Material Characteristics and Failure Prediction of SA 213 Superheater Boiler Tube in Power Plant with 315 MW Capacity

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Abstract

This study was conducted at the Rembang Semarang Unit 2 power plant in Indonesia, with a capacity of 315 MW. The plant has been in operation since 2011, totaling about 13 years or over 100,000 equivalent operating hours (EOH). High-temperature operations can damage tube materials due to temperature, corrosive environment, pressure, and stress. At the end of 2022, a condenser leak at the plant necessitated an assessment of the boiler tube material. This study focuses on evaluating the SA 213 T91 (chromium (Cr) and molybdenum (Mo) alloy steel) superheater tube, a known for its excellent high-temperature mechanical and thermal properties and corrosion resistance. The research aims to assess potential failures in the boiler tube and guide future operational and maintenance plans. The analysis includes destructive testing, SEM, EDX metallography, and creep rupture testing. Results show corrosion and hard scale deposition inside the tube. Its is shown that creep strength decreases significantly at high temperatures, leading to faster material rupture.

Keywords : lifetime prediction, superheater boiler tube, power plant, prediction

Abstrak

Penelitian ini dilakukan di PLTU Rembang Semarang Unit 2 di Indonesia, dengan kapasitas 315 MW. Pembangkit listrik ini telah beroperasi sejak tahun 2011, dengan total operasi sekitar 13 tahun atau lebih dari 100.000 jam EOH (*equivalent operating hours*). Operasi pada temperatur tinggi dapat merusak material *tube* karena temperatur, lingkungan korosif, tekanan, dan tegangan. Pada akhir tahun 2022, terjadi kebocoran kondenser sehingga diperlukan asesmen kondisi pada *tube boiler*. Penelitian ini berfokus pada evaluasi *tube superheater* SA 213 T91, baja paduan kromium (Cr) dan molibdenum (Mo), yang dikenal dengan sifat mekanik dan termal suhu tinggi yang sangat baik serta ketahanan terhadap korosi. Penelitian ini bertujuan untuk menilai potensi kegagalan pada tube boiler dan memberikan rencana operasional dan pemeliharaan di masa depan. Analisis meliputi pengujian destruktif, SEM, metalografi EDX, dan pengujian *creep rupture*. Hasilnya menunjukkan adanya korosi dan endapan kerak keras di dalam *tube*. Hal ini menunjukkan bahwa *creep strength* menurun secara signifikan pada suhu tinggi, yang menyebabkan pecahnya material lebih cepat.

Kata kunci : prediksi sisa umur, *tube boiler superheater*, pembangkit listrik, prediksi

1. Introduction

Environmental factors such as moisture, radiation and chemical pollutants can accelerate the degradation process of materials. For example, humidity can cause corrosion in metals, while radiation can damage the crystal structure of materials. Chemical pollutants can react with materials and reduce their strength. Therefore, understanding and managing these environmental factors is critical to improving material life and reliability. By addressing critical aspects of material degradation and integrating advanced technologies, this research contributes to the development of more reliable and efficient engineering systems [1,2].

The research conducted by D. Koszelow et al. [3] revealed that the corrosion rates of porous and solid alloys are comparable, with acceptable corrosion kinetics at 700°C. However, at temperatures exceeding 850°C, significant changes in the alloy's microstructure occur, leading to complete oxidation within 100 hours. Tomographic analysis provides a comprehensive understanding of the microstructure and the distribution of corrosion sites. Based on these findings, a methodology for predicting the service life of the alloy has been proposed.

The research by F. Weber et al. [4] offers insights into the influence of surface roughness on the durability of 20MnMoNi5-5 steel used in spray lines of German nuclear power plants. The MiDAcLife life prediction method was employed to assess five distinct surface conditions. This study also evaluates the potential impact of surface roughness on the S-N curve, specifically in terms of its influence on material fatigue. The measured surface roughness was modeled using Fourier transformation to obtain factors that can be used in the calculation of fatigue parameters. This method

