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Designing Water Quality of Circulatory Cooling System for Extending Useful Life of Reheating Furnace Skid Pipe

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Abstract:

Influence of quality, flow velocity and temperature, of water on corrosion for skid pipe of reheating furnace was evaluated, and the way to operate the open circulatory cooling water system at low risk is proposed. Improvement result of cooling water quality in reheating furnace of hot rolling mill at Kurashiki is reported.

1. Introduction

Because water leaks and blockage problems caused by corrosion occurred frequently in reheating furnace skid pipes at the hot strip mill at JFE Steel West Japan Works (Kurashiki) in comparison with other hot strip mills in JFE Steel, the corrosion phenomenon was elucidated and improved.

2. Experimental Elucidation of Skid Pipe Corrosion Phenomenon

2.1 Condition of Skid Pipe Corrosion

An example of a skid pipe which was blocked internally by an accretion at the Kurashiki hot strip mill (HSM) is shown in **Photo 1**, and the results of a component analysis of the accretion that caused the blockage are shown in **Table 1**. A comparison of the corrosion rates of the skid pipes at the HSM and other rolling mills in Kurashiki is shown in **Fig. 1**, and the water quality values and flow velocities of each mill are shown in **Table 2**. Since the main component of the skid pipe accretion is iron oxides and the fraction of suspended solids (SS) in the HSM cooling water is small, it is reasonable to conclude that the pipe was occluded due to enlargement of the corrosion product of the skid pipe itself. Furthermore, large differences were observed in the corrosion rates at each plant, even though the circulating cooling water at each plant is industrial water taken from the same raw water source.

Photo 1 Blockage of the skid pipe

2.2 Corrosion Experiment

2.2.1 Experimental equipment and method

A corrosion experiment was conducted to identify the factors that influenced the difference in the corro-

Table 1 Result of component analysis of adhered material in skid pipe

XRD analysis of adhered material (%)	
FeO	2.6
Fe_2O_3	3.2
Fe_3O_4	82.1
FeOOH	11.4
$CaCO_3$	0.9

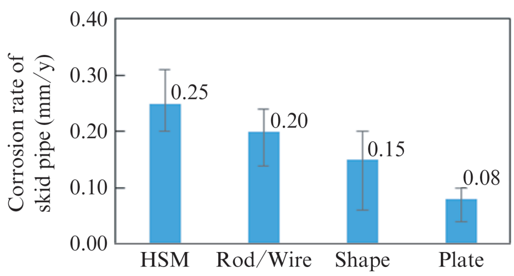

Fig. 1 Corrosion rate comparison among mills in Kurashiki

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Table 2 Water quality and operating conditions at mills in Kurashiki

	Water quality items						Operating conditions	
	pH (@20°C)	M-alkalinity (ppm)	Ca hardness (ppm)	Suspended solids (ppm)	Langelier's index (@50°C)	[Cl-] (ppm)	Flow velocity (m/s)	Water temparature @exit (°C)
HSM	7.3	31	46	3	−0.9	28	0.21	48.0
Rod/Wire	7.2	22	47	5	−1.2	62	0.23	36.9
Shape	7.7	38	76	5	−0.1	279	0.09	41.9
Plate	7.2	40	117	4	−0.5	177	0.10	36.7
Raw water	7.4	40	36	1	−0.8	6	—	—

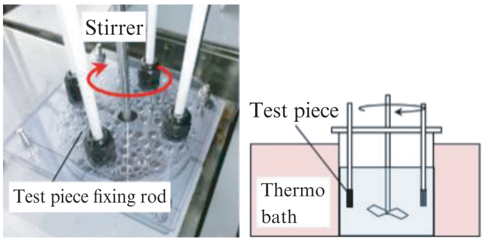

Fig. 2 Experimental equipment

Table 3 Experimental condition

Sample water	Circulatory cooling water of each mill
Flow velocity V	0, 0.3, 0.6 (m/s)
Water temperature T	30, 50 (°C)
Experimental period	2 (days)
Test piece	Carbon steel (SS400)

