Application of Recycled Refractories in a Heating/Reheat Furnace in a Hot Rolling Mill.

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1. Abstract

In general, the used refractories in a steelmaking works are mostly disposed as waste materials. To reduce the amount of waste materials, a study was conducted on the recycling of these used refractory materials[1].

It is well known that used refractory materials can be used again as castable or gunning refractories, but this study focused on using them as the hearth bottom lining material in a heating/reheat furnace in a hot rolling mill, which is a new application for recycled refractories. It was considered that it would be good to make the scale removal work on the surface of the hearth bottom easier, by using recycled materials there, and, in addition, it was expected to reduce the repair cost by greatly reducing the need to replace bottom bricks.

After several trials, a new application technology was established for recycled refractories, the cost of the hearth refractories was reduced, and the scale removal work was made faster and easier.

2. Introduction

Many types of refractories are used for many applications in a steelmaking plant. And most of the refractories used in the steelmaking process are disposed as waste materials. To reduce the amount of disposed materials, it is important to use the waste materials effectively as recycled materials, in addition to reducing the waste generation by increasing the service life of refractories. Therefore, work was undertaken to increase the recycling of these used refractory materials. Figure 1 is a flow chart of the recycling process of refractories, after use in Yawata Works[2].

The main use of recycled refractories has been as repair materials, such as castables and gunning materials, etc. used in the ironmaking and steelmaking process, as shown in Table 1[3] [4]. But the intent of this study was to find a new applications for recycled refractories, which focused on the hearth bottom of a heating/reheat furnace in a hot rolling mill.

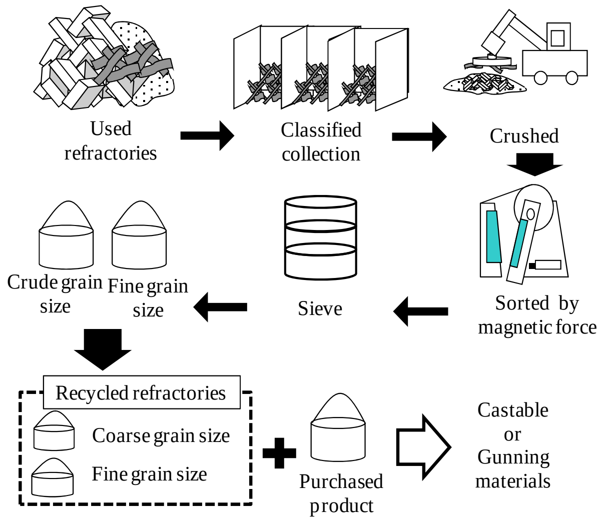


Figure 1 Flow chart of the recycling process for used refractories in Yawata Works.

Table 1 Main applications of recycled refractories

Process	Facility	Application of recycled refractories
Iron making	Blast furnace	・Gunning refractory materials
Steel making	Torpedo car	・Gunning refractory materials ・Castable
Steel making	Ladle	・Gunning refractory materials ・Castable
Steel making	Converter	・Gunning refractory materials ・Hot casting repair mix
Steel making	Tundish	・Gunning refractory materials

3. Application of recycled refractories in a heating furnace in a hot rolling mill

3.1 Review of the heating furnace in a hot rolling mill

Figure 2 shows a cross-section schematic view of the heating furnace in a hot rolling mill. The heating furnace consists of skid beams, which support the steel plates, that are moved forward, fixed skid posts which support the skid beams, and movable skid posts, which move the steel plates forward intermittently, by their repeated rectangular motion. The furnace is divided into three zones, namely, the pre-heating zone, heating zone, and soaking zone, from the charging side. The steel plates are inserted into the furnace from the charging side, and are heated up gradually; at the same time, iron oxide, called “scale” (FeO,Fe_2O_3), forms on the surface of the plates. The scale falls to the hearth bottom and deposits there. With time, it becomes necessary to remove the scale deposit during the periodic repairs of the furnace.

