FAILURE ANALYSIS OF SKID PIPE LEAKS IN WALKING BEAM TYPE REHEATING FURNACE APPLICATIONS

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ABSTRACT: This study investigates the failure of skid pipes within a walking beam reheating furnace at PT. X, Cilegon City. Visual inspection, chemical composition analysis, and corrosion rate evaluation revealed physical damages such as cracks, black and white scale deposits, bulging, and a 47% reduction in pipe thickness from the original 25 mm. The damage mechanism is initiated by high levels of Fe oxides causing corrosion with a dominant wustite (FeO) phase, and elements such as Ca, Mg, and Si contributing to scale formation. High water hardness (82.02 mg/L in pipe circulation) also supports scale formation. The LSI and RSI indices indicate highly aggressive water with high corrosiveness, causing localized overheating of the skid pipes. This increases the creep rate due to refractory damage, leading to high-temperature exposure and subsequent pipe leakage marked by bulging. Enhanced slag control within the reheating furnace, routine slag cleaning, and a review of cleaning schedules and frequencies to prevent similar failures.

KEYWORDS: skid pipe leakage; walking beam reheating furnace; localized overheating; creep; refractory.

1. INTRODUCTION

The iron and steel industry is a crucial indicator of economic strength, with China leading global production. Indonesia's steel consumption, while growing, remains below that of other Southeast Asian nations [1]. Steel is essential for manufacturing and infrastructure, making the industry's health vital for economic progress. Maintaining the reliability of production facilities in Indonesia is key to meeting steel demand. Unplanned downtime due to equipment failure can lead to significant losses. Steel production involves complex, interconnected steps, from ore processing to final product rolling, requiring robust and well-maintained equipment [2]. The final steel product is tailored to the customer's needs in sheets with certain dimensions or rolls, namely hot-rolled coils or cold-rolled coils [3].

This research focuses on failures in reheating furnaces, particularly the walking beam type used in modern steel manufacturing. These furnaces operate at high temperatures, moving steel plates using skid pipes cooled by water [4]. Failures in these systems can severely disrupt production. This type of reheating furnace works with a complex system and high temperatures. Hence, damage to supporting facilities such as pipes and other components often occurs, as reported in several literature studies.

Ávila et al. conducted a failure analysis on the reheat furnace cooling system pipe due to damage to the pipe protective refractory. Damage to the refractory results in high temperatures in the pipe, triggering a drastic corrosion process [5]. Al-Meshari et al. showed that the pipe failure was caused by creep-induced deformation accelerated by heavy carburization and uneven heating [6]. Sahoo et al. revealed a failure analysis of grade S355J0 seamless steel pipe in a walking beam-type reheat furnace. The failure was caused by microstructural transformation due to excessive heating and cyclic stress. Scale deposits are caused by metal oxidation and increased hardness of circulating water. This causes cracks in the skid pipe [7].

Kubo Takanori's research improved water quality in reheat furnace pipes using corrosion inhibitors and calcium dispersants. This reduced corrosion significantly, especially in pipes with slow flow and high chloride levels, cutting the corrosion rate to less than 1% of the original [8]. Chaudary et al. analyzed failures in aluminosilicate-based refractories in reheat furnace bullnose structures. Post-repair tests revealed a reaction between alumina and sodium oxide, forming an anorthite solution. This caused volume expansion and stress, leading to refractory warping [9]. Ul-Hamid analyzed radiant pipe failures in ethane pyrolysis furnaces. Pipes had longitudinal cracks from high-temperature carburization and creep damage. Recommends better temperature control and using HP + W grade steel above 900°C to prevent these issues [10]. Babakr et al. reported a reheating furnace pipe support beam failure after six months at 850°C. The beam, made from HK alloy, experienced microstructural changes, reducing mechanical properties due to sigma phase formation [11].

