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THE STATE AND THE FUNCTION OF A THICK SLAG LAYER IN THE SMELTING REDUCTION PROCESS

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Synopsis: The state of the slag layer in smelting reduction with a large amount of slag was measured with various devices, and its influence on the characteristics of operation was investigated.

(1) The state of slag: The average density of the slag layer calculated by the detected slag height was 0.6-1.1 t/m^3. The temperature difference between the slag layer and the metal bath was 30°C or less. The amount of metal droplets in the upper 70 volume % of the slag layer depends on the stirring intensity of metal bath and slag compositions. 85-95 wt% of these originated in the stirred metal bath according to the tracer test.
By combining the sampling test and the calculation, the distribution of carbonaceous materials in the slag layer could be obtained.

(2) The influence of the state of slag on the characteristics of operation: The increase of metal droplets in the slag layer decreases post combustion and increases iron dust generation. The increase of the amount of slag decreases the generation of iron dust and carbon dust. When coal is used instead of coke, the carbon content of the metal bath decreases. These phenomena were explained by the distribution of carbonaceous materials and metal droplets in the slag layer.

Key-word: Smelting reduction, Slag layer, Carbonaceous material, Dust generation

1. Introduction

The smelting reduction process, in which the stirred metal bath is separated from an oxygen jet by a thick layer of slag, is under research.[1)-3)]

The slag layer is composed of molten slag, gas bubbles, metal droplets, and carbonaceous materials. The state of slag should influence the operational characteristics: post combustion, heat efficiency, dust generation, carbon content of metal bath, and so on.

The measurement of the slag layer was conducted by various devices, and the relationship among operational conditions, the state of the slag layer, and the characteristics of operation was discussed.

2. Experimental method

100 ton scale smelting reduction furnace was used. Specifications and experimental conditions are shown in Table 1. Fig. 1 provides a picture of the smelting reduction furnace. The metal bath is stirred by bottom bubbling gas. Oxygen was blown onto the slag layer. Raw materials (iron ore, carbonaceous materials, and lime) were charged from feeding bins above the furnace in order to keep the temperature of the molten bath almost constant. Varied conditions for test were the amount of bottom bubbling gas, the amount and the composition of slag, and the sort of carbonaceous materials (coke or coal).

Table 1 Experimental conditions.

Smelting reduction furnace	· Top-and-bottom blowing converter · Height ; 8,900mm · Inner diameter ; 5,400 mm
Operation	· Amount of metal;Max.100t · Temperature of metal ; 1400±50°C · Amount of slag ; 20-45t · Basity of slag ; CaO/SiO_2=1.1-1.4 · Top blowing ; O_2=20,000 Nm^3/h · Bottom bubbling ; N_2
Raw materials	· Iron ore (wt%) T. Fe 68.0 / SiO_2 0.96 / Al_2O_3 0.57 / H_2O 0.15 / Size lump and fine · Carbonaceous materials (wt%) Coke: FC 87.3 / VM 0.6 / Ash 12.1 / S 0.36 Coal: FC 55.2 / VM 36.5 / Ash 8.3 / S 0.70 Size: 5-25mm (85wt%) · Flux ; Lime

Iron ore (wt%):

T. Fe	SiO_2	Al_2O_3	H_2O	Size
68.0	0.96	0.57	0.15	lump and fine

Carbonaceous materials (wt%):