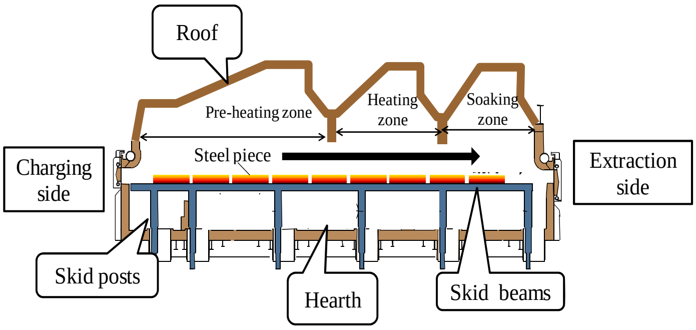


Figure 2 Cross-section schematic view of a heating/reheat furnace in a hot rolling mill

3.2 Study of effective use of recycled refractories

The appearance of the furnace refractories, used for more than 30 years, are shown in Figure 3. There were some cracks and holes where refractory pieces spalled off the surface of the roof and side wall refractory. On the other hand, the hearth bottom refractory was fully covered by scale deposits. It was assumed that the scale dropped from the steel plates, melted on the surface of the bottom, and adhered to the bottom refractories. It was decided to consider the application of recycled refractory materials to prevent scale adherence to the bottom refractories.

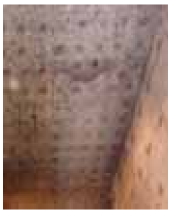
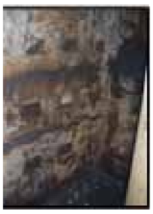
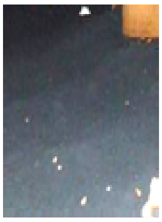
Site	Roof	Side wall	Hearth
Appearance			

Figure 3 Photographs showing heating furnace refractories used for more than 30 years

3.3 New application of recycled materials

A schematic image of the damaged hearth bottom refractories, with adhering scale, is shown in Figure 4. The deposited scale reacted with the bottom refractories and corroded them at high temperature for a long time. During the periodic repairs, the adhering scale deposit was broken up with a rock drill and removed. It was difficult to remove only the adhering scale and to avoid the mechanical damage of the bottom refractories. But it was considered to be possible to do little or no damage to the bottom refractories, if the adherence or bonding of scale to the refractories was suppressed, so the scale could be easily removed. Then, it was decided to try a ballast lining, composed of recycled refractories on the surface of the bottom bricks as a protective barrier.

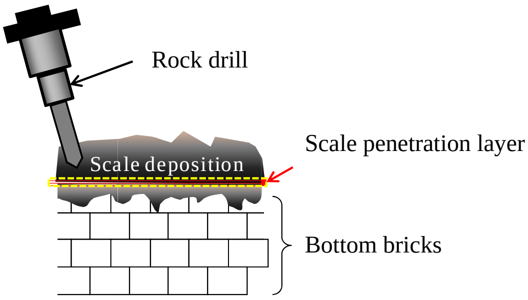


Figure 4 Schematic view of the hearth bottom refractories with adhering scale.

4. Development of a ballast lining of recycled refractories

4.1 Concept of the ballast lining design

The protective lining concept was based mainly on the following two points.

1. To choose the appropriate recycled material which had good corrosion resistance against the molten scale.

2. For the ballast barrier to have good structure, so that it would retain enough thickness during the long-term periods of operation.

4.1.1 Selection of recycled materials

In Yawata Works, there were four types of refractory materials available as recycled materials - Al_2O_3-MgO, MgO-C, Al_2O_3-SiC-C, and Al_2O_3-SiO_2. Of these recycled materials, the Al_2O_3-SiO_2 material was little used, and the other three type materials were used for several applications. Therefore, the Al_2O_3-SiO_2 material was considered to be the appropriate one to evaluate for the barrier layer.

4.1.2 Evaluation of the corrosion resistance of Al_2O_3-SiO_2 recycled materials

In this study, the corrosion resistance of the four recycled materials was evaluated against the molten scale at 1200°C, to select the appropriate material that did not react with the scale, and didn't form liquid phase, to avoid penetration, bonding, and adherence of the scale to the hearth bottom.

The comparison of recycled materials was carried out by the crucible corrosion test method. The scale chemical composition, shown in Table 2, was put into crucibles (inner diameter: 30 mm, outer diameter: 80 mm, height 60 mm) made of the recycled materials. The crucibles were heated for 3 hrs. at 1200°C, which was assumed to be the hearth bottom temperature.

Figure 5 shows the crucible corrosion test results. All four of the recycled refractories showed the same good corrosion resistance. So the Al_2O_3-SiO_2 recycled material was judged to be the most appropriate for actual testing in the heating furnace.