The numerous failures occurring in walking beam reheating furnace facilities underscore the complexity of such failures. These failures extend beyond the Skid pipes to other components like pipe support beams, refractories, recuperators, etc. However, this study focuses on the failure of the Skid pipes. The performance of these pipes must exhibit high resistance to deformation pressure and impact resistance at elevated temperatures. The behavior of materials at high temperatures can provide insights into the root causes of these issues.

Additionally, maintaining the quality of the water in the cooling system for the Skid pipes is crucial. Poor water quality can lead to scale formation, which deposits in the pipes, causing blockages in the cooling system. Suppose the cooling system is obstructed, and the pipes are continuously exposed to high temperatures within the reheating furnace. In that case, the pipe's durability will diminish, leading to damage and subsequent production halts, incurring losses for the company [12].

Therefore, failures in the Skid pipe system can be attributed to two primary causes: exposure to high temperatures and the cooling water quality. Undesirable components in the water can form scale deposits that hinder heat exchange processes, while excess heat leads to metal oxidation [7]. This results in localized heating that leads to leaks due to creep.

In this study, a leakage failure occurred in the Skid pipes of a walking beam reheating furnace at a steel company in Indonesia, which will be investigated. Several tests will be conducted to determine the leakage's causes and propose preventive measures.

2. EXPERIMENTAL

The pipe is cut vertically to take samples of scale deposits from the pipe. Meanwhile, the skid pipe sample was taken from the end of the cut pipe, as shown in Fig. 1. To take samples for cooling system water quality tests, a 100 ml bottle was taken from the cold water basin located at the water treatment process (WTP).

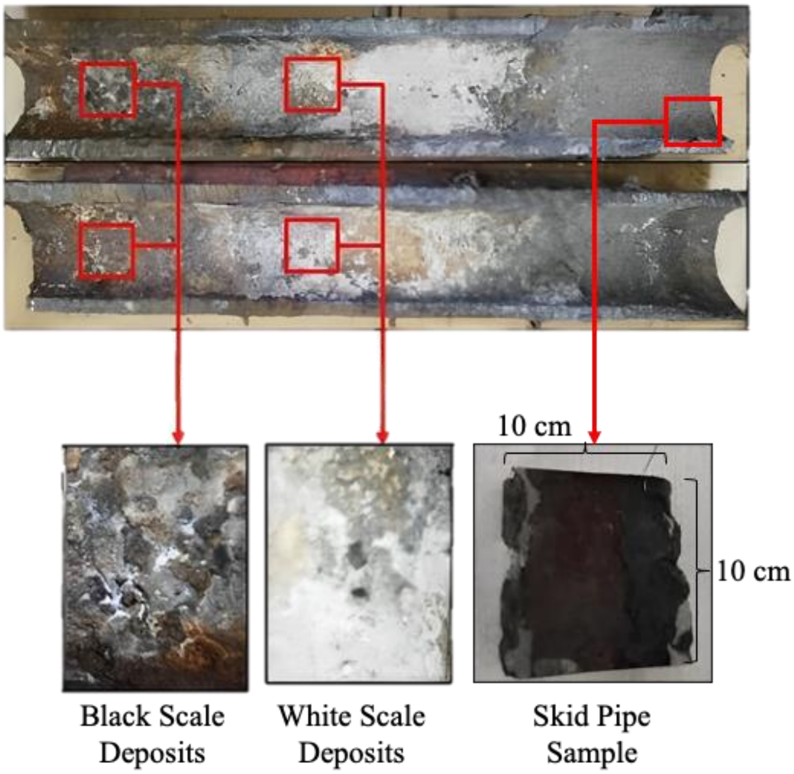


Fig. 1. Vertical pipe cut for scale and skid pipe samples

3. RESULTS AND DISCUSSION

3.1. Problem Identification

In this study, the skid pipes' failure was initiated by a significant daily increase in temperature at specific points along the skid pipes. Fig. 2 illustrates the timeline of the skid pipes' failure within the reheating furnace.