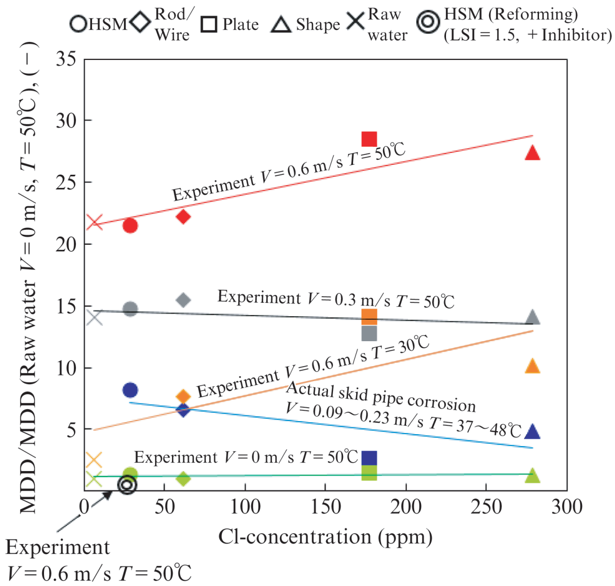

Fig. 3 Result I (effect of Cl ion)

sion rates at the respective plants. The experimental equipment is shown in **Fig. 2**, and the test conditions are shown in **Table 3**. During the experiment, the test pieces were immersed and held in a fixed condition, the sample water was stirred at a set flow velocity, and the temperature was kept constant by a thermo bath. The weights of each test piece were measured before and after the experiment, and the average corrosion rate MDD (mg/dm^2·day) was obtained from the corrosion weight loss of the specimens.

2.2.2 Result I (Influence of water quality — Chloride ion)

The influence of the chloride (Cl) ion on the corrosion rate is shown in **Fig. 3**. In Fig. 3, the specific corrosion rate is shown on the vertical axis. The specific corrosion rate was obtained by dividing the MDD obtained in each experiment by the MDD of the experimental condition raw water, V=0 m/s, T=50 °C. The horizontal axis shows the Cl ion concentration.

From Fig. 3, it can be understood that the influence of the Cl ion concentration on the corrosion rate varies depending on the flow velocity condition. Under the high flow velocity condition (V=0.6 m/s), the corrosion rate showed a tendency to increase as the concentration of the Cl ion increased. On the other hand, no correlation between the Cl ion concentration and the corrosion rate was seen under the low flow velocity conditions (V≤0.3 m/s).

The difference in the corrosion phenomenon depending on the flow velocity is considered to be due to the oxide film breaking effect of the Cl ion.

According to Kinoshita et al.[1], under an environment where the flow velocity exceeds 0.5 m/s, the corrosion rate increases as the ion concentration becomes higher. This is explained as follows: When the flow velocity exceeds 0.5 m/s, the supply of dissolved oxygen (DO) to the steel surface is sufficiently abundant to form a dense oxide film, and the self-protective effect of this oxide film reduces the corrosion rate. However, when the Cl ion concentration is high, the formed fine oxide film is broken, and stable formation of the protective film cannot be maintained. Based on this, it can be said that the Cl ion concentration has a large influence on the corrosion rate under high flow velocity environments.

However, considering the corrosion environment of

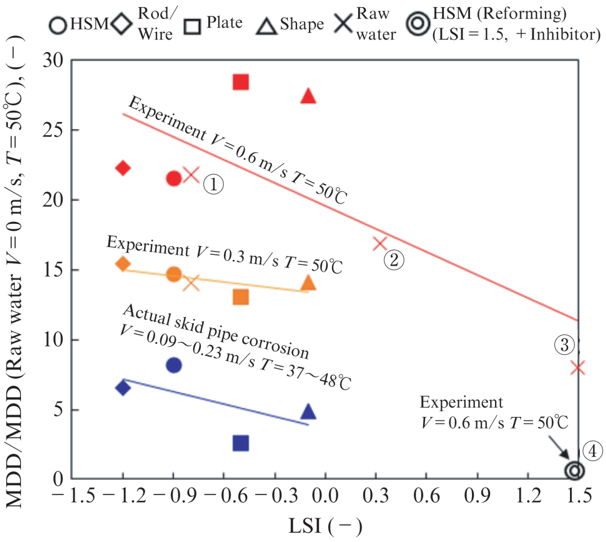

Fig. 4 Result II (effect of LSI and inhibitor)

the actual skid pipes, from Fig. 3, it is thought that the Cl ion concentration does not have a significant effect on the corrosion rate in the actual mills, as the flow velocity is less than 0.3 m/s in all cases.

