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Development of Steel Scrap Melting Process

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Abstract:

Scrap Steel is a valuable iron source. Recently in the Japanese steel industry, a problem of surplus scrap steel is coming to surface with a steady increase in scrap generation against stagnant steel production that uses scrap steel. Against this background, Nippon Steel has been working on the development of technology for melting large amounts of scrap. In 1993, Hirohata Works shut down its blast furnace and commercialized the process of melting scrap in the basic oxygen furnace (BOF). In this paper, the importance of scrap melting is described, Nippon Steel's BOF scrap melting process is explained, and its activities concerning the recycling of scrap as typified by steel cans are introduced.

1. Introduction

Japan's steel accumulation has been yearly increasing, exceeded 1 billion tons in 1992, and is expected to grow further in the future. Along with the increasing steel accumulation, scrap supply has been increasing and amounted to some 50 million tons in 1990.

Scrap is consumed mainly in electric arc furnaces (EAFs) and partly in the blast furnace (BF)-basic oxygen furnace (BOF) process. Scrap is an iron source that needs no reduction energy, as compared with iron ore. Increasing the scrap consumption by developing a process that can increase the scrap recycle ratio will not only contribute to energy conservation, but also solve such problems as exhaustion of natural resources and global warming due to increasing emissions of carbon dioxide gas (CO_2). This is one of the challenges confronting the steel industry.

Nippon Steel commissioned a BOF scrap melting process at Hirohata Works in June 1993 to pioneer a new form of scrap melting. Steel cans and other scrap generated in the market, let alone return scrap or home scrap, are recycled and melted into steel products.

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This article explains the importance of scrap melting, describes Nippon Steel's scrap recycling activities, and introduces the BOF scrap melting process developed to support the scrap recycling activities.

2. Importance of Scrap Utilization Technology

Scrap may be broadly classified into home scrap generated at steelworks, prompt industrial scrap generated in the course of steel processing at machine shops and the like, and dormant scrap comprising obsolete, worn or broken products of steel consuming industries. Generation of home scrap has little changed in recent years thanks to various measures taken to improve yield, such as continuous casting. This is also true of prompt industrial scrap, which reflects the cost-saving effort of users. Dormant scrap now accounts for a little over one half of the total scrap supply, and is predicted to increase further with increasing accumulation of steel on the market.

The above situation is graphically represented in **Fig. 1** by the annual changes in steel accumulation and market scrap (or prompt industrial scrap and dormant scrap). Japan's steel accumulation has yearly increased, marked a little less than 1 billion tons in 1991, and is projected to grow further in the future. Generally, generation of dormant scrap can be estimated from the service life and accumulation of various steel products. Roughly speak-

