Improvement of Sidewall Castable for Steel Ladles at Kashima Steel Works

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ABSTRACT

The life of the steel ladles at Kashima Steel Works depends on the wear and residual thickness of the sidewall castable in the ladles. According to the observation of the sidewall refractories through the ladle campaigns, it was revealed that the decrease of the sidewall thickness was not large until reaching about 70 charges, and thereafter, the sidewall thickness decreased stepwise ranging from 20-50 mm in thickness. It was considered that the sidewall refractories were not seriously damaged by slag corrosion, but the thickness was reduced sharply by spalling. Based on the field observation of the damage condition of the sidewall refractories, and the laboratory investigation of the used refractory materials, three modified castables were selected for trial, to reduce the damage by spalling. The field results showed that all three castables showed better residual thickness than the castable used previously.

Keywords: refractory; sidewall castable; spalling; observation

INTRODUCTION

Kashima Steel Works is one of the largest steelworks of Nippon Steel & Sumitomo Metal Corporation (NSSMC), with an annual production of 7.5 million tons (18% of NSSMC total production). Kashima Steel Works has two steelmaking plants; the No.2 Steelmaking Plant is the main plant, with an annual production of 4.5 million tons, therefore, it is necessary to maintain high productivity.

Figure 1 shows the steelmaking flow chart for the No. 2 Steelmaking Plant, where common steel is made by the simple refinement process; that is, KR (Kanbara Reactor), converter, and RH degasser. The refractory cost of the steel ladle, which transfers the molten steel from the converter to a continuous casting machine, accounts for a large portion of the cost in this plant, therefore a reduction of the steel ladle refractory cost is an important issue.

There have been many studies about the improvement of steel ladle refractories[1), 2)], where the investigations and the discussions were based on the physical properties of the refractories and laboratory tests. But there have been few studies based on the results of observations and measurements of the steel ladle refractories in actual operation. This paper discusses our study to improve the service life of the ladle

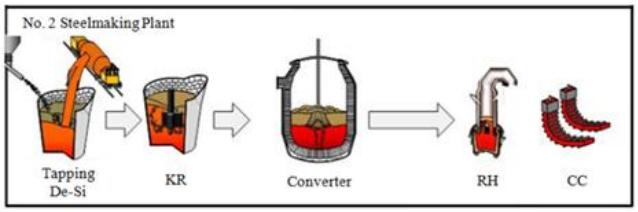

Figure 1 Process flow of steelmaking in Kashima Steel Works

Table 1 shows details of the steel ladle fleet at the No. 2 Steelmaking Plant. Figure 2 shows a cross section view of the steel ladle refractory lining. Magnesia carbon (MgO-C) bricks are used for the slagline. Alumina magnesia (Al_2O_3-MgO) castable refractories are used for the sidewall and bottom (metal bath zone). Al_2O_3-MgO precast blocks are used for the bottom impact area, which has to withstand the full force of the molten steel stream during tapping. As shown in Table 1, the ladle capacity is 345 t/charge (ch.), and the total number of ladles is 24. The daily operation usually involves 8, 9 or 10 ladles.

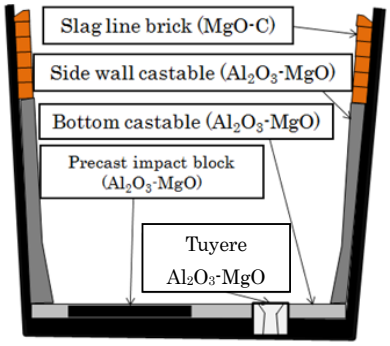

Figure 2 Cross section view of steel ladle lining

Table1 Outline of the steel ladle fleet

Topic	Content
Ladle capacity(t/ch)	345
Number of ladles	24
Number of ladles in operation	8～10

Figure 3 shows the typical sequence of ladle repairs. The repair timing was judged by the residual thickness of the refractories, as measured by a laser profile meter. Normally, the repairs were performed about 2 or 3 times, at intervals of 60 to 100 charges (chs.). Usually, a full repair was done after about 208 chs., when the residual thickness of the sidewall refractory became thin(≦50mm), even though the refractories in the other parts were considered to be thick enough. The purpose of sidewall repair was to use all of the ladle lining refractories properly in the well balanced condition. Therefore, it was necessary to improve the sidewall refractory to improve the life and reduce the cost of the ladle refractories.

