Technology

UDC 666 . 763 /. 764 : 621 . 746 . 328

Refractory Technology of Ladle

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Abstract

In this report, we describe the functions and the refractory lining technology of the ladle, and the historical change in the improvement of material technology of refractories installed on the side wall of the ladle. The casting technique and the drying technique used to install monolithic refractories to the side wall of the ladle are then introduced. In addition, we provide examples of material improvement based on the damage mechanism of refractories and repairing technique with regard to monolithic refractories controlling the life of the ladle. Finally, we introduce the technique to prevent molten steel leaking from the ladle which is essential for the safety of steel-making plants.

1. Introduction

A molten steel ladle has the following three functions.

(1) Transportation of the molten steel that is tapped off from a BOF or an electric arc furnace at a temperature somewhere between the range of the latter halves of 1 500°C and 1 700°C to the continuous casting process or the ingot casting process

(2) Reactor of secondary refining treatment to enhance the quality of the molten steel

(3) Supply of molten steel to a tundish or to an ingot mold, variably controlling the teeming flow rate

2. Refractory Lining of Molten Steel Ladle

Figure 1 shows a schematic drawing of the refractory lining of a representative molten steel ladle. Magnesia carbon bricks excellent in corrosion resistance and resistance to structural spalling are employed in the slag line region where the refractory is exposed to slag, and in the region where the refractory is exposed to molten steel (side wall and bottom), the monolithic refractory of the alumina·magnesia system excellent in structural stability is employed.[1] Additionally, for the impact pad provided at the bottom of the molten steel ladle on which molten steel impinges at the time of tapping from a BOF or an electric arc furnace, to secure shock resistance, a precast block of monolithic refractory of the alumina·magnesia system of a dense structure[2] is employed.

In the region exposed to molten steel, high silicate bricks (roseki brick) were used originally. However, after the 1960s, zircon bricks began to be used instead to cope with the harsher refractory working conditions brought forth by the wider application of secondary refining and continuous casting. Furthermore, driven by the need to employ monolithic refractory to develop the mechanization and labor saving of brick work in furnaces that emerged around 1970, and by the need to eliminate silica in refractories to meet the demand for

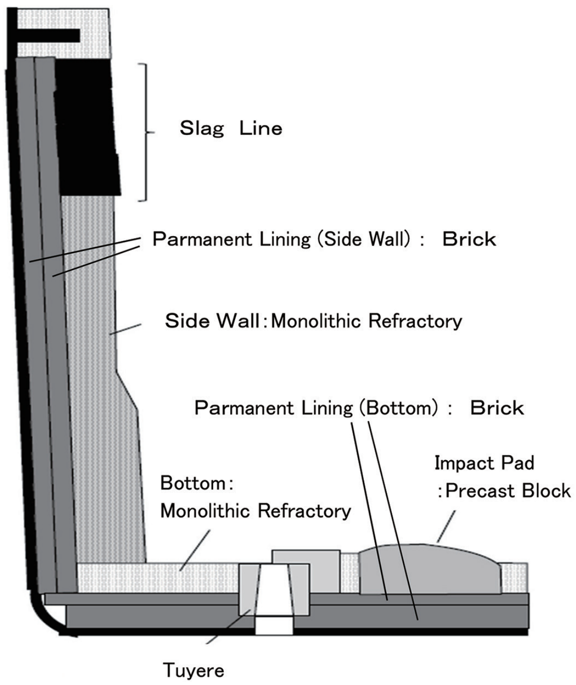

Fig. 1 Refractory lining of ladle[1]

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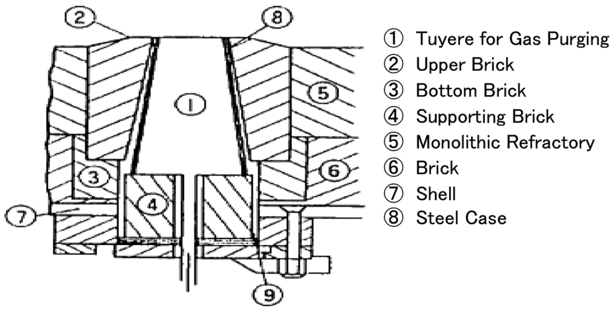

Fig. 2 Schematic diagram of gas purging instrument installed at the ladle bottom[5)]

high purity steel, the monolithic refractory of the alumina·spinel system was developed in the latter half of the 1980s and practically applied.

