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The Use of Monolithic Refractories and Microwave Drying for RH Steelmaking Vessels

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Monolithic refractory technology has been developed for RH vessels, with the purpose of reducing the total refractory cost. The technology includes the use of an improved monolithic refractory and microwave drying. The improved monolithic refractory was an alumina-spinel composition, of the type used in steel ladles, to which fine alumina was added to increase the density and corrosion resistance. The microwave drying method, previously developed and used to dry the monolithic lining in steel ladles[1)], was modified for use in drying the dense, 500mm thick lining in RH vessels. This work has resulted in significant cost savings.

Key words: Microwave, Drying, Monolithic, Refractories, RH

I. Introduction

The shortage of skilled brick masons for installing refractory linings has become a big problem in the Japanese steel industry. This problem has arisen mainly for two reasons, (a) a long time required to train skilled workers and (b) the bad working conditions on the job, including heat, dust, and noise. An effective way to overcome this problem is to use more monolithic refractories in the furnaces, vessels, etc. Installation of monolithic refractories doesn't require well-trained, skilled workers and the installation can be done quicker, under better working conditions, than brick installations.

Monolithic linings have a further important advantage in reducing in the total refractory cost, including savings associated with the use of installation equipment. It is also possible to prolong vessel life, and reduce the amount of refractory to be removed and discarded, by doing partial lining repairs during mid-campaign, in which monolithic refractory is installed directly over the worn lining that remains. The term "endless ladle linings" has been used for this repair technology.

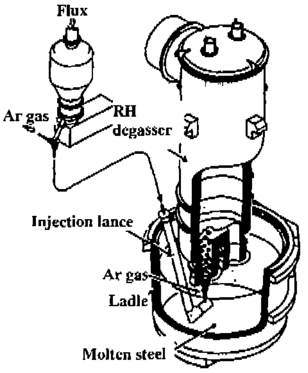
Many steel companies have successfully introduced monolithic refractory linings in ladles and tundishes. On the other hand, monolithic refractory linings have not yet been adopted for steelmaking furnaces such as BOF and RH vessels, because of the severe operating conditions.

However, we have developed improved monolithic refractory technology for RH vessels, through the use of an improved castable refractory and microwave drying. The success of this technology has been confirmed at Oita Works. Previously, refractory installation and repair of various vessels were done in different locations at Oita Works. It has been found necessary to consolidate the repair sites to achieve cost savings. Furthermore, it was necessary to expand the variety of vessels, in which linings were installed and repaired at the one location to gain the most efficient use of the workers and equipment. Now at Oita Works, refractory linings are being installed and repaired in RH vessels, ladles, tundishes, and lances at one site.

II. General Characteristics of Refractories for RH Vessels

The RH injection process, shown in Fig. 1, in which argon gas is injected through a lance for effective stirring of the molten steel, has been used at Oita Works since 1985. This process has two significant merits, which are (a) to stir molten steel effectively by injecting argon gas near the bottom and (b) to refine high quality steel by injecting refining powders such as CaO, CaF_2 with the argon gas.

It is known that refractories for RH vessels must have good chemical corrosion resistance against slag, molten fluxes and powders, under high temperature vacuum conditions, as well as physical erosion resistance against stirred



	RH No.1	RH No.2
Diameter of lower vessel	ϕ2300mm	ϕ2300mm
Diameter of throat	ϕ750mm	ϕ750mm
Method of steel circulation	Injection lance	Injection lance
Injection of flux	Yes	No

Fig. 1. Schematic diagram of RH-Injection process.

molten steel. The vessels are sometimes cooled down for repair, so the refractories need to withstand thermal shock. Therefore, the monolithic refractories for RH vessels must have good resistance to chemical corrosion, physical erosion, and thermal shock.

III. Development of Monolithic Refractories for RH Vessels

Historically, direct-bonded magnesia-chrome brick linings have typically been used in RH vessels. Our post-mortem study of used bricks showed that the direct-bonded magnesia-chrome bricks were mainly damaged by thermal shock after slag penetration. Therefore, an alumina-spinel monolithic refractory of the type used in steel ladles, which has lower corrosion resistance but higher thermal shock resistance than direct-bonded magnesia-chrome bricks, was the first material selected for testing in the RH vessel.