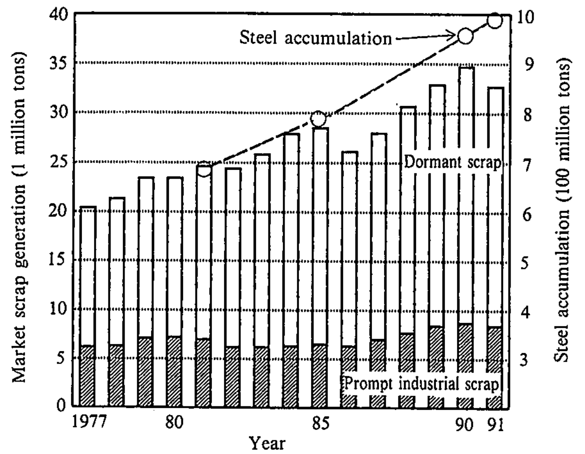


Fig. 1 Annual changes in steel accumulation and market scrap generation in Japan

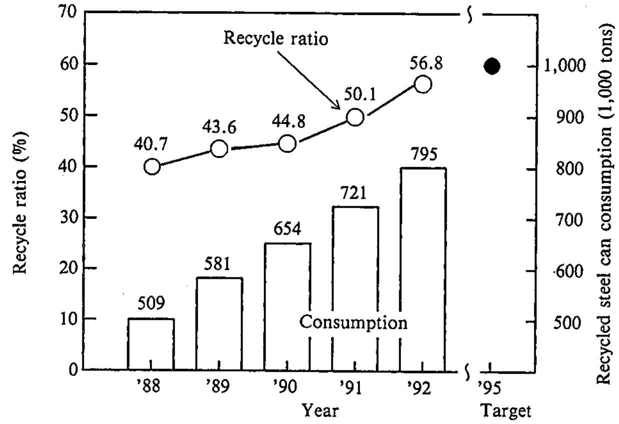


Fig. 2 Changes in recycled steel can tonnage and recycle ratio

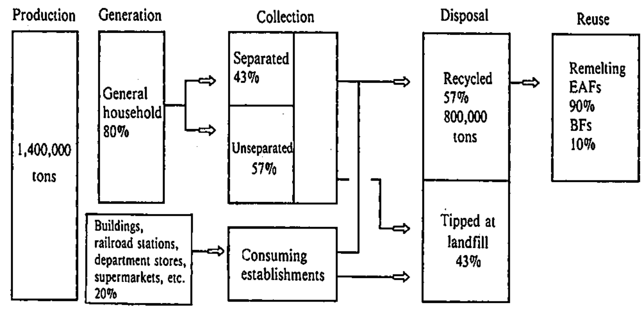


Fig. 3 Steel can retrieval in 1992

ing, the generation of dormant scrap is proportional to the accumulation of steel on the market. In recent years, generation of dormant scrap has increased with increasing steel accumulation. Market scrap now totals more than 30 million tons per year.

In contrast with this scrap generation, the steel demand is not expected to grow under the current environment surrounding Japan's steel industry, and the increasing trend of scrap supply as an iron source cannot be overlooked. In other words, scrap is an iron source that does not need reduction energy as iron ore does. Efficient melting of scrap is considered to reduce the total cost of steel production, depending on the scrap price, to prevent natural resources from being exhausted, and to reduce carbon dioxide emissions. Increase of scrap supply against scrap demand means that if scrap consumption does not increase, scrap, particularly dormant scrap, will be left discarded as polluting waste in increasing quantities.

Against this background, Nippon Steel has been positively carrying out scrap recycling activities. As an example, steel can recycle is introduced below. Nippon Steel's technology for increasing the amount of scrap melting in the BOF and the new BOF scrap melting process it developed as an extension of the conventional technology are also described.

3. Actual State and Future Targets of Steel Can Recycle

The Japan Used Can Treatment Association has been carrying out a steel can recycling campaign. Nippon Steel is participating in the campaign.

Fig. 2[1)] shows the recent statistics of steel can recycle ratio and recycled steel can consumption in Japan. Production of steel cans in 1992 was 1.4 million tons, of which 800,000 tons or 57% were recycled. Production and recycle figures are as shown in **Fig. 3**.

Beverage cans are either steel cans or aluminum cans. Steel sheet for steel cans can be produced with only one-eighth of the energy required for the production of aluminum sheet for aluminum cans. Steel cans can be easily separated from other wastes by magnets. If steel cans are collected as separated at sources in increasing amounts, their recycle ratio will improve further.

The Japan Used Can Treatment Association in which Nippon Steel taken part is working toward a target steel can recycle ratio of over 60% in 1995. Particular efforts are exerted for increasing the consumption of recycled steel cans to more than 200,000 tons annually in the blast furnace operation.

The history of technology development for melting large amounts of scrap is described in the next chapter.

4. Progress in Technology of Melting Scrap in BF-BOF Process

In the BOF steelmaking process that uses the heat of carbon oxidation, the heat of reaction from C to CO is mainly used. The heat of reaction from CO to CO_2, however, is much greater than that from C to CO as given by Eqs. (1) and (2). If the secondary combustion (post combustion) step from CO to CO_2 is utilized, the amount of scrap melting can be increased without prolonging the tap-to-tap time.

$$C + 1/2O_2 = CO + 9{,}209\ \text{kJ/kg-C} \quad (1)$$

$$CO + 1/2O_2 = CO_2 + 23{,}567\ \text{kJ/kg-C} \quad (2)$$

In normal BOF operation, the ratio of CO burned to CO_2 (the post combustion ratio) is 5 to 10%. It has been confirmed that the amount of scrap melting can be increased by increasing the post combustion ratio. For example, the scrap ratio can be increased by 3.4% by increasing the post combustion ratio by 10%.

In view of the importance of grasping the post combustion behavior during BOF refining, Nippon Steel worked to clarify the mechanism of post combustion. The post combustion mechanism is explained hereunder from the behavior of an oxygen jet in the BOF as illustrated in **Fig. 4**.

