Summarized achievements of the porous meso-mosaic texture sinter research project (Review)

T.KAWAGUCHI et al.

Research Group on Porous Meso-mosic Texture Sinter in ISIJ was established from 2001 to 2004 fiscal years to overcome difficulties to use the great amount of goethite in sintering and at the same time to improve the sinter quality. Especially, since the beginning of the present research project the ratio of Marra Mamba goethitic ore was considered to increase rapidly, and the amount of sinter necessary for the Japanese integrated steel industries was thought hard to be produced satisfactorily, because Marra Mamba ore having high combined water content and high porosity was expected unsuitable for sintering. Therefore, the method of using goethite had been studied and the combination with low slag ratio important for melting behavior of goethite was investigated.

Each university had been engaged in basic research such as granulation, agglomeration, evaluation of reaction in a blast furnace to propose a new process for "porous meso-mosaic texture sinter" which was anticipated simultaneously to realize high strength and high reducibility under the conditions of low slag and high goethite ratio in sintering.

By combining these basic researches, the theory of agglomeration and the engineering foundation for raw material/sintering/blast furnace process were discussed and a new process for "porous meso-mosaic texture sinter" based on improving granulation process of raw material was searched. As a result, proposed was the MEBIOS (Mosaic Embedding Iron Ore Sintering) method which involved arranging dense pre-granulated pellets (firing cured bed) in a sinter induction bed with a raw material composition capable of forming a suitable void network under normal sintering conditions.

(cf. *ISIJ Int.*, **45** (2005), 414)

Properties of Iron Ore and Sinter Feed

Marra mamba ore, its mineralogical properties and evaluation for utilization (Review)

J.OKAZAKI et al.

This paper provides an overview of chemical and physical properties of Marra Mamba ores as well as their influence on sintering performance. Evaluation tests focusing on basic characteristics, granulation ability and melting behavior have been conducted by using Ore W, a newly shipped bland of Marra Mamba ore. Although the amount of gangue minerals in Marra Mamba ores is smaller than that of other Australian ores, they have high combined water content and high fraction of fine particles. They have inferior granulation ability and required high moisture content in granulation due to their porous structure. Cohesive strength of fine ores is still low level even at high moisture content due to small kaolinite content. Penetration behavior of melt from fine particles is superior due to their low gangue mineral content, while assimilation behavior of coarse ores is inferior, resulting in poor agglomeration despite favorable behavior during heating-up in term of crack formation. Pot test results performed by BHP Billion showed decrease of strength and product yield with large amount of use. Improvement of strength was achieved by increasing moisture content during granulation. Intensification of granulation with pre-treatment or palletizing of Marra Mamba ores must be one of the key technologies for utilization of them.

(cf. *ISIJ Int.*, **45** (2005), 427)

A perspective of goethitic ore sintering fundamentals (Review)

C.E.LOO

The main purpose of iron ore sintering is to produce a strong agglomerate for the blast furnace. This is achieved by partially melting a sinter mix at high temperature and then allowing the melt to solidify into a bonding phase for the unreacted material. The melt formation and subsequent solidification processes are highly dependent on the composition of the blended mix. This paper summarises the differences in sintering behaviour between hematite ores and goethitic ores based on past research programs carried out at BHP Billiton. From a fundamental evaluation of the sintering process, it is clear that productivity can be an issue with goethitic ores because of their low bulk density and high porosity. This paper recommends steps towards overcoming losses in productivity. The effect of goethitic ores on coke rates is also a matter of general concern and this study shows that the addition energy required to dehydrate goethites and remove the additional water introduced into the system is comparatively small. The properties of the melt have been shown to be particularly important in determining yield from a sinter machine and it is evident that the easy-melting properties of goethitic ores will also have an impact on this area. This paper also reviews our current understanding of how goethitic ores can influence the sinter quality. The implication of fundamental knowledge on practical sinter plant operation is discussed throughout and collated at the end of the paper.

(cf. *ISIJ Int.*, **45** (2005), 436)

Fundamental factors determining laboratory sintering results

C.E.LOO et al.

