Development of EAF Dust Recycling and Melting Technology Using the Coal-based FASTMELT® Process

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INTRODUCTION

The accumulation of EAF dust and its disposal have become a serious issue worldwide. EAF dust contains valuable metal resources such as iron, zinc, lead and other elements. Effective recovery of these metals would contribute to the development of a sustainable society.

Kobe Steel, Ltd. and Midrex Technologies, Inc. have developed and commercially applied the FASTMET® Process for both direct reduced iron (DRI) production and steel mill waste recycling. Since 2003, Kobe Steel has carried out a process development project, including three years beginning in 2005, of pilot plant operations at Kakogawa Works in Japan. This project, titled "Development of Valuable Metal Recovery Technology by Using a Rotary Hearth Furnace (RHF)," was subsidized by Japan's Ministry of Economy, Trade and Industry (METI).

The purpose of the process development project was to:

- Produce DRI from EAF dust using the coal-based FASTMET® Process.
- Effectively recover valuable metal resources such as zinc in the flue gas.
- Melt the DRI into hot metal using the coal-based FASTMELT® Process to increase added value of recovery metal.

As a result of the study and pilot plant operations, the follow ing points are discussed in this article:

- The FASTMET Process offers a solution to EAF dust recovery.
- The FASTMELT Process enables the production of hot metal from iron ore or steel mill by-products.

CHARACTERISTICS OF EAF DUST AND THE CONVENTIONAL RECYCLING METHOD

EAF Dust

Table I shows the chemical composition of electric arc furnace (EAF) dust, which we acquired from EAF steelmakers. Table II shows the chemical composition of blast furnace (BF) wet dust and basic oxygen furnace (BOF) dust as a comparison. The main component of all the dust is iron oxide. EAF dust is especially high in zinc since it contains very fine particles smaller than one micron, making it difficult to agglomerate. In Japan, EAF dust is designated as a special management industrial waste. Moreover, because EAF dust includes dioxin, plants in Japan that recover zinc from EAF dust are designated as special facilities under the *Law Concerning Special Measures Against Dioxins*.

EAF Dust	Total Fe	Zn	Pb	C	CaO	SiO_2	S	Cl
Group 1	31~33	17~19	1	3	3~4	4~8	0.4	1~4
Group 2	21~25	26~29	1~3	3~6	2~4	3~5	0.4~0.6	5~7

Table I - EAF Dust Chemical Composition (mass %)

BF and BOF Dust	Total Fe	C	Zn	Cl	F	S	Na_2O	K_2O	CaO	SiO_2
BF Wet Dust	31.8	37.6	1.2	0.07	0.16	0.70	0.2	0.6	3.1	4.1
BOF Dust	53.6	0.7	2.5	3.30	0.96	0.10	1.0	5.8	5.0	0.8

Table II - BF and BOF Dust Chemical Composition (mass %)

Location	By-product (Tons/Year)	RHF Dia. (m)	Start-Up
Nippon Steel Hirohata, No. 1	190,000	21.5	Apr - 00
Kobe Steel Kakogawa	14,000	8.5	Apr - 01
Nippon Steel Hirohata, No. 2	190,000	21.5	Feb - 05
Nippon Steel Hirohata, No. 3	190,000	21.5	Dec - 08

Table III - FASTMET® Commercial Plants

Conventional Method of Recycling Steel Mill Dust

The Waelz Kiln process is a well-established technology that uses a rotary kiln to treat steel mill dust. Dust containing zinc oxide and a carbon source, such as coke, are charged into the rotary kiln and heated by combustion heat. Compared to the FASTMET Process, the rotary kiln has lower productivity because of a lower operating temperature and less contact between dust and coal. The temperature in the kiln is generally below 1,200° C to prevent "kiln rings" from forming. Kiln rings are accretions of material that build up on the inside of the kiln shell. Contact between dust and coal is not as good as in FASTMET because in the kiln process, coal is added separately from the dust; whereas, FASTMET uses a pellet with coal and dust combined.

Because of its lower operating temperature and inferior dust and coal contact, the Waelz Process achieves lower iron metallization and less dezincification than FASTMET. Therefore, the iron product cannot be used as a metallic in blast furnaces, basic oxygen furnaces and electric arc furnaces, and it must be disposed of in special landfills. Such disposal is becoming more difficult and expensive. Also, there is a growing trend toward zero emissions of steel mill waste and EAF dust.

The FASTMET Process as a New Method of Recycling EAF Dust

FASTMET is an improved method of treating EAF dust. Several plants using the FASTMET Process to recycle steel mill waste have started up in Japan since 2000, and they have achieved high operating rates and good productivity. Several other plants are under construction.

Table III shows the three operating commercial plants in Japan that use the FASTMET Process.