2.2.3 Result II (Influence of water quality — LSI and corrosion inhibitor)

The influence of LSI (Langelier stability index) and a corrosion inhibitor on the corrosion rate is shown in **Fig. 4**. LSI is an index of the stability of calcium carbonate in water. When LSI>0, the water is in a saturated condition and solid calcium carbonate precipitates easily. Conversely, when LSI<0, the water is undersaturated and precipitation of solid calcium carbonate is less likely to occur.

Although a weak negative correlation between LSI and the corrosion rate at the actual mills can be seen in Fig. 4, there was no clear difference in the corrosion rate in the experiment under the conditions of V=0.3 m/s, T=50 ˚C, which are close to the actual mill environment. Based on this, it is reasonable to think that some factor other than LSI had a larger effect on the negative correlation. Here, the faster corrosion rates with the sample water of the plate and shape mills under the experimental conditions of V=0.6 m/s, T=50 ˚C are attributed to the oxide film breaking effect of the Cl ion, as described previously in section 2.2.2.

On the other hand, when the LSI of the raw water was adjusted to a large positive value by adding calcium nitrate tetrahydrate (② and ③ in Fig. 4), the corrosion rate showed a large decreasing tendency. **Photo 2** shows a comparison of the surface condition of the test pieces after the corrosion experiment. Since calcium carbonate precipitated on the test piece surfaces, it is thought that the decrease in the corrosion rate was due to the environmental blocking effect of formation of the calcium film. Moreover, when the corrosion inhibitor was added to the sample water (④ in Fig. 4), the environmental blocking effect became stronger, and corrosion hardly progressed.

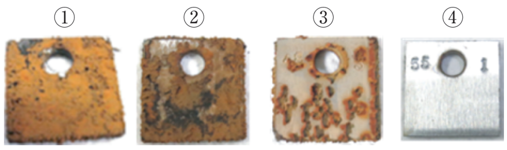

Photo 2 Appearance of test pieces (Each number corresponds to ① to ④ in Fig. 4)

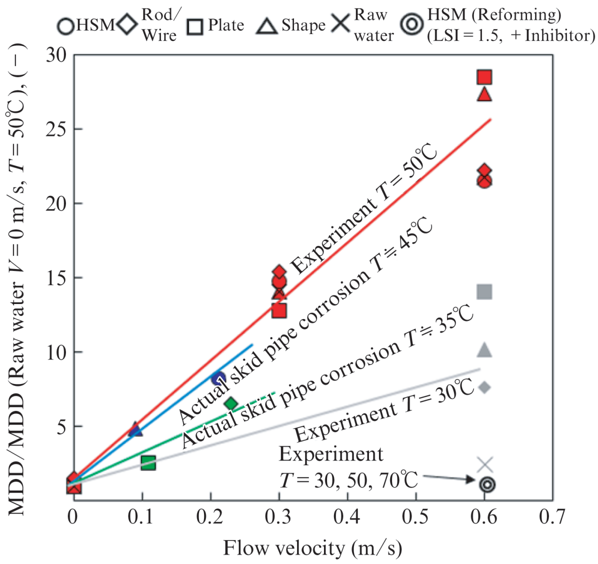

Fig. 5 Result III (effect of flow velocity and water temperature)

2.2.4 Results III (Influence of environment — Cooling water flow velocity and temperature)

The influence of the cooling water flow velocity on the corrosion rate is shown in **Fig. 5**. The corrosion rate increased greatly as the flow velocity and water temperature increased. This result is attributed to the change in the amount of DO supplied to the steel surface.

Figure 6 shows the state of diffusion of DO on the steel surface. According to Miyasaka et al.[2], in the region where the flow velocity is 0.5 m/s or less, where DO on a steel surface is not saturated, the amount of DO supplied is rate-controlling for the corrosion rate. This is because the rate of the oxidation-reduction reaction is significantly faster than the oxygen diffusion rate.