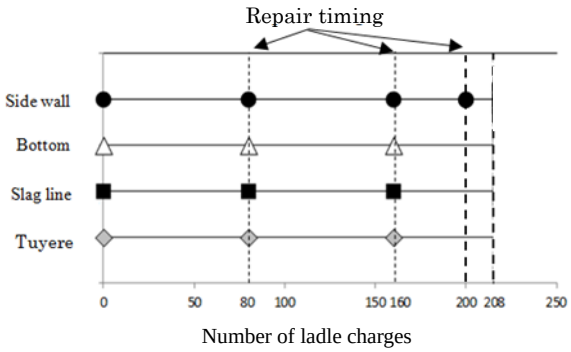

Figure 3 Typical sequence of ladle repairs

Figure 4 shows several examples of sidewall castable refractory observations during operation. After 109 chs., cracks and a narrow area of spalling were observed. After that, as the number of ladle chs. increased, the spalling area increased. From these observations, the initial crack formation and propagation was considered to be the main cause of the wear.

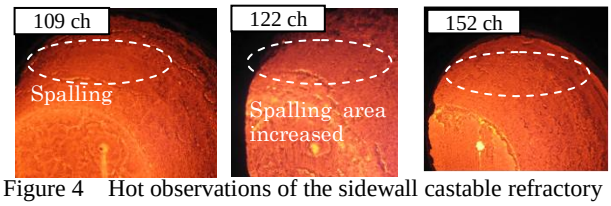

Figure 4 Hot observations of the sidewall castable refractory

To clarify the emphasis or focus of the refractory improvement, the change in residual thickness of the sidewall, at a fixed position, measured by laser profile meter, was monitored. The fixed position was 3.0 m below the top of the ladle, and on the side opposite the slag discharge side (0 °), as shown in Figure 5. The laser measurement frequency was every 10 chs. up to 70 chs., every 2 chs. from 70 to 130 chs., and every charge after 130 chs.

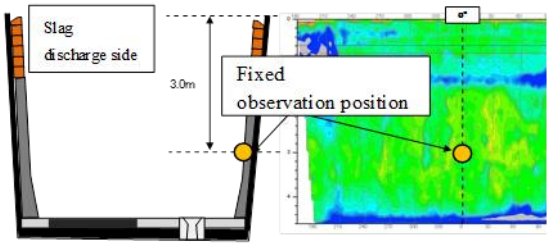

Figure 5 Position of residual thickness measurement

Figure 6 shows the transition of the sidewall residual thickness at the fixed position. According to the observation of the sidewall refractories through the ladle campaign, it was revealed that the decrease of the sidewall thickness was not large until about 70 chs., and the thickness then showed a stepwise decrease of 20-50 mm after that. The sidewall refractories were seemingly not seriously damaged by slag corrosion, but the thickness was sharply reduced by spalling.

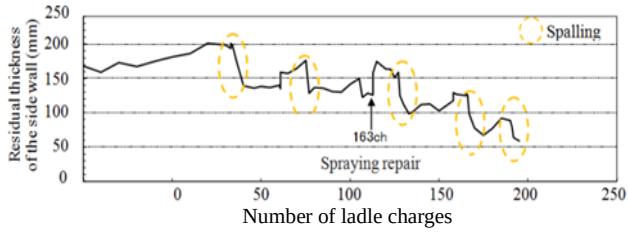

Fig.6 Transition of the residual thickness of the sidewall at the fixed position

From the observation of the damaged sidewall castable, the cracks could be classified into two types – that is, parallel and perpendicular, to the working surface. It was considered that the parallel cracks were generated inside the castable by the compressive stress which came from the expansion of the refractory, due to the constraint during heating. But the perpendicular cracks were considered to be generated on the working surface due to shrinkage of the castable during cooling. It was considered that these cracks were extended by the repetitive heating and cooling, which finally led to the spalling damage.