Comparison of the RHF Process and Rotary Kiln Process

The characteristics of the FASTMET Process, versus the rotary kiln process, are as follows:

- FASTMET operates at higher temperatures, over 1,300° C.
- FASTMET achieves higher metallization and dezincification because of the higher temperatures and higher uniformity of the mixed EAF dust and carbon source before they are fed into the RHF.
- FASTMET DRI can be used as a metallic in BFs, BOFs and EAFs because of the higher metallization and recovery of zinc in the DRI.
- Fines generation is lower because the agglomerated raw materials (iron ore and coal) do not roll, but are stationary on the rotary hearth.
- The zinc content of the recovered flue dust is higher because the amount of dust generated is lower and the dust can be separated in the flue gas system.
- The amount of dioxin in the DRI is lower because the dioxin in the EAF dust is broken down under high temperatures.
- The amount of dioxin in the flue gas is lower, because the hot flue gas from the RHF is cooled rapidly in the flue gas system to prevent de novo formation.

The PROCESS DEVELOPMENT PROJECT

Themes

The KSL project for METI includes an RHF and melter. The RHF was designed to produce DRI from EAF dust, with the melter generating hot metal from the DRI using oxygen and a carbon source.

In order for the FASTMET/FASTMELT Process to treat EAF dust, the following technical themes were undertaken:

- Produce agglomerated mixed material in the form of briquettes.
- Produce higher strength DRI from the briquettes.
- Recover a higher amount of zinc in the form of zinc oxide in the flue gas.
- Prevent erosion, corrosion and adhesion in the flue gas system. (Some of the elements in EAF dust, especially zinc, are ten times higher than that of other steel mill waste.)
- Confirm that the amount of dioxin in the flue gas is lower.
- Confirm that the DRI produced can be melted into hot metal using the FASTMELT Process.

The project was carried out at Kobe Steel's Kakogawa Works. A photo of the FASTMET pilot plant, known as the Kakogawa Pilot Plant (KPP) is shown in Figure 1.

Project Schedule

The project was begun in 2003 and demonstration operation at Kakogawa Works was carried out until 2007. The total period from start to finish was about five years.