Historically, in the first half of the 1990s, the present monolithic refractory of the alumina·magnesia system was put into practical application to suppress the structural spalling (peeling of slag-penetrated layer) of the monolithic refractory of the alumina·magnesia system and to enhance durability.[3)] The monolithic refractory of the alumina·magnesia system prevents slag penetration by the structure densification effect realized by $MgO \cdot Al_2O_3$ and/or $CaO \cdot 6Al_2O_3$ that is formed and volumetrically expanded during usage. In the process toward the practical application of the monolithic refractory of the alumina·magnesia system, to suppress the generation of thermal stress cracking due to excessive volumetric expansion in usage, optimization of the chemical compositions such as MgO, CaO and SiO_2 and blending of the raw material particle-size have been implemented.

Furthermore, for the region exposed to slag, monolithic refractory of the magnesia·zircon system and the synthetic clinker of the magnesia·zirconia system were practically applied, and the application of monolithic refractory to the entire inner linings of molten steel ladles was achieved.[4)] However, because of the unsuccessful elimination of the structural spalling, use of magnesia·carbon bricks has been resumed at present.

Secondly, in order to efficiently implement the function of secondary refining treatment of molten steel as a processing equipment, some of the ladles are equipped with a gas blowing-in apparatus of the porous plug type installed on the ladle bottom as shown in **Fig. 2**.[5)] By blowing argon gas into the molten steel through the porous brick shown as ① in Fig. 2, the molten steel is stirred and the refining process is promoted. For the porous brick, one of the materials of the mullite system, alumina system, magnesite chrome system and magnesia system is used depending on the required usage condition and/or durability.

Furthermore, to implement the function of supplying molten steel to a tundish or ingot molds, a molten steel teeming apparatus as shown in **Fig. 3** is installed on the bottom of a ladle. Figure 3 shows an example of the structure of the sliding nozzle type[6)] as a method of teeming molten steel. For the bottom plate, slide plate,[7)] upper nozzle and the lower nozzle[8)] shown in the figure, a material of the carbon·alumina system is mainly used.

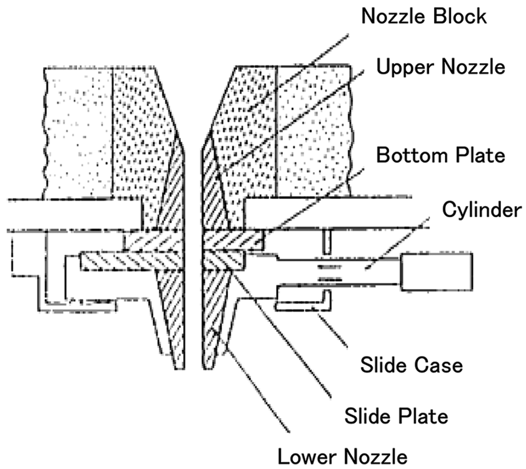

Fig. 3 Typical parts arrangement of sliding nozzle[6)]

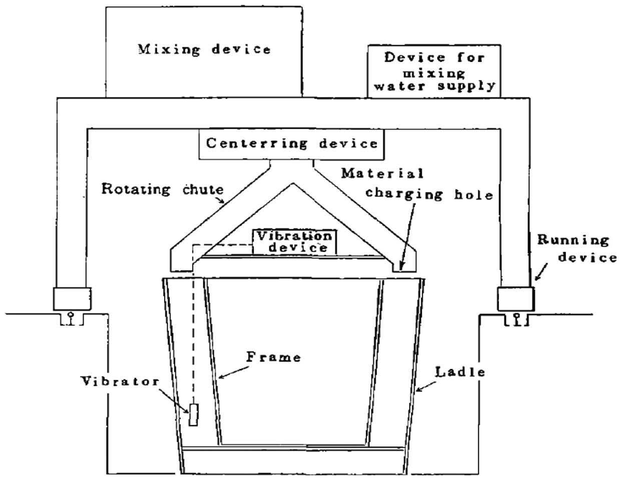

Fig. 4 Schematic diagram of casting instrument[9)]

3. Casting and Drying Techniques of Monolithic Refractory for Side Wall

Figure 4 shows the casting equipment developed for constructing monolithic refractory on the side wall.[9)] The construction procedure is shown below. A molten steel ladle is installed with a frame and a running car carries the casting equipment over the molten steel ladle. Next, the rotating chute is positioned in the casting position by the centering apparatus. After the monolithic refractory is kneaded with water by the automatic kneading water supply apparatus and the kneading apparatus installed on the running car, the monolithic refractory is cast to the space formed by the inner side of the molten steel ladle and the frame. By providing vibration with a vibrator during or after casting, air bubbles trapped in the monolithic refractory are released. By repeating this process, monolithic refractory is constructed on the side wall.

