Abridged version

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Development of a Smelting Reduction Process for Recycling Steelmaking Dust

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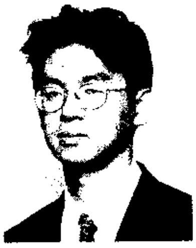
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Kawasaki Steel has developed, in Chiba Works, a new smelting reduction process for the recycling of the steelmaking dust containing valuable metals. This process is characterized by a coke packed-bed shaft furnace with two-stage tuyeres (STAR process) which enables direct use of dust without agglomeration. Bench-scale and pilot-plant tests were carried out to confirm the principles and effectiveness of the process. A commercial plant with the metal production of 140 t/d started its operation in May, 1994 and has been operating successfully. Development of the STAR process has enabled to improve the retrieving ratio of metallic sources (Fe, Cr, Ni) contained in steelmaking dust.

1 Introduction

A new process for treating steelmaking dust containing valuable metals and recovering them as smelting-reduced metals was developed at the Chiba Works of Kawasaki Steel. The coke packed-bed shaft furnace with two-stage tuyeres (the STAR process)[1] developed at Kawasaki Steel was applied in this dust treatment process.

The dust generated in a steelmaking plant contains large quantities of valuable components and it is environmentally beneficial to recover and reuse them. Steelmaking dust has so far been formed into briquettes, which have been reinjected into the converter. However, because part of the dust recharged as briquettes generates dust, this recycling method has been inefficient. In the new process, however, dust is directly injected into the tuyeres in powder form without being briquetted, making it possible to recover the valuable metals contained in dust at high yield ratios. For this reason, the water-treatment sludge containing the small-particle dust from the pickling line of a rolling mill can also be used as the raw material.

In developing this process, bench-scale fundamental studies were first conducted. Then the principles of the process were confirmed and its superiority were demonstrated by conducting experiments in a 10 t/d pilot plant[2]. After that, the pilot plant was scaled up to a commercial plant with metal production of 140 t/d[3]. The commercial plant has been running smoothly since its start-up in May 1994[4]. This report describes the principle of the coke packed-bed shaft furnace with two-stage tuyeres for recycling steelmaking dust and the contents of the pilot plant test, and gives an overview of the equipment and operation of the commercial plant.

2 Principle and Features of this Process

A conceptual diagram of this process is shown in **Fig. 1**. The furnace body is a coke packed-bed vertical shaft furnace with two-stage tuyeres and the raw materials are injected in powder form into the upper tuyeres together with blast. The raw materials thus injected are fused instantaneously in the high-temperature region at a theoretical flame temperature of 2 500°C or above formed in the upper tuyeres to prevent them from scattering. The fused oxides are reduced and become molten metal while dripping down through the high-temperature, intensively reducing region formed in the coke-packed bed between the upper and lower tuyeres. The heat necessary for the reaction is compensated by the heat of combustion in the lower tuyeres.

The features of this process are described below.

(1) Because raw materials are injected through the upper tuyeres in powder form and are smelted, the agglomeration process can be omitted.

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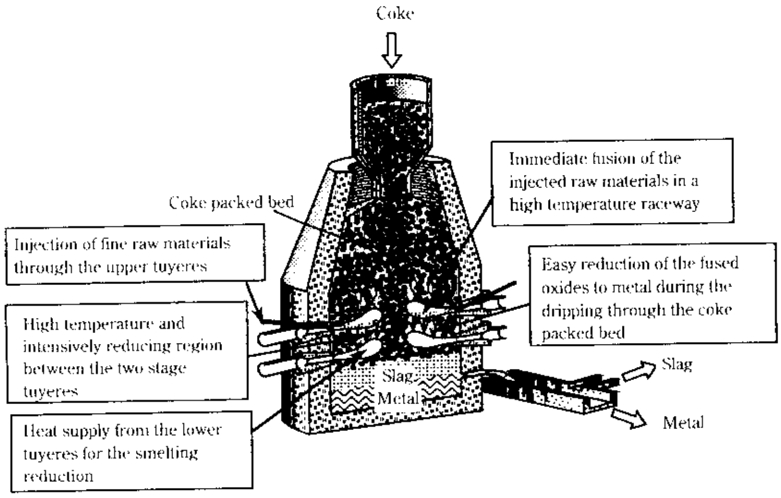

Fig. 1 Concept of the coke-paked bed with two stage tuyeres

(2) It is possible to reduce difficult-to-reduce oxides by utilizing the high-temperature, intensively reducing region between the upper and lower tuyeres in a coke packed-bed shaft furnace with two-stage tuyeres.
(3) Because this shaft furnace has a lower height than the blast furnace and there is no ore in the shaft portion, the permeability of the furnace is high and small lumps of coke can be used.
(4) Because the reaction is almost 100% direct reduction, it is possible to recover by-product gas that is higher in calories than the by-product gas from the blast furnace.
(5) Because the construction of the lower part of the furnace is almost the same as the blast furnace, the refractories wear less than with the iron bath type.