Figure 1 - Kakogawa Works FASTMET® Pilot Plant

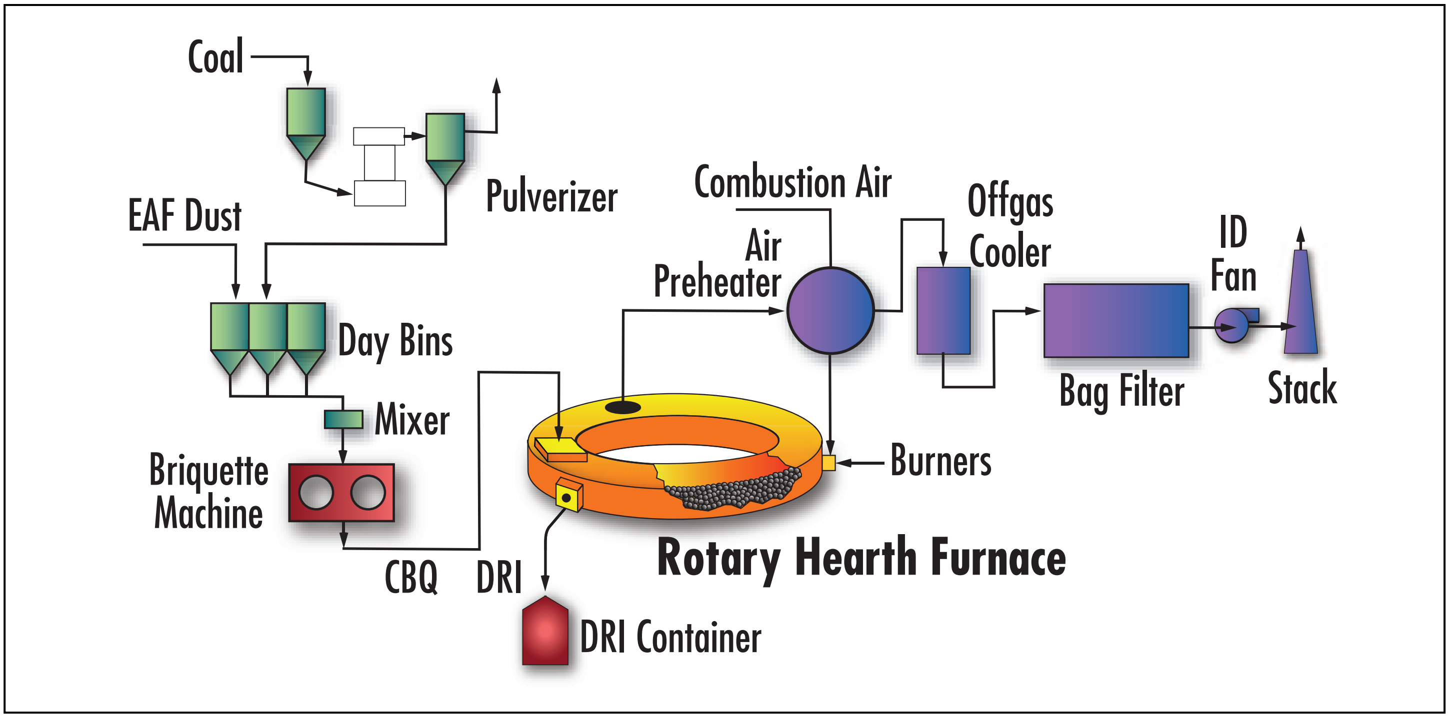

Figure 2 - Kakogawa Pilot Plant Flowsheet

PILOT PLANT TESTS USING EAF DUST

Process Flowsheet and Equipment

Figure 2 shows the process flowsheet for the FASTMET pilot plant and Table IV provides details of the feedstock and equipment. The Rotary Hearth Furnace has the capacity to process approximately 20,000 tons of dust per year.

EAF dust, pulverized coal for the reductant and a binder are mixed together. Then the mixture is agglomerated into cold briquettes (CBQ). The CBQ, fed into the RHF, are heated rapidly to temperatures of 1,200° C -1,400° C. The iron oxide in the CBQ is reduced to metallic iron. Zinc, lead and other volatile substances are vaporized and reoxidized in the flue gas.

The product DRI goes into the DRI container and is cooled with nitrogen. The vaporized substances in the flue gas are collected in a bag filter and the zinc is recovered as zinc oxide. The sensible heat of the flue gas is recovered by combustion air using a heat exchanger.

Item	Description
Feedstock	Iron ore, EAF Dust Bituminous, Non-coking Coal
RHF	11.5 meter OD Capacity: 20,000 t/y Feed Offgas Temperature: max. 1,400° C

Table IV - Feedstock and Equipment Details

Characteristics of EAF Dust and Coal

The chemical compositions of the EAF dust and coal used in the project are shown in Table V. EAF dust was classified into two groups. Group I contained higher total iron (Total Fe) and lower zinc.

EAF Dust

	Total Fe	Zn	Pb	C	CaO	SiO_2	S	Cl
Group 1	31~33	17~19	1	3	3~4	4~8	0.4	1~4
Group 2	21~25	26~29	1~3	3~6	2~4	3~5	0.4~0.6	5~7

Coal

C	H	N	O	S
83.4	4.1	2.1	0.9	0.3

Table V - Chemical Compositions of EAF Dust and Coal

IN	EAF Dust	263 t
	Coal and other	63 t
	Total	**326 t**
OUT	DRI	144 t
	Zinc oxide	79 t
	Gas and other	103 t
	Total	**326 t**

Table VI - Mass Balance of RHF Using EAF Dust

Test Results

Table VI shows the mass balance for the project. The amount of EAF dust treated was 263 tons, which produced 145 tons of DRI and 79 tons of crude zinc oxide. The remaining output was vapor and other constituents.

Figure 3 shows the material flow and photos of the raw materials, cold briquettes and DRI.

Table VII shows the chemical composition of the DRI and the baghouse dust under the test conditions. The DRI metallization averaged 73 to 88 percent.

The residual zinc content in the DRI was 1-4 percent, giving a dezincification degree of 91-98 percent. The baghouse dust had 57-70 percent zinc as zinc oxide, with less than one percent iron. The dezincification degree is calculated using the following formula:

$$\text{De-zinc } (\%) = \{1 - (\text{ZnO in DRI} / \text{T.Fe in DRI}) / (\text{ZnO in dry ball} / \text{T.Fe in dry ball})\} \times 100$$

Most of the zinc in the EAF dust was vaporized and then re-oxidized in the flue gas.