Fick's law of diffusion is shown in Eq. (1), and the diffusion coefficient D of oxygen in water is shown in Eq. (2).

$$J = DC/\delta \quad \cdots\cdots (1)$$

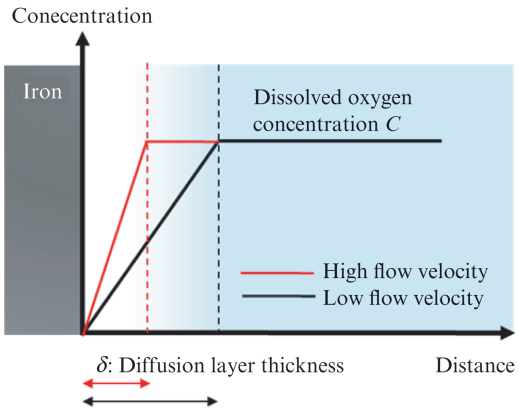

Fig. 6 State of dissolved oxygen diffusion on steel surface

$$D=2.04\times10^{-9}\,(1.04)^{T-20} \quad (2)$$

where, J is the amount of DO supplied, C is the concentration of DO, δ is the diffusion boundary layer and T is the water temperature.

When the flow velocity increases, the diffusion boundary layer δ becomes thinner, and when the water temperature T increases, the diffusion coefficient D also increases. As a result, the amount of DO supplied J increases, and the corrosion rate increases.

Since the cooling water flow velocity of actual skid pipes is in the region where the amount of DO supplied is rate-controlling, a correlation exists between the corrosion rate and the flow velocity and water temperature. However, when the corrosion inhibitor was added to the sample water, corrosion hardly progressed even under high flow and high temperature conditions.

3. Improvement of Skid Pipe Cooling Water at Kurashiki Hot Strip Mill Reheating Furnace

Based on the experimental results, the circulatory cooling water of the Kurashiki hot strip mill reheating furnace was improved as follows.

(1) Adjustment of LSI from −0.9 to 1.5

At the same time, a calcium dispersant was also added to avoid the risk of blockage by calcium carbonate precipitation.

(2) Addition of corrosion inhibitor to circulatory cooling water

Before and after these improvements, test pieces were set in the actual skid pipes for 2 weeks each, and the corrosion rates were compared.

The results are shown in **Photo 3**. As a result of the above-mentioned measures, the corrosion rate at the hot strip mill could be reduced to less than 1/100 of the original rate.

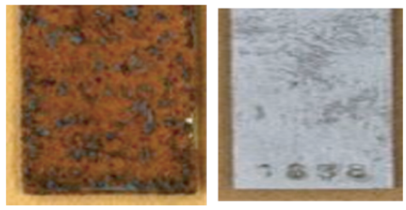

Photo 3 Appearance of test pieces after 2 weeks of corrosion test under actual environment

4. Conclusion

The influence of the main water quality items and use environment conditions (flow velocity, water temperature) in an open circulatory type cooling system on the corrosion phenomenon of reheating furnace skid pipes was clarified. In addition, the corrosion environment at the Kurashiki hot strip mill was changed by improvements in the cooling water. As a result, the following knowledge was obtained.

(1) The difference in the corrosion rate in the Kurashiki primary mill skid pipes occurred mainly due to the flow velocity and water temperature. This is because the cooling water flow velocity of the actual skid pipes is slower than 0.5 m/s, and as a result, corrosion was occurring in the region where the corrosion rate is limited by the amount of DO supplied.

(2) Increasing the LSI or adding a corrosion inhibitor to promote formation of a corrosion protection film makes it possible to suppress corrosion by an environmental blocking effect.

(3) The corrosion rate increases under the combined conditions of a high chloride ion concentration and high cooling water flow velocity.

(4) By implementing improvements of the skid pipe cooling water at the Kurashiki hot strip mill reheating furnace, it was possible to reduce the corrosion rate to less than 1/100 of that when using the conventional cooling water.

References

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