EFFECT OF THE CURING CONDITION ON THE DURABILITY OF THE INJECTION REFRACTORIES FOR RH DEGASSER REPAIR

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ABSTRACT

In the steelmaking process, the RH degasser is a major facility for improving steel cleanliness, by removing gases and non-metallic inclusions from the molten steel. To improve the productivity of the RH degasser, it is necessary to extend the life of the lower vessel and snorkels to reduce the time loss that occurs when they are exchanged. Injection refractories are widely used to repair the lower vessel and snorkels of the RH degasser. At Oita Steel Works, alumina-magnesia (Al_2O_3-MgO) castable refractories are used as the injection refractories. This study focused on the effect of the curing temperature and time on the lifetime of the injection refractories in the actual RH degasser.

In the actual RH degasser, the curing temperature of the snorkel was measured and it was less than 100°C, which indicated that the free water in the injection refractories did not completely dehydrate, whereby the injection refractories were exposed to high temperature steam during the curing time. To evaluate the effect(s) of high temperature steam, the castable refractories were cured at high temperature, in a sealed condition, and the cured strength was measured. The test results made it clear that the high temperature steam caused strength deterioration of the alumina-magnesia castable, because of the hydration of MgO. To suppress this strength deterioration, the curing, including dehydration, should be completed within 4 hours. By applying this new, controlled curing condition in the field, the wear rate of the injection refractories in the actual RH degasser was reduced by 14%.

1. INTRODUCTION

An injection repair is a build-up repair method of pumping and filling castable refractories from the outside of a furnace into the damaged region of a lining, without cooling the furnace[1],[2]. In steelworks, injection repairs are carried out to repair refractories of blast furnace walls, RH degassers, and converter furnaces.

Injection repair is done to the RH degasser at high temperature, during the period between steelmaking operations. Therefore, the repair conditions, such as the temperature in the vessel during the repair, and the curing time after the injection, have a great influence on the durability of the injected materials[3],[4].

At Oita Works, the goal was established to extend the life of the RH vessel by conducting injection repairs repeatedly and so, it was important to increase the durability of the injected refractory materials. In this paper, the influence of the curing time and the temperature on the durability, especially the strength, of the castable refractories was investigated.

2. OVERVIEW OF THE STEELMAKING PROCESS IN OITA WORKS

Fig. 1 shows the steelmaking process in Oita Works. Hot metal from the blast furnace is received by a torpedo car, and after removing the silicon, the hot metal is discharged to a hot metal ladle, and dephosphorization and desulfurization are carried out by ORP-M (optimized refining process-multiple); then, another dephosphorization and decarburization treatment is carried out in a converter, followed by secondary refining in an RH degasser, and there is the only one secondary refining facility in Oita Works.

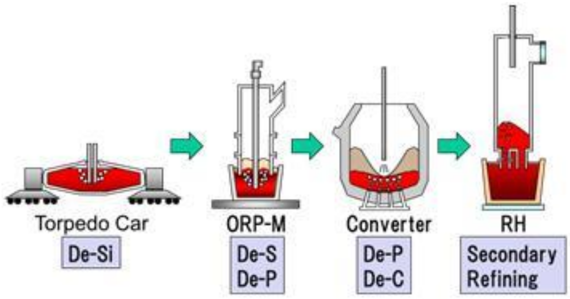

Figure 1. Steel refining process in Oita Works.

Fig. 2 shows schematic illustrations of the RH degasser in Oita Works. The RH equipment consists of an upper vessel, lower vessel, and snorkels. During service, the refractories are severely damaged at the following three specific locations, namely (a) the side wall of the lower vessel, due to corrosion by molten slag, (b) the bottom of the lower vessel due to abrasion by molten steel circulation, and (c) the snorkel periphery is corroded by slag in the molten steel ladle.

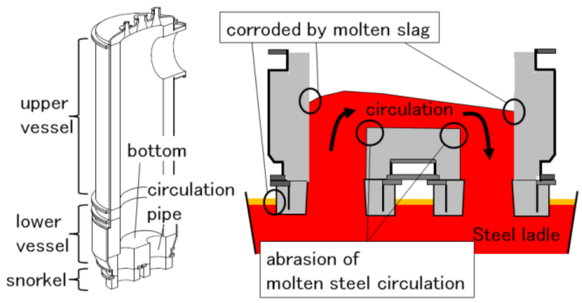

Figure 2. Schematic illustrations of the RH degasser.

3. REVIEW OF THE ISSUES FOR INJECTION REPAIR

The bottom of the RH lower vessel was particularly worn, because of the abrasion by molten steel circulation and corrosion by molten slag [5]. Therefore, to prolong the service life of the lower vessel, the refractories are repaired by the injection repair method every certain number of heats. Fig. 3 shows a schematic illustration of the injection repair method. Cylindrical molds are placed into the snorkel, and with a circulation pipe, the injection refractory was pumped into the gap between the worn refractory and the mold.