For the drying of the monolithic refractory constructed on the side wall, hot air produced by the combustion of burners is used as a heat source. However, in this method, since mild heating is required to prevent the explosion of the monolithic refractory during drying, a long time is necessary to complete drying. To solve this problem, a micro-wave drying method[10)] that features internal heating was developed. In **Fig. 5**, a schematic drawing of the micro-wave drying apparatus is shown. A micro-wave generated by a micro-wave generator and transmitted via a wave guide pipe is radiated uniformly in the molten steel ladle by a stirrer in combination with a reflector and the system is structured so as to circulate hot air as a heat source and

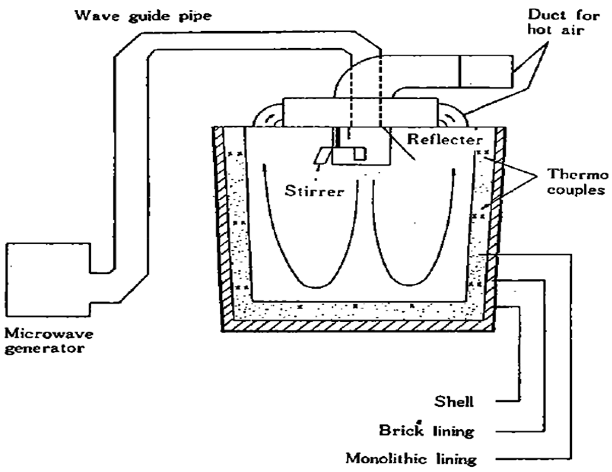

Fig. 5 Schematic diagram of micro-wave drying instrument[10]

supply auxiliary heat.

4. Damage and Repair of Monolithic Refractory

The damage of the monolithic refractory of the alumina·magnesia system used for the side wall is peeling caused by the penetration of slag, heat spalling and excessive sintering. To obtain high corrosion resistance, the following two measures were pursued. The first is intended to enhance the heat resistance of refractory and concerns the development of a binder that does not contain alumina cement[11] and the monolithic refractory applied with a cement consisting of a compound of the $SrO\text{-}Al_2O_3$ system,[12, 13] having a melting point higher than that of alumina cement.

The second is intended for the densification of the refractory structure and concerns the application to practical use of the monolithic refractory that can be constructed by kneading with a lesser amount of water than before by using the high performance dispersing agent that is practically used for concrete.

To enhance the resistance to heat spalling, focus was placed on elastic modulus that governs the generation of thermal stress and a monolithic refractory that defines ordinary temperature sonic velocity elastic modulus after heating for three hours at 1 500°C or hot compressive elastic modulus at 1 000°C was developed.[14, 15] To suppress peeling due to excessive sintering, temperature dependency of the permanent linear change was investigated. By controlling the morphology of $CaO·6Al_2O_3$ generated at high temperatures as shown in **Fig. 6**[16] to a columnar shape, the monolithic refractory with improved temperature dependency of a permanent linear change like the trial product shown in **Fig. 7** was put into practical application.[17] The permanent linear change of the trial product increases along with the rise of the heating temperature unlike the conventional product whose permanent linear change has the maximum value as shown in Fig. 7.[17]

In the precast block of monolithic refractory of the alumina·magnesia system used for the impact pad, damage progresses due to peeling caused by crack initiation during operation. To suppress peeling damage, in addition to the resistance to heat spalling, a material with improved creeping property at 1 500°C as shown in **Fig. 8** was developed by controlling the behavior of the liquid phase formation at high temperatures.[18]

The damaged portion is repaired and restored by the wet type gunning method[19] or by the continuous instantaneous kneading and gunning method[20] conducted at an ordinary temperature. Furthermore, there is another repairing technique implemented for suppressing the damage of refractory and maintaining stable operation thereby. By online measurement of the remaining thickness of the side wall refractory by a laser profile meter and by identifying the damaged portion early thereby, the subject damaged portion is repaired by hot gunning.[21, 22]

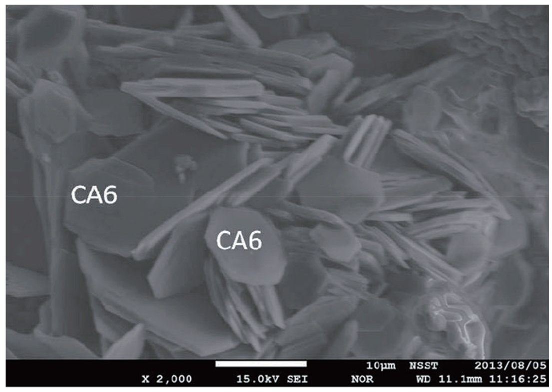

Fig. 6 Morphology of $CaO·6Al_2O_3$ (CA6) generated at high temperature[16]