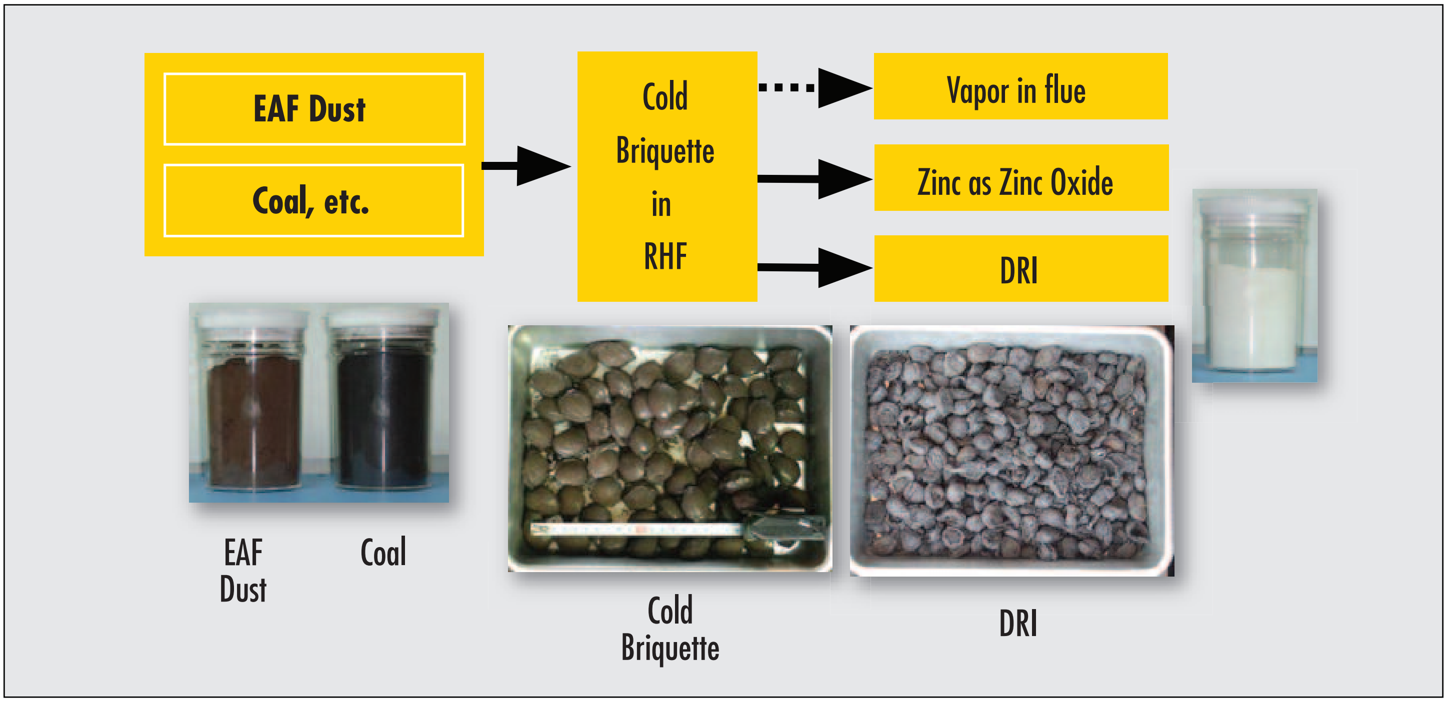

Figure 3 - Material Flow and Photos

DRI and Baghouse Dust

	(Mass %)	Total Fe	Metallic Fe	Zn	Pb	C	CaO	SiO_2	S
DRI	**Group I**	46 – 53	40 – 46	0.7 – 2.4	0.1	5 – 11	5 – 8	9 – 13	0.6
	Group II	42 – 50	35 – 41	1 – 4	0.1 – 0.6	3 – 15	6 – 12	8 – 14	0.6 – 1.0
	Average Met (%)		73 – 88	De-Zn Degree (%)		91 – 98	De-Pb Ratio (%)		87 – 97
	(Mass %)	**Total Fe**	**Zn**	**Pb**	**C**	**CaO**	**SiO_2**	**S**	**Cl**
Crude Zinc Oxide	**Group I**	0 – 0.2	64 – 70	3 – 4	0 – 0.1	0.1 – 0.2	0.1 – 0.2	0.4	5 – 8
	Group II	0 – 0.7	57 – 62	4 – 6	0 – 0.1	0.1 – 0.8	0.1 – 0.2	0.2 – 0.5	9 – 16

