VIEW POINTS AND POSSIBILITY FOR INNOVATION OF BLAST FURNACE IRONMAKING[1]

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Abstract

Reduction of CO2 emission is the most important subject in a blast furnace operation. The key point of reduction of CO2 emission is to decrease the Fe-FeO-CO-CO2 equilibrium temperature in the blast furnace shaft. Considering the equilibrium temperature is decided by the carbon solution loss reaction, an acceleration of its reaction might be the key technology in the blast furnace ironmaking. Recently, various methods such as the carbon composite agglomeration and the alkali addition to the coke have been studying to accelerate the carbon solution loss reaction and the iron ore reduction. In these studies, it was found that the beginning temperature of carbon solution loss reaction was decreased by the vicinity arrangement of ore and coke. It shows the possibility of innovative blast furnace ironmaking lead to CO2 gas reduction. This paper introduces the acceleration effects of iron ore reduction and carbon gasification reactions by the vicinity arrangement of ore and coke.

Key words: CO2 emission; Blast furnace; Carbon solution loss reaction; Reduction; Vicinity arrangement of ore and coke

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1 INTRODUCTION

In the new century, the demand for the CO_2 reduction has strengthened more and more for solving environment and energy problems in worldwide. Under this situation, the reduction of CO_2 emission is the most important subject in the iron and steel industry that is using about the half of the fossil fuel, and especially in the ironmaking section that is using about 70% of energy in iron and steelmaking. Japanese steel companies had set the independent action target of the CO_2 reduction by 10.5% until 2010 compared with that in 1990, and have been had various approaches such as the improvement of coke reactivity, the properly of gas and the solid flow in the blast furnace and the waste plastic injection, etc., for aiming at the decrease of coke ratio of blast furnace. However, accomplishment of a goal is extremely difficult under the situation in which the crude steel production increases and the iron ore quality deteriorates. Therefore, an innovative ironmaking technology is necessary for a great improvement of the blast furnace energy consumption. Here, the view points and the possibility for innovation of blast furnace ironmaking are described standing on the base of the reduction and the smelting reaction of iron ores.

2 CURRENT SITUATIONS AND ISSUES OF CO_2 REDUCTION

Figure 1 shows the transition of the energy consumption in Japanese steel industry from 1990. The CO_2 emission had been decreased from 1990 to 2001 satisfactory. However, it changed to the increase again in 2001 because of the increase of a worldwide steel production, and the reduction amount of CO_2 in 2006 has stayed in 5.1%. Considering the continuation of the crude steel demand, it is worried that the CO_2 reduction in 10.5% until 2010 is very severe. Figure 2 shows the relationship between the reducing agent rates (RAR) and the production ratio in the blast furnace operation in the world. In order to achieve the CO_2 reduction in 10.5%, the decrease in RAR from 500 to 450 kg/t-p and the increase in production ratio from 2.2 to 2.7t/dm^3 are necessary with an innovative improvement of blast furnace ironmaking.

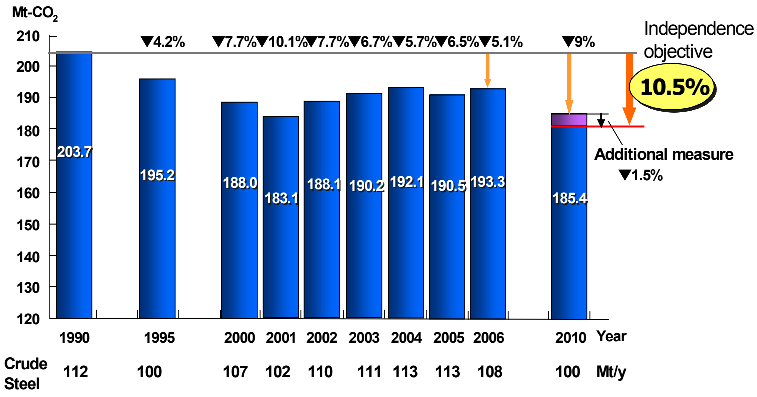


Figure 1. Trend of energy consumption in Japanese steel industry.

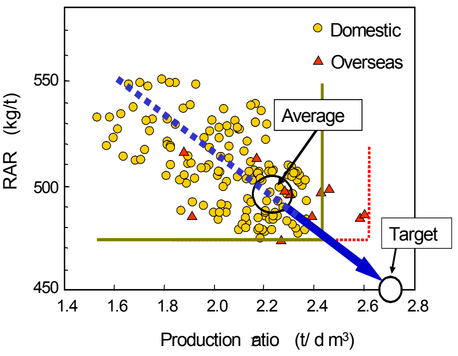


Figure 2. Relationship between RAR and production ratio.