It was also necessary to consider the contribution of slag penetration to the spalling. The spalling caused by slag penetration, or so-called "structural spalling", was a phenomenon in which stress is generated by the difference in the expansion coefficient of the slag-penetrated layer and the original refractory layer. Figure 7 shows the estimated damage mechanisms of the sidewall castable refractory. The cracks initiated by thermal shock and slag penetration were the main causes for the severe spalling damage of the sidewall castable refractory.

In this report, the countermeasures against the cracks initiated by thermal shock and slag penetration, which triggered the spalling, will be discussed separately.

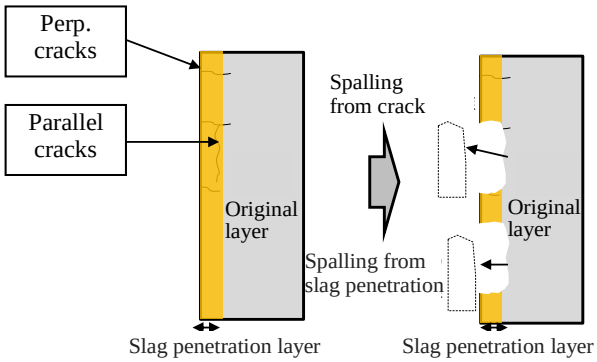

Fig.7 Damage mechanism of the sidewall

According to the three considerations discussed below, three modified Materials, A, B, and C were field-tested in the sidewall of the steel ladle. Table 2 shows the composition and physical properties of the three castables tested, and the reference base castable.

Table 2 Composition and properties of sidewall refractories

Section		Test material			Base
		A	B	C	D
Chemical composition(%)	Al_2O_3	90	90	92.5	90
	MgO	7.5	8	4.5	7.5
	CaO	-	1	0.9	-
Permanent linear change (%)	1500℃-12h	1.12	1.92	2.37	1.82
Apparent porosity (%)	1500℃-12h	23.2	20.2	24.9	24.5
Modulus of rupture (MPa)	1500℃-12h	22.2	19.5	10.9	24.4
Modulus of elasticity (MPa)	1500℃-12h	71.5	118.1	64	149.8
Thermal shock damage resistance	1500℃-12h	0.28	0.09	0.07	0.09
Additive water (%)		5.5	4.4	5.5	5.5

Material A: To reduce the thermal spalling, the grain size distribution was changed to increase the coarse grains, for the purpose of decreasing the elastic modulus and thermal expansion coefficient.

Material B: To reduce the structural spalling, the dispersing agents were changed and the amount of the water addition was decreased, aiming to decrease the pores which were the pathways for the slag penetration.

Material C: To reduce the structural spalling, fine alumina powder was added, and the magnesia content was reduced, aiming to decrease the slag penetration. It was estimated

that the avoidance of spinel ($MgAl_2O_4$) formation, which had high wettability with molten slag, based on the balanced adjustment of alumina and magnesia, would be effective in preventing the slag penetration. [3)]

RESULTS

Figure 8 shows the results of the wear rate and service life for each test castable, and the base castable. The field test results showed that all three of the test castables had better residual thickness than the base castable.