permits the estimation of the S-N curve with just one fatigue test (an increased load test) and demonstrates that the impact of surface roughness on material life is only significant above a certain threshold. Additionally, the research underscores the necessity of monitoring changes in surface characteristics during fatigue tests, as well as the importance of statistical validation and testing across different material types and operational temperatures.
The study by Wang Z et al. [5] indicates that optimizing control by considering boiler heat storage can enhance the flexibility and efficiency of coal-fired power plants with dual reheat systems. The findings demonstrate that the implementation of an optimized control strategy enables power plants to operate more responsively to load fluctuations and maintain high efficiency, even with varying energy demands. Boiler heat storage plays a crucial role in maintaining operational stability and enhancing system dynamic response, thus enabling the power plant to adapt more quickly to varying operating conditions [6].
The accuracy of locating and identifying failure points in a material allows for a significant increase in the percentage safety value of that material. Such identification allows for the implementation of more targeted preventative measures, thus reducing the risk of future damage or failure. Furthermore, the identification of the point of failure allows for the optimisation of the manufacturing process, which in turn improves production efficiency. This efficiency can be manifested in the form of reduced production time and costs, waste minimization, and the more optimal utilization of resources [7,8]. This study focuses on the SA 213 T91 specification final superheater tube in a 315 MW pulverized coal boiler (PC) steam power plant (PLTU). The PLTU has been in operation for approximately 100,000 equivalent operating hours (EOH) since April 2011. At the end of 2022, a condenser leak occurred, necessitating an assessment of the impact on the boiler tubes. Previous cases have shown that condenser leaks can lead to damage to boiler tubes such as corrosion, hydrogen embrittlement, and even tube rupture, rendering the unit inoperable.

2. Materials and method

The method used in this study involved testing samples of SA 213 T91 final superheater tubes in their as-received condition, with destructive testing conducted in the laboratory. The test results were compared with the standard characteristics of the tube material to assess degradation that occurred during operation. The methods included thickness testing, creep testing (stress rupture), Hardness, SEM-EDX testing, and metallography. The chemical composition test follows the ASTM A751 standard [9] and is conducted using the PMI Master Pro device, with sample preparation including polishing to remove oxides, dirt, or fingerprints. Thickness testing follows the ASTM E797 standard [10] and utilizes an ultrasonic system wall thickness meter. Creep testing and test samples are conducted and made following ASTM A 370 standards [11], as shown in Figure 1. SEM-EDX testing adheres to the ASTM E2142 standard [12]. Metallography testing refers to the ASTM E3 and ASTM E407 standards [13,14], with examination carried out using an optical microscope and a 3D optical microscope with magnifications of 50-1000x.

3 Results and discussion

The thickness calculation was measured based on the following locations as shown in Figure 1. The average thickness was 8.15-8.25 mm in all locations, except for the elbow location where the thickness was recorded with only 7.01 mm. this thinning indicates that the thickness of the elbow from boiler tube have thinner than other locations.

Point	Thickness (mm)				
	A	B	C	D	E
1	8.57	8.60	7.70	8.28	8.53
2	8.02	8.07	6.04	8.08	8.09
3	7.94	7.91	6.94	7.90	7.96
4	8.38	8.41	7.34	8.35	8.34
Ave.	8.23	8.25	7.01	8.15	8.23

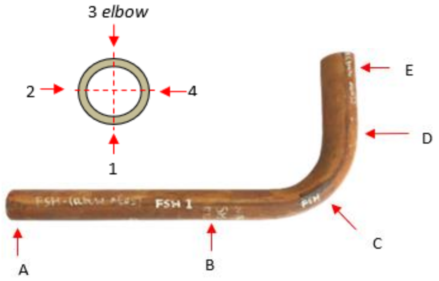

Figure 1. Thickness measurement of the boiler tube (left), and the location of measurement (right)

Further analysis related to the hardness of the tube are applied for the boiler tube that facing temperature 750°C and 800°C in the actual operation. The results of hardness compared to the specimen before creep and references can be seen in Figure 2. The ref. hardness was captured from previous work [15], where the steel before applied with creep test was listed as before creep. The results of hardness showed that the hardness fallen for all samples where it applied with heat treatment. The decreased of hardness also indicate the reduce of the mechanical properties of the materials.

