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A Review of The Final Turbine Inspection Report at the Lahendong Geothermal Power Plant

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Abstract. In this paper, the author employs a review method based on the results of a turbine inspection conducted by the maintenance service unit of PT Indonesia Power in 2023. The review presents a comprehensive evaluation of the condition of rotor blades in the steam turbine of the Lahendong Unit 1 Geothermal Power Plant. The objective of this study is to assess the material integrity through a series of non-destructive testing (NDT) methods, as part of the Remaining Life Assesment (RLA) of the turbine components. The inspection included visual inspection, magnetic particle inspection (MPI), ultrasonic flaw testing, penetrant testing, in-situ metallography, hardness testing, as well as XRD and XRF analysis. Significant findings include pitting corrosion, rubbing, material loss, water droplet erosion, and cracks in several rotor stages. Microstructural analysis revealed the presence of martensite, retained austenite, and carbides, with indications of cavities along grain boundaries that have progressed to directional oriented cavities and even microcracks. Based on Neubauer's classification, several blades have reached stage 4 and 5 (end of life), indicating substantial degradation. These findings provide a strong technical basis for predictive maintenance strategies and re-blading decisions in the next overhaul.

Keywords: *creep, in-situ metallography, remaining life assesment, steam turbine blade*

1 Introduction

Reliability, defined as the probability of a system or component performing its intended function under specified conditions for a designated period, is a key metric in power system performance[1]. It directly affects maintenance costs and, ultimately, the profitability of utility providers. Over time, a product's reliability degrades due to age and environmental factors, necessitating proactive management strategies.

A crucial aspect in ensuring supply reliability is the performance of core components within power generation systems. One such component is the turbine, which plays an essential role in the energy conversion process. Assessing turbine reliability is vital to detect early signs of degradation, define appropriate maintenance strategies, and avoid operational disruptions that may affect electricity availability.

Among turbine components, blades are particularly susceptible to degradation due to continuous cyclic loading, leading to fatigue, erosion, corrosion, and crack formation. Blade failure can compromise overall turbine performance and result in power outages. Therefore, a robust real-life reliability assesment is essential to accurately predict the remaining useful life of turbine blades and prevent premature failures. This study aims to compare the results of inspection/maintenance with the standard service life of the component.

1.1 Failure Models in Materials

A material that undergoes slow and continuous deformation over time under constant load or stress at high temperatures until fracture is said to exhibit creep behavior[1]. The term "high temperature" in this context generally refers to temperatures equal to or greater than 40% of the material's melting point. Creep may also occur at temperatures below or equal to 40% of the melting point, although the phenomenon becomes more difficult to observe clearly under such conditions[2].

Creep is a phenomenon of slow and progressive deformation experienced by a material when subjected to constant stress at high temperatures over an extended period. This condition is commonly observed in power plant components operating under extreme thermal environments. The behavior of creep is highly relevant for analysis, as it can lead to structural failure even when the applied stress remains below the material's elastic limit.

Creep analysis is typically conducted through material testing under specific load and temperature conditions, producing strain–time curves that represent the material's behavior. The results from such tests can be applied in predictive approaches such as the Larson–Miller parameter, which allows estimation of service life based on actual operating conditions.

Periodic monitoring of creep is crucial in the context of safety and operational efficiency, especially for high-pressure industries such as power generation. Without proper inspection, creep-induced failure may result in severe damage and increased maintenance costs, as well as unexpected shutdowns that threaten the continuity of the power system’s operation.

Another commonly observed failure in metals is corrosion. Corrosion is the degradation process of metal that occurs due to chemical reactions with the surrounding environment, such as oxidation or contact with corrosive substances. Corrosion can lead to a reduction in material strength, deformation, and a decrease in the service life of a metal component. There are several common types of corrosion, including:

- Uniform Corrosion, which occurs evenly across the entire metal surface.
- Pitting Corrosion, which causes small, deep holes on the metal surface.
- Stress Corrosion Cracking (SCC) → cracking caused by the combined effects of stress and a corrosive environment.

2 Methodology

In this paper, the author employs a review method based on the results of a turbine inspection conducted by the maintenance service unit of PT Indonesia Power in 2023. The inspection carried out in that year was conducted using two methods, visual inspection and in-situ metallography. Visual inspection is the process of examining a component or equipment using the naked eye to detect defects or damage. Optical aids such as illuminators, mirrors, borescopes, and others can be used to enhance the ability to perform visual inspection. Cameras, computer systems, and digital image analyzers can also be utilized to further extend the capabilities and benefits of visual inspection.

