Technical Report

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Development of a Cooling Technology for LD-ORP Slag at Nagoya Works

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Abstract

The molten pig iron from the blast furnaces of Nagoya Works mostly undergoes pretreatment in converter type vessels (LD-ORP). Since the slag from this process contains fine solids in higher percentage than converter slag does, significant dust arises during its cooling. A new method of cooling this slag using rotary coolers has been developed to solve the problem, and a commercial plant based on the method has been constructed.

1. Introduction

The Chubu Region of Japan around Nagoya is one of the centers of the automotive industry. Nagoya Works of Nippon Steel & Sumitomo Metal Corporation was initially built and has expanded its production capacity, aiming principally at supplying steel sheets to the industry. The request for corrosion resistant automobiles has been strongly growing since 1975, and the demand for high-grade, heavy-coating galvanized steel sheets grown rapidly. In response, the Works developed the converter type large-capacity hot metal pretreatment process and began its commercial operation at the melting shop in 1989, and various efficiency enhancement measures have been introduced to the process ever since. The slag stemming from the pretreatment process was cooled and treated in open spaces, as was the case with converter slag, but the pretreatment slag contains solid in high percentages and is easily pulverized. On the other hand, it became necessary to take measures to suppress dust emission, and as a countermeasure, the Works developed a process to cool and treat the slag indoors. This paper reports the developed slag treatment process.

2. Basic Studies on Slag Treatment

2.1 Change in social requirements regarding iron/steel slag

The public concern about environmental pollution has grown since the 1970s, and accordingly, legal regulations such as the Air Pollution Control Act and the Water Quality Pollution Control Act have been enacted. Moreover, as is widely known, the Japanese steel industry has taken various environmental protection measures in response. Converter slag, however, is not easily usable as a material for civil construction because, besides being highly alkaline, it is prone to swell and break down. To solve the problem, the steam aging method and other processes have been developed to reform the slag.[1–3]

On the other hand, in the 1980s, different types of large-capacity hot metal pretreatment methods were developed and put into daily practice at various integrated steel works in Japan.[4] Consequently, hot metal pretreatment slag took over converter slag becoming responsible for the major part of steelmaking slag. Since the process temperature of hot metal pretreatment is lower than that in converters, its slag contains solids in high percentages, which means that much dust is emitted if it is cooled and treated in the open air in the same manner as converter slag is. In addition, social requirements have changed such that, in newly cultivating commercial use of the pretreatment slag making the most of its properties, securing high traceability of production conditions has become essential for the reliability of the product.

To solve these problems and to enable indoor treatment under centralized dust collection and treatment charge by charge of the processing vessels, the authors contemplated a rapid slag cooling and treatment method using a rotary cooler as the main equipment.

2.2 Studies on slag treatment process

Two types of slag stem from iron- and steelmaking processes: blast furnace and steelmaking slags. Various methods for granulating blast furnace slag using water were developed since the 1970s, and its use as blast furnace cement rapidly expanded.[5, 6] Meanwhile, mainly for converter slag, which is substantially in the liquid phase at the time of formation, various rapid cooling methods such as ro-

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tating vane cooling (the equipment commercialized by the name of "Slagulator")[7] and air granulation[8] were developed, which led to the use of the slag as abrasives and the like. However, because of the problems peculiar to steelmaking slag, such as mixing of solid metal and non-reacted calcium oxide, few successful methods were developed for treating steelmaking slag. Despite the difficulty, some new processes have been developed: Astec Irie Co., Ltd. developed the Irie Slag Chilled (ISC) method, whereby the slag is rapidly cooled on a steel plate,[9] and more recently, Baosteel, China, devised the Slag Short Flow (BSSF) process[10] using a drum cooler.