As shown in the figure, oxygen jet discharged from the top blowing lance nozzle propagates through the supersonic and transition speed regions until it becomes a free jet. The reaction between the oxygen jet and the CO gas (gas produced by decarburization) entrained by the free jet forms a jet predominantly composed of CO_2. In the surface layer of the CO_2 jet or at velocities lower than the critical velocity, some CO_2 escapes from the CO_2 jet while accompanying the CO gas flow generated at the lower hot spot. The post combustion ratio depends on the ratio of the amount of fugitive CO_2 to the amount of CO generated by the decarburization reaction[2]. The possibility of controlling the post combustion ratio from the jet behavior has been elucidated.

A coal top blowing process (ALCI process) was developed as a positive method of adding a heat source in the BOF[3]. The ALCI process injects coal at high speed into the bath in the furnace and promotes the post combustion of CO by a lance with main and auxiliary oxygen holes. The benefit of the ALCI process is shown in **Fig. 5**. As compared with the conventional top coke addition process, the ALCI process was found to provide a higher scrap ratio at the same amount of carbon combustion. This benefit may be explained from improvements achieved in the carbon yield and post combustion ratio.

The new BOF scrap melting process developed against the above-mentioned technological background is described in the chapter that follows.

5. BOF Hot Heel Scrap Melting Process

5.1 Outline[4]

Nippon Steel commercialized a new BOF scrap melting process at Hirohata Works in July 1993. When the switchover was made from the conventional BF-BOF process, the new process concept was formed from the following considerations:

(1) Utilize the existing BOF to reduce the equipment cost and retain the freedom of raw materials and fuel use.
(2) Separate the scrap melting furnace and the decarburizing furnace to secure high productivity and high product quality.
(3) Minimize the total production cost through the effective utilization of waste energy, such as recovering the off-gas via the OG system of the BOF plant.

Accordingly, Nippon Steel developed the new BOF hot heel scrap melting process as shown in **Fig. 6**.

Fig. 7 shows the flow chart of melting operation by the new process. Scrap is charged into the melting furnace from above through a chute, and coal and oxygen are blown into the charge as fuels through the bottom of the furnace. The scrap is rapidly melted by the heat of post combustion by the top lance as well. Upon completion of the scrap melting period, a half of the hot metal is tapped from the melting furnace, desulfurized and otherwise treated, and charged into the decarburizing furnace. Features of this process may be summarized as follows:

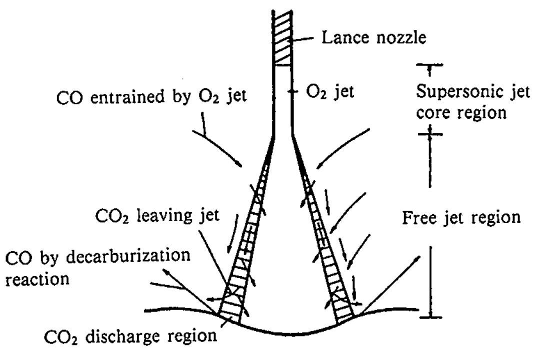


Fig. 4 Schematic illustration of post combustion mechanism

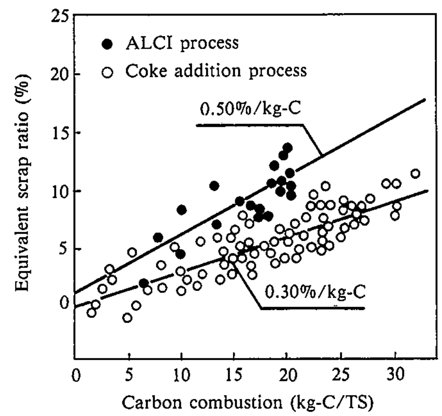


Fig. 5 Benefit of ALCI process

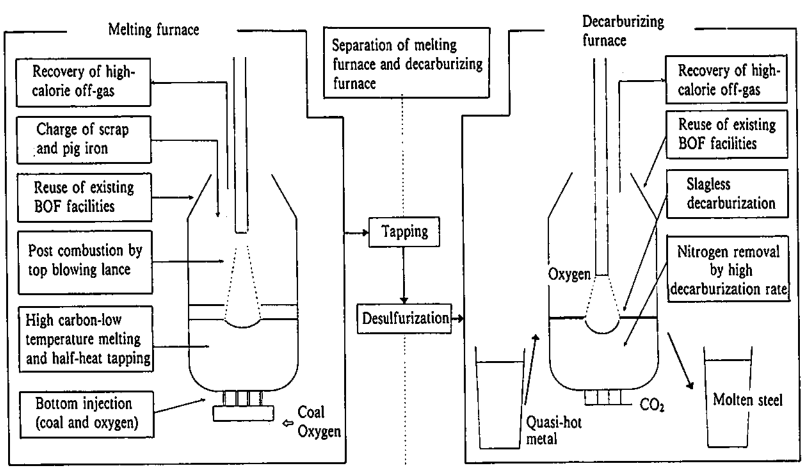


Fig. 6 Hot-heel BOF scrap melting process

(1) Fast and stable melting of scrap by leaving a half of each heat in the melting furnace
(2) Stable production of clean steel through the treatment of quasi-steel by the process similar to the conventional process
(3) Extended refractory life under low-temperature melting
(4) Simultaneous securement of melting heat source by controlling the post combustion ratio and utilizing the recovered off-gas
(5) Bottom injection of pulverized coal in the utilization of low-cost coal and from the viewpoint of hot metal carburization in the vicinity of scrap melting

The constituent techniques that support the new process are described in the sections that follow.

5.2 Importance of post combustion in melting furnace; Control method

An example of heat balance in the melting furnace is shown in **Fig. 8**. The heat of post combustion from CO to CO_2 is extremely large, and an increase in the amount of post combustion leads to an improvement in the melting productivity. From the standpoint of recovered gas quality, however, an excessive increase in the amount of post combustion is not preferred, and therefore the control of post combustion is important.

As to the mechanism of BOF post conbustion, only the behavior of the top-blown oxygen jet described in the preceding chapter has been given due consideration[2]. Since this model is intended only for top-blowing conditions, it was reviewed for the addition of coal and oxygen bottom injection. Assuming that the CO evolving from the bottom-blown oxygen and hydrogen introduced by the bottom-injected coal only serve to dilute the gas evolving from the top blowing, simplified model equations were prepared for estimating the post combustion ratio[5].

$$PCR' = 10(x/d)^{0.3} - 100(x/d)^{-0.7} + 1 \quad \cdots\cdots (3)$$

$$PCR = R \cdot PCR'/(1 + PCR' - R \cdot PCR') \quad \cdots\cdots (4)$$

where PCR' is the post combustion ratio with top blowing alone; PCR is the post combustion ratio with both top and bottom blowing; x is the length of the free jet (mm); d is the lance hole diameter (mm); and R is the top blow ratio.

The relationship between PCR' back calculated from the mean post combustion ratio during the melting period and the top blow ratio and x/d is shown in **Fig. 9**. The relationship between the observed mean post combustion ratio and the post combustion ratio calculated by the above model is shown in **Fig. 10**. The data obtained verified the validity of the new simplified model for predicting the post combustion ratio during the melting period and controlling the amount of post combustion in the melting furnace.

The target post combustion ratio can be achieved by changing the lance shape, lance height, and other relevant conditions as required.

5.3 Scrap melting behavior

Understanding the scrap melting mechanism is important in not only predicting process productivity but also controlling the temperature and carbon content of hot metal. Described below are the results of melting behavior experiments using 500-kg and 5-ton furnaces and melting model studies.

In the 5-ton furnace, copper was added to hot metal before scrap melting, and the scrap melting ratio was determined from the dilution of the copper. The bath temperature variation during the melting period was also measured. The results are given