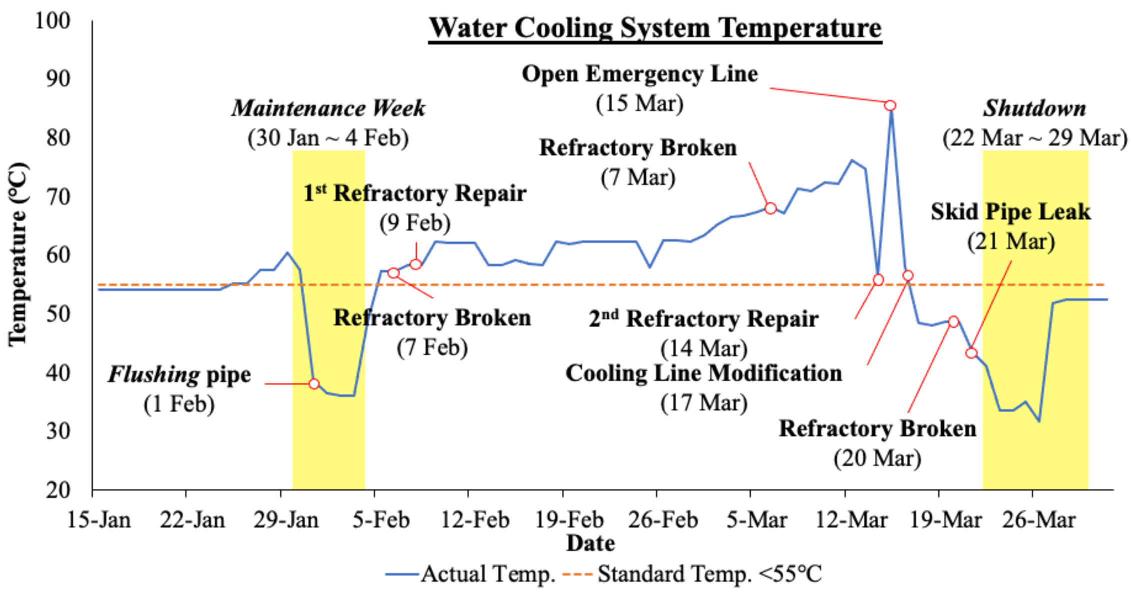
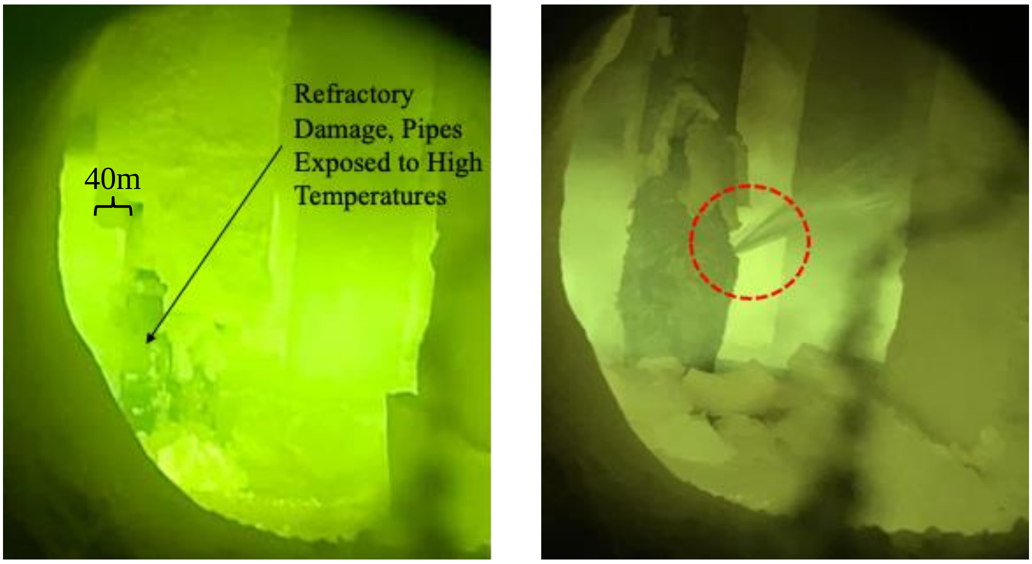