Another reason for the difficulty in developing the processes to treat steelmaking slag is that, because the melting point of hot metal pretreatment slag is higher than the temperature of hot metal, it is necessary to cool the slag containing solid iron in the slag processing. Hence, air cooling in open spaces, water spray cooling, and immersion of slag pans in water have conventionally been the principal cooling methods for this type of slag. Considering the situation and to solve the above problems, the authors started development studies for slag processing using a drum cooler. As will be explained later herein, the developed process also proved effective in separating solid metal from slag.

2.3 Basic studies of rotary cooler

2.3.1 Evaluation of physical properties of slag

Typical chemical composition of the pretreatment slag is provided in **Table 1**. To design a rotary cooler for processing the slag, it is necessary to know the basic properties of the slag to process. The chemical composition, the specific heat, the bulk density, and the particle size distribution of the slag were evaluated for model calculation; the specific heat was measured using a differential scanning calorimeter on finely crushed real slag.

The measurement result of the specific heat is presented in **Fig. 1**; the values and their temperature dependence agreed comparatively well with those of di-calcium silicate given in relevant past literatures.[11, 12]

Table 1 Typical slag composition

Component	(wt%)
CaO	53.1
SiO_2	24.3
T-Fe	7.7
MgO	3.4
F-CaO	4.6

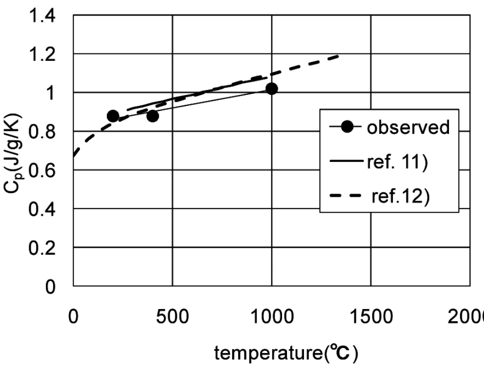

Fig. 1 Temperature dependence of the slag specific heat

Next, **Fig. 2** shows the particle size distribution of the slag; "water cooled" indicates slag specimens cooled in a conventional manner, i.e., in open spaces with water spray, and "air cooled" those cooled without using water for trial purposes. The particle size of the water-cooled samples was larger than that of the air-cooled. This is presumably because in water cooling, fine particles adhered to large particles. The average size of the air-cooled specimens (at 40% cumulative distribution) was approximately 2 mm.

The bulk density was determined by weighing slag specimens packed in a container of a prescribed inner volume; the readings ranged from 1 800 to 2 000 kg/m^3, and the 1 900 kg/m^3 value was used for the model calculation.

2.3.2 Study of cooling capacity using Kiln-simulator[13]

After determining the basic property values of the slag to treat, the cooling capacity of the rotary cooler was estimated through model analysis. The concept of the heat transfer model is given in **Fig. 3**. This model considers the five different heat transfers given in the diagram. The most significant of them are the following: first, between the slag being cooled and the cooling gas flowing in the direction opposite to the slag travel, second, between the slag and the cylindrical cooler body, and third, between the cooler body and the atmosphere and the water sprayed onto the cooler outer surface. The calculation formulae of the commercially available Kiln-simulator[13] were used for the analysis model, introducing modifications according to the developed process. **Table 2** shows the parameters regarding the heat transfers that the model considered and their definitions.

Figure 4 schematically shows a longitudinal differential cell used for the simulation model to calculate the heat transfer between the slag and cooling gas or water sprayed in the inside of the cooler