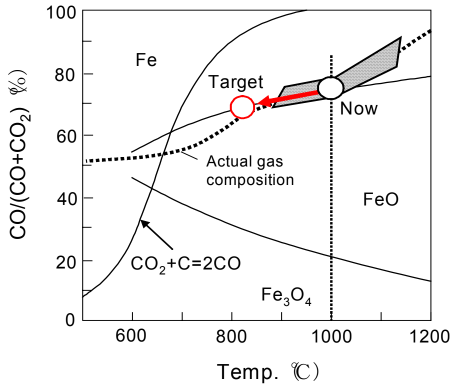
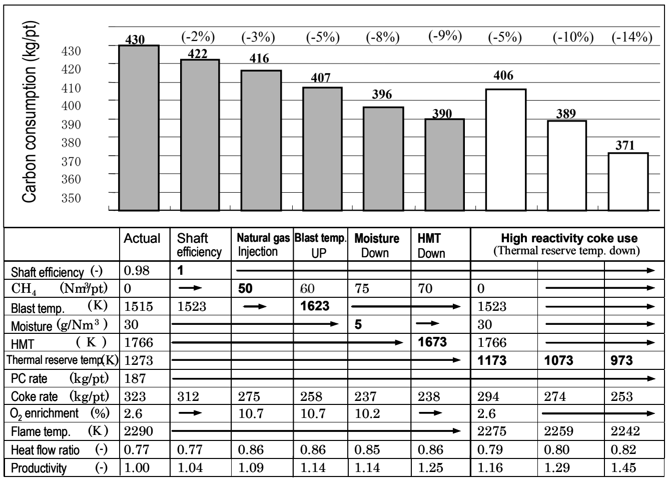


Figure 3. Gas composition in actual blast furnace.



	Actual	Shaft efficiency	Natural gas Injection	Blast temp. UP	Moisture Down	HMT Down	High reactivity coke use (Thermal reserve temp. down)		
Shaft efficiency (-)	0.98	1	→	→	→	→	→	→	→
CH_4 (Nm³/pt)	0	→	50	60	75	70	0	→	→
Blast temp. (K)	1515	1523	→	1623	→	→	1523	→	→
Moisture (g/Nm³)	30	→	→	→	5	→	30	→	→
HMT (K)	1766	→	→	→	→	1673	1766	→	→
Thermal reserve temp(K)	1273	→	→	→	→	→	1173	1073	973
PC rate (kg/pt)	187	→	→	→	→	→	→	→	→
Coke rate (kg/pt)	323	312	275	258	237	238	294	274	253
O_2 enrichment (%)	2.6	→	10.7	10.7	10.2	→	2.6	→	→
Flame temp. (K)	2290	→	→	→	→	→	2275	2259	2242
Heat flow ratio (-)	0.77	0.77	0.86	0.86	0.85	0.86	0.79	0.80	0.82
Productivity (-)	1.00	1.04	1.09	1.14	1.14	1.25	1.16	1.29	1.45

Figure 4. Effect of operation condition on coke rate and productivity by Rist diagram.

3 THEORETICAL ASPECTS TO DECREASE THE REDUCING AGENT RATES OF THE BLAST FURNACE

The typical gas composition in ordinary blast furnace is shown on the Fe-C-O system as Figure 3. The gas composition in many blast furnaces is almost on the Fe-FeO equilibrium in the area from 900 to 1000 °C as shown in the shaded portion in Fig.3. This means that the reduction rate is determined by the carbon solution loss reaction (Boudouar reaction). On the other hand, the CO gas concentration in the area above 1000°C becomes lager than that in the Fe-FeO equilibrium by the enhancement of the carbon solution loss reaction. This means that the reduction rate is determined by the both of the iron reduction and the carbon solution loss reaction. The temperature in which the carbon solution loss reaction is activated is corresponded to the temperature of the thermal reserve zone (Here, it named as TRZ). Based on the RIST diagram, the decrease in the temperature of TRZ leads to the reduction of the reducing agent rates of the blast furnace. S.Ujisawa[1] et al. had calculated the change of the reducing agent rates in various operation condition of blast furnace by using the RIST diagram. Figure 4 shows the effects of CH_4 gas injection and the temperature of TRZ on the reducing agent rates and the production rates of blast furnace. As shown in the figure, the influence of the temperature of TRZ is very large comparing with CH_4 injection, and the reducing agent rates decreased by 20kg/p-t for 100°C reduction in the temperature. Considering this calculation results, it can be estimated that the CO_2 reduction by 6.5% as the target in ironmaking field is achieved by lowering the temperature of TRZ up to 850°C.