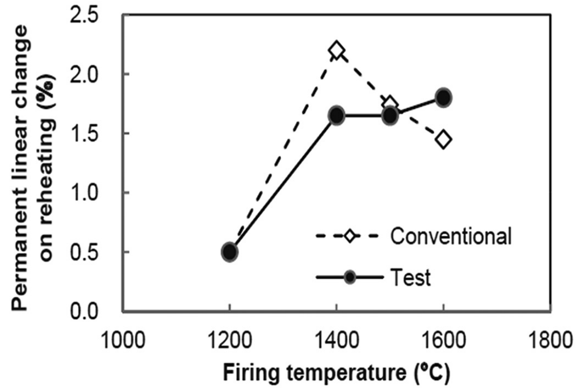

Fig. 7 Time-dependence on permanent linear change[17]

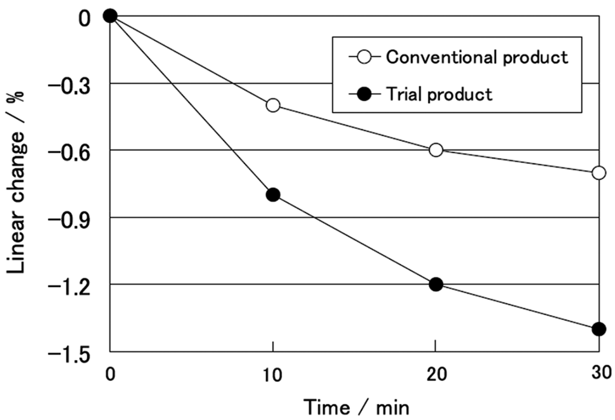

Fig. 8 Creep behavior under pressure of 0.2 MPa at 1 500°C[18]

5. Prevention of Molten Steel Leak in Molten Steel Ladle

A molten steel ladle holds molten steel exceeding 1 500°C, tapped off from a BOF or an electric arc furnace, and transfers it to a continuous casting machine via secondary refining treatment. Therefore, such a serious accident as the leak of molten steel through the perforation of the ladle steel shell caused by the disappearance of the inner lining during transportation must be absolutely prevented from the viewpoints of safety and disaster prevention. To this end, beneath the inner lining refractory of the side wall and the bottom of a molten steel ladle, a layer of refractory bricks deemed the permanent lining is constructed (Fig. 1). The following two leak-prevention functions are afforded to the permanent lining.

(1) An alarm function that indicates visual inspection is required to confirm the disappearance of the wear refractory due to erosion

(2) A function to guarantee the continuation of safe operation of the subject heat even in the case of the disappearance of the wear refractory

To secure these two functions sufficiently, utmost attention must be paid to the material and the structure of the refractory used for the permanent lining. The material to be employed should be studied taking into account the operating conditions such as molten steel temperature, compositions of molten steel and slag and with or without stirring in secondary refining treatment. Generally, high alumina bricks are selected in many cases. However, the selection of roseki bricks is an option when stirring of molten steel is not applied.[23]

Furthermore, magnesia bricks and/or magnesite-chrome bricks are selected where the slag of high temperature and slag of high basicity come into contact. Furthermore, from the viewpoint of structural reliability, two or more layers are desirable and when the thickness of a layer is very small, separation or falling-off occasionally takes place. Furthermore, the permanent lining, as is self-explanatory, is assumed to be used for a long time without exchange. As the exchange is costly and takes a long time, it is very important to maintain the permanent lining in a sound condition by clarifying the exchange standard and by observing the standard.

In recent years, online measurement of the remaining thickness of refractories by the steel shell temperature monitoring system with an infrared ray camera (thermo-viewer) and/or by a laser profile meter is conducted and the quantitative management technology of the remaining refractory thickness has become more widely used. Minimization to the extent possible of the risk of the occurrence of molten steel leak accidents is to be pursued by combining such diagnosis technology and the optimization and the soundness of the permanent lining.

6. Future Considerations

For the stable, long-term operation of molten steel ladles, enhancement of the durability of the monolithic refractories of the side wall that is life-limiting to the molten steel ladle and the establishment of the molten steel leak prevention technology by enhancing the furnace operation technology and by utilizing the newly developed sensing technology are important.

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