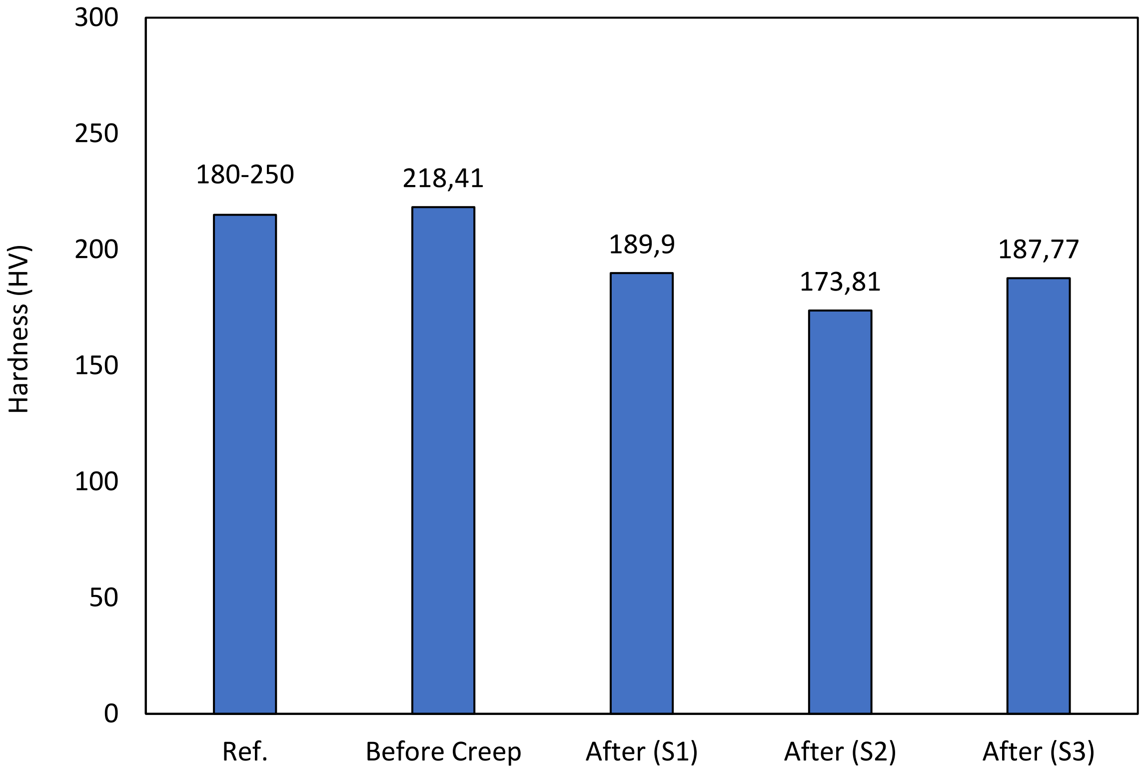

Figure 2. Hardness measurement before and after creep test

The test of creep of all samples are seen in Table 1. It is shown that the stress is sudden decreased with the higher temperature. The stress also decreased with the time exposure where the high temperature was applied to the specimen.

Table 1 Creep test results

Dia.	area	Temp.		Stress	Time	LMP
	Ø (mm²)	°C	K	MPa	Δt (h)	
4.01	12.63	800	1073	7.92	19.38	33.57
4.02	12.69	800	1073	39.39	8.53	33.19
4.07	13.01	750	1023	61.49	12.09	31.80
4.04	12.82	750	1023	78.01	2.59	31.11

