong, "An Investigation of Creep Resistance in Grade 91 Steel through Computational Thermodynamics," *Engineering*, no. December, 2020, doi: 10.1016/j.eng.2019.12.004.

[12] L. Kloc, P. Dymáček, and V. Sklenička, "High temperature creep of Sanicro 25 austenitic steel at low stresses," *Mater. Sci. Eng. A*, vol. 722, pp. 88–92, 2018, doi: 10.1016/j.msea.2018.02.095.

[13] E. A. Ogiriki, Y. G. Li, T. Nikolaidis, T. E. Isaiah, and G. Sule, "Effect of Fouling, Thermal Barrier Coating Degradation and Film Cooling Holes Blockage on Gas Turbine Engine Creep Life," *Procedia CIRP*, vol. 38, pp. 228–233, 2015, doi: 10.1016/j.procir.2015.07.017.

[14] V. Knezevic, A. Schneider, and C. Landier, "Creep behaviour of thick-wall alloy 617 seamless pipes for 700°C power plant technology," *Procedia Eng.*, vol. 55, pp. 240–245, 2013, doi: 10.1016/j.proeng.2013.03.249.

[15] I. M. W. Ekaputra, W. G. Kim, J. Y. Park, S. J. Kim, and E. S. Kim, "Influence of Dynamic Strain Aging on Tensile Deformation Behavior of Alloy 617," *Nucl. Eng. Technol.*, vol. 48, no. 6, pp. 1387–1395, 2016, doi: 10.1016/j.net.2016.06.013.

[16] V. T. Phan, X. Zhang, Y. Li, and C. Oskay, "Microscale modelling of creep deformation and rupture in Nickel-based superalloy IN 617 at high temperature," *Mech. Mater.*, vol. 114, pp. 215–227, 2017, doi: 10.1016/j.mechmat.2017.08.008.

[17] A. Narayanan, K. Dubey, C. M. Davies, and J. P. Dear, "The creep of alloy 617 at 700 °C: Material properties, measurement of strain and comparison between finite element analysis and digital image correlation," *Int. J. Solids Struct.*, vol. 129, pp. 195–203, 2017, doi: 10.1016/j.ijsolstr.2017.08.021.

[18] G. S. Tibba and H. Altenbach, "Modelling Creep Behaviour of Superheater Materials," *Energy Procedia*, vol. 93, no. March, pp. 197–202, 2016, doi: 10.1016/j.egypro.2016.07.170.

[19] D. P. Rao Palaparti, E. Isaac Samuel, B. K. Choudhary, and M. D. Mathew, "Creep properties of grade 91 steel steam generator tube at 923K," *Procedia Eng.*, vol. 55, pp. 70–77, 2013, doi: 10.1016/j.proeng.2013.03.221.

[20] T. W. B. Riyadi, F. H. Ahmad, I. Veza, A. S. Darmawan, A. D. Anggono, and J. Purbolaksono, "Study of the creep deformation of sanicro 25 austenitic steel by computer simulations," *Mater. Sci. Forum*, vol. 961 MSF, pp. 156–162, 2019, doi: 10.4028/www.scientific.net/MSF.961.156.