

Development of Gunning Material with Excellent Adhesivity at High Temperatures and Numerical Simulation of Heat Loss Reduction

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Abstract

Lowering of EAF inside temperature during gunning repair work conducted at intermediate interval between production causes slowdown of operation rate and increases of electric power consumption which is required to recover from the lowered temperature. We developed a new gunning material with superior adhesivity at high temperature. Its effects were evaluated in this research work. It was clarified with a hot gunning test on a high surface temperature test panel that, in comparison with the merely 2 % adhesion rate of conventional gunning material, the newly developed gunning material exhibits 45 % adhesion rate. It was confirmed with numerical simulation that, due to such difference in adhesivity at high temperature, the waiting time for starting repair work is shortened by roughly 75 % in association with reduction of heat loss during recovery from lowered temperature of hot-heeled molten steel by one half. It is expected that new repair work operation with the developed gunning material will contribute to improvement of operation rate, energy saving and lightening of the environment load in EAF operation.

1. Introduction

The steel industry is engaging in the reduction of CO₂ gas emission as one of the high priority challenging issues as part of the worldwide trend toward the achievement of carbon neutrality. Along with this trend, shifting from blast furnace-converter furnace method to electric arc furnace (hereinafter referred to as EAF) method is attracting attention as one of the dominant alternatives. In comparison with the blast furnace-converter furnace method, a larger amount of electric power is consumed in EAF operation, thus, improvement in energy efficiency in EAF operation is the key technology in anticipation of shifting to EAF method. Lowering the inside temperature of the EAF during furnace refractory repair work in daily operation induces an increase in

electric power consumption for regaining furnace temperature as well as deterioration of operating rate. This is a large obstacle to high productivity as well as lightening the environmental load. In order to solve such a hindering problem, operational technology for minimizing heat loss and suppressing temperature drop of the EAF during daily furnace refractory repair work is necessitated. Improvement of operation rate and reduction of electric power consumption were targeted by developing new gunning material with superior adhesivity at elevated temperatures, which suppress furnace temperature drop during repair work in this research work. Furthermore, by calculating heat loss reduction effect by applying newly developed gunning material quantitatively, a new technological method for improving energy efficiency in EAF operation is proposed in this article.

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2. Operational Backgrounds and Tasks for Problem Solution

A schematic diagram of EAF is shown in Fig. 1. In EAF operation, repair work is generally conducted at intermediate interval between production by gunning refractory material on the furnace wall so as to protect relined refractories and extend service life. In one time of repair work, several tons of gunning material is gunned in roughly 30 minutes, during which, because the furnace cover is opened, furnace temperature drops. In cases where gunning work is carried out with hot-heeled molten steel in the EAF to maintain productivity, adhesivity of gunning material tends to deteriorate because of the high temperature of the furnace wall refractories, especially, at the initial stage of repair work. Due to such a disadvantageous situation, repair time is extended because of the longer standby until furnace temperature drops to the appropriate range for gunning operation and/or because of necessity for a larger amount of gunning so as to

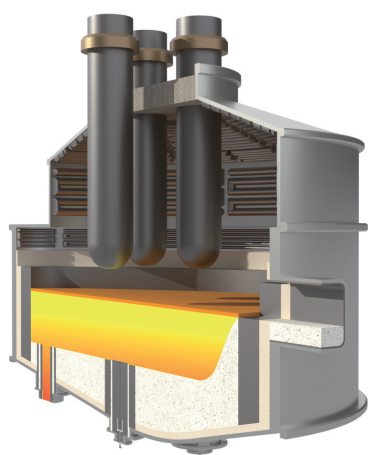


Fig. 1 Schematic diagram of electric arc furnace.

Table 1 Binder system of conventional and developed gunning material

	Conventional product	Developed product
Aggregate	MgO	MgO
Binder composition	Silicate	Silicate Binder A Binder B

compensate for the deteriorated adhesivity. Therefore, technology which enables short time repairing with improved adhesivity of gunning material is desired.