3 Pilot Plant Test

In order to apply the coke packed-bed shaft furnace in dust treatment, a test was conducted in the pilot plant for the purpose of gathering data for demonstrating this technique and scaling up the pilot plant.

3.1 Test Method

Figure 2 shows a schematic diagram of the equipment of the pilot plant of a coke packed-bed shaft furnace with two-stage tuyeres. This pilot plant was composed of the furnace proper with an inside diameter of 1.2 m, a raw material supply device by air stream transport, a hot blast generator and a waste gas treatment device. The operation conditions are shown in **Table 1** and the chemical composition of the dust used in the test is shown in **Table 2**. The blast volume and feed rate of the raw material were varied in order to evaluate the smelting capacity. The dust was mixed with flux to adjust the composition of generated slag and was injected through the upper tuyeres.

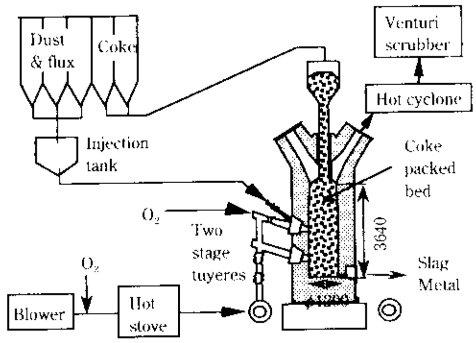

Fig. 2 Schematic diagram of the process flow for pilot plant

Table 1 Operation conditions

Blast volume	(Nm^3/h)	1 150~1 130
Enriched oxygen	(Nm^3/h)	150~170
Blast temperature	(°C)	750~830
Feed rate of raw material	(kg/h)	630~1 100
Coke rate	(kg/t)	1 405~1 573

Table 2 Dust composition

(%)

T.Fe	T.Cr	CaO	SiO_2	Al_2O_3	C
61	7.3	2.3	1.0	0.9	4.0

3.2 Results of Test

After the furnace body was heated by blowing hot blast and injecting iron ore, steelmaking dust was injected for about 3 days. The transition of operation during this period is shown in **Fig. 3**. During the test period it was possible to keep the metal temperature at 1 450°C or above and the FeO concentration of slag at 1.0% or less; there was no problem in reduction or

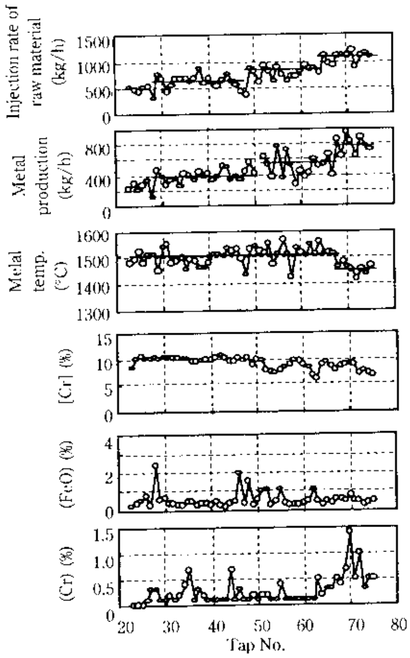

Fig. 3 Operation results

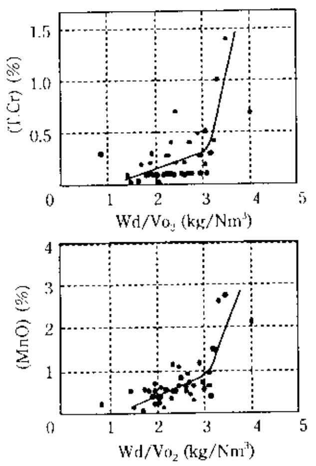

Fig. 4 Relation between Wd/V_{O_2} and (T.Cr) and (MnO)

metal/slag balance and operation continued smoothly. Metal production was 14.9 t/d maximum. From the results of this test, it was possible to demonstrate that the smelting reduction of steelmaking dust can be conducted in the pilot plant of a coke packed-bed shaft furnace with two-stage tuyeres.