1. Preliminary Test

The alumina-spinel monolithic refractory and direct-bonded magnesia-chrome bricks were both installed on the inner face of the RH snorkel, for comparative evaluation. Comparative properties of the two refractories tested are shown in Table 1.

Results of the preliminary refractory comparison test are shown in Figs. 2 and 3. Fig. 2 shows the corrosion rate and depth of slag penetration, and Fig. 3 shows the change in chemical composition of the refractories tested.

It was determined from the above results that while the direct-bonded magnesia-chrome bricks had superior corrosion and erosion resistance, these were inferior in slag penetration and damaged by structural spalling. On the contrary, there was very little slag penetration (less than 10 mm) in the monolithic refractory, and although it was not damaged by structural spalling, it corroded 1.7 times faster than the bricks. Obviously the corrosion and erosion resistance of the initial monolithic refractory tested was not adequate for use in the RH vessel.

Table 1. Properties of Typical Castable for Ladle and Magnesia-chrome Direct Bonded Brick for RH

Item		Castable	Direct bonded brick
Material		Alumina Spinel	Magnesia Chrome
Bond		Cement bond	Ceramic bond
Chemical composition (%)	MgO	4.9	72.6
	Al_2O_3	92.7	SiO_2(2.1)
	Cr_2O_3	–	11.6
Thermal expansion(%) at 1500C		+1.30	+1.78
Modulus of rupture (MPa)	after drying	4.7	6.4
	1500C×3 hrs	20.0	–
Hot modulus of rupture (MPa) at 1500C		5.4	4.0
Apparent porosity (%)	after drying	19.3	16.0
	1500C×3 hrs	23.0	–

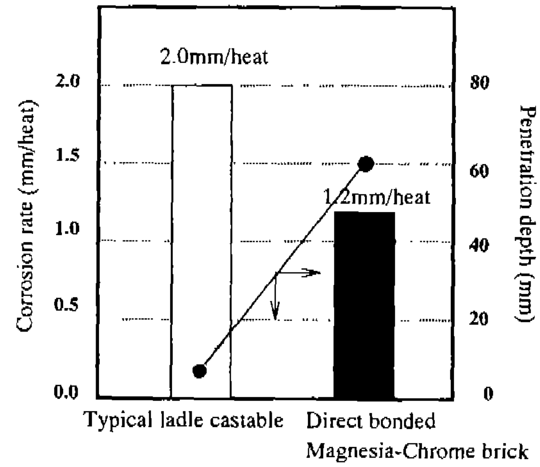


Fig. 2. Corrosion and penetration resistance in service.

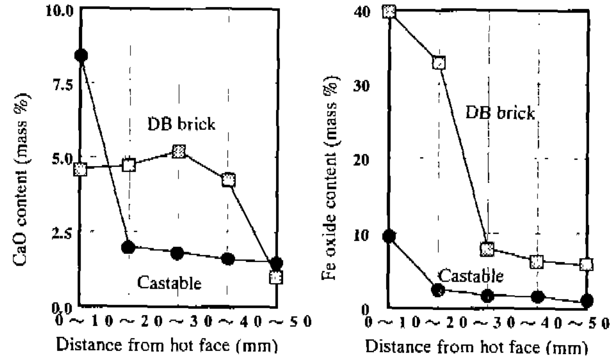


Fig. 3. Chemical profile of the hot face region of a typical ladle castable and direct-bonded magnesia-chrome brick, after service.

2. Options for the Improvement of the Monolithic Refractory

Based on the preliminary test results, several options were considered for improving the monolithic refractory for the RH vessel lining. Densification of the structure, using higher purity raw materials, and optimization of the cement binder, were chosen as the action items for improving the corrosion and erosion resistance of the alumina-spinel monolithic refractory, as shown in Table 2.