Table 2 Chemical composition of scale

Chemical composion of scale (mass%)					
FeO	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO
1.1	97.1	0.9	0.3	0.3	0.2

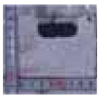
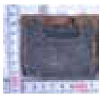
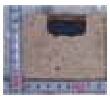
		Al_2O_3-MgO type	MgO-C type	Al_2O_3-SiC-C type	Al_2O_3-SiO_2 tyepe
Chemical composion (mass%)	Al_2O_3	83	75	73	45
	MgO	10	15		
	SiC			3	
	C			15	
	SiO_2				53
Crucible cross section					
Wear amount (mm)		0mm	0mm	0mm	0mm

Figure 5 Results of the crucible corrosion test

4.1.3 Evaluation of the ballast barrier structure

It was decided to spread the recycled material ballast layer all over the hearth bottom of the heating furnace, but it became a matter of concern that the gas jet flow from the gas burners might blow away the ballast material.

For the test materials, it was decided to use all (100%) recycled materials, including large grains and fine powders. Three different barrier structures were evaluated (Cases 1,2,3), using fine powders (<1 mm) and coarse particles (5 mm～50 mm under), as shown in Figure 6.

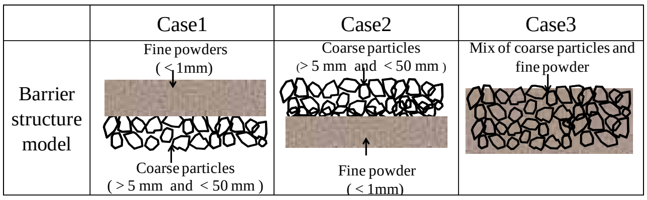


Figure 6 Schematic view of the barrier structure models

The stability of three different barrier structures, which were all 100 mm thick, were tested against the strong gas flow of gas jets (4 m/s and 7 m/s) for 3 min. The weight change of the barrier structures, before and after the test, was measured, and the results, are shown in Figure 7.

Figure 7 shows the relationship between the gas jet flow rate and the weight reduction of the three barrier structures, composed of 100% recycled material. When the gas jet flow was 4 m/s, there was no weight loss for any of the barrier structures, but weight losses did occur when the gas jet flow was increased to 7 m/s. It was obvious that Case 2 was better than the others, so the Case 2 barrier structure was adopted for the actual furnace test.

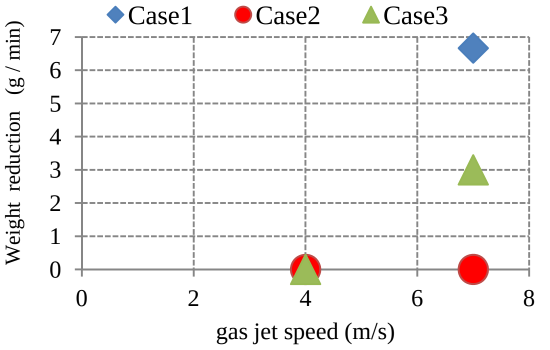


Figure 7 Relationship between the gas jet flow rate and the weight reduction of the recycled materials

5. Ballast lining in the actual furnace test

The barrier structure of Case 2, with the Al_2O_3-SiO_2 recycled material, was field-tested in the actual heating furnace. The Al_2O_3-SiO_2 recycled material ballast structure included coarse particles in a 50 mm thick layer and fine powder in a 50 mm thick layer; this ballast layer was spread over the whole hearth bottom, from the preheating zone to the soaking zone of the heating furnace, as shown in Figure 8.

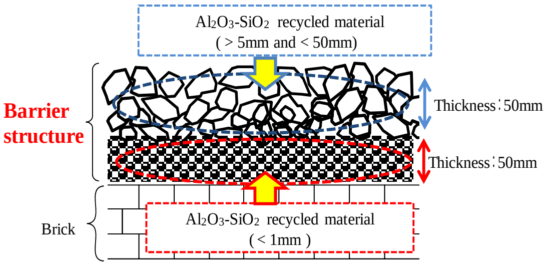


Figure 8 Schematic view of the ballast lining design/structure in the actual heating furnace test

6. Results of furnace field test

Photographs of the Case 2 hearth bottom, before the start of furnace operation, and after about 6 months of operation, are shown in Figure 9. Figure 9-3 shows that the hearth bottom brick under the Al_2O_3-SiO_2 recycled material was not damaged by the scale and it was clear that the Case 2 barrier layer of Al_2O_3-SiO_2 recycled material could successfully prevent the penetration of the high temperature molten scale into the bricks, and the associated adherence of the scale.