Fig. 2. Timeline of failure in skid pipes

On January 29, 2023, the highest recorded temperature was 60.3°C, prompting flushing of the skid pipes during maintenance week. However, by February 7, 2023, after maintenance, the temperature remained at 58.2°C. Field checks revealed minor refractory damage, which was repaired using the spray method on February 9, 2023. However, this did not reduce the drain box's cooling system temperature or water flow rate. On March 7, 2023, the temperature rose to 67.1°C, causing further refractory damage. The second repair on March 14, 2023, was followed by an extended repair period that caused creep in the skid pipes. By March 15, 2023, the temperature peaked at 85.2°C, indicating blockages in the skid pipes. An emergency cooling water route was opened, reducing the temperature to 58.1°C. On March 17, 2023, a modified cooling water supply route was implemented by adding a new pipe, effectively reducing the temperature to 48.1°C. Despite these efforts, severe refractory damage occurred on March 20, 2023, and on March 21, 2023, a leak in the skid pipes halted production for repairs and investigation. The condition of the refractory and skid pipes is shown in Fig. 3.



(a) (b)

Fig. 3. Skid pipe condition (a) before leak (b) during leak

The investigation into the skid pipe leakage in the reheating furnace began by cutting the pipes, revealing significant scale deposits inside (Fig. 4). These blockages indicate poor cooling water quality, characterized by high hardness, alkalinity, and temperature, which leads to scale formation and corrosion. This, in turn, reduces heat transfer efficiency and causes localized overheating, exacerbating creep in the pipes [13]. The problem is worsened by the position of the skid pipes directly in front of the burner mouth (Fig. 5).