In addition to the refractory material improvement, it was considered necessary to employ microwave drying for drying the thick monolithic lining in the RH vessel because the shell doesn't have any weep holes for steam escape, due to the need for vacuum sealing during operation. The microwave drying technology was previously developed for steel ladles and used in actual steel making process[1]. This technology was modified, as explained later, and was used to dry

Table 2. Options for Improving Monolithic Refractory

Technical problems for applying monolithic refractories		Specific goals of development	Measures to solve problems
Refractory Material	Material stability under the conditions of vacuum and high temperature	Choice of high stable material at high temperature	Application of materials in the $A_{12}0_3$-MgO system
	Abrasion resistance against molten steel flow	Keeping strength at high temperature	Densification Choice optimum bond system Adoption of pure raw materials Utilization of most suitable spinel
	Corrosion resistance against powders and flux	Corrosion resistance against CaO and SiO_2	
	Corrosion resistance against FeO caused by removing skull	Materials capable of forming solid solution with FeO	
Drying	Migration and vaporization of water from thick installed body	Study of efficient drying method	Introduction of drying technique with microwave

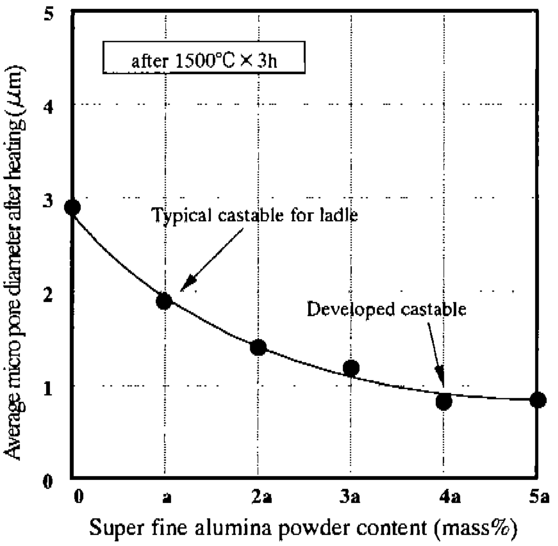


Fig. 4. Relationship between the content of ultrafine alumina powder and the average pore diameter.

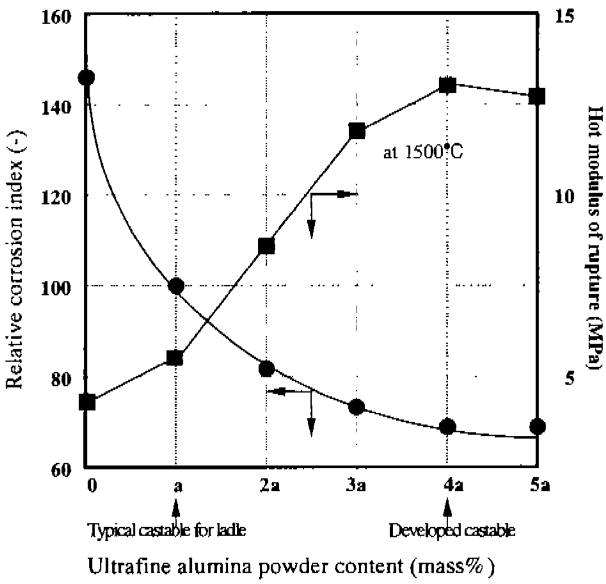


Fig. 5. Relationship between the content of ultrafine alumina and the corrosion index and hot modulus of rupture.

the monolithic RH vessel lining.

3. Densification of the Monolithic Refractories

It was necessary to make the refractory denser to improve the resistance to penetration, corrosion, and erosion. Ultrafine alumina powders were added to the alumina-spinel monolithic refractory that was used in the preliminary test to reduce the pore diameter. Fig. 4 shows the relationship between the amount of ultrafine (under 10 μm) alumina powder added and the pore diameter of the refractory structure, after heating for three hours at 1500°C. It was found that the pore diameter was less than half that of the initial refractory body for a 4 a mass% addition of ultrafine powder. Fig. 5 shows the relationship between ultrafine powder content, corrosion index, and hot modulus of rupture at 1500°C. It was observed that the refractory structure was much denser and 30 mass% more resistant to corrosion than the initial material. The higher modulus of rupture indicates not only higher density but also higher corrosion resistance.