	FC	VM	Ash	S	Size
Coke	87.3	0.6	12.1	0.36	5-25mm (85wt%)
Coal	55.2	36.5	8.3	0.70	

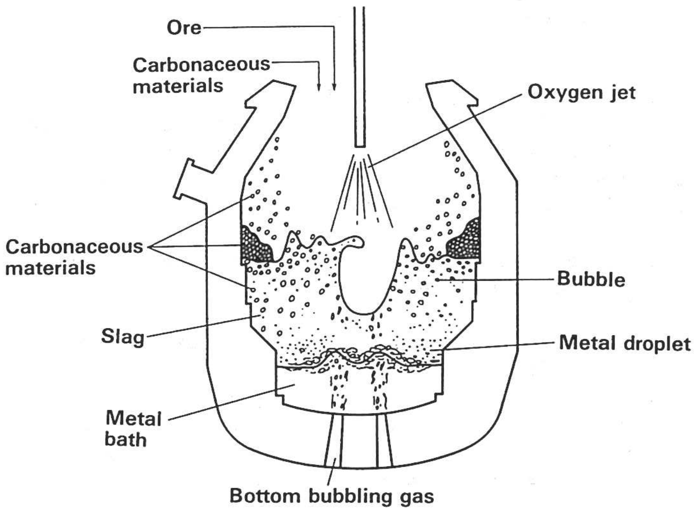

Fig. 1 Image of smelting reduction with a thick layer of slag.

The items measured in the slag layer are average density, distribution of temperature, the amount and the composition of metal droplets, and the size and the amount of carbonaceous materials.

3. Experimental results

3.1 Measurement of slag layer

(1) Density of slag layer

The slag surface can be detected by a change in electric conductivity. Average density was calculated by using the measured slag height (Fig. 2). Average density of the slag layer decreases with the increasing rate of CO gas evolution per cross area. When the rate of gas generation is high, the average density increases with the amount of slag. In the practical smelting reduction conditions, the average density of slag layer seems to be 0.8-1.0 t/m^3. Assuming that all the carbonaceous materials are entrapped in the molten slag layer, the average proportional volume of the slag layer can be calculated as follows: molten slag: 22-28 volume %, carbonaceous materials: 22-28 volume %, and gas bubbles: 44-55 volume %.

(2) Distribution of temperature

Temperatures at three points were measured simultaneously. The temperature of the lower 75% of the slag layer is almost equal to that of the metal bath. In the upper 25% of the slag layer, measured temperatures were 80-200°C higher than that of metal bath in some case, but in many case, the maximum difference in temperature is 30°C. As gas temperature is 200-300°C higher than that of the metal bath, the temperature in the former case seems to be influenced by the space involved.

(3) Metal droplets in slag layer

The amount of metal droplets in the slag layer is related to the vertical position, the intensity of stirring by bottom bubbling, and slag composition, that is, viscosity of slag (Fig. 3). When Mo was added to the metal bath as a tracer, the average Mo content of metal droplets was 85-100% that of the metal bath. On the size of the metal droplets, more than 90 wt% were larger than 1 mmϕ.

This means that more than 85-95% of the metal droplets in the slag layer is originated in the stirred metal bath.

(4) Carbonaceous materials in the furnace

When the furnace was tilted and bottom bubbling stopped, flotation of carbonaceous materials on the slag surface was observed. Though the size of coke and coal before charging were almost the same, the size distribution was shifted to the smaller side in the case of coal.

On the other hand, samples were taken from the slag layer during oxygen blowing and the carbon content in a ground sample was analyzed. The results show that the carbonaceous materials in the slag layer are average 30% of that in the assumption that all the carbonaceous materials are entrapped uniformly in the slag layer. As the data are scattering, the distribution of carbonaceous materials in the vertical direction is not clear.

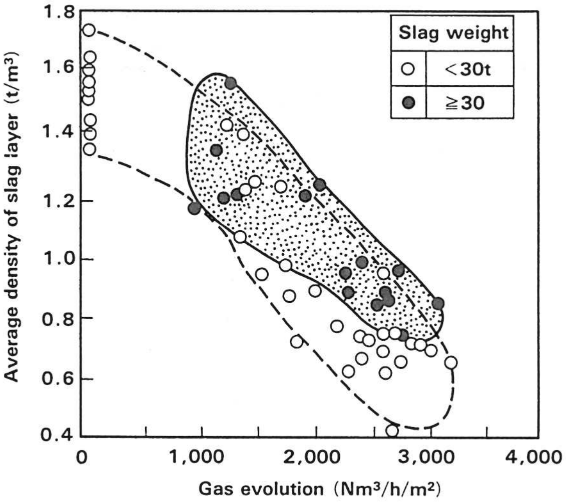

Fig. 2 Influence of gas evolution and amount of slag on average density of slag layer.