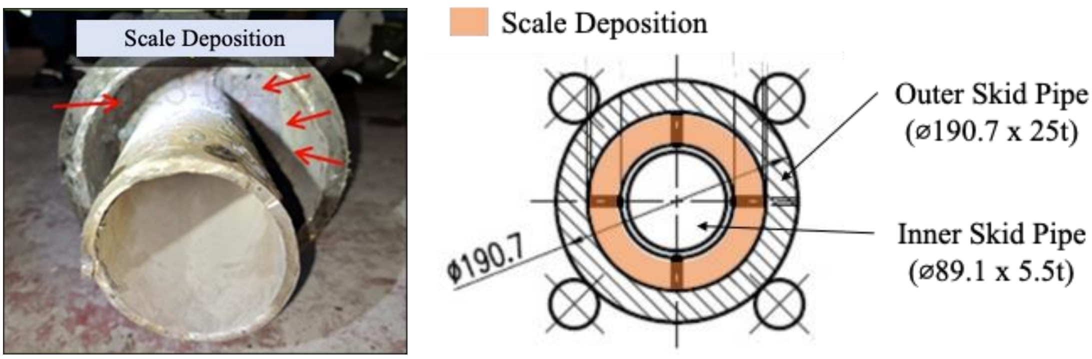


Fig. 4. Scale blockage inside the pipe

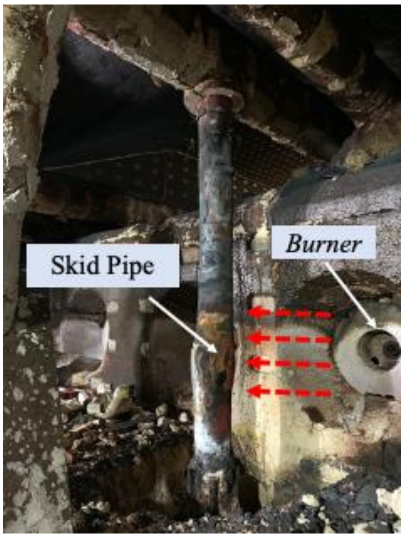


Fig. 5. Position of skid pipe to burner

3.2. Visual Observation

A visual inspection of the skid pipes in the reheating furnace revealed significant leakage issues. After longitudinally cutting the pipes, measurements showed the pipe thickness reduced from 25 mm to 13.27 mm (47% reduction) near the crack and to 19.27 mm (23% reduction) farther from the crack (Fig. 6). A horizontal crack of approximately 10 mm was found (Fig.7). The pipes experienced severe vibrations, impacts, and abrasion due to the cylinder's movement, leading to creep and bulging (Fig. 8) [14]. Internal scale deposits indicated uneven heating, causing localized overheating and thick oxide layer formation, weakening the pipe walls and increasing stress [15]. Iron oxide layers inside the pipes (Fig. 9) were due to high temperatures from cooling system blockages, accelerating oxidation [16].

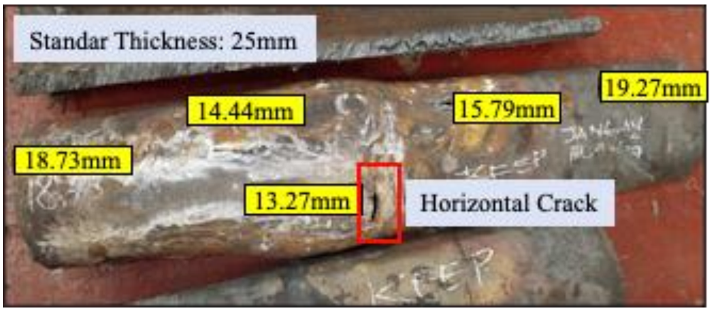


Fig. 6. Thickness distribution

Fig. 7. Crack condition

Fig. 8. Bulging Phenomenon

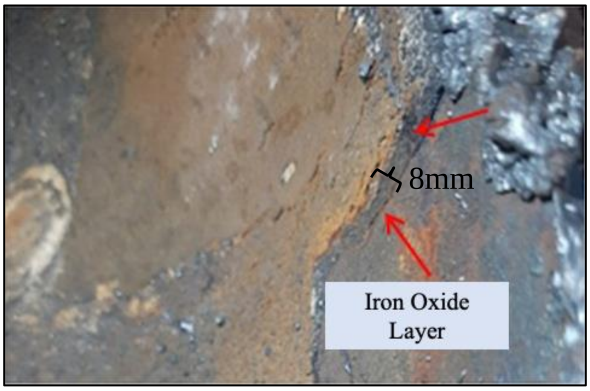


Fig. 9. Iron oxide layer formation

3.3. Chemical Analysis Testing

Chemical composition testing was performed on samples from skid pipe pieces with black and white scale deposits inside the pipe and samples from the water cooling system. Various tests were conducted to analyze the elements contributing to the failure.

3.3.1. Wet Analysis Testing

The chemical analysis of black scale deposits revealed a high Fe content (37.33%), as shown in Table 1, indicating oxidation and corrosion on the skid pipe's surface at high temperatures, forming predominantly FeO with minor Fe_3O_4 and Fe_2O_3 [17]. Oxygen levels and temperature conditions influence this oxide layer formation, where FeO dominates under reducing conditions and higher temperatures [16]. Similar findings from previous studies confirmed FeO as the dominant oxide at elevated temperatures [7][18], contributing to local heating and material degradation due to prolonged oxidation. White-scale deposits with lower Fe content suggest reactions with contaminants from the cooling water system, facilitating oxide layer formation and contributing to potential failure mechanisms, notably creep [19].