4. Optimization of the Cement Binder

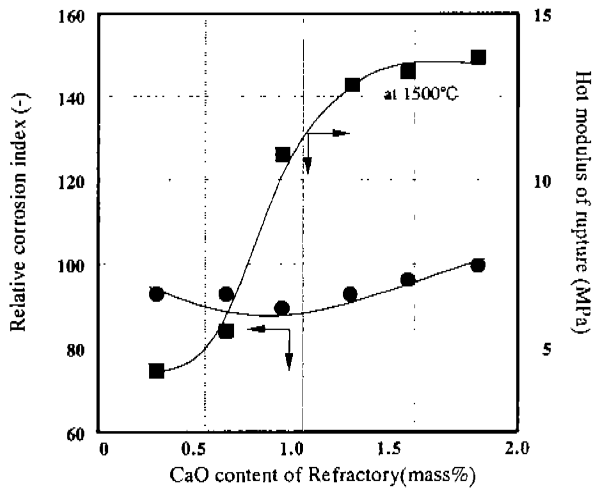


Fig. 6. Relationship between the CaO content and the corrosion index and hot modulus of rupture.

The initial monolithic refractory was improved by adding ultrafine powder. We have also studied whether the corrosion resistance could be further improved by reducing the amount of alumina cement in the composition. Fig. 6 shows the relationship between the CaO content, which is contributed by the alumina cement in the refractory, and the corrosion resistance and the hot modulus of rupture. From this study, it is clear that an addition of alumina cement, which yielded 0.9 mass% CaO in the refractory, is effective for increasing the corrosion resistance.

5. Purification of Raw Material

It is well known that the addition of spinel is effective in improving the corrosion resistance of alumina refractories and in preventing iron oxide penetration by making solid solutions[2]. It has been reported that single crystal spinel raw materials are more stable than the polycrystalline type in a vacuum atmosphere[3].

The initial alumina-spinel monolithic refractory tested contained polycrystalline spinel(spinel-A). A comparative test was run in which spinel-A was replaced by single crystal spinel (spinel-B), which is purer than spinel-A. Fig. 7 shows the effect of spinel-A and -B on the corrosion and slag penetration. The laboratory test results indicate that the monolithic refractory containing spinel -B has better resistance to corrosion and penetration. The improved monolithic refractory was estimated to have two times better corrosion resistance and four times better slag penetration resistance than these of the initial monolithic refractory, respectively.

6. Summary of the Alumina-Spinel Monolithic Refractory Developed for RH Vessels

The alumina-spinel monolithic refractory was developed by adding ultrafine alumina powder, reducing the amount of alumina cement and replacing thc polycrystalline spinel with a single crystal type of higher purity. The final version of the alumina-spinel monolithic refractory developed for the RH vessel is shown in Table 3.

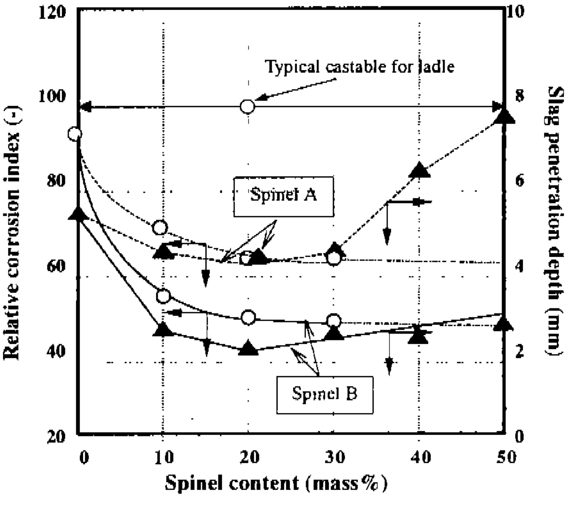


Fig. 7. Relationship between spinel content and the corrosions index and depth of slag penetration.