The main purpose of sinter pot studies is to quantify the common indicators of performance *viz.*, mix moisture, productivity, coke rate and sinter quality. For three ore blends—containing 50 mass% pisolite ore and up to 30 mass% Marra Mamba ore—sintering studies were carried out using two laboratory sintering techniques, and the fundamental factors influencing these key indicators were accurately quantified. The study supports previous findings that pre- and post-ignition airflow rates provide invaluable information on flame front properties, sintering time and sinter strength. Sintering results obtained for the two techniques were very different because of differences in flame front properties. Clearly, a good understanding of the influence of flame front temperature, sintering energy requirements, airflow rate and bed thermal capacity on heat transfer and bed airflow resistance is necessary to explain the fundamental sintering behaviour of ore blends. To help quantify these links, the factors governing airflow through a sintering bed and the drivers causing the flame front to descend down a bed were also presented from a theoretical perspective. As expected, both theory and test results show that post-ignition airflow rate, the level of coke in the granulated mix, and endothermic reactions such as calcination were very important factors influencing flame front resistance and, therefore, the sintering performance of ore blends.

(cf. *ISIJ Int.*, **45** (2005), 449)

Fundamental insights into the sintering behaviour of goethitic ore blends

C.E.LOO et al.

The main purpose of this paper is to examine the effect of altering the sintering parameters—*viz.*, bed height, suction, and the levels of return sinter fines, coke, mix moisture, and limestone—of two blends, one containing over 50 mass% pisolite ore and the other 50 mass% pisolite ore and 30 mass% Marra Mamba ore. Pre- and post-ignition airflow rates were determined together with the traditional performance measures *i.e.*, sintering time, yield, productivity, coke rate and sinter tumble index. Results from such a study would provide useful information on tolerable variations in the sintering process parameters and insights into which are the more important parameters controlling sinter plant performance. Sinter pot test results show significant changes in airflow rates and sintering performance when the sintering parameters were altered, although the two blends did not always respond in the same manner. Many of the obtained relationships (*e.g.* increasing bed height results in the formation of stronger sinter) are well known, but in this study explanations on why and how the relationships exist are given. It is very clear from this study that the temperature of the flame front, which has a significant influence on flame front permeability and the melt formation process, has a very large influence on sintering performance and the strength of the ensuing sinter.

(cf. *ISIJ Int.*, **45** (2005), 459)

Sintering fundamentals of magnetite alone and blended with hematite and hematite/goethite ores

L.X.YANG

This work overviews the properties and sintering behaviour of Chinese magnetite concentrates, and interactions between magnetite concentrates and imported hematite, hematite/goethite ores in sintering. Sintering performance of several Chinese ore blends was also presented to provide greater understanding of the behaviour of imported hematite and hematite/goethite ores.

Chinese magnetite concentrates are generally more complex in chemistry and mineralogy and less reactive compared to hematite, Marra Mamba and goethite ores. Sinter beds formed from blends containing high level of magnetite concentrate are more deformable, and thus this could reduce their green bed permeability during charging and application of suction. SFCA formation in magnetite sintering occurs primarily in the cooling stage as magnetite oxi-

dation is rather limited prior to the arrival of high temperature zone.

Porous hematite and Marra Mamba ores are easy to react and hence assist melt formation. Addition of porous hematite and Marra Mamba ores to magnetite concentrates improves granulation efficiency and sintering performance considerably.

(cf. *ISIJ Int.*, **45** (2005), 469)

Granulation of Sinter Mixture

Effect of adding moisture and wettability on granulation of iron ore

T.MAEDA et al.

As the fundamental study for determining the optimum moisture content for granulated particle, the contact angle between iron oxide and water was measured by the sessile drop method using reagent hematite samples that have different porosity and five kinds of iron ores. The granulation experiment was conducted by using five kinds of iron ores and the effects of adding moisture and wettability on the granulation property were investigated. The contact angle of reagent hematite sample and iron ore became large as the surface roughens becomes large. Therefore, the wettability between iron oxide and water greatly influenced the surface roughness of iron oxide. When iron ore with high wettability was used for nuclei particles, it can be granulated under all conditions in this study. On the other hand, when iron ore with low wettability was used for the nuclei particles, it was remained some fine iron ore particles without granulating. Therefore, when iron ore with low wettability was used for the nuclei particles, it was necessary to increase the adding moisture in order to improve the granulation property of fine particles. The fracture strength increased with decreasing the contact angle without regard to the kind of iron ore using for nuclei particles. Consequently, It was necessary to increase the adding moisture in order to improve the fracture strength.