4 CONTROL THE TEMPERATURE OF THERMAL RESERVE ZONE

In order to lower the temperature of thermal reserve zone, it is necessary to enhance the carbon solution loss reaction in 800-1000°C region. In general, the carbon solution loss reaction can be activated by various methods such as the pore control of coke, the addition of the metallic iron and the alkali catalyst to the coke, and the vicinity arrangement of iron ore and coke etc. The effects of the vicinity arrangement of iron ore and coke and the catalyst addition to the coke are presented as follows.

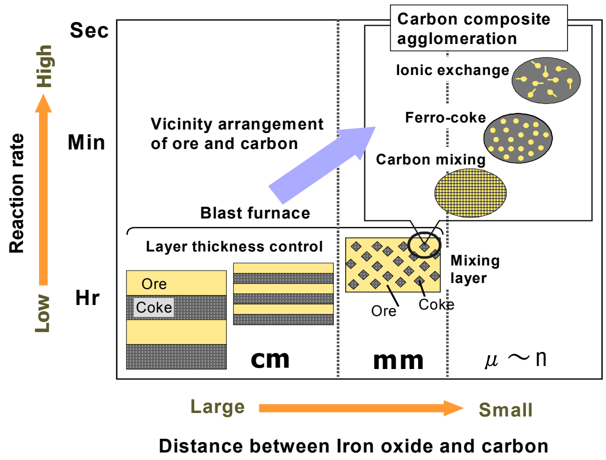


Figure 5. Relationship between reaction rate and arrangement of iron oxide and carbon.

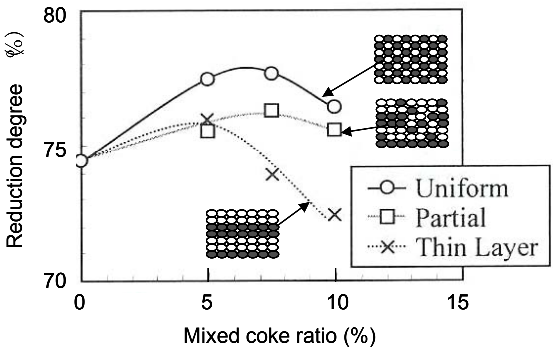


Figure 6. Change in reduction degree by mixed coke with mixing way at 1200°C.

4.1 Vicinity Arrangement of Iron Ore and Coke

The iron ore reduction and the carbon solution-loss reaction in a lumpy zone of blast furnace are greatly depending upon the diffusion of CO and CO_2 molecule in the solid particles and the gas film on the solids surface. Therefore, the particle arrangement which minimizes the diffusion resistant and the diffusion length is very effective for a drastic improvement of a reaction rate and its efficiency. Figure 5 shows the effect of the arrangement of iron ore and solid carbon on the reaction rate. The reaction rate will be increased in exponential with vicinity arrangement of iron ore and solid carbon from the layer by layer structure to the mixture. The increase in the reaction rate by the vicinity arrangement of iron ore and solid carbon is caused by the decrease in the gas diffusion resistant and the increase in the chemical potential of reducing gas by the carbon gasification reaction at contacting area of ore and carbon. Figure 6 shows the changes in the reduction rate by the mixed charging of ore and coke at actual blast furnace[2]. As shown in the figure, the reduction rate increases with uniformity of ore and coke mixture. Furthermore, when the iron ore was arranged close by the carbon, it was found out that the beginning temperature of the carbon solution-loss reaction became to lower apparently. This phenomenon is caused by the partial heat radiation from iron ore particles to the solid carbon as shown in Figure 7. This means the effect of coupling reaction between the reduction reaction with exothermic and the carbon solution-loss reaction with endothermic. Figure 8 shows the behavior of carbon solution-loss reaction detected by using the facing pair of hematite and carbon plate[3]. As shown in the figure, the beginning temperature of carbon solution-loss reaction was decreased by around 300 °C in the facing pair comparing with the single plate of carbon. This result shows that the carbon solution-loss reaction can be accelerated from the low temperature region by the vicinity arrangement of iron ore and carbon. Figure 9 shows the changes of in-furnace gas composition when the carbon composite iron ore briquettes were used in the model blast furnace test [4]. The reduction equilibrium temperature has decreased by about 200 °C comparing with that in sinter ore charging. This result shows the possibility that the coke ratio of blast furnace can be reduced drastically by the vicinity arrangement of iron ore and coke.