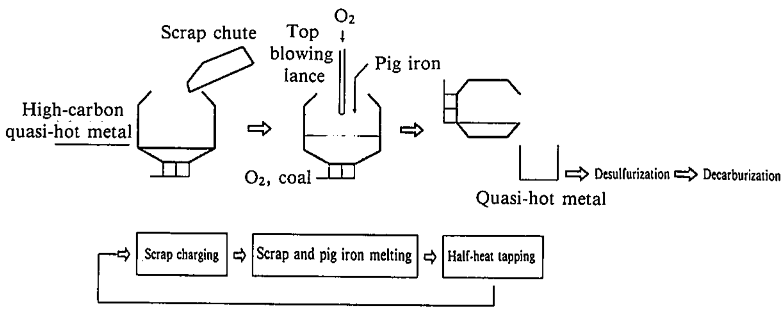


Fig. 7 Flow chart of melting in hot-heel BOF scrap melting process

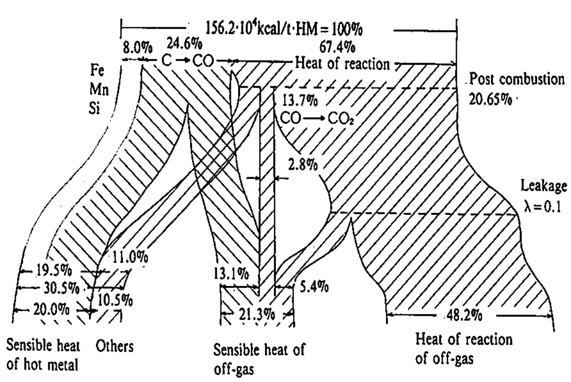


Fig. 8 Example of heat balance assumed for full-scale scrap melting furnace

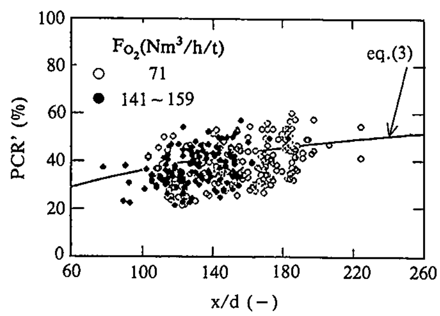


Fig. 9 Relationship between PCR' and x/d

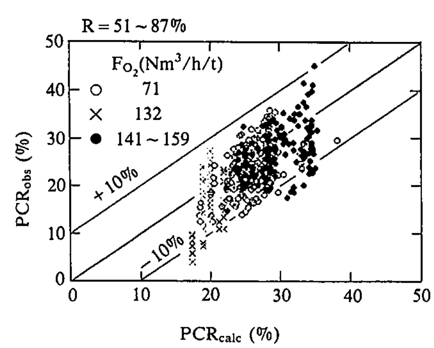


Fig. 10 Comparison of measured and calculated PCR

in **Fig. 11**. In the initial melting stage, the bath temperature dropped, and the melting ratio did not rise. After 10 minutes into the melting process, the melting ratio and bath temperature both started to rise.

The carbon and temperature profiles near the scrap-hot metal interface during the melting period are schematically illustrated in **Fig. 12**. The melting of scrap is promoted by the following conditions:

(1) Increase of interface carbon content C_s with increasing bath carbon concentration
(2) Increase of interface carbon content C_s and interface temperature T_s with increasing bath stirring force
(3) Rise in the bath temperature

To quantify the factors that promote the scrap melting, a melting behavior model[6] that allows for simultaneous heat and mass transfer, and a BOF heat and mass balance model[7] were combined to build a scrap melting model[8]. It was confirmed that the model brings out results that practically agree with the experimental results shown in **Fig. 11**.

5.4 Effect of coal melting on scrap

For appropriate control of the bath carbon concentration during the scrap melting period and for the promotion of the above-mentioned scrap melting behavior, the melting behavior of the coal injected into the hot metal must be clarified. The melting of coal was analyzed using the 500-kg and 5-ton furnaces.

Various carbonaceous materials were placed on the molten iron bath in the 500-kg furnace, and the resultant carburization rate under gas stirring was measured. The carbonaceous materials used in the experiment are shown in **Table 1**. The apparent mass transfer coefficient was calculated from the obtained carburization rate and bath cross-sectional area, and was compared with the sulfur content of coal, as shown in **Fig. 13**. The carburization rate decreases with increasing sulfur content. This effect can be explained by the action of sulfur that is a surface active element. The carburization rate increases with decreasing volatile matter of coal.

Assuming that the coal melting rate is controlled by the metal mass transfer, a model for predicting the coal melting rate was studied.

The carburization rate measured without top blowing is considered to correspond to the difference between carburization from the bottom-injected coal and carburization from the bottom-blown oxygen, and is given by

$$d[C]/dt = k\cdot(A/V)\cdot([C]_s - [C]) \quad \cdots\cdots (5)$$

where A is the reaction interface area defined by the amount of coal in suspension and the specific surface area of coal. The amount of coal in suspension is determined from the hot metal rising rate[9] and coal injection rate.

Using the model, the results of the 5-ton furnace experiment under the conditions of **Table 2** were evaluated (see **Fig. 14**). As the bath carbon concentration increases to approach saturation, the melting rate of the bottom-injected coal declines. When the coal is high in sulfur and low in carburization nature, the coal melting rate is lower under a lower bath carbon concentration.

Measurements were made also of the carbon concentration in the dust generated when scrap was melted with the top-blown oxygen. When different types of coals were used, unmelted coal particles were observed in the dust if the carburization rate fell below a certain level.

Thus, the promotion of coal melting calls for the selection of low-sulfur and low-volatile coal and the injection of pulverized coal.