Figure 4 shows the relationship between the raw material injection rate (Wd) per O_2 volume (V_{O_2}) in the blast in the upper tuyeres, i.e., Wd/V_{O_2} (the raw material injection rate per quantity of heat input in the upper tuyeres), and the concentrations of total Cr and MnO of slag ((T.Cr) and (MnO)). Because (T.Cr) and (MnO) increased abruptly at Wd/V_{O_2} of about 3 kg/Nm^3 and the

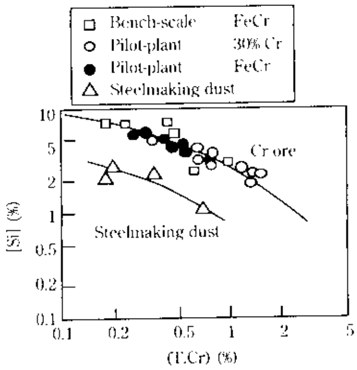

Fig. 5 Relation between (T.Cr) and [Si]

metal temperature also showed a tendency to decrease, this value might represent the upper limit of raw material injection rate in the pilot plant in terms of smelting capacity.

The relationship between (T.Cr) and the Si concentration of metal ([Si]) is shown in **Fig. 5**. A comparison at the same [Si] level shows that steelmaking dust has lower (T.Cr) than Cr ore. Because [Si] changes depending on the furnace heat level, it is apparent that steelmaking dust has better reducibility than Cr ore.

4 Construction of Commercial Plant

4.1 Scaling up to Commercial Plant

The smelting region in this process is between the raceways of the upper and lower tuyeres and the limit of smelting capacity was evaluated by the heat utilization rate between the upper and lower tuyeres determined based on a partial heat balance model.

$$Ef = Qred/(Qin - Qloss) \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Qred: Sum of the necessary heat for smelting reduction of raw materials and the sensible heat of melt

Qin: Heat input to the region between the upper and lower tuyeres

Qloss: Loss of furnace body heat between the upper and lower tuyeres

In order to obtain correspondence between the heat utilization rate and the scale of equipment, the cylindrical region between the upper and lower tuyeres shown in **Fig. 6** was regarded as the smelting region and a parameter of heat utilization ratio $(L/G)/(XR/At)$[5] was introduced. This parameter is defined by the product of the ratio of the surface area of coke in this region to the cross sectional area of hearth and the ratio of volume flow rate of gas to melt. In this parameter, L denotes the volume flow rate of melt, G denotes the volume flow rate of gas, XR denotes the surface area of coke in the smelting region, and At denotes the cross sectional area of the hearth.

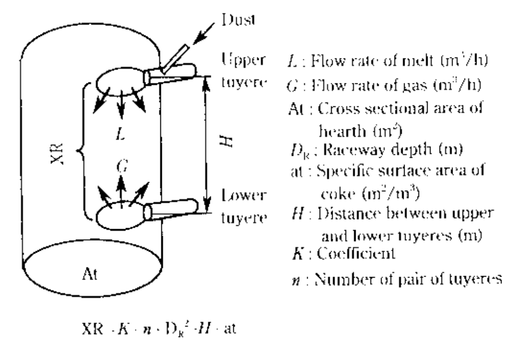

Fig. 6 Concept of smelting region

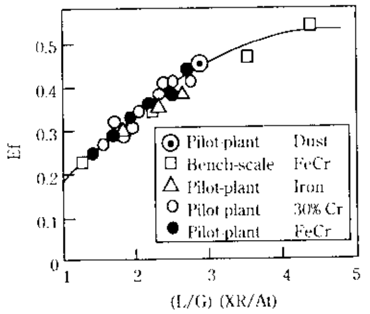

Fig. 7 Relation between (L/G)(XR/At) and Ef

The limit of smelting capacity in the treatment of steelmaking dust in the pilot plant is, as mentioned earlier, at Wd/V_{O_2} of 3 kg/Nm^3 at which (T.Cr) and (MnO) increase abruptly in Fig. 4, where the heat utilization ratio Ef was 0.44.