3. Development of Gunning Material with High Adhesivity at High Temperature

3. 1 Design policy for newly developed gunning material

When gunning is done on a refractory surface with high temperature, the water component admixed in the gunning material is vaporized and a certain level of vapor pressure is generated. It is presumed that the following two factors are dominant for deterioration of adhesivity of gunning material gunned on hot surfaces; (1) Due to the slow reaction rate of blended binder, it takes a certain amount of time to manifest sufficient mechanical strength of the gunned refractory body to overcome vapor pressure. (2) Adhesion strength between base furnace wall refractory and gunned material is too small to withstand vapor pressure. It is inferred that, due to one or both of these factors, the gunned refractory falls off due to overwhelming vapor pressure at the initial stage of its setting. By examining combinations and blended amounts of various types of binders, establishment of adequate binder system which enables manifestation of sufficient mechanical strength of the gunned body with proper reaction rate under high temperature was pursued.

3. 2 Hot gunning test

The binder system of the newly developed gunning material is compared with conventional gunning material in Table 1. The binder system applied for the new gunning material consists of a silicate binder, which is used for conventional gunning material, and also two additional binders, binder A, which accelerates the reaction rate and binder B, which softens at high temperature and imparts a plastic property to gunned body of gunning material. The adhesivity of the conventional and developed gunning materials were evaluated by hot gunning test. A schematic diagram of the test is illustrated in Fig. 2. In hot gunning test, gunning material was meanderingly gunned on a test panel with a surface heated up to 1100 °C by burner in

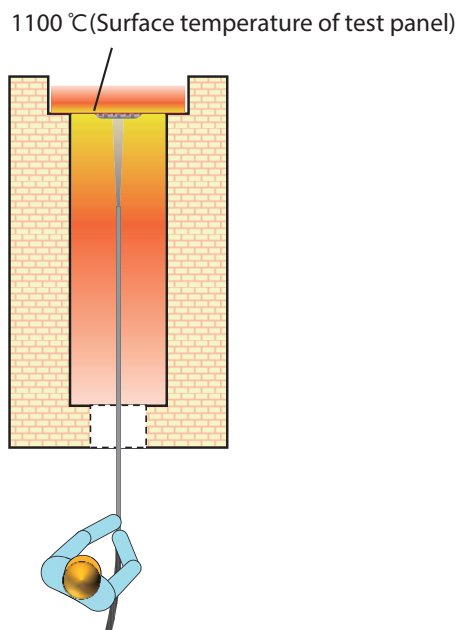


Fig. 2 Schematic diagram of hot gunning test.

advance. The adhesion rate is calculated by measuring the amount of gunning material adhered to the test panel.

3. 3 Results of hot gunning test

The appearances of the gunned bodies of the conventional and developed materials in the hot gunning test are comparatively shown in Fig. 3, and the adhesion rate of each gunning material is summarized in Fig. 4. Conventional gunning material did not adhere to the test panel heated-up to 1100 °C at all, especially, in the early stage of the hot gunning test, resulting in a merely 2 % adhesion rate. The developed gunning material stably adhered to the hot panel from the beginning of the hot gunning test and exhibited a 45 % of adhesion rate. It was clarified that, due to the new binder system, the developed gunning material exhibits superior adhesivity under high temperature conditions. For reference, the chemical compositions and particle size distributions of the conventional and developed gunning materials are summarized in Table 2.