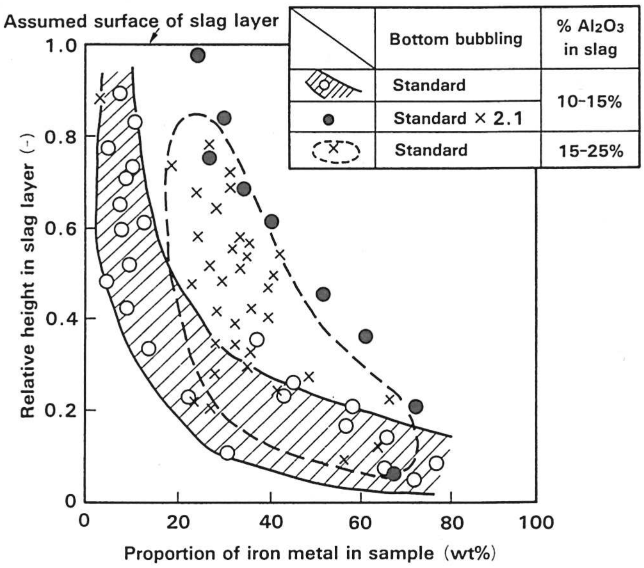

Fig. 3 Influence of stirring intensity and slag composition on amount of metal droplet in slag layer.

3.2 Influence on characteristics of operation

As the amount of metal droplets in the upper 70% of the slag layer increases, the iron dust generation increases, and post combustion decreases (Fig. 4).

As the amount of slag increases, the dust generation of iron and carbonaceous materials decreases at the same time. When there is a large amount of slag and the stirring by bottom bubbling is moderate, the carbon content of the metal bath is near the saturation point with coke. But, if the carbonaceous materials in the furnace are replaced by coal, the carbon content of the metal bath decreases. In this condition, supplying coke increases the carbon content again to over 4% (Fig. 5). Decarburization of the metal bath with coal is suppressed by increasing the stirring intensity.

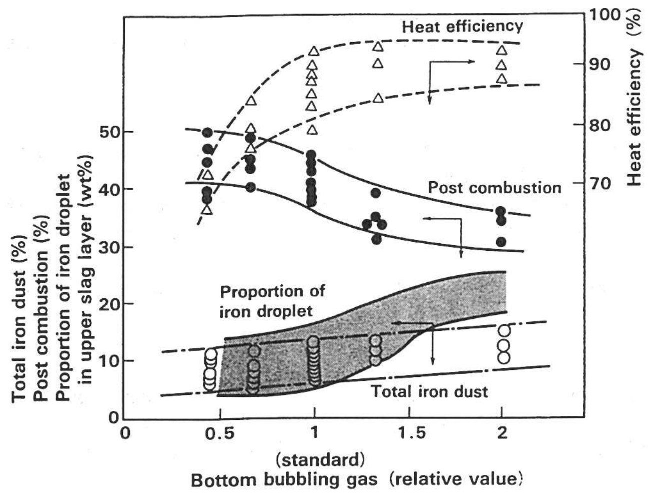

Fig. 4 Influence of bubbling intensity on characteristics.

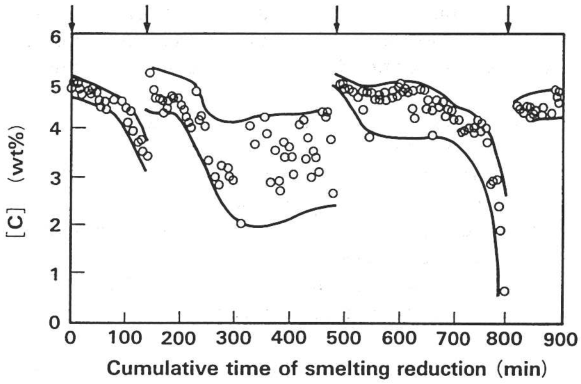

Fig. 5 Behavior of C content of metal bath during semi-continuous smelting reduction with high VM coal. (Coke was added only at the time shown by ↓)