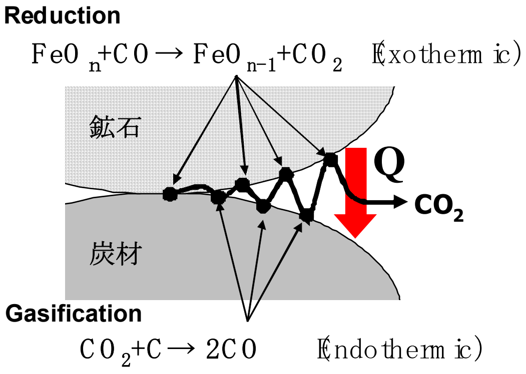


Figure 7. Coupling reaction effect between reduction of iron oxide and Boudouard reaction.

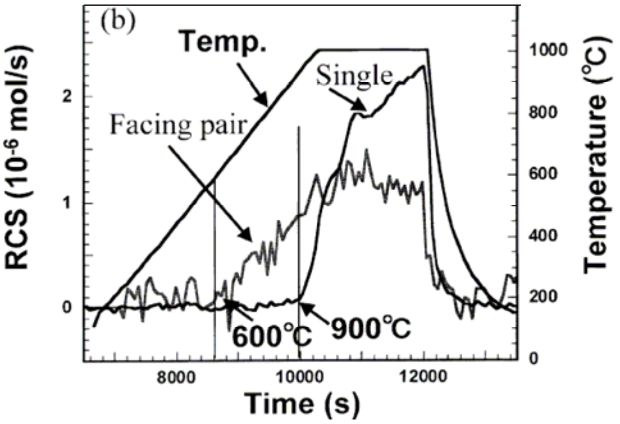


Figure 8. Comparison of reaction rate between the facing pair and the single graphite in Ar-30vol%CO2.

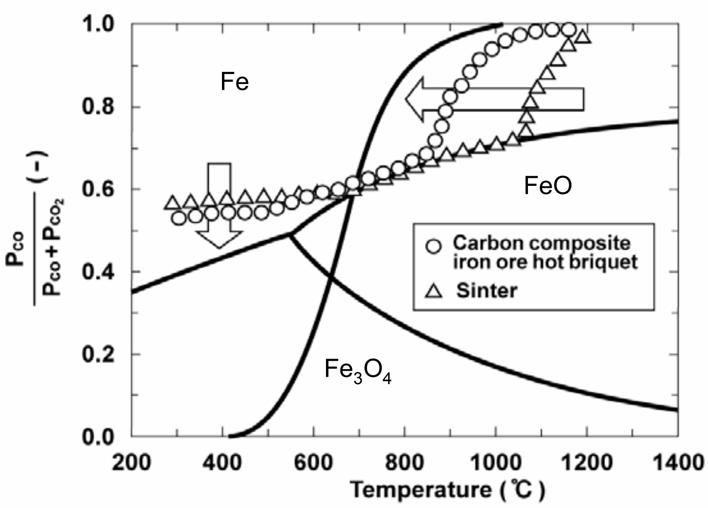


Figure 9. Change of reduction reaction equilibrium at charging of CCB in model blast furnace test.

4.2 Improvement of Coke Reactivity by Catalyst Addition

Aiming at the acceleration of carbon solution–loss reaction in lower temperature, the improvement of coke reactivity have been examined by adding the various catalyst to the coke. In the recent researches,[5,6], it was founded that the addition of Fe or Ca powder to the coke was very effective for the improvement of reaction rate of coke with CO_2 gas (Figure 10 and Figure 11). The most important problem in the catalyst addition was a decrease in coke strength. The catalyst addition by the ion exchange method was tried as a method to prevent the decrease in coke strength. Figure 10 and Figure 11 show the effects of metallic Fe or Ca addition[5,7] by the ion exchange method on the carbon solution-loss reaction, respectively. The reactivity of coke has been remarkably improved by Fe or Ca catalyst addition without the decrease in coke strength. From these results, the catalyst addition to coke by the ion exchange method is expected as innovative method for improvement of the reactivity of coke.