Table VII - Chemical Composition of DRI and Baghouse Dust

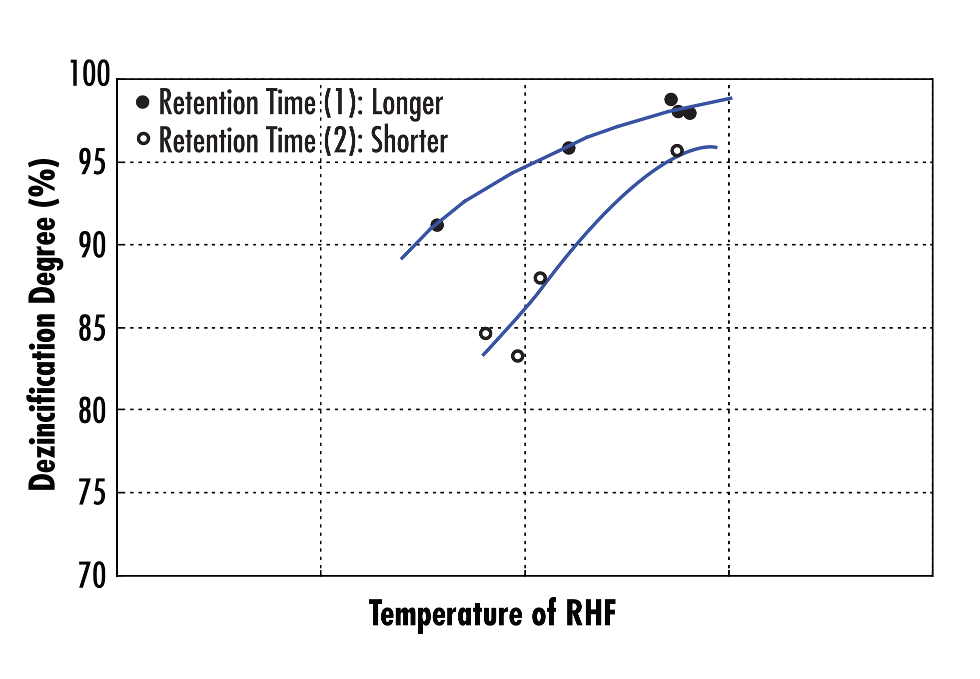

Figure 4 - Relationship of Temperature of RHF and Dezincification

NO_x (ppm)	SO_x (ppm)	Dust (g/Nm³)	Dioxin (ng-TEQ/Nm³)
<40	<50	<0.015	<0.1

Table VIII - Emissions Data of RHF at KPP

Figure 4 shows the relationship between the temperature in the RHF and dezincification degree. As the temperature in the RHF increases, the dezincification degree also rises. In addition, the dezincification degree increases with longer retention time.

Table VIII shows the emissions data of the RHF at KPP. Samples were taken at the outlet point of the bag filter. The NOx content in the flue gas was controlled to less than 40 ppm (12 percent O_2) and the dioxin content was lower than 0.1 ng-TEQ/Nm³.

DEVELOPMENT OF THE COAL-BASED FASTMELT PROCESS

Development Features of FASTMELT

KSL and Midrex Technologies, Inc. offer the FASTMELT process, using an Electric Ironmaking Furnace (EIF) to melt hot DRI and produce hot metal. Figure 5 shows the features considered in the development of the coal-based melter, which is a cylindrical stationary furnace operating at low pressure. The ultimate goal is continuous operation of the coal-based melter.