4. Estimation of Energy Saving Effect by Application of Developed Gunning Material

Using numerical simulation, we estimated the energy saving effect of the developed gunning material. Fig. 5

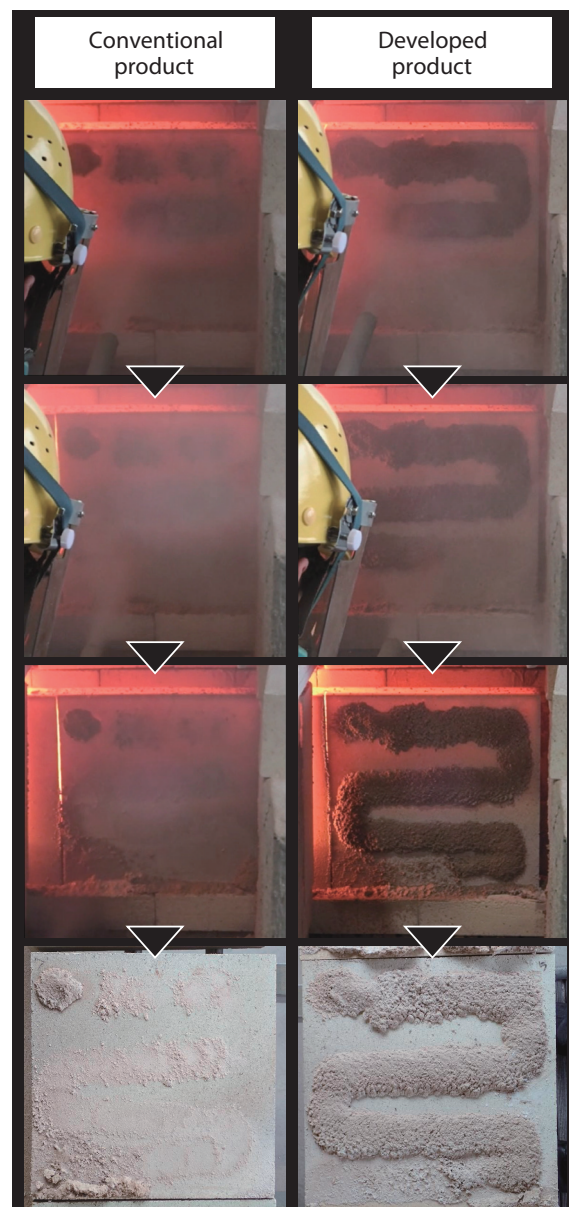


Fig. 3 Appearances of gunned body of conventional and developed gunning material in hot gunning test.

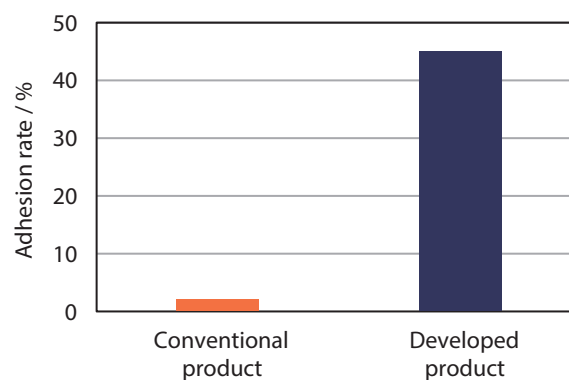


Fig. 4 Adhesion rate of conventional and developed gunning material.

shows the model used for the numerical simulations. The model is an axisymmetric representation of the EAF body and the approximately 30 t of molten steel remaining in the hot heel. Additionally, a molten slag layer was modeled on top of the molten steel.

Table 2 Chemical composition and particle size distribution of conventional and developed gunning material

		JTM-M-370	JTM-M-642
Chemical composition / %	MgO	84	82
	Al ₂ O ₃	-	-
	CaO	2	3
	SiO ₂	6	9
Grain size distribution / %	Max. size (mm)	3	3
	+1mm	35	38
	1-0.3mm	25	26
	-0.3mm	40	36
Remarks		Conventional product	Developed product

The thermal properties of the gunning material and the configuration elements of EAF wall at 500 °C are summarized in Table 3. Similarly, the thermal properties of molten steel and slag are summarized in Table 4. In the simulation works, EAF wall temperature distribution after 14 heats of operation was adopted as the initial condition. A boundary condition of 30 °C ambient temperature was applied on the exterior of the furnace, and it was assumed that radiation within enclosed space dominates heat transfer inside the furnace. Furthermore, it was defined that, the hot face of the furnace wall is cooled by forced convection induced by gunning. The heat transfer coefficients between the surface and furnace body and the ambient atmosphere, h [$\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$], was calculated with equation (1)¹⁾.