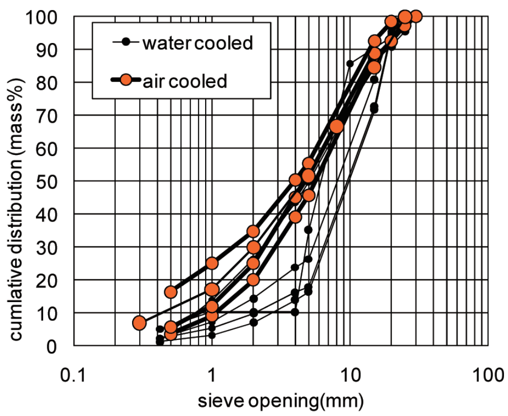

Fig. 2 Particle size distribution (cumulative) of slag

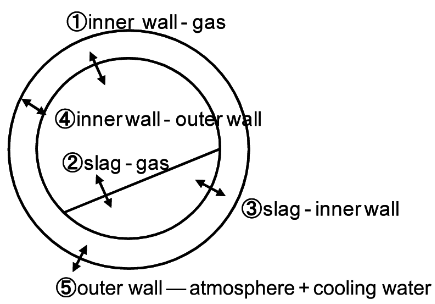

Fig. 3 Concept diagram of the heat transfer mechanism

Table 2 Parameter about the heat transfer included in the model

①	$\mathrm{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}\ (T_g < T_i)$ $\mathrm{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3}\ (T_g > T_i)$
②	$\mathrm{Nu} = 0.46\,\mathrm{Re}_0^{0.535}\,\mathrm{Pr}^{0.104}\,\xi^{-0.341}$ $\mathrm{Re}_0 = D^2\omega\rho_g/\mu_g$, ξ : Filling ratio
③	Penetration theory $h_{is} = (\lambda_s C_{ps}\,\omega/\pi\varphi)^{1/2}$, φ : Filling angle
④	$q = -\lambda\,\partial T/\partial r$
⑤	$\mathrm{Nu} = (0.60 + 0.37\,\mathrm{Ra}^{1/6}/[1+(0.559/\mathrm{Pr})^{9/16}]^{8/27})^2$ $\mathrm{Ra} = \mathrm{Gr}\cdot\mathrm{Pr}$, $\mathrm{Gr} = \beta\rho_g^{\,2}D^3(T_f - T_s)/\mu_g^{\,2}$, $\mathrm{Pr} = \mu C_p/\lambda$ In case of free convection

Table 3 Specification of pilot plant

Hopper size	2 m^3
Slag feeding speed	10 t/h
Shell diameter	1.93 m
Shell length	7.4 m
Cooling water (outside)	30 t/h
Cooling water (inside)	1 t/h
Cooling air	140 Nm^3/min
Rotation speed	1 rpm
Tilting angle	1/100
Filling ratio	10%

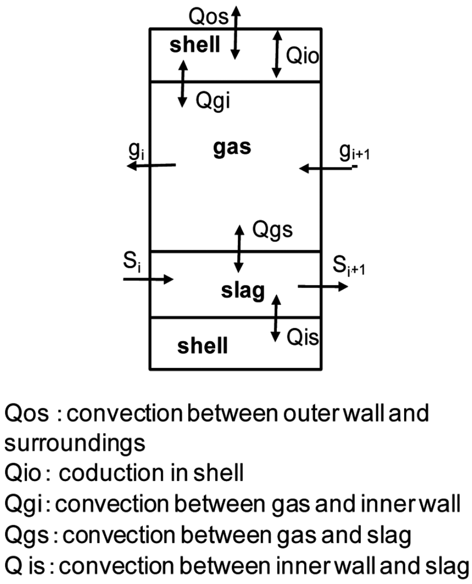

Fig. 4 Schematic diagram of calculation model

and another between the cooling gas or water and the cooler body. In addition, the heat transfer between the cooling air and the cooling water sprayed on the cooler outer wall is considered here. Heat transfer by radiation, except for that in the axial direction, is also accounted for in relation to the heat transfers inside the cooler and at its outer wall. The temperature distribution and the material flow inside the cooler are simulated by longitudinally dividing the cooler inside space into cells of an infinitesimal length, and by solving the material balance and the heat balance between adjacent cells. Note that the specific heat and the bulk density of the slag used for the simulation were those actually measured as stated in 2.3.1 above, and the heat conductivity coefficients of the air, water, and the cooler body were taken from literatures.[14, 15] Sullivan's equation,[16] given below, was used for the estimation of the travelling speed of the slag inside the cooler, because, of various empirical equations already proposed, it yielded the result that best agreed with the test result on the pilot plant.