Table 3. Properties of Developed Castable and its Comparison

Item	Typical castable for ladle	Developed castable
Material	Alumina Spinel	Alumina Spinel
Bond	Cement bond	Low cement bond
Chemical composition (%) MgO	4.9	5.3
Al_2O_3	92.7	93.3
Thermal expansion (%) at 1500C	+1.30	+1.33
Modulus of rupture (MPa) after drying	4.7	4.5
1500C×3 hrs	20.0	27.4
Hot modulus of rupture (MPa) at 1500C	5.4	11.5
Apparent porosity (%) after drying	19.3	14.5

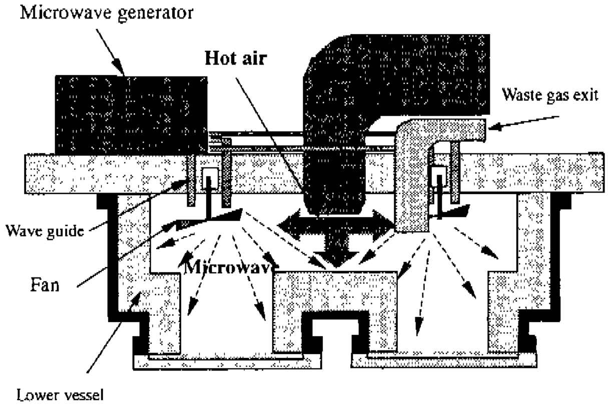


Fig. 8. Schematic diagram showing the microwave drying equipment with hot air boost.

IV. Microwave Drying Method

There are two main problems for drying a 500 mm thick monolithic lining by gas heating; an explosion and a long dry time. Because the improved castable was denser than initial castable tested, the possibility of explosion during drying was much higher. For these reasons, it was decided to introduce the microwave drying method for the RH vessel lining. A schematic drawing of the microwave drying system is shown in Fig. 8. As shown, the system uses both microwave and hot air drying. The generated power of the microwave was 20kw.

The typical temperature change of the monolithic refractory in the RH vessel during drying is shown in Fig. 9. The point at which the temperature went up from a constant

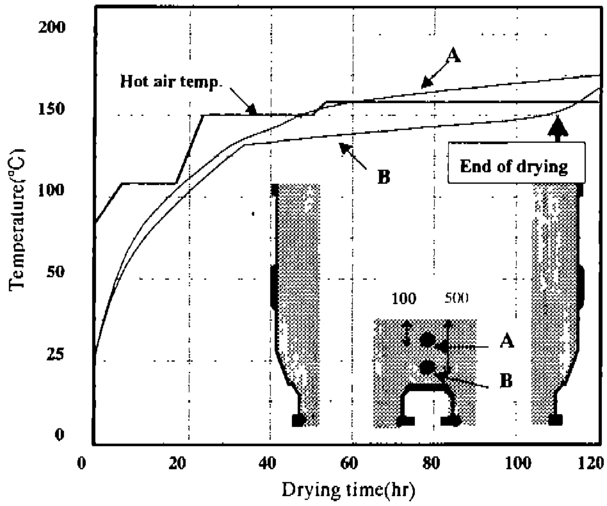


Fig. 9. Temperature changes during microwave drying.

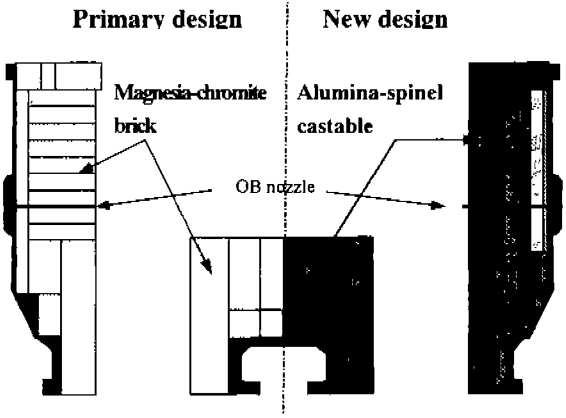


Fig. 10. Cross section showing the previous and new lining designs for the RH vessels.

level, where there was evaporation of contained water, was judged to be the end point of drying. It was confirmed by actual trials that the RH vessel lining could be dried without any accident. The drying period was established based on the trial results, and it was adopted in actual operation.