Control of the post combustion ratio with attention focused on the lance conditions, and optimization of the scrap melting

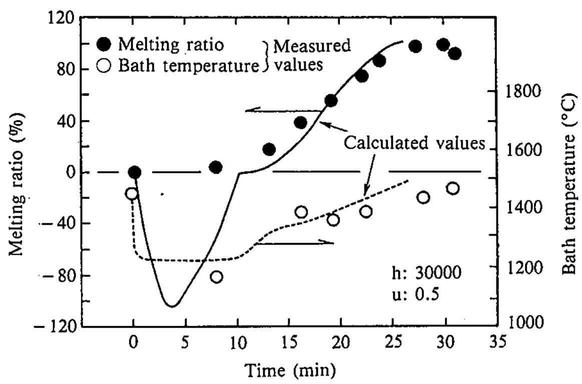
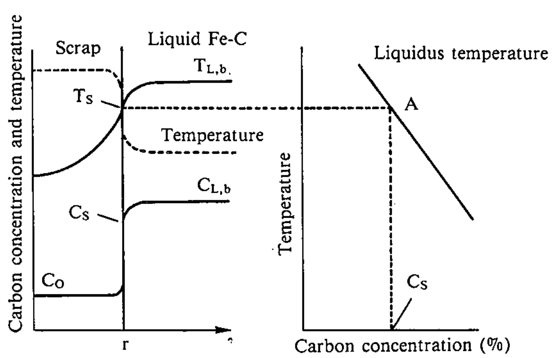


Fig. 11 Changes with time in melting ratio and bath temperature (5t pilot furnace)



(a) Temperature and carbon concentration profiles (b) Carbon concentration versus liquidus temperature

Fig. 12 Bath carbon concentration and temperature near scrap-bath interface

Table 1 Compositions of carbonaceous materials

(wt%)

Material	FC	VM	S	Ash
A (graphite)	98.8	0.8	tr	0.4
B (coke)	84.5	3.4	0.50	12.1
C (coal)	78.9	6.7	0.08	14.4
D (coal)	79.6	6.0	0.33	14.5
E (coal)	59.3	32.8	0.50	7.9

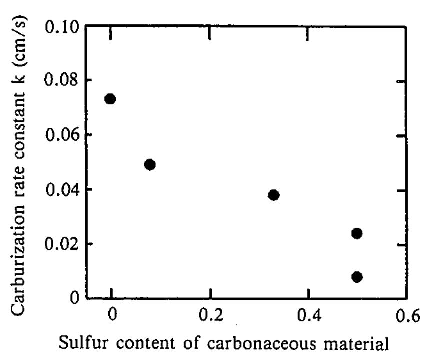


Fig. 13 Effect of sulfur content of coal on carburization rate

Table 2 Experimental conditions

Hot metal	5 tons, 1300-1500°C $[C]_{ini}$: 2.0-3.5%
Gas flow rate	N_2: 1.6-5.8 Nm^3/min O_2: 0.0-3.5 Nm^3/min LPG: 0.0-0.2 Nm^3/min
Coal feed rate	9.0-12.5 kg/min

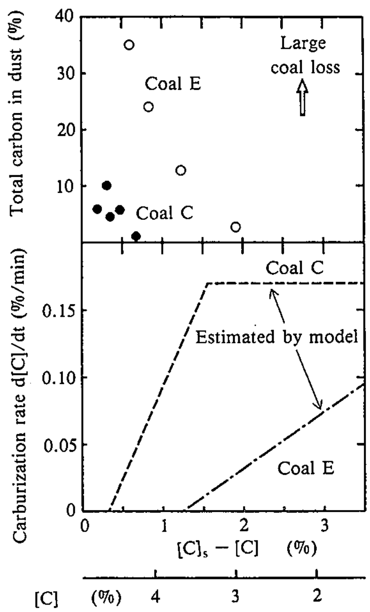


Fig. 14 Effect of coal type on carburization rate

rate that depends on the bath carbon concentration and stirring force and of the coal melting rate as required to maintain the desired bath carbon concentration are important in the new hot-heel BOF scrap melting process.

6. Future Outlook

Recycling of used materials is becoming a worldwide trend, as symbolized by the issues of the global environment. The hot-heel BOF scrap melting process will draw attention as a new process that can solve the iron source problem while making effective use of the structure of existing steel plants.

As an integrated steelmaker, Nippon Steel has pioneered effective scrap utilization processes, as represented by the new hot-heel BOF scrap melting process, and has moved to address future changes in the iron source structure. The authors intend to push ahead with studies for an early commercialization of new technologies through the activities of the Environmentally Friendly Advanced Steelmaking Process Forum that has been researching on the effective utilization of low-grade scrap.

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