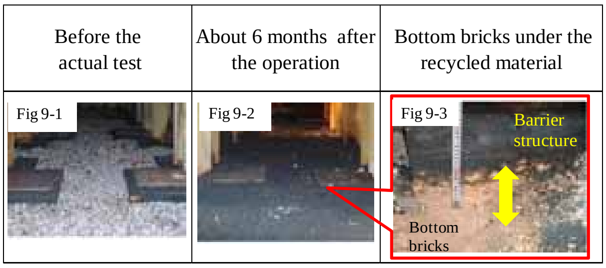


Figure 9 Photographs of the Case 2 ballast layer and bottom bricks after the actual furnace test

The condition of the Al_2O_3-SiO_2 recycled material barrier layer was investigated in detail, after use. A part of the barrier material was removed by a scoop from the hearth bottom, as shown in Figure 10-1, and observed carefully. The molten scale penetrated into the fine powder layer but did not reach the bottom bricks, as shown in Figure 10-2. Figure 10-3 shows that the molten scale penetrated into the coarse particle zone, covered the coarse particles, and reacted with them. Therefore, it was concluded that the Case 2 Al_2O_3-SiO_2 recycled material barrier layer succeeded in protecting the hearth bottom bricks from attack by the molten scale for the operating period, between the periodic repairs of the hearth bottom.

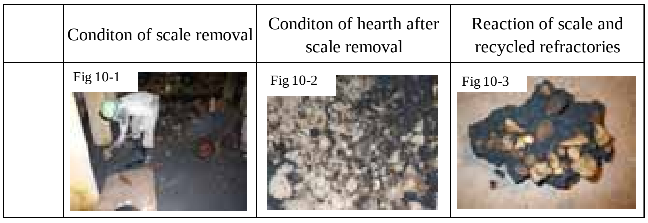


Figure 10 Photographs of the removal of the bottom hearth scale deposits after the heating furnace test

The labor effort required to remove the scale deposition from the hearth bottom, before and after adoption of the ballast barrier method, was compared. Figure 11 shows that the labor efficiency was three times better using the ballast barrier than for the conventional method.

Furthermore, it became clear that the repair cost of the hearth bottom was reduced about 90%, as shown in Figure 12, because there was no adhering layer of scale bonded to the bottom bricks, so demolition work was not needed, and the replacement cost of the bottom bricks was saved.

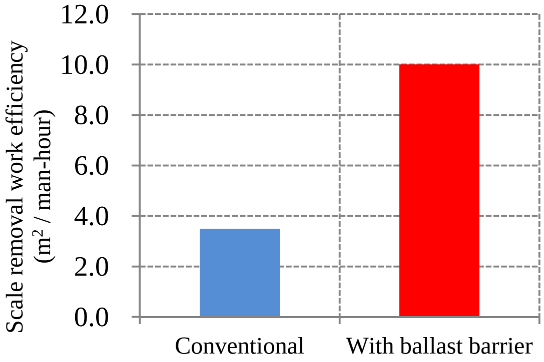


Figure 11 Comparison of the removal work of the bottom hearth scale deposits

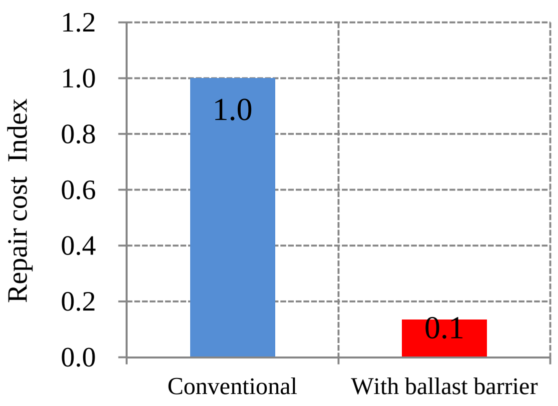


Figure 12 Comparison of the repair cost index

7. Discussion

Work was done to scientifically evaluate the effects of furnace operation on the barrier zone.