V. Observations from Field Experience

1. RH Vessel Lining

The monolithic lining in the RH vessel is shown in Fig. 10, compared with the conventional brick lining. As shown in the figure, the wear lining consisted of the improved monolithic refractory and the permanent lining including the conventional bricks.

2. Refractory Condition after Use

The monolithic refractory lining was examined after 315 heats. It was confirmed that there were not any unusual defects, such as large cracks or peeling, as shown in Fig. 11. The wear rate of the monolithic refractory in the RH vessels was slightly higher than that of the conventional direct bonded magnesia-chrome bricks, as shown in Fig. 12, but the difference is not considered to be significant for actual use.

Fig. 11. Appearance of the refractory lining in the lower vessel after service.

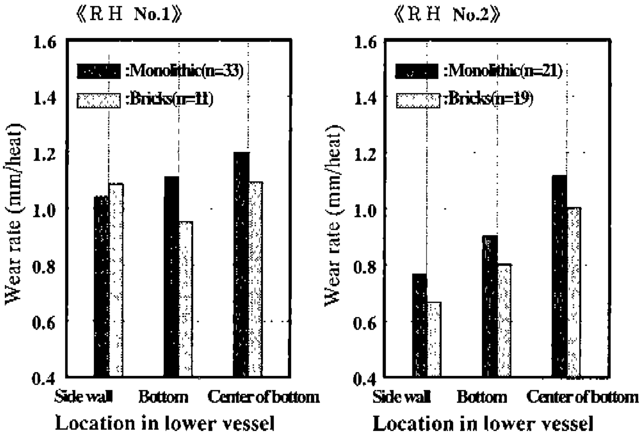


Fig. 12. Comparison of the wear rates for different location in the developed castable and brick linings in RH vessels 1 and 2.

Fig. 13. Cross section view of the developed castable refractory from the bottom center of the RH vessel.

3. Analysis of Used Refractory

Figs. 13 and 14 show the cut face of used refractory samples from the bottom center and the sidewall of the RH vessel. It was observed that the altered layer of the bottom refractory was about 25 mm thick and there were some cracks along which slag penetrated. However, there were

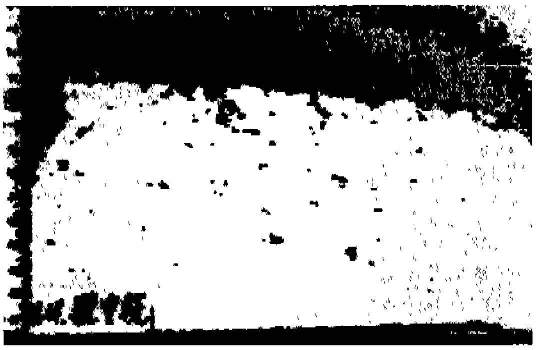


Fig. 14. Cross section view of the developed castable refractory from the sidewall of the RH vessel.

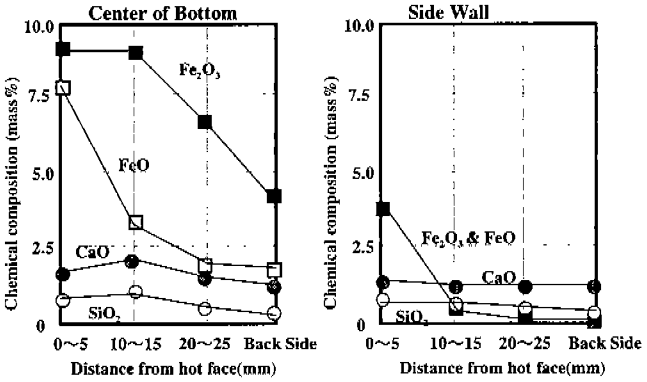


Fig. 15. Chemical profile of the hot face region and the back side, of the developed castable refractory, after service in the RH vessel.

not many cracks in the sidewall refractory, and the depth of slag penetration was only about 2mm. These observations indicate that the bottom was worn not only by slag corrosion but also by structural spalling, which might be responsible for the higher wear rate in the bottom center, as shown in Fig. 12.