The injection repairs were repeated several times during a campaign, and it was observed that the durability of the injected materials varied, and were not stable. Therefore, it was necessary to improve the durability of the injected refractories.

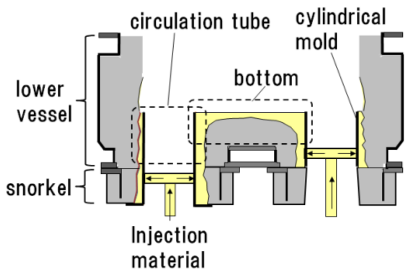

Figure 3. Schematic illustration of the injection repair in the lower vessel of RH.

4. INSTALLATION CONDITIONS FOR THE INJECTION MATERIAL

4.1 Effect of Curing Conditions on the Durability of the Injection Material

It was considered that differences in the installation conditions affected the durability of the injected materials. Fig. 4 shows a flow chart of the injection repair. The time from the cooling down and removal of the snorkel, to the start of the injection of materials was fixed at 10 hrs. But the curing time from the injection to the drying was not defined. Therefore, it was considered that the variation of the curing time had an influence on the durability of the injected material, so the curing condition of the hot injection repair was investigated.

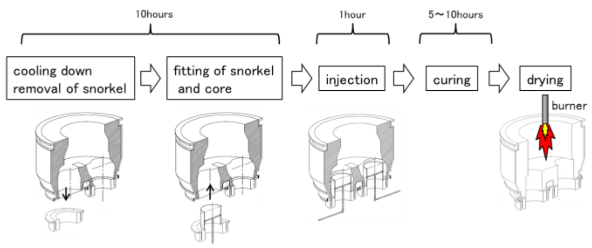

Figure 4. Flow chart of the injection repair.

4.2 Temperature Measurement of the Injection Materials

To investigate the curing condition of the injected material, the temperatures of the material at several positions were measured. Before the injection, a cylindrical mold with three thermocouples for measuring the temperatures, was inserted into the circulation pipe. Fig. 5 shows the positions of the thermocouples and the results of the temperature measurement.

In the case of position A, the highest measuring position, the temperature rapidly increased after the injection, and reached 200°C three hours later, and then increased to a constant temperature of 230°C.

In the case of B, the temperature of the injected material reached 100°C two hours after the injection, and became constant at 100°C due to the dehydration of free water; the temperature increased above 100°C after the completion of the dehydration. After that, the temperature continued to increase and reached 200°C after ten hours.

But in the case of C (the lowest measuring position), the temperature of the injected material did not increase, and remained at about 50°C until the start of the drying. Thereafter it rapidly increased to 100°C after the start of drying, and after the completion of dehydration the temperature exceeded 100°C.

It became obvious that the temperatures of positions A and B increased quickly, but not in position C, because of the outside air cooling. Therefore, it was considered that free water remained in position C, and became water vapor during the curing, which affected the refractories above, like in positions A and B, at the temperature higher than 200 °C.

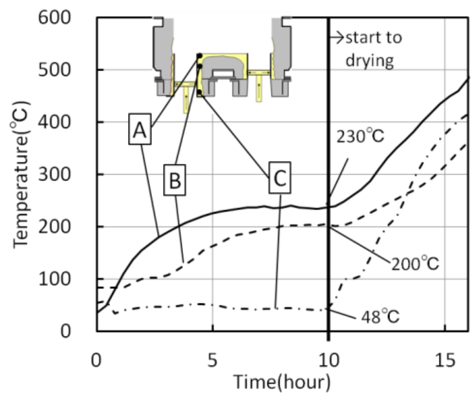

Figure 5. Positions of thermocouples and results of temperature measurement.

In the past study of Takahashi et al[4] , the temperature of the injected materials after five hours curing, was 350°C at point A and 250°C at point B. They said that the lower the temperature, the denser the material, which also had higher strength. The results of our measurements showed that the temperatures of points A and B were lower than those measured by Takahashi et al. so it could be presumed that material with denser structure could be obtained in positions A and B. And, it could be presumed that the refractories in position C, cured nearly at room temperature, could have a stable structure.

It was estimated that the dehydration of the free water in the injected material located in the lower area, around position C, was not completely finished during the early stage of curing, and that area provided the source of high temperature steam and then, that steam dispersed through the pores of the whole mass of injected material. Therefore, the effect(s) of the high temperature steam on the injected materials was examined.

5. OPTIMIZATION OF THE CURING CONDITIONS FOR THE INJECTION REPAIRS

Based on the temperature measurements, the physical properties of the injection material were examined under the simulated curing conditions of the bottom of the RH lower vessel.