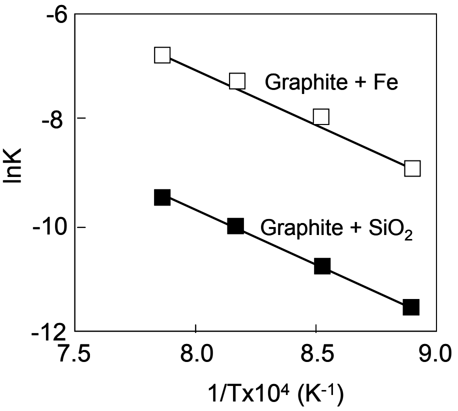


Figure 10. Effect of Fe addition on the gasification rate of graphite in 20% CO_2-CO mixture.

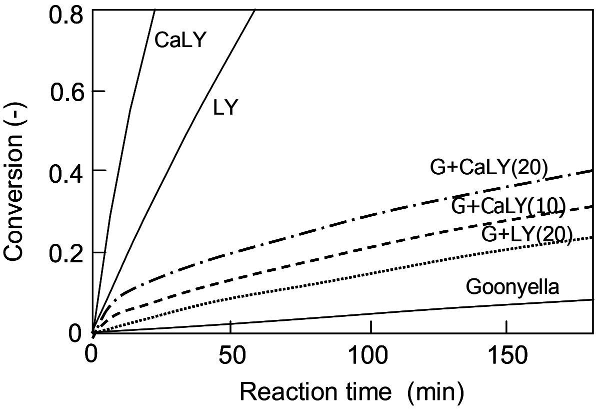


Figure 11. Time-conversion curves for various cokes during CO_2 gasification (CO_2/N_2-50/50,1000°C).

5 IMPROVEMENT OF MELTING PROPERTY OF REDUCED IRON ORE

In order to decrease the reducing agent rates in a blast furnace operation with high ore to coke ratio, it is necessary to maintain a high gas permeability and a smoothly burden descent by the rapid melting of reduced iron ore in the lower part of blast furnace. Figure 12 shows the hanging and slipping phenomena of impermeable cohesive layer in the lower part of a model blast furnace.[8] As shown in the figure, the hanging and slipping in moving bed were occurred easily by the increase in the gas pressure when the impermeable cohesive layer was formed widely in the lower part of blast furnace. Considering the enlargement of the cohesive layer with decrease in coke rates, the rapid melting of reduced iron ore is very important to maintain a stable operation of blast furnace. The melting property of reduced iron ore is evaluated with the change of pressure loss as shown in Figure 13 which is measured in the high temperature deduction test with load**.** The pressure loss in the cohesive zone is strongly depended upon the width of the cohesive layer, and it can be decreased by lowering the melt-down temperature (MT) and raising the softening temperature (ST) of reduced iron ore or by lowering the maximum pressure drop (ΔP_{max}). In previous studies, it has been presented that MT and ΔP_{max} are decided by the carbon dissolution rate into the metal and the melting temperature of the slag. Figure 14 shows the changes of gas pressure drop of iron ore bed with increase in mixing ratio of carbon composite iron ore (CCA) into sinter ore bed [9]. The pressure drop at high temperature zone in which the iron ores become softening and melting is drastically decreased by mixing of the carbon composite iron ore. This result means that the reduced iron ores melt down rapidly by the carburization of metallic iron. From these results, it can be thought that the vicinity arrangement of ore and coke is very effective to accelerate the melting rate of the cohesive layers.

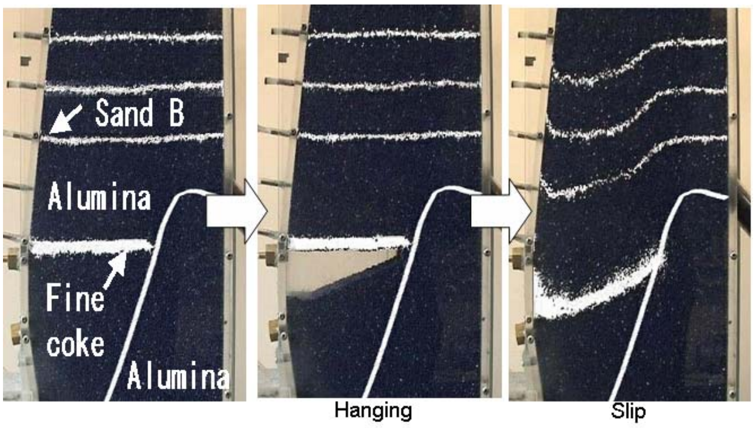


Figure 12. Hanging and slip caused by formation of impermeable layer in the lower part of blast furnace.