4. Discussion

(1) Calculation of the distribution of carbonaceous materials in the slag layer

As it is difficult to observe the distribution of carbonaceous materials in the slag layer by sampling, a calculation was performed. The flow of the slag layer was assumed to be caused only by bottom bubbling from the center of the furnace, without considering the effect of gas generation by the oxide reduction in slag. The movement of carbonaceous materials in the slag layer was assumed to be determined by the flow of slag layer, flotation of carbonaceous materials. The carbon content at the outer and upper corner was defined as being 1.0, and the distribution of carbon was calculated. Though, in practice, carbonaceous materials are consumed and supplied during smelting reduction, a stationary condition is assumed in this calculation.

An example of the calculated flow pattern in the slag layer is shown in left part of Fig. 6.

The rate of the flotation of carbonaceous materials influences on carbon distribution, but it is difficult to calculate it theoretically. Therefore, the value was assumed from the X-ray fluoroscopic observation.[4] When carbonaceous material is graphite of 10 mmϕ, the measured velocity of flotation is about 90 mm/sec. Based on this value, terminal velocity of the flotation of coke in foamy slag is assumed to be 120 mm/sec. The calculated distribution of carbonaceous materials in the slag layer in that condition is shown on the right side of Fig. 6. The relative carbon content at the position where sample was

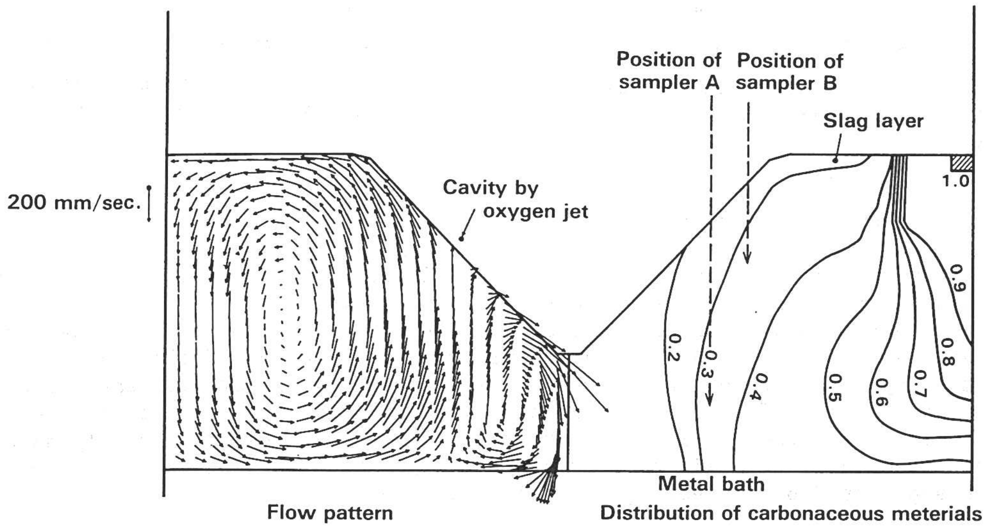

Fig. 6 Calculated flow pattern in slag layer and distribution of carbonaceous materials when floating velocity is 120mm/sec.

actually taken, is about 0.3. This value is about 60% of the average content of carbon in slag layer.

On the other hand, the velocity of flotation when coal is used was thought to be 160 mm/sec by considering the size distribution of carbonaceous materials and the change of density by the attached gas bubble on their surface.

The calculated distribution of carbonaceous materials for coal is shown in Fig. 7. The amount of carbonaceous materials is shifted to the outer and the upper side of slag layer.