Table 1. Wet analysis test results

Element	Laboratory Results (%)	
	Black Scale Deposits	Black Scale Deposits
Fe	37.33	7.47

3.3.2. XRF Analysis

The testing results (Table 2) found that the most significant elements were SiO2, CaO, and MgO. The SiO2 content in the white scale deposits (57.05%) was higher than in the black scale deposits (24.40%). This indicates that silica (Si) is the primary component in the white-scale deposits. Calcium (Ca) and magnesium (Mg) were also detected in white and black-scale deposits. The research conducted by Muryanto et al., Si, Ca, and Mg can form compounds such as calcium magnesium silicate (CaMgSi2O6) or calcium magnesium carbonate ((Mg, Ca)CO3) under different environmental conditions [20].

Moreover, the Al2O3 content in the scale deposits tends to be very low. The refractory material used to protect the skid pipes is high alumina castable (HACT 165), applied with a thickness of 40mm. This refractory material has a chemical composition of 58% Al2O3 and 36% SiO2, as shown by the data provided by Chosun Refractories [21]. By comparing the Al2O3 and SiO2 compositions in the scale deposits and the refractory material, it can be concluded that the refractory composition does not significantly influence the scale deposits. Therefore, it can be assured that the initial leakage originates from the inside towards the outside. During operation, the skid pipes are coated with refractory, and overheating can only occur under abnormal conditions or if there is damage to the refractory.

Potential damage to the refractory can stem from the up-and-down movement of the cylinder, which is hindered by slag from the slab surface in the reheating furnace that falls and accumulates, causing abrasion and compromising the refractory's performance. The operational conditions in this area include heavy abrasion from the movement of the skid pipe, severe mechanical impact over time, exposure to high temperatures with heavy loads, and contact with aggressive scale slag. These conditions can lead to a rapid reduction in refractory thickness due to the heavy slag buildup preventing free movement of the skid pipe [14].

Table 2. XRF test results

Element	Laboratory Results (%)	
	Black Scale Deposits	White Scale Deposits
SiO_2	24.40	57.05
Al_2O_3	0.502	0.236
CaO	12.53	17.87
MgO	8.24	7.00
P	2.70	2.39
MnO	0.218	-

3.3.3. OES Spectrometer

Tests were carried out using optical emission spectrometer techniques on cut samples of the skid pipe. The test results are then compared with the basic specifications of the skid pipe. This is done to ensure that there are no deviations in composition as triggers for failure due to manufacturing. The results of this test can be seen in Table 3.

Table 3. OES test results

Element	Standard (%)		Laboratory Results (%)
	Min	Max	
Carbon (C)		0.25	0.206
Silicon (Si)		0.35	0.223
Manganese (Mn)	0.30	0.90	0.492
Phosphorous (P)		0.04	0.019
Sulphur (S)		0.04	0.003

The table results compare the chemical composition of laboratory test results with the standard chemical composition of Carbon Steel JIS G 3445 Grade STKM 13A material. These results indicate no deviations in the material composition from the skid pipe samples that failed in the form of leaks. The conclusion is that no manufacturing error occurred.

3.3.4. Water Chemical Analysis Testing

Water samples used in the skid pipes' cooling system were tested to determine the contamination levels in the water that affect scale formation within the skid pipes, leading to local heating. These tests are conducted monthly as a quality control measure for the cooling system water. Several control elements must be monitored to maintain the quality of the cooling system water. The results of the chemical analysis of the water are shown in Table 4.

Table 4. Water chemical analysis test results

Parameter	Skid Pipe	Makeup
Turbidity (NTU)	1.1	1.3
Ca Hardness (mg/L)	82.02	18.96
Cl- (mg/L)	32.3	6.8
Fe (mg/L)	0.009	0.032
M-Alkalinity (mg/L)	50.2	15
pH	8.26	7.23
PO_4 (mg/L)	5.49	ND
SiO_2 (mg/L)	91.96	32.67
Conductivity (µS/cm)	434	138.4

The test results were obtained immediately after a failure occurred in the skid pipes. Several significant elements were identified. Firstly, the Ca Hardness value exceeded the company's control standard of < 80 mg/L, with the skid pipe showing a value of 82.02 mg/L, while the make-up water was much lower at 18.96 mg/L. This significant increase in Ca Hardness in the skid pipe compared to the make-up water indicates the presence of calcium carbonate (CaCO3) scale deposits within the pipes, marked by white scale deposits [22].