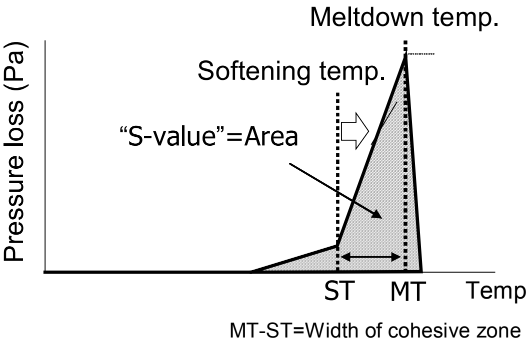


Figure 13. Change of gas pressure loss in softening and melting of iron ore bed.

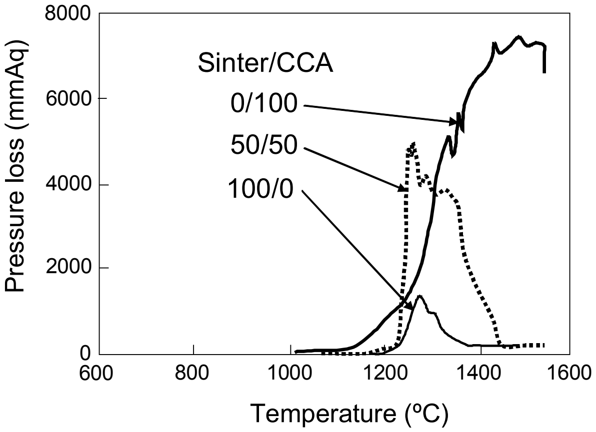


Figure 14. Changes of gas pressure drop of iron ore bed by mixing the carbon composite iron ore.

In addition, Figure 15 shows the melting properties of carbon composite iron ore pellets. The melt down temperature of the reduced pellets were plotted on the liquidus in the diagram of Fe-C system and its lower limit is almost equal to the melting point of the slag. This property means that the carbon dissolution into the metal progresses rapidly with the melting of the slag. From these results, it can be estimated that the design of slag composition is the key to melt the cohesive ore layers rapidly.

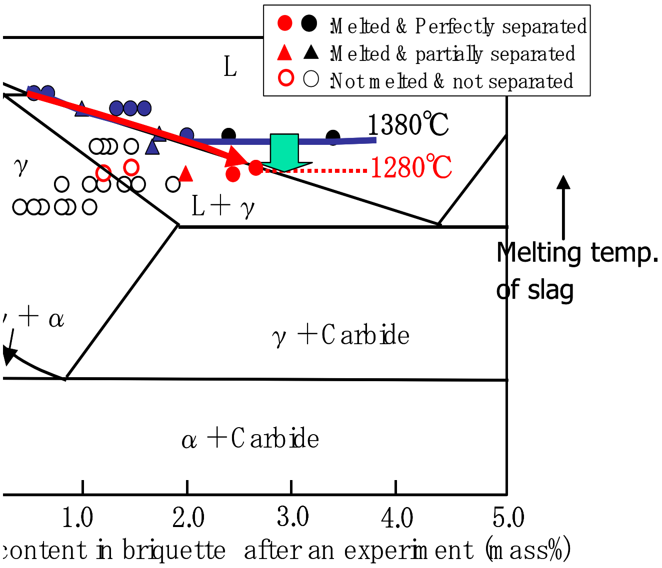


Figure 15. Melting temperature of carbon composite iron ore briquette.

6 VIEW POINTS OF BLAST FURNACE IRONMAKING TECHNOLOGY FOR THE FUTURE

Recently, the developments of some new technologies of blast furnace ironmaking, such as a top gas re-circulation with CO_2 gas removal system, a natural gas or a coke oven gas injection, a mixed charging of coke and ore, a charging of the carbon composite iron ore briquette to the blast furnace et al., are advanced aiming at the decrease of CO_2 gas emission. In here, considering the shortage of a high quality iron ore and a coal, the research and development of new technologies should be directed harmonizing the energy with the resource and the environment. It is thought that the key to sustainable development of ironmaking is in the research and development that stands in a global aspect.

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