$$h=2.56\cdot(T_S-T_A)^{0.25}\cdot\left(\frac{w+0.348}{0.348}\right)+\sigma\cdot\varepsilon\cdot\left(\frac{T_S^4-T_A^4}{T_S-T_A}\right)\cdot\dots(1)$$

Table 3 Thermal properties of gunning material and configuration elements of furnace at 500 °C

	Gunning material	Work brick	Permanent brick	Insulator	Steel shell
Material type	MgO gunning material	MgO-C brick	MgO brick	AES* wool	Structural steel
Density / $\text{kg}\cdot\text{m}^{-3}$	2.8×10^3	2.8×10^3	2.9×10^3	1.4×10^2	7.9×10^3
Thermal conductivity / $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$	1.7	6.4	6.2	8.7×10^{-2}	3.6×10
Specific heat capacity / $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$	1.3×10^3	1.3×10^3	1.2×10^3	1.1×10^3	8.0×10^2

*Alkaline earth silicate

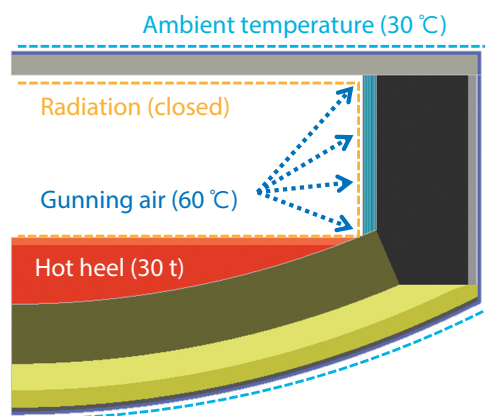


Fig. 5 Model for heat transfer calculation of EAF gunning repair.

Table 4 Thermal properties of molten steel and slag

	Molten steel	Molten slag
Density / $\text{kg}\cdot\text{m}^{-3}$	7.3×10^3	2.8×10^3
Thermal conductivity / $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$	1.0×10^3 *	7.0×10^{-1}
Specific heat capacity / $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$	7.0×10^2	1.6×10^3

*Value chosen sufficiently large to simulate homogenization by convection

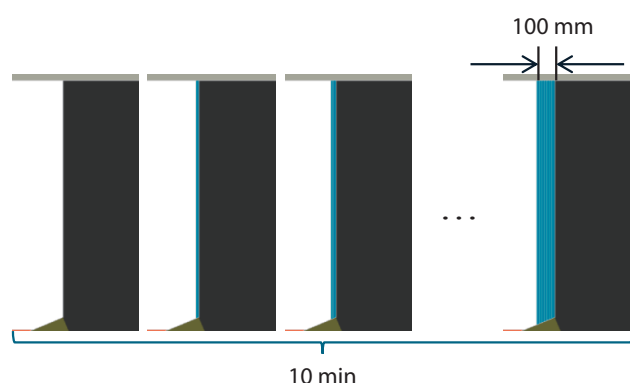


Fig. 6 Model of incremental increase in thickness of adhered gunning material in numerical simulations.

Where, T_s [K], T_A [K], ϵ , w [m·s⁻¹] and σ are the surface temperature, the ambient atmosphere temperature, the emissivity at surface, the wind velocity and the Stefan–Boltzmann constant [$\sigma=5.67 \times 10^{-8}$ W·m⁻²·K⁻⁴], respectively.

5000 W·m⁻²·K⁻¹ of the constant value was used as the contact heat transfer between the melts and the furnace body. As illustrated in Fig. 6, the adhesion of the gunning material on the hot face of the furnace wall was assumed to increase incrementally, resulting in a 100 mm thick gunned layer after 10 min of gunning. Considering the differences in adhesivity at high temperature between the conventional and developed gunning materials, it was presumed that the gunning operation begins once the hot face temperature decreases to appropriate level for stable application. Specifically, this temperature is 900 °C for the conventional material and 1100 °C for the developed material.