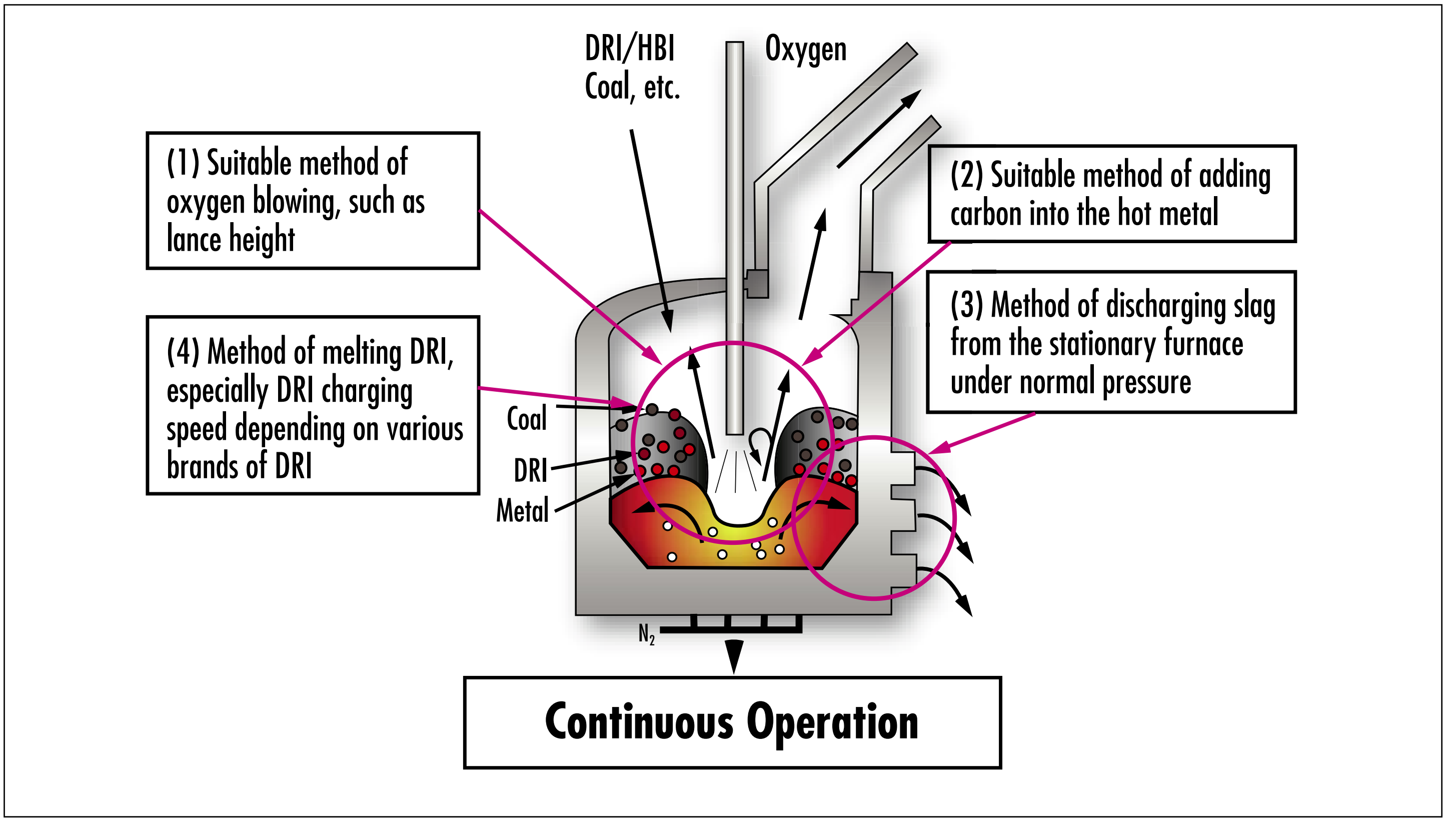

Figure 5 - Coal-based Melter Features

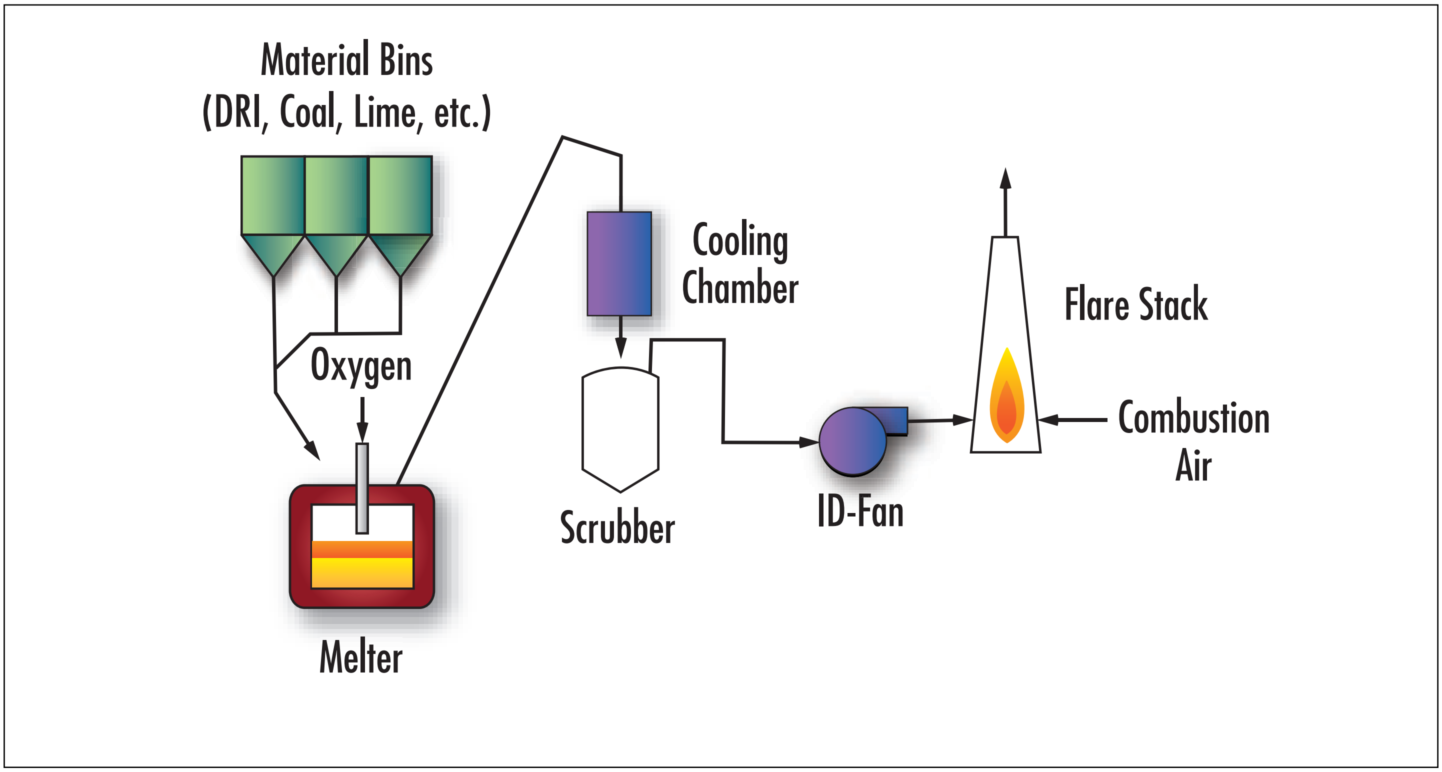

Figure 6 - Process Flowsheet of the Coal-based Melter

Cylindrical Stationary Furnace Method
Tapping: Drilling
Dimension: I.D. 2m x 2.6m
Capacity: 16,000 t/y Hot Metal