Ef is plotted against (L/G)/(XR/At) in **Fig. 7**. The values of Ef in the treatment of steelmaking dust in the pilot plant can be rearranged on almost the same curve as that of the benchscale test with different conditions of Cr ore injection and scale of test. Therefore, it is apparent that the calculation of the operation parameters of a commercial plant and the design of the spacing between the two-stage tuyeres, etc., can be carried out from the partial heat balance model and the relationship shown in Fig. 7. In the construction of the commercial plant, the smelting capacity was also examined from the standpoint of rate of reduction reaction of FeO and Cr_2O_3 on the coke surface.

4.2 Overview of Equipment

The process flow and main specifications of the commercial plant are shown in **Fig. 8** and **Table 3**, respectively. This plant, which has a hearth diameter of 4.0 m, a furnace height of 11.5 m and an inner volume of 140 m^3, is a smelting reduction shaft furnace of the coke packed-bed type equipped with 4 sets of upper and lower tuyeres in the lower part of the shaft. The flow of dust treatment process is described below:

(1) The dust recovered from the steelmaking waste gas and the sludge from the pickling line are received as a slurry. The moisture content of the slurry is controlled to about 50% by a decanter. The slurry is stored in a slurry tank and then spray-dried rapidly by a spray dryer, so that it becomes a powder with moisture content of 0.5% or less and particle size of 10–700 μm.

(2) After the dried powder is mixed with flux to control the slag composition, it is injected into the furnace along with hot blast through the upper tuyeres by air stream transport and is recovered as molten metal from the iron notch.

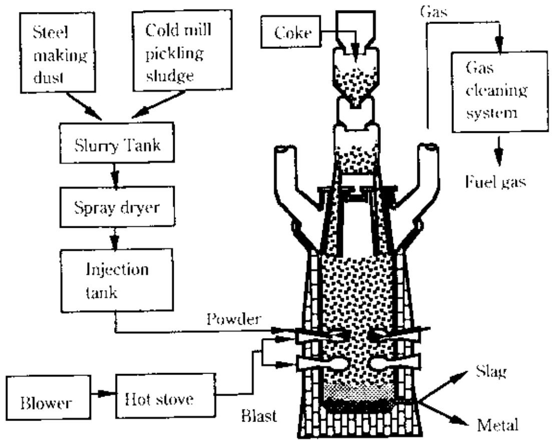

Fig. 8 Process flow of commercial plant

Table 3 Main specifications of commercial plant

Total volume	(m^3)	140
Hearth diameter	(m)	4
Furnace height	(m)	11.5
Cooling devices		Cooling stave
Number of tuyeres		4 × 2 stage
Number of iron notches		1

Because only small lumps of coke are charged as the reducing agent from the furnace top, the top gas contains about 53–55% CO and about 1–2% H_2 and is higher in calories (about 1 670 kcal/Nm^3) than blast-furnace gas. This top gas is recycled after the dust removal by a gas cleaning system.

5 Operation of the Commercial Plant

5.1 Condition of Operation

The commercial plant was brought into operation in May 1994. The transition of metal production since the blowing-in is shown in **Fig. 9**. The designed production capacity of 140 t/d was achieved after the start-up period of about 6 months, and production has since been further increased to about 150 -160 t/d.

The operation conditions are shown in **Table 4**. The reason why the coke rate is about three times the level of blast furnace is that the reaction is almost 100% direct reduction and that the melt heat is taken away by the

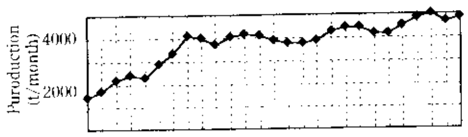

Fig. 9 Trend of metal prodution

Table 4 Operating conditions

Metal production (t/d)	158
Coke rate (kg/t)	1 350
Blast volume (Nm^3/min)	195
Oxygen enrichment (Nm^3/min)	36
Hot metal temperature (°C)	1 470

Table 5 Composition of metal (%)

Cr	Ni	C
7.7–8.5	1.0–1.6	3.9–4.2

Table 6 Composition of slag (%)

T.Fe	T.Cr	CaO	SiO_2	Al_2O_3
0.18–0.27	0.12–0.18	37–38	36–37	14

radiation heat of the furnace body due to the small furnace volume. The required quantity of heat for reduction is about 660 Mcal/t-metal, which accounts for about 38% of the heat of combustion of coke to CO, which is 1 730 Mcal/t-metal. The metal temperature is controlled by changing the blast and oxygen distribution ratio between the upper and lower tuyeres according to the amount of injected raw materials so that it becomes 1 450°C to 1 550°C. The method of furnace heat control is described in detail in the following sub-section.