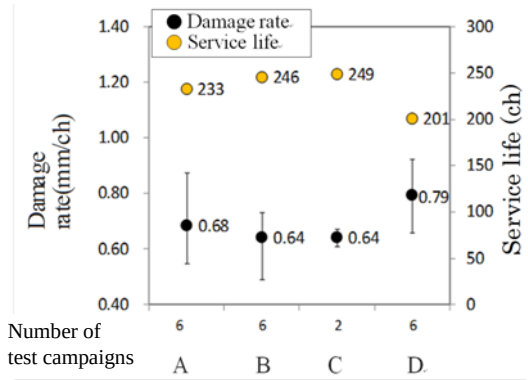

Figure 8 Results of wear rate and service life of each castable

Figure 9 shows a cross section of each test castable after use in the ladle sidewall. The penetrated layer (black area) of each trial castable was thinner than that of the base castable. Particularly, that of castable C, with a penetrated layer of about 10 to 12 mm, was much thinner than the other castables.

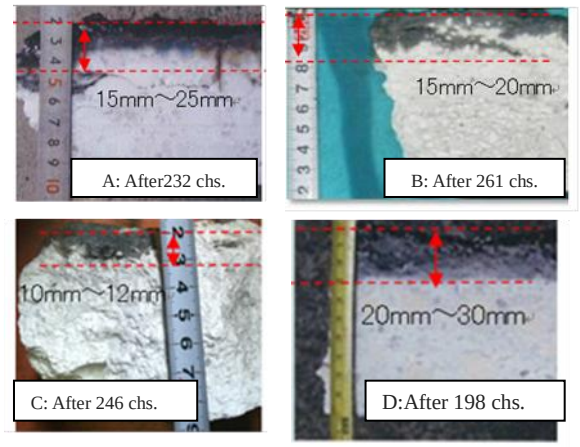

Figure 9 Cross section of Materials A,B,C, and D after use in the ladle sidewall.

DISCUSSION

To clarify the details of the improvement of the castables tested, the residual thickness change at a fixed position was measured. Figure 10 shows the relationship between the number of ladles used and the transition of the sidewall residual thickness for each material. It was revealed that the thickness decreased stepwise, with spalls ranging from 20-50 mm in thickness. It is estimated that all the test materials were similarly damaged by spalling, as was the base material. To quantitatively evaluate the damage of the test castables, the damage was compared by determining the charge at which spalling first occurred, and the average thickness of the spalled layer. "Spalling" was defined as those occasions when the residual thickness decreased by 10 mm or more, calculated from the latest minimum residual thickness, and this sharp residual thickness change occurred within three chs. This definition was needed to avoid the false recognition of the decrease of residual thickness due to corrosion, or the loss of adhering slag.