Table IX - Profile of Coal-based Melter

Feed Material	Metallization	Total Fe	Metallic Fe	C
Iron Ore	86.0	77.3	66.5	7.9
EAF Dust Carbon Steel	82.4	58.1	47.0	7.2
EAF Dust Stainless Steel	73.2	35.4	25.3	3.1

Table X - Typical Chemical Composition of DRI (mass %)

Process Flowsheet and Facility

Figure 6 shows the process flow and Table IX provides details of the equipment for the coal-based melter. DRI, coal and other materials are charged into the melting furnace from the top by gravity. Oxygen is blown into the furnace from the top using lances, and input energy is obtained from the oxidation of carbon. The flue gas passes through a cooling chamber that cools the flue gas down to less than 500° C using atomized water. This is followed by a wet scrubber to remove dust. The flue gas then goes to an induced draft fan and then to a flare stack. Combustibles in the flue gas are completely burned before discharge to the atmosphere. The capacity of the facility is 16,000 tons of hot metal per year.

Test Results

A typical chemical composition of the DRI produced using various feed material is shown in Table X. Figures 7 and 8 show typical operations data during

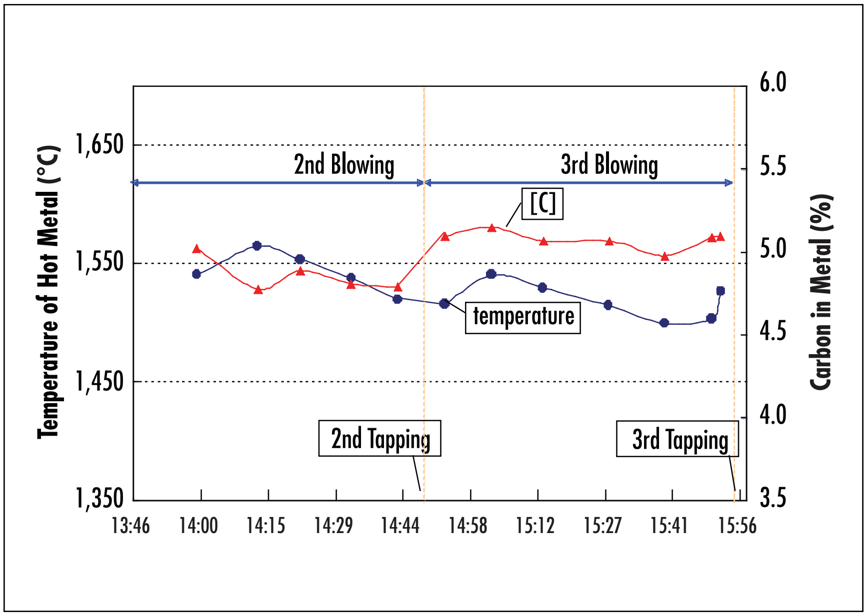

Figure 7 - Transition of Metal Temperature and Carbon Content

the testwork. The DRI charging rate was adjusted to control the temperature of the hot metal. The carbon content in the hot metal was kept above 4.7 percent.

Technical factors affecting the melting process were investigated during the numerous test runs.

The following results were achieved: development of suitable methods of oxygen blowing and lance height, adding coal, smooth tapping of hot metal iron using the coal-based melter.

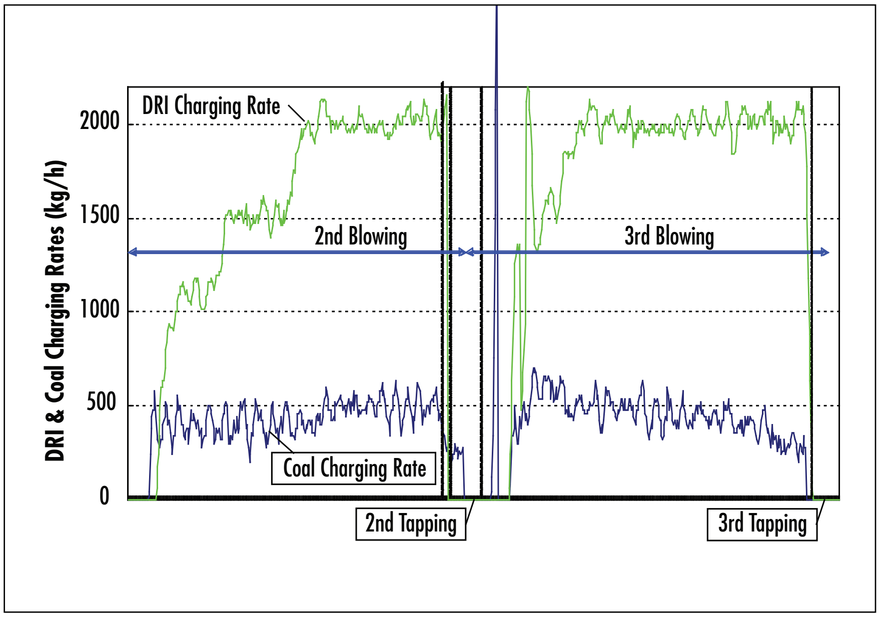

Figure 8 - Transition of DRI and Coal Charging Rates

FASTMELT Plant

The complete process flowsheet for a FASTMELT Plant is shown in Figure 9. DRI is produced in the RHF and fed hot to the melter to make hot metal.