The results of chemical analysis of the observed refractories are shown in Fig. 15. It is apparent that there was much more iron oxide penetration than CaO and SiO_2, especially in the bottom refractory. This is probably caused by molten iron oxide that forms during oxygen blowing, which sometimes melt large steel buildups on the sidewall.

On the other hand, the iron oxide penetration of the sidewall refractory was less than that of the original alumina-spinel castable tested (see Fig. 3). It was apparent that the improved monolithic refractory was superior to the original material for an RH vessel.

4. Economic Benefits

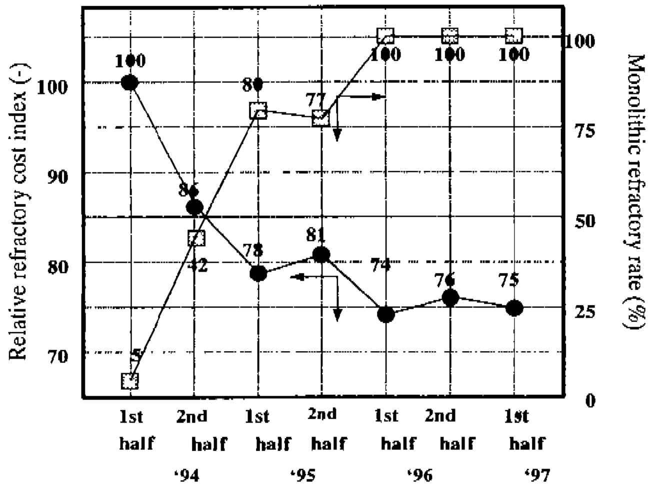


Fig. 16. Plot showing the change in refractory cost in Relation to the monolithic refractory use ratio.

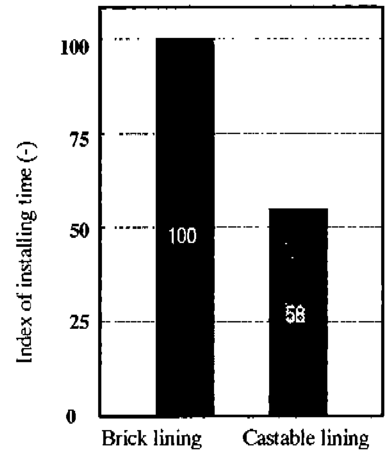


Fig. 17. Chart showing the relative difference in lining installation time for brick and castable linings in the RH vessels.

The use of monolithic refractory in the RH vessel lining resulted in a cost reduction for both the refractory and the installation. It was possible to more efficiently utilize the refractory lining because of the ability to install monolithic refractory over the remnant monolithic lining, as needed during the campaign. Fig. 16 shows the change in refractory cost, according to the adoption ratio of monolithic refractory in the RH vessel. The installation cost was reduced about 40% compared with a brickwork lining, as shown in Fig. 17.

VI. Conclusions

Monolithic refractory technology has been developed for RH vessels, with the intent of reducing the total refractory cost. The technology involves the improvement of an alumina-spinel monolithic refractory, of the type used in steel ladles, and the adoption of microwave drying, using a modification of the method which was previously developed and successfully used to dry the monolithic lining in steel ladles. An alumina-spinel monolithic refractory was improved by adding ultrafine alumina powder, reducing the amount of alumina cement, and using single crystal spinel. The improved, dense monolithic RH vessel lining of 500 mm thickness was successfully dried by the modified microwave method and the monolithic lining performed well in service. It was confirmed that both the refractory cost and installation cost were significantly reduced by the technology developed in this work.

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