Fig. 7 shows the simulated temperature changes on the hot face of the work bricks in the furnace wall from the end of tapping to the completion of gunning. The hot face temperature decreased gradually from 1472 °C at the end of tapping and then, dropped sharply at the start of gunning due to heat transfer to the gunning materials. The conventional material required 28 min before the gunning operation could commence. In contrast, the developed material reduced the waiting time to 7 min before gunning could be performed. The changes of the temperature distributions in

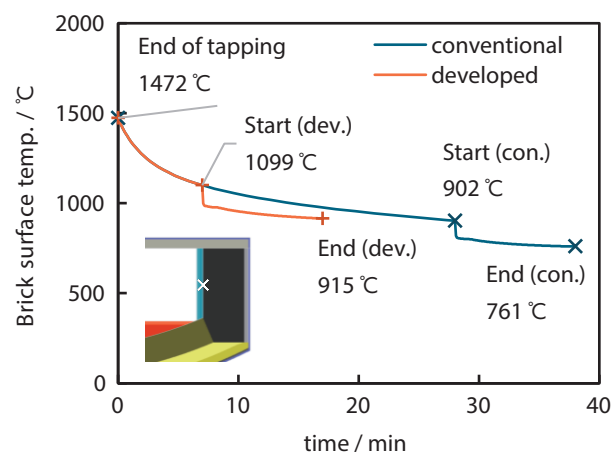


Fig. 7 Simulation results of hot-face temperature changes in wall bricks from the end of tapping with conventional (con.) and developed (dev.) gunning materials.

the furnace wall are shown in Fig. 8. The brick hot face temperature after gunning the conventional material decreased to 761 °C. In contrast, when using the developed material, the temperature remained at 915 °C. These results indicate that the developed material can reduce the repair time and better retain the furnace body temperature.

Fig. 9 shows the simulated change of the hot heel temperature. Starting from the temperature of 1598 °C at the end of tapping, the temperature decreased to 1568 °C when using the conventional material, and to 1585 °C when using the developed material by the end of the repair. The energy required to reheat the cooled molten steel up to 1600 °C was calculated to be 188 kWh for the conventional material and 90 kWh for the developed material, resulting in over a 50 % reduction in energy consumption. In summary, the simulation results demonstrated that accelerating the repair process is effective in reducing energy consumption by shortening the repair time. A key purpose of the hot heel is to accelerate the initial melting of scrap in the subsequent EAF charge operation. Maintaining a high molten steel temperature is considered to make the hot heel more effective. Combined with rapid repair, it is expected to reduce the overall cycle time, contributing to higher operational rates and improved productivity.