5.1 Examination Methods

Tab. 1 shows the properties of the Al_2O_3-MgO castable refractory, that was used as injection material. The modulus of rupture (M.O.R.) and the bulk density in Table 1 are values after curing at room temperature for 24 hours.

Fig. 6 shows a schematic view of the testing procedure conducted to simulate the curing condition of the bottom of the RH lower vessel. The mixed injection material was cast into a mold, which formed three 40mm × 40mm × 160 mm bars for measuring the M.O.R. after heating. The mold was covered by a 4kg iron lid to avoid the escape of high temperature steam during the exposure to the simulated curing condition, with heating at 110 °C and 200 °C. For comparison, a similar test was carried out for bars, without the lid.

Samples were removed at several curing times to measure the progressive change in bending strength (curing strength) and weight loss.

Table 1. Properties of Al_2O_3-MgO castable refractory.

Chemical composition / mass%	Al_2O_3	89
	MgO	9
Physical properties	MOR/ MPa	3.9
	Bulk density/ g・cm^{-3}	2.8

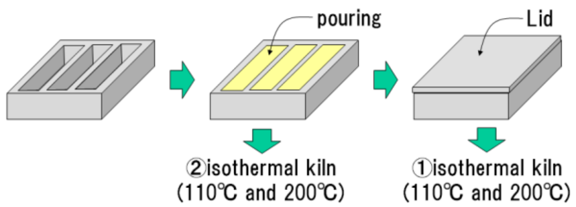

Figure 6. Schematic view of the curing test procedure.

5.2 Review of Test Results

Fig. 7 shows the relationship between the curing time and the bending strength (M.O.R.) for the lid-covered condition. In the case of curing at 110 °C, the curing strength increased to 2.8 MPa after 6 hours of curing and then decreased, reaching 1.8 MPa after 24 hours.

In the case of curing at 200 °C, although the strength increased to 1.9 MPa after 2 hours, the strength decreased after that and became 0.9 MPa after 10 hours.

Fig. 8 shows the relationship between the curing time and the weight loss for the condition with a lid. At 110 °C, the weight loss proceeded moderately and continued for 24 hours. But at 200 °C, the weight loss reached a maximum after 10 hours and then became constant.

The relationship between the curing time and the bending strength (M.O.R.), for the condition without a lid, is shown in Fig. 9. In the case of curing at 110 °C, the strength increased from 1 hour after curing started and reached about 5 MPa after 10 hours. For the curing at 200 °C, the strength increased to 2.9 MPa after 2 hours of curing, and after that the strength trend varied, but reached 2.5 MPa again, after 10 hours.

Fig. 10 shows the relationship between the curing time and the weight loss for the condition without a lid. At 110 °C, the weight loss reached a maximum value after 10 hours. But for the condition at 200 °C, the weight loss reached a maximum value after 3 hours, and then reduced and became constant.

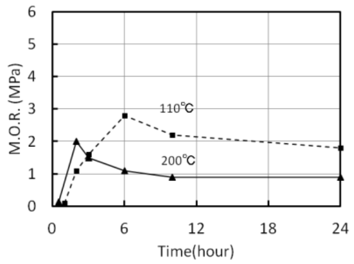

Figure 7. M.O.R. of the specimens cured with a sealing lid.

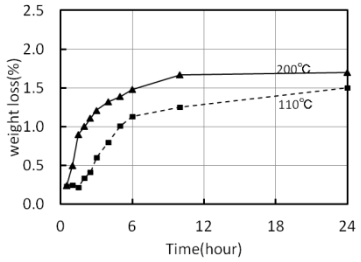

Figure 8. Weight loss of the specimens cured with a sealing lid.

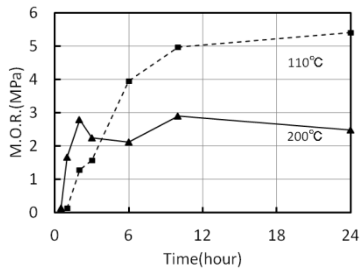

Figure 9. M.O.R. of the specimens cured without a sealing lid.

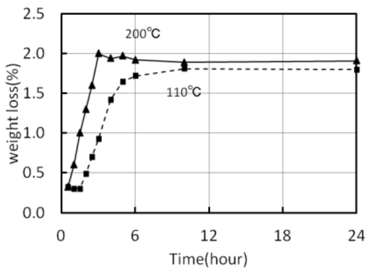

Figure 10. Weight loss of the specimens without a sealing lid.

5.3 Discussion

As mentioned before, the injected castable refractory located in the vicinity of position C of the snorkel, where the temperature for the curing period was nearly room temperature, and the material developed a dense structure with properties similar to the values shown in Table 1. On the other hand, the castable refractories in positions A and B were affected seriously by being exposed to the conditions of high temperature (>200 °C) and humidity for a long time, so that hydration occurred for both the cement of the castable[6] bond, and the MgO refractory grains[7],[8] at almost the same time, during the drying period. Therefore, it was necessary to carefully consider the effect(s) of these factors.