CONCLUSION

Trials conducted at the Kobe Steel Kakogawa Pilot Plant with the support of METI provided the following results for the FASTMELT Process treating EAF dust and iron oxide:

- Development of an agglomerating technology to mix EAF dust and coal.
- Development of technology to achieve dezincification of over 95 percent, higher metallization and higher strength DRI than the rotary kiln process. As a result, the DRI can be used as a metallic feedstock for steelmaking, rather than being disposed of.
- RHF operations using EAF dust were undertaken without plugging, erosion and corrosion problems in the flue gas system. This is a challenge because EAF dust often contains ten times the amount of zinc as ordinary steel mill waste.
- Baghouse dust from the flue gas contained a higher zinc content than the rotary kiln product and less than one percent iron.
- NOx, SOx and dioxin emission levels were lower than for the kiln process. Dioxin emissions were less than 0.1 ng-TEQ/Nm^3.
- The FASTMELT process produced hot metal from iron ore fines and coal.
- The basic characteristics for melting various types of DRI using oxygen and carbon were confirmed.
- Discharging slag from the stationary furnace under normal pressure was carried out smoothly.
- The cycle of DRI melting to produce hot metal and tapping were repeated successfully.

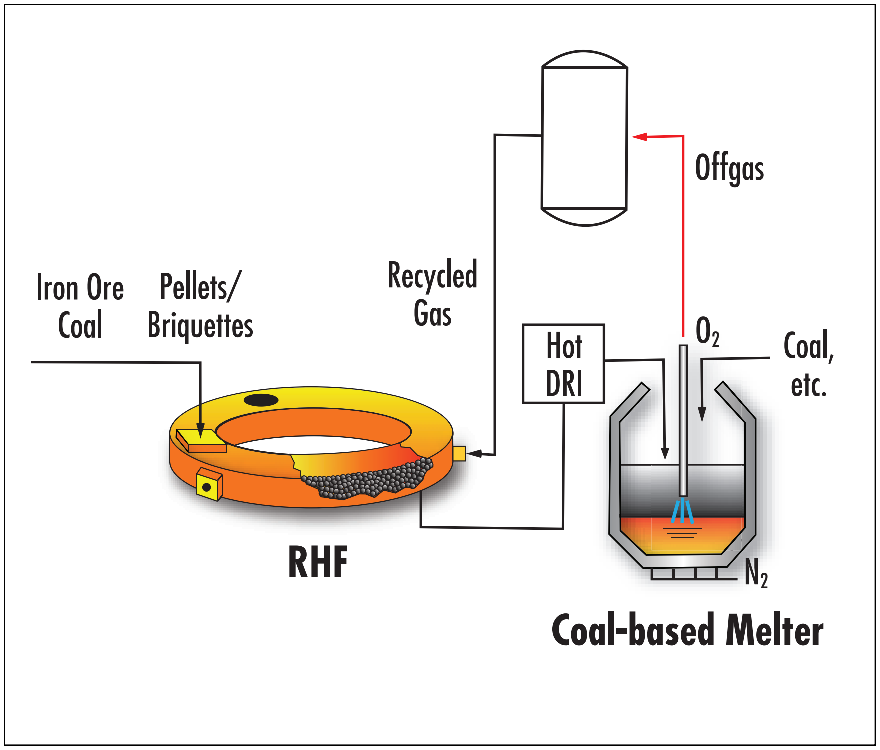

Figure 9 - FASTMELT Plant Flowsheet

The coal-based FASTMET Process provides a viable method to recover valuable metals using a rotary hearth furnace. Based on the results gained from the pilot plant, we were able to develop both the basic concept and engineering for the FASTMET Process. Taking an extra step using the FASTMELT Process, we successfully produced hot metal from the DRI. Based on these results, Kobe Steel is promoting commercial plants using the FASTMET Process to make DRI and the FASTMELT Process to make hot metal.

When EAF dust is used as the raw material, both processes can be used not only to recycle EAF dust, but also to effectively collect difficult-to-recover zinc, which can be subsequently recovered. In this way, these two innovative direct reduction processes can reduce the burden on the environment and contribute to the development of a sustainable society.