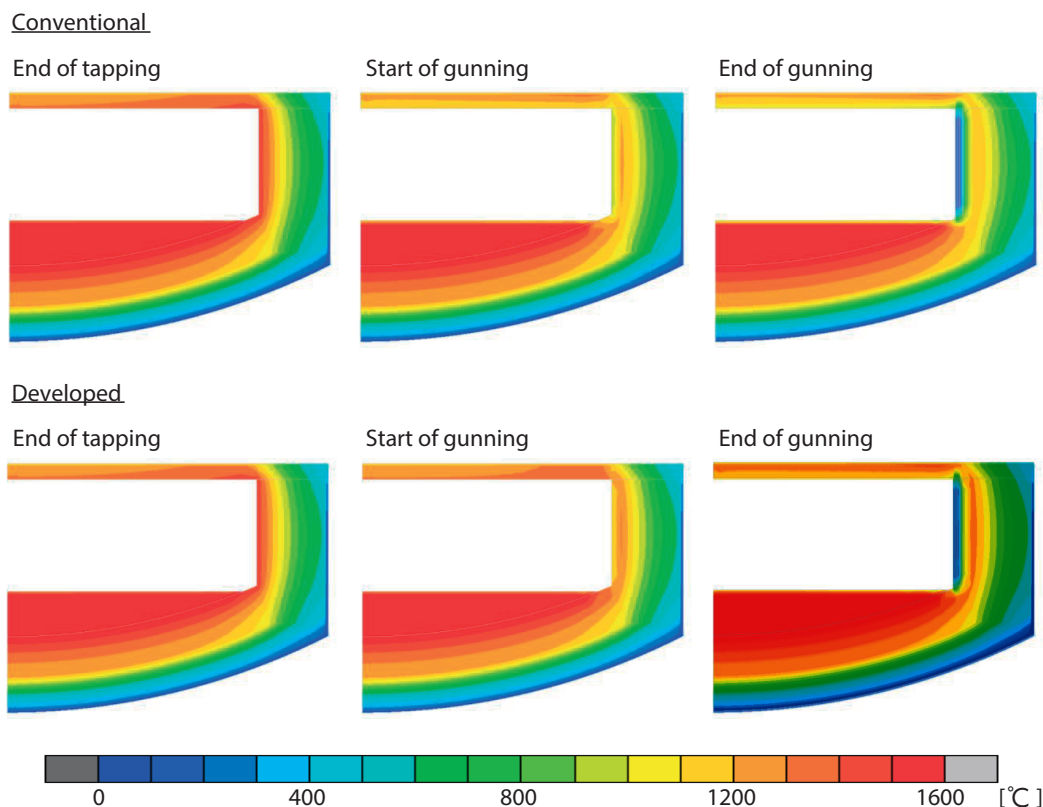


Fig. 8 Simulation results of temperature distribution changes using conventional and developed repair materials.

5. Conclusions

A new gunning material with superior adhesivity at high temperature was developed for the purpose of suppressing EAF temperature drop during gunning repair work conducted at intermediate intervals between production. It was clarified by hot gunning test onto a test panel with 1100°C surface temperature that, in comparison with the merely 2 % adhesion rate of conventional gunning material, the newly developed gunning material exhibits 45 % adhesion rate. It was confirmed with numerical simulation that, due to difference in adhesivity at high temperature, the waiting time for starting repair work is shortened from 23 minutes to 7 minutes. Consequently, temperature drop of the hot-heeled molten steel is suppressed, resulting in reduction of heat loss for recovering the lowered temperature of molten steel to 1600°C from 188 kWh to 90 kWh. It is concluded with these results that the newly developed gunning material is effective

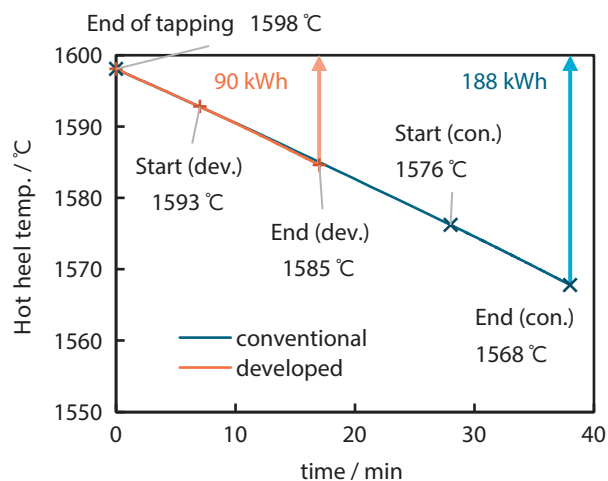


Fig. 9 Simulation results of hot heel temperature changes from the end of tapping with conventional (con.) and developed (dev.) gunning materials.

for improvement of energy efficiency in EAF operation and contributes to improvement of operation rate as well as to lightening the environment load.

Reference

- 1) Refractory Handbook ver. 12, Edited by The Technical Association of Refractory Japan (TARJ), (2015) pp. 589