$$V_S = \frac{51.6\,D_i\,\omega\,\tan\psi}{\beta + 24}$$

V_S: Slag transfer speed (m/s)
D_i: Inside diameter of shell (m)
ω: Rotation speed of shell (rad/s)
ψ: Tilting angle of shell (rad)
β: Dynamic angle of repose (deg)

Photo 1 10-t/h pilot plant

2.3.3 Verification tests on pilot plant

Based on the results of the above calculations, a pilot slag cooling plant having a capacity for 10 ton/h was constructed at Nagoya Works as per the specifications given in **Table 3**, and a series of slag cooling tests were conducted. As seen in **Photo 1**, the plant comprised a receiving hopper, vibrating feeder, rotary cooler, cyclone dust collector, and cooling air blower.

Hot slag was charged into the receiving hopper using a power shovel, and temperature was continuously measured as follows: slag temperature before charging, in the receiving hopper, and at the exit from the rotary cooler; the air temperature at the exit from the cooler; and the cooling water temperature at the entry to and the exit from the piping.

The operation results of the 10-ton/h pilot cooling plant were examined and verified using the simulation model. From the calculations, it was presumed that the rate of the heat transfer depended on the heat transfer between the slag bed inside the cooler and the air blown into it. It was presumed further that, when the slag temperature at the entry to the cooler was high, spraying water onto the slag in the cooler in addition to the cooling air would be effective at increasing the cooling capacity (see **Figs. 5** and **6**). In this case, it is possible to increase the cooling capacity and keep the product slag dry by spraying the water only when the feed slag temperature is above a prescribed value. The combined air and water cooling proved to be an excellent method in terms of operational flexibility.

3. Construction of Commercial Plant

A commercial plant to process hot metal pretreatment slag with two rotary slag coolers, which were designed based on the results of the operation of the pilot plant and the simulation, was constructed.

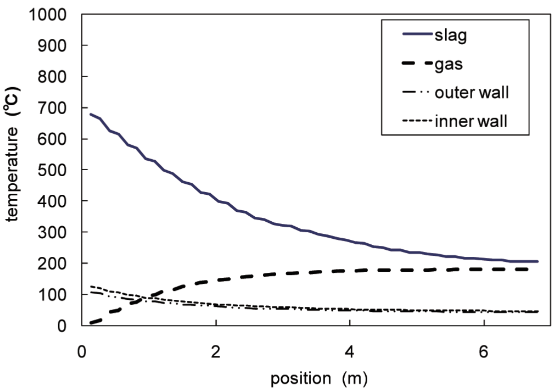

Fig. 5 Temperature simulation without internal water spray

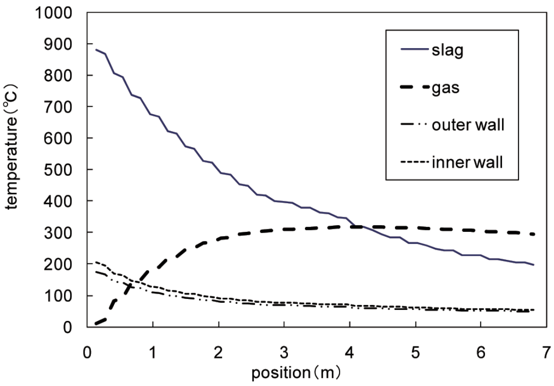

Fig. 6 Temperature simulation with internal water spray

The plant was designed to have the capacity to cool all the slag generated at that time. **Figure 7** shows the layout of the slag processing plant. The entire plant is centrally operated from the operating room, and the cranes from a crane operating room in the building. The dust collecting system is connected to local suction hoods provided in the building and each of the rotary coolers to collect the dust arising from the processing to prevent it from escaping from the plant building.