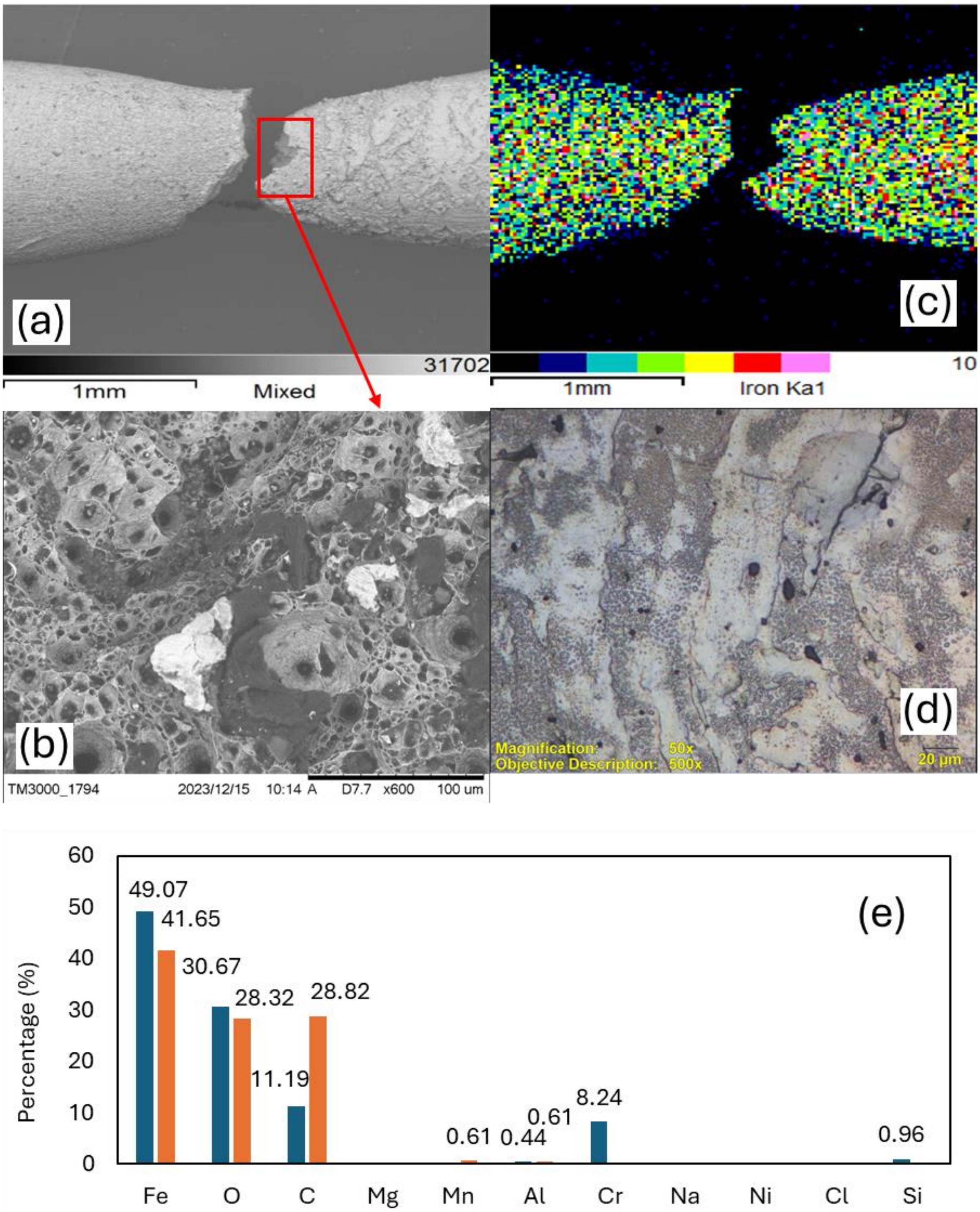

Figure 3. SEM analysis of specimen (a-c), (d) Metallography analysis of fractured specimen, (e) Chemical composition of sample exposure of 800°C temperature

After failure, specimen then applied SEM-EDS analysis and metallographic evaluation as seen in Figure 3. The fracture area recorded using SEM as seen in Figure 3 (a) where the macro scale presented. The Fe composition also indicated as seen in Fig. 3 (b) followed by micro-scale SEM image are presented in Figure 3 (c). the metallographic image that shown in Figure 3 (d) indicated that the crack and void are presented. The metallography image indicated that the effect of temperature and time exposure triggered crack propagation and void occurred in the surface of the specimen. Chemical composition of the specimen is reflected in Figure 3 (e) where the oxidation was severe occurred on the surface of the materials and triggered with void occurrence and trans granular cracks.