In this calculation, the frequency of carbonaceous materials' entrapment in the slag layer is not considered. As it is thought that carbonaceous materials unwettable to slag are difficult to be entrapped stationarily in the slag layer, unstational entrapment, e.g. by rolling of the slag layer, ought to be predominant. It means that, at the standard point, the density of carbonaceous materials changes time by time.

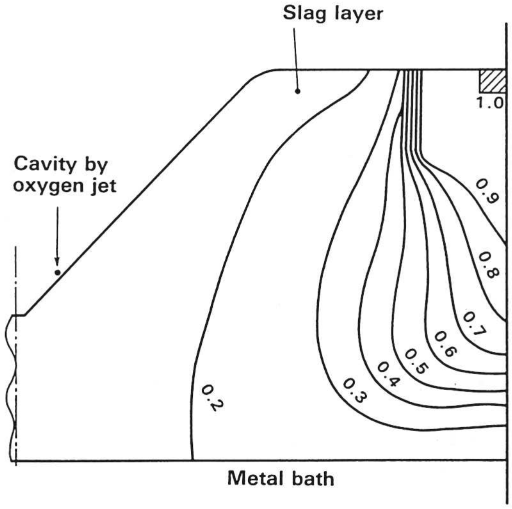

Fig. 7 Calculated distribution of carbonaceous materials when floating velocity is 160mm/sec.

(2) State of slag favorable to characteristics of operation and its control

Iron dust generation and post combustion

When metal droplets contact with oxygen jet or oxidizing atmosphere, the reaction

$$\underline{C} + \frac{1}{2} O_2 \rightarrow CO \quad \cdots\cdots \quad (1)$$

occurs and leads to an increase in dust generation, especially from the bursting of bubbles, and a decrease in post combustion. In order to suppress the contact of metal droplets and the oxidizing atmosphere, it is desirable to decrease the amount of metal droplets in the upper part of the slag layer as much as possible.

Carbon dust generation

When charged coal is fractured by rapid heating in a smelting reduction furnace, some portion of particles less than 2 mm is carried by rising streams of gas. The essential measure for decreasing carbon dust is the suppression of coal fragmentation by controlling heating,[5] but carbon dust generation is decreased by increasing the amount of slag. The assumed reason for this is that the amount of carbonaceous materials existing in the slag layer increases with an increase in the amount of carbonaceous materials, as shown in Table 2 which is obtained by calculation same as that described above. This is based on the assumption that carbonaceous materials in the slag layer are protected from a rising stream of gas in the furnace.

Table 2 Influence of slag amount on calculated relative carbon content in slag layer.

Amount of slag	Calculated relative carbon content in slag layer
20 t	0.3
30 t	0.5
45 t	1.0

Carbon content of metal bath

It is thought that carburization of the metal bath is accelerated by the contact of metal droplets and carbonaceous materials. When coal is used, the average content of carbonaceous materials in the lower 30% of the slag is decreased, compared to when coke is used. This seems to be the reason for the decrease of carbon content in the metal bath.

In order to improve various characteristics at the same time, it is necessary to adjust the distribution of the metal droplets, carbonaceous materials and oxygen gas jet in the slag layer as follows:

(a) The oxygen gas jet should not enter in the lower part of the slag layer, where there is a large amount of metal droplets.
(b) The amount of metal droplets in the upper part of the slag layer, where the oxygen gas jet enters, should be as low as possible.
(c) A sufficient amount of carbonaceous material can enter the lower part of slag layer, and can circulate.

These conditions can be realized by an appropriate combination of the amount of slag, the conditions of oxygen top blowing and bottom gas bubbling, and controlling the size of carbonaceous materials.

5. Summary

Various measurements of the slag layer in smelting reduction with a large amount of slag were performed, and the relationship among operational conditions, the state of the slag layer, and the characteristics of the operation were discussed.

In order to simultaneously realize high post combustion, acceleration of reduction and heat transfer, suppression of dust generation, and adjusting the carbon content of the metal bath, the control of the distribution of metal droplets, carbonaceous materials, and the oxygen jet in the slag layer is important.

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