Fig. 11 shows the drying rate for curing at 200 °C. The water evaporated through the upper window space of the metal mold frame (40 mm × 160 mm), and the drying rate was defined as the weight loss per unit area and time (to 12 hours).

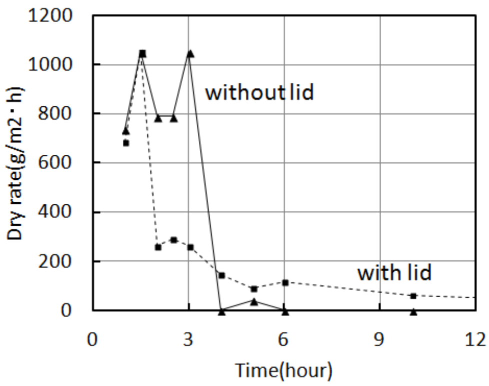

Figure 11. Drying rate of the specimens cured at 200 °C.

For the condition with a lid, the drying rate was high at first but decreased soon, and continued to 12 hours. It could be estimated that the low rate of evaporation didn't remove the large heat of vaporization, and the injected castable material was exposed to high temperature steam for a long time.

Kitamura et al.[7] investigated the hydration of high purity MgO crystals by autoclave tests and stated that full hydration was achieved within 5 hours at 200 °C with a water vapor pressure of 1.6 MPa.

Sugawara et al.[8] confirmed that cracks occurred in 4~6 hours in the Al_2O_3-MgO castable, under a water vapor pressure of 0.2 MPa, at the boundaries of the coarse grains and matrix, and the strength decreased because the MgO grains in the refractory material hydrated and expanded. This study indicated a decrease of the curing strength of the castable material with a lid in 3~10 hours, as shown in Fig. 7.

There was a small difference of the weight losses between the materials with and without a lid after curing at 200 °C for 24 hours. The weight loss of the material with a lid was 1.65% and it was 0.3% less for the material without a lid, which meant that the material with a lid was slightly heavier. It was estimated that the material with a lid retained more water as hydrated MgO. It could be said that the MgO material at the bottom of the lower vessel tended to hold water as the hydrate, even after a long time at 200°C.

Shinpo et al. investigated the curing behavior of castable refractories using alumina cement at high temperatures[9]. The strength immediately increased upon curing, and the highest strength was attained in 2 ~ 3 hours at 150 °C curing.

This report agreed with the test results shown in Figure 9. They didn't mention the reason why the increase of strength stopped after 3 hours. However, it was presumed that the increase of strength stopped because the material was completely dried within the first 4 hours, which was suggested from the sharp decrease in drying rate at the beginning of curing for the condition without a lid, as shown in Fig. 11.

From the results mentioned above, it became clear that the curing of the injected material should be completed within four hours and the drying operation should be started after four hours of curing to suppress the hydration of the MgO grains by the high temperature steam, to get high strength material at the bottom of the RH.

6. IMPROVEMENT OF RH REPAIRS

A change in curing time was adopted for RH repairs in Oita Works. The curing time was fixed at four hours, as shown in Fig. 12, which shows the repair schedule before and after the improvement. The reduction of the curing time was practiced step by step, with confirmation that there was no explosion during the drying.

The wear rate of actual injected material was measured to evaluate the effect of the improved repair method. The wear of new repair material was taken ten times in one campaign of the RH lower vessel, and the average wear rate of the ten measurements is shown in Fig. 13. It was determined that the wear rate of the injected material was reduced (improved) 14%.

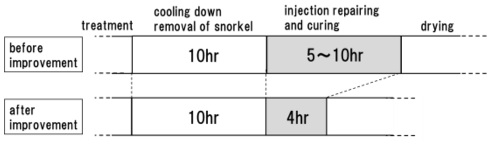

Figure 12. Schedule of the injection repair process before and after the improvement.

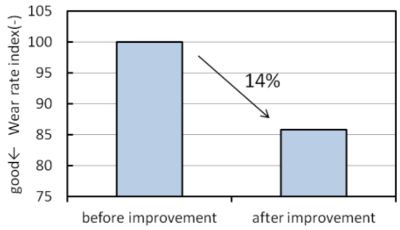

Figure 13. Wear rate index of the injected material.

7. CONCLUSIONS

To improve the service life of RH injection materials, the influence of the curing conditions on the strength of the injected refractory material was investigated, and the following conclusions were obtained:

1) The temperature of the injected materials at the bottom of the lower vessel, during curing, was 200~230 °C.
2) The injected material couldn't develop a high strength, stable structure during the long curing time.
3) By reducing the curing time from 5~10 hours to 4 hours, the wear rate was reduced by 14%.

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