2.1 Material of Steam Turbine Blade

The turbine blades used in the Lahendong Geothermal Power Plant Unit 1 are made of stainless steel 410, commonly known as SS 410. SS 410 is basic Iron-Chrome martensitic alloy with good mechanical strenght and can be hardened/tempered as per application. Alloy 410 exhibit range of mechanical properties with different types of Heat Treatment. The mechanical properties of that turbine blades as shown in the table below:

Table 1 Mechanical properties of SS 410

Parameter	Value
Yield 0,2% (MPa/N.mm^2), Min	205
Tensile (MPa/N.mm^2), Min	450
Elongation (% in 50 mm), Min	30
Reduction Area (%), Min	20
Hardness (BHN), Max	217

2.2 Non-Destructive Test

Non-Destructive Test (NDT) in material testing is a method used to evaluate the integrity, properties, structure, or defects of a material or component without damaging or altering the physical form of the test object. NDT is essential in engineering industries to ensure the safety, quality, and reliability of components, especially in pressurized equipment, structural parts, and rotating machinery. Some examples of NDT are as follows: visual inspection, magnetic particle testing, ultrasonic testing, and in-situ metallography. To ensure that no microstructural damage has occurred in the material, a metallographic test is performed. This type of testing typically requires taking a sample by cutting a portion of the material. However, with the in-situ metallographic method, the test can be carried out without cutting (damaging) the test material.

Figure 1 illustration of inspection using in-situ metallography kit [3]

2.3 Remaining Life Assesment

Remaining Life Assesment (RLA) is a critical aspect for industries aiming to extend the operational lifespan of equipment without the need for complete replacement. Accurate estimation of remaining life greatly supports preventive maintenance decision-making, thereby enhancing operational efficiency, system reliability, and process stability. Every piece of equipment is designed to operate under specific conditions and has a projected service life. However, if operated beyond the designated design limits, its service life can be significantly reduced.

The results obtained from NDT are usually qualitative in nature, thus requiring assesment based on applicable standards such as American Petroleum Institute (API). API are one of the world's leading engineering standards organizations, playing a vital role in the development of technical specifications, safety codes, and quality guidelines across various industries, particularly in mechanical engineering, materials, manufacturing, energy, and petrochemicals.

3 Test Results and Analysis

3.1 Visual Inspection

Figure 2 Pitting on the surface of turbine blades [4]

Pitting was predominantly found on the leading edge of the blades. The primary causes of this damage are steam impurities and surface deposits, with chlorides (Cl) and sulfates (S) identified as the main corrosive elements. These substances can easily diffuse up to 3–4 mm into the blade material. Additionally, the accumulation of dissolved oxygen within liquid films and wet deposits can promote pitting formation, especially during unit shutdown periods.

Figure 3 Crack presence on the shroud and root of the stage-5 turbine blade [4]

Crack formation was observed in stage-5, specifically in the shroud and root areas of the turbine blade. Visual inspection revealed that the cracks appeared linear and aligned with the axial direction of the rotor blade. The average crack length measured approximately 7 mm on the shroud and around 10 mm on the blade root. This condition is particularly concerning since the root area is subjected to the highest stress concentration within the blade structure. Moreover, the widespread presence of pitting corrosion on the rotor blade components could have acted as a trigger for initial crack development.

The cracks found in the shroud and root of the stage-5 blade exhibit a straight pattern, following the axial orientation of the blade, which is indicative of a fatigue failure mechanism. Fatigue can be influenced by both environmental and mechanical factors. In this case, the environmental influence stems from severe pitting corrosion, while the mechanical aspect is related to cyclic loading experienced by the rotor blade. Based on the evidence, it is highly likely that both factors contributed to the development of cracks in this component.

Referring to API 687 section 3.4.2, blades can generally be repaired if the crack is caused by a foreign object. If the crack is caused by factors other than a foreign object, further analysis is required. Therefore, an in-situ metallographic test was conducted.

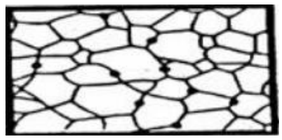
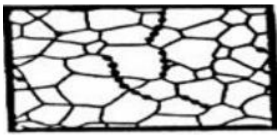
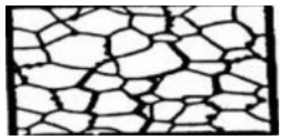
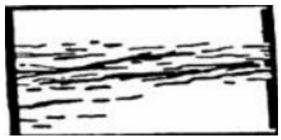
3.2 In-Situ Metallography

Materials operating under high temperatures and sustained stress conditions are highly prone to experiencing creep. This phenomenon is commonly characterized by the emergence of grain boundary voids and the accumulation of carbide precipitates. Here are some results from the visual inspection of the turbine blades.