Figure 13 shows a schematic view of the hearth bottom with scale deposition, both for the conventional and the improved designs. In the conventional case, the upper layer of the bottom brick lining, where the molten scale penetrated, was destroyed during the demolition. However, for the improved design, the material to be demolished was limited to only the ballast barrier layer with scale penetration, and the bottom bricks were not damaged. The compressive strength was determined for the scale-penetrated layer of the bottom brick and the ballast barrier, for samples from the heating furnace bottom. The results are shown in Figure 14. It is clear that the strength of the scale-penetrated ballast material was 1/20 of the scale- penetrated brick, and thus it could be removed very easily.

To verify the reaction between the Al_2O_3-SiO_2 recycled material and scale, x-ray diffraction (XRD) was done on the ballast samples taken from the hot surface of the barrier layer and about 30 mm below the hot surface, after use. Table 3 shows the results of the XRD examination. The recycled Al_2O_3 -SiO_2 material consisted of Al_2O_3, SiO_2 and mullite ($3Al_2O_3$-$2SiO_2$). The barrier surface sample contained iron-cordierite ($2FeO$-$2Al_2O_3$-$5SiO_2$) as a reaction product, which had a melting point of 1083°C. This indicated that there might be liquid phase in that area, where the temperature was about 1200°C during furnace operation. However, the iron-cordierite was not present in the sample taken from about 30 mm below the hot surface. Therefore, it was presumed that the reaction between the scale and recycled material did not occur at that level because the temperature was lower.

Based on these results, it was concluded that the area where the scale caused serious damage was limited to the region within 30 mm of the hot surface.

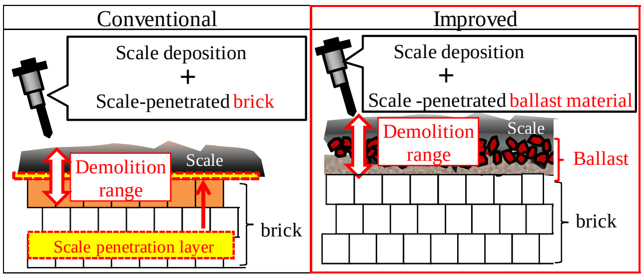


Figure 13 Schematic views of the hearth bottom with scale deposition, showing the demolition range.

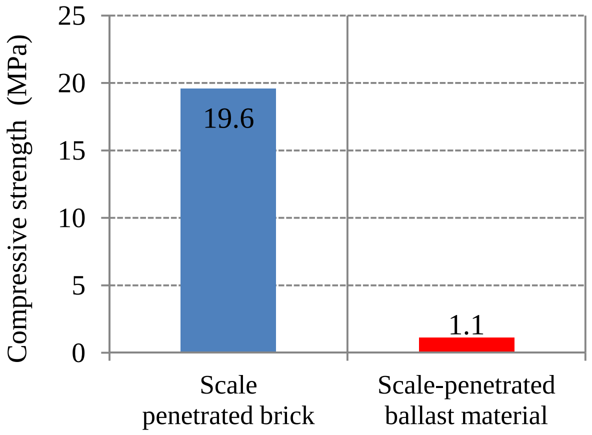


Figure 14 Results of compressive strength test

Table 3 Results of XRD examination of the used barrier layer samples

	Al_2O_3	SiO_2	$3Al_2O_3 \cdot 2SiO_2$	Fe_2O_3	$2FeO \cdot 2Al_2O_3 \cdot 5SiO_2$
Hot surface	+++++	+++	+++++	+	+
About 30mm from the hot surface.	+++++	+++	+++++	+	-

8. Conclusions

The goal of this work was to reduce the waste refractory material in Yawata Works. Effort was focused on the Al_2O_3-SiO_2 type recycled material for use in the hearth bottom of a heating furnace, to protect the bottom bricks from scale penetration/bonding, and damage during periodic scale removal.

Success was achieved in preventing scale penetration on the bottom brick by adopting a size-graded, layered ballast barrier that was 100% Al_2O_3-SiO_2 recycled refractory material.

The efficiency of the scale removal work was increased about three times for the ballast barrier layer, compared with the conventional practice, and the repair cost was reduced 90%, because the need to replace bottom bricks after demolition was greatly reduced.

9. References

[1]S.Hanagiri. et al. Sinnittetsu Giho 94, 388; 2008
[2]H.Imagawa.Taikabutsu, 441, 68; 2016
[3]A. Shimpo, et al. Proc. UNITECR’07 #32 586-589 ;2007
[4]S.Maruyama et al. Proc. UNITECR’11 1-A-14 ; 2011