Secondly, chloride levels were higher in the skid pipe (32.3 mg/L) compared to the make-up water (18.96 mg/L), indicating a potential risk of corrosion in the pipes. This will be further assessed in subsequent discussions by calculating the corrosion rate using corrosion coupon evaluation. Thirdly, the pH value in the skid pipe exceeded the company's control standard of 7-8, measuring at 8.26. This alkaline condition enhances the formation of the CaCO3 scale. Lastly, the silicon dioxide (SiO2) level in the skid pipe was significantly higher (91.96 mg/L) compared to the make-up water (32.67 mg/L), indicating a high silica content in the skid pipe, marked by white scale deposits. This also corroborates the XRF test results, showing no significant impact on scale composition due to refractory damage.

Based on the chemical composition testing of scale deposits, supported by the chemical analysis of the cooling system water for the skid pipes, it can be concluded that the main components of the scale are calcium (Ca), silica (Si), and magnesium (Mg), potentially forming compounds such as calcium magnesium silicate (CaMgSi2O6) or calcium magnesium carbonate ((Mg, Ca)CO3). Scale formation in the pipes increases stress on the walls due to uneven heating and thermal expansion, initiating cracks and supporting the creep phenomenon in the pipes [23].

3.3.5. Langelier and Rzynar Index

The Langelier and Ryznar indices were calculated from the water chemical analysis data to determine the levels of scaling and corrosivity in the cooling system water. The results of these calculations are shown in Table 5.

Table 5. Langelier and Ryznar test results

Index	Calculation Result	Water Tendency
Langelier	-1.2	**LSI < 0**, Water is undersaturated concerning calcium carbonate. Undersaturated water tends to dissolve the protective calcium carbonate layer in pipes. **LSI -2.0 < -0.5**, Serious corrosion.
Ryznar	11	**RSI > 8.5**, Water is very aggressive. **RSI > 9**, Corrosion is intolerable.

A Langelier Index (LI) of -1.2 indicates that the water is highly corrosive, which can exacerbate creep in the skid pipes by accelerating material degradation [24]. Proper water quality management for the cooling system is essential, as maintaining an appropriate LI is crucial to prevent corrosion and clogging in the pipes.

A Ryznar Index (RI) of 11 indicates that the water is extremely aggressive, with intolerable levels of corrosion. The scale accumulation can cause stress concentration and local temperature variations, worsening creep damage, which is the slow plastic deformation of metals under stress and high temperature [25]. Furthermore, scale and corrosion can create uneven stress distribution and microstructural changes in the pipe material, further impacting the creep rate [26].

4. CONCLUSIONS

1. **Physical Damage Observations**: The skid pipe exhibited significant physical damage, including cracks, black and white scale deposits, bulging, and a reduction in wall thickness by 47% from its original measurement.
2. **Damage Mechanism**: The failure was initiated by high Fe oxide levels, which significantly contributed to corrosion, predominantly in the form of wustite (FeO). Additionally, elements such as Ca, Mg, and Si contributed to scale formation, supported by high water hardness (82.02 mg/L for the skid pipe circulation). The LSI and RSI indices indicated that the water was highly aggressive and intolerably corrosive. The scale formation caused localized overheating, increasing the creep rate due to refractory damage, which exposed the pipe to high temperatures, ultimately leading to leakage and bulging.
3. **Need for Slag Control**: Prioritizing slag control within the reheating furnace is crucial, leading to refractory damage through abrasion. Therefore, routine slag cleaning and a review of cleaning schedules and frequencies are required.

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