The process flow in the plant is as follows (see Fig. 7):

(1) Hot slag in slag pans is brought by rail from the hot metal pretreatment facility to the slag processing plant building.
(2) The slag pan is hoisted by a crane and tilted to discharge the slag to a primary cooling pit.
(3) The slag in the primary cooling pit is raked for cooling, and large lumps of solid metal are removed using a power shovel.
(4) The slag is charged by the power shovel to the receiving hopper of the rotary cooler, sieved by a vibrating grizzly provided at the entry to the receiving hopper, with the minus sieve falling down into the hopper and the plus sieve being returned to the ground. The minus sieve slag in the hopper is fed by a vibrating feeder at a prescribed rate to the inside of the cooler.
(5) The slag is cooled in the cooler to 100°C or below in a resident time of approximately 30 min.
(6) The cooled slag is transferred on a slag conveyer and a tripper to storage pits.
(7) Samples are collected from each of the storage pits and sent through pneumatic tubes to the chemical laboratory for composition analysis. After confirming that the chemical composition conforms to applicable standards, the slag is transferred to aging yards.

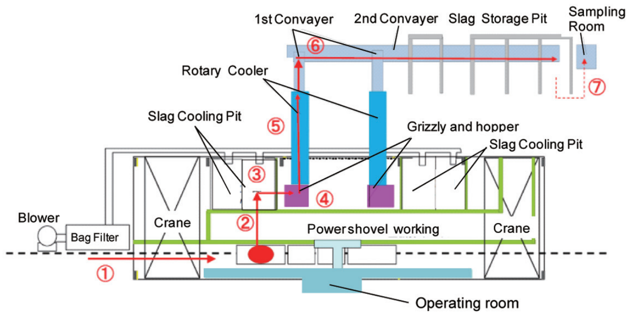

Fig. 7 Layout of the ORP slag processing plant

4. Closing

As a preparatory study for the construction of a cooling plant with two rotary coolers for the slag stemming from hot metal pretreatment at Nagoya Works, the authors examined the basic properties of the slag, and based thereon, studied the feasibility of the slag cooling using a numerical model on heat transfer. Then, a 10-ton/h pilot plant was built to verify the results of the model study. Finally, based on those study results, a 50-ton/h commercial slag cooling plant has been built and put into operation.

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References

1) Sano, N. et al.: Tetsu-to-Hagané. 65 (12), 1787 (1979)
2) Sasaki, M. et al.: Tetsu-to-Hagané. 68 (6), 641 (1982)
3) Takayama, S. et al.: J. of Jpn. Soc. Civil Engrs. 32 (544), 177 (1996)
4) Inoue, S. et al.: Limits of Impurity Removal at Steel Production in Quantities. Iron & Steel Inst. Jpn. (ISIJ), 19th Steelmaking Committee, Japan Society for the Promotion of Science, 1996, p. 151
5) Gotoh, K.: J. Ceramic Ass. Jpn. 720, 48 (1956)
6) Abe, Y. et al.: Seitetsu Kenkyu. 301 (6), 93 (1980)
7) Shigematsu, Y. et al.: Tetsu-to-Hagané. 64, S605 (1978)
8) Ono, M. et al.: Nippon Kokan Tech. Rep. 96, 693 (1982)
9) Takashima, T. et al.: Seitetsu Kenkyu. 301 (6), 110 (1980)
10) http://bsee.baosteel.com/english/tech5_4.htm
11) ISIJ: Handbook on Properties of Molten Iron and Slag. 1972, p. 198
12) ISIJ: Chemical Properties of Molten Slag. 1991, p. 9
13) Kiln-Simu: VTT Technical Research Center of Finland
14) Jpn. Soc. Mech. Engineers. (JSME): Data Book Thermo-physical Properties of Fluid. 1st Edition. 1983
15) JSME: Heat Transfer. 4th edition. 1986
16) Sullivan, J.D. et al.: U.S.Bureau of Mines, Technical Paper 384. 1927, p. 1


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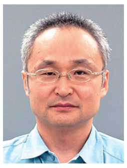
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