Creep in a material may develop as a result of cavity formation, which is initiated by sustained stress under high-temperature conditions. These cavities arise from the clustering of atomic vacancies that become increasingly concentrated along grain boundaries during prolonged thermal and mechanical exposure. As these vacancies merge over time, they can evolve into interconnected voids, eventually leading to microcrack formation. Neubauer and Wedel categorized the stages of this cavity formation process as follows:

Table 2 Classification based on microstructure developed by Neubauer and Wedel [5]

Grade	Microstructure	Picture
0	New Material	NA
1	Normal (No Cavities)	NA

2	Presence of Isolated Microcavities	
3	Presence of Directional Oriented Microcavities	
4	Presence of Microcracks	
5	Presence of Macrocracks	

Besides the classification by Neubauer and Wedel, there are technical standards and guidelines issued by VGB PowerTech, an international association based in Germany for power and heat generation technology. In terms of metallic material inspection, the VGB Guidelines provide standards for damage evaluation, inspection, and remaining life assesment.

Table 3 guidelines for inspection interval and when to replace [5]

Grade	Damage	Recommendations Precautions
1	Normal (No Cavities)	None
2	Single Cavities	Re-Examine after approximate 20.000 hours operation
3	Coherent Cavities	Re-Examine after approximate 15.000 hours operation

4	Creep Cracks (Micro)	Re-Examine after approximate 10.000 hours operation
5	Creep Cracks (Macro)	The plant is contacted immediately

In this test, a 1000x magnification of the microstructure of the stage-5 turbine blade was performed using metallographic equipment. Two observation points were selected for microstructural analysis: one at the location of the crack and the other at a point distant from the crack.

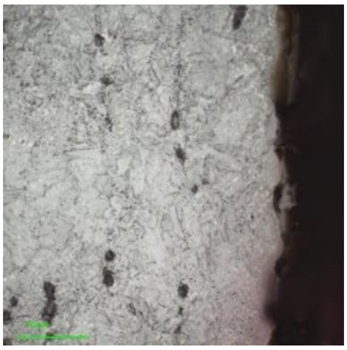


Figure 5 The crack location on the stage-5 turbine blade magnified at 1000x [4]

Indications of cavities were found along the grain boundaries, progressing into the stage of directionally oriented cavities leading to microcrack formation. Visually, macrocracks were also observed. According to Neubauer's standard, this condition corresponds to Grade 5, for which blade replacement is recommended based on VGB Guidelines. Initially, based on the results of visual inspection and with reference to API 687, the turbine blade was considered for repair; however, further analysis indicated that blade replacement is required.

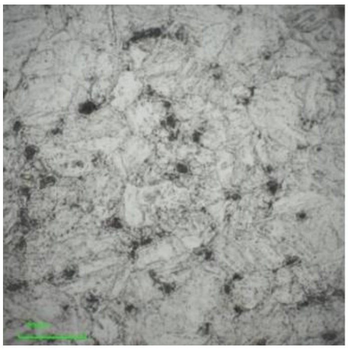


Figure 6 Magnification of 1000x on the stage 5 turbine blade, that far from the crack area [4]

Indications of cavities were also identified along the grain boundaries, entering the stage of directional cavity formation toward microcracks. Based on Neubauer's classification, this condition falls under Grade 4, and it is recommended to perform a reinspection after 10.000 hours of operation.

4 Conclusions

1. Pitting corrosion was primarily caused by steam impurities and chemical deposits, with chlorides and sulfates identified as the main corrosive agents.

2. Based on Neubauer's classification, the 5th stage turbine blade condition falls under Grade 4, and it is recommended to perform a reinspection after 10.000 hours of operation.

The combination of visual inspection, in-situ metallography, and references to API 687 standards and Neubauer's classification revealed clear signs of material degradation. Surface damage such as pitting corrosion was extensively found on the leading edge of the blades, while linear cracks were identified in the shroud and root areas, aligned axially—indicating a typical fatigue failure mechanism. Further investigation confirmed subsurface damage in the form of cavities progressing toward microcrack formation.

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