The chemical compositions of the generated metal and slag are shown in **Tables 5** and **6**, respectively. The Ni and Cr content of this metal ([Ni] and [Cr]) vary depending on the kind of product in the steelmaking shop. The metal is used as the raw material for steelmaking and the yield of Cr from this by-product has increased from 90% to 97%. (T.Cr) is low at 0.12–0.18%, and the slag is used again as the blast-furnace slag.

5.2 Furnace Heat Control

In order to investigate the effect of the heat input distribution ratio of upper and lower tuyeres, we can refer to the relationship between heat and metal temperature shown in **Fig. 10**. Specifically, this figure shows the relationship between the ratio of the total heat supplied from the upper and lower tuyeres (T.Qin) to the quantity of heat necessary for reducing the material (Qred), T.Qin/Qred, and the metal temperature. It also shows the relationship between the ratio of the heat supplied from the lower tuyeres (L.Qin) to the necessary heat for

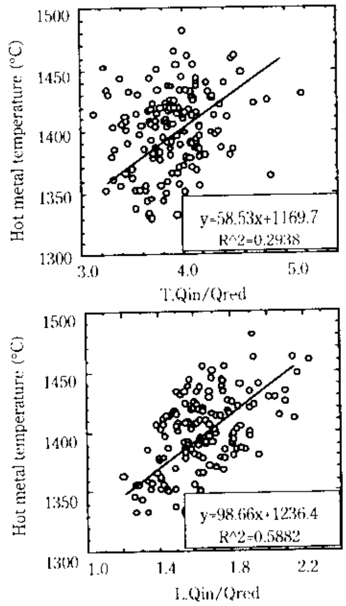

Fig. 10 Relation between heat input and metal temperature

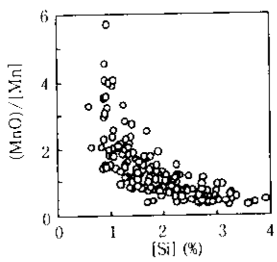

Fig. 11 Relation between [Si] (%) and (MnO)/[Mn]

reduction (Qred), L.Qin/Qred, and the metal temperature. In both cases, the metal temperature rises if the heat input increases relative to the necessary heat Qred. However, L.Qin/Qred has a stronger correlation to the metal temperature than T.Qin/Qred, indicating that the metal temperature is raised by increasing the distribution ratio of heat supplied from the lower tuyeres even if the total heat input is the same. This proves that changing the heat input from the lower tuyeres is effective as a means of controlling furnace heat in this process.

The effect of the furnace heat on the reduction behavior is shown in **Fig. 11**. The furnace heat was evaluated by [Si] and the reduction behavior was evaluated by the ratio of (MnO) to the Mn concentration of the metallic by-product ([Mn]), (MnO)/[Mn]. It is apparent that the higher [Si], the lower (MnO)/[Mn]; in other words the higher the furnace heat, the greater the reduction of MnO. The reduction behavior of Cr_2O_3 and FeO was also investigated and similar results were obtained[6].

It became apparent from the foregoing that not only the furnace heat, but also reduction can be controlled by adjusting the heat supplied from the lower tuyeres by the blast volume and enriched oxygen after calculating the necessary heat for reduction from the composition and feed rate of raw material powder.

6 Conclusions

Kawasaki Steel developed a new process for the smelting reduction of steelmaking dust and recovery of valuable metal components at high yields using a coke packed-bed shaft furnace with two-stage tuyeres (the STAR process).

Before the construction of the commercial plant, a pilot plant test was conducted to demonstrate the principles and superiority of the process and the following results were obtained:

(1) Continuous operation for about three days was possible at metal temperatures ≧ 1 450°C and FeO concentrations of slag ≦ 1.0%.

(2) It is possible to evaluate the upper limit of smelting capacity from the relationship between the raw material injection rate relative to heat input and the total Cr and MnO concentrations of slag.

On the basis of the above test results, the pilot plant was scaled up to a commercial plant (metal production capacity: 140 t/d) which started operation in May 1994. After the start-up period of about 6 months, the designed production capacity of 140 t/d was achieved and the commercial plant has since been operating smoothly.

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