4 Conclusion

Based on the evaluation and analysis of the test results, the condition of the final superheater SA 213 T91 tube after the creep test can be summarized as follows:
The visual inspection reveals that the superheater tube was in relatively good condition before the creep test, showing only minor corrosion and some reddish-brown hard scale on the inner surface. The material's test results conform to the SA 213 T91 specification, affirming its compliance with design standards. SEM-EDX analysis indicates the presence of shear cracks, most pronounced at 800°C as the severe condition. Fractography of the cross-sections of all samples confirms the occurrence of creep voids, with trans-granular fractures noted at 800°C. Metallographic examination shows increased creep void distribution at higher temperatures and spheroidization of the microstructure. The Larson Miller parameter suggests a remaining tube life of 325.28 years based on the current condition. It's an warning note that the creep strength deteriorates rapidly at higher temperatures, leading to accelerated material rupture.

References

[1] K. Zhang, M. Liu, Y. Zhao, H. Yan, J. Yan, Design and performance evaluation of a new thermal energy storage system integrated within a coal-fired power plant, J Energy Storage 50 (2022) 104335. https://doi.org/https://doi.org/10.1016/j.est.2022.104335.
[2] A.D. Nugraha, Harianto, M.A. Muflikhun, Failure in power plant system related to mitigations and economic analysis; A study case from steam power plant in Suralaya, Indonesia, Results in Engineering 17 (2023) 101004. https://doi.org/10.1016/j.rineng.2023.101004.
[3] D. Koszelow, M. Makowska, F. Marone, J. Karczewski, P. Jasiński, S. Molin, High temperature corrosion evaluation and lifetime prediction of porous Fe22Cr stainless steel in air in temperature range 700–900 °C, Corros Sci 189 (2021). https://doi.org/10.1016/j.corsci.2021.109589.
[4] F. Weber, P. Starke, Implementation of modelled surface roughness in the accelerated lifetime prediction of a 20MnMoNi5-5 steel, Int J Fatigue 186 (2024). https://doi.org/10.1016/j.ijfatigue.2024.108391.
[5] Z. Wang, M. Liu, Y. Zhao, C. Wang, D. Chong, J. Yan, Flexibility and efficiency enhancement for double-reheat coal-fired power plants by control optimization considering boiler heat storage, Energy 201 (2020) 117594. https://doi.org/https://doi.org/10.1016/j.energy.2020.117594.
[6] R.A. Himarosa, S.D. Hariyanto, W.H. Hasan, M.A. Muflikhun, Failure Analysis of Platen Superheater Tube, Water Wall Tube, and Sealpot Plate: A case study from Electricity Power Plant in Indonesia, Eng Fail Anal (2022) 106108. https://doi.org/10.1016/j.engfailanal.2022.106108.
[7] Z. Wang, M. Liu, H. Yan, J. Yan, Optimization on coordinate control strategy assisted by high-pressure extraction steam throttling to achieve flexible and efficient operation of thermal power plants, Energy 244 (2022) 122676. https://doi.org/https://doi.org/10.1016/j.energy.2021.122676.
[8] M.A. Muflikhun, M. Adyudya, N.F. Rahman, J. Sentanuhady, S.N.V. Raghu, Comprehensive analysis and economic study of railway brake failure from metal-based and composites-based materials, Forces in Mechanics 12 (2023). https://doi.org/10.1016/j.finmec.2023.100223.
[9] Chemical Analysis of Steel Products 1, n.d.
[10] Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method 1, (n.d.). https://doi.org/10.1520/E0797_E0797M-15.
[11] ASTM A370 mechanical testing of steel product, (n.d.).
[12] Standard Test Methods for Rating and Classifying Inclusions in Steel Using the Scanning Electron Microscope 1, (n.d.). https://doi.org/10.1520/E2142-08R15.
[13] Designation: E407 − 07 (Reapproved 2015) ´1 Standard Practice for Microetching Metals and Alloys 1, (n.d.). https://doi.org/10.1520/E0407-07R15E01.
[14] Standard Guide for Preparation of Metallographic Specimens 1, (n.d.). https://doi.org/10.1520/E0003-11R17.
[15] M.Z. Hamzah, M.L. Ibrahim, Q.H. Chye, B. Ahmad, J.I. Inayat-Hussain, J. Purbolaksono, Evaluation on the hardness and microstructures of T91 reheater tubes after post-weld heat treatment, Eng Fail Anal 26 (2012) 349–354. https://doi.org/10.1016/j.engfailanal.2012.08.019.