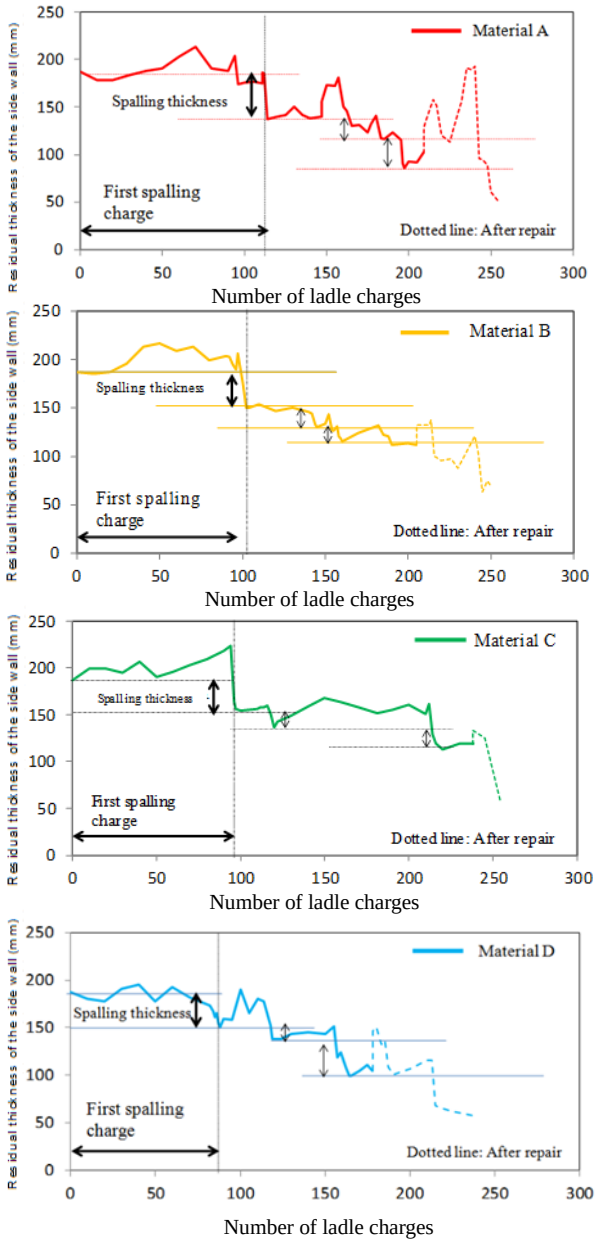

Figure 10 Transition of the sidewall residual thickness for Materials A, B ,C and D

Table 3 shows the comparative results of the charge where spalling first occurred, and the average thickness of the spalled layer. The first spalling charge of Material A, in which a countermeasure was adopted against cracking, was the 114th charge, which was the latest among the castables tested. On the other hand, the average thicknesses of the spalling layers of the Materials B and C, adopted the countermeasures against slag penetration, were smaller than others and it was considered that slag penetration was reduced in both materials. Thus, it was confirmed that the spalling damage of all three of the test castables was effectively reduced.

Table 3 Comparative results of the first spalling charge and the average thickness of the spalled layer

Section	Test material			Base
	A	B	C	D
First spalling charges (ch)	114	102	97	88
Average thickness of the spalling layer (mm)	16.1	11.7	10.4	16.5

The three modified castables were all field-tested in the ladle sidewall at Kashima Steel Works, and they all showed better residual thickness than the base castable, which was used previously, as indicated in Figure 11. The damage rate of the three test castables in the ladle sidewall was reduced as follows:

Material A (to reduce the thermal spalling): 13.9%.

Material B (to reduce the structural spalling): 19%.

Material C (to reduce the structural spalling): 19%.

The tested castables were mainly damaged by spalling, which was similar to the base castable, but the first spalling occurred some charges later and the average thickness of the spalled layer was thinner than the base castable.

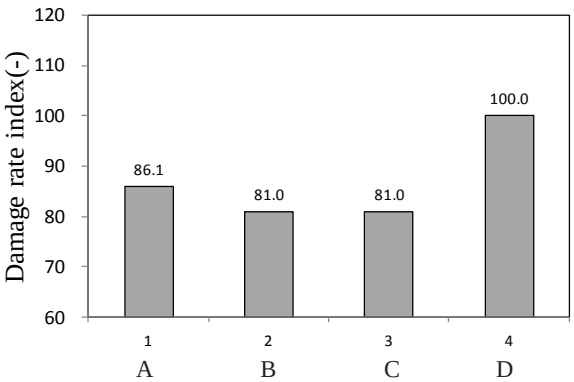

Figure 11 Comparison of the sidewall damage rate index for the test Material A, B, C vs. the base Material D

CONCLUSIONS

To clarify the direction of the sidewall refractory improvement, the change in residual thickness, at a fixed position, measured by laser profile meter, was investigated. Through these measurements it was found that the thickness of the side wall refractories was reduced sharply by spalling. Three modified castables, which had higher resistance to thermal and structural spalling, were field-tested in the sidewall of steel ladles, for comparison with the base castable. The test castables showed a damage rate that was 13.9 ~ 19% less than the base castable, used previously. As a result, the plan to optimize the sidewall life and cost reduction involved resistance to spalling according to the damage condition..

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