(cf. *ISIJ Int.*, **45** (2005), 477)

Influence of the nuclei particle properties on granulability of marra mamba iron ore by high speed agitating mixer

T.MATUMURA et al.

The newly developed brand Marra Mamba ore from Australia has a comparatively high water absorptivity, and since many fine ore is contained, if it is used as a raw material of sintered ore, it will cause the fall of permeability, and the productivity fall of a product sinter by the fall of the granulability. By blending nuclei particles with this Marra Mamba ore, the granulability and the permeability have improved sharply by processing them in a high-speed agitating mixer. This that point, about 25 mass% is suitable for nuclei particle mixture ratio to a high-speed agitated material.

Moreover, the granulability was improved by using the ore containing much 1–3 mm particles. As for this, it is considered that the granulation of a middle size ore domain is accelerated, because of the consistency of the particle size composition of the material processed and pot characteristic of high-speed agitating mixer.

(cf. *ISIJ Int.*, **45** (2005), 485)

The effect of marra mamba ore addition on the granulation characteristics of pisolite based and hematite based sinter blends

R.BERGSTRAND et al.

The granulation characteristics of two quite different sinter blends have been studied. One comprises a significant proportion of pisolite ore, and the other is dominated by hematite ores. The effect on granulation of adding a significant proportion of West Angelas, a Marra Mamba type ore, into both blends is also studied. The relationship between blend moisture content and green permeability is measured, as is the size distribution of the granulated blends at different moisture contents. It is clear that when West Angelas ore displaces a denser, less porous ore type in a sinter blend, additional granulation moisture must be added to ensure optimal granulation performance. A petrographic study of granule morphology at different blend moisture contents is reported, with particular reference to the features of the adhering layer. The important role of ultrafines, particularly the $-50\,\mu$m 'superfine' fraction, in the granulation process is discussed. The variations in mineralogical and textural characteristics of West Angelas ore with size are presented. It is proposed that the mineralogical and textural characteristics of the superfine particles are an important factor in the granulation performance of an ore or a blend of ores.

(cf. *ISIJ Int.*, **45** (2005), 492)

Numerical simulation model for granulation kinetics of iron ores

J.KANO et al.

A numerical simulation model was developed to analyze the granulation kinetics by using the Discrete Element Method (DEM). The experiment of granulation was performed to understand the actual granulation behavior of iron ore particles. The granulation rate goes up with a decrease in a particles charge ratio and with an increase in a rotational speed of a drum mixer in the experiment. The granulation could be consisted of two processes: One is "a growing process" and the other is "a breaking process". The former would be related to the rotation of granules and the latter would be dependent on the impact, which granules receive from others and/or a drum mixer wall. Then rotational kinetic energy and impact energy of a granule were calculated by using the DEM simulation. A granulation energy composed of both the impact energy and the rotational kinetic energy was proposed for analyzing the granulation kinetics. It increases as the rotational speed of the drum mixer rises and as the granule charge ratio drops. The granulation energy would be correlated with the actual granulation process. When the drum mixer diameter becomes large, the granulation energy decreases. When the drum mixer is leaned, the granulation energy becomes larger than at the lean of 0 degrees. That is, the drum mixer has a possibility to improve a granulation process. When the drum mixer is leaned further, the granulation energy rapidly decreases at the lean of 60 degrees. The optimum leaning angle must be existed.

(cf. *ISIJ Int.*, **45** (2005), 500)

Sintering Reaction

Effect of Al_2O_3 and MgO additions on liquidus for the $CaO–SiO_2–FeO_x$ system at 1573K

H.KIMURA et al.

Phase diagrams for the $CaO–SiO_2–FeO_x–Al_2O_3$ or –MgO systems at various oxygen partial pressures are necessary for the design of raw material for ironmaking, the analysis of smelting reaction and sintering process. To clarify the effect of Al_2O_3 or MgO content on the formation of melts in the sintering process is important for the development of new sinter. In this study, liquidus for the $CaO–SiO_2–FeO_x–Al_2O_3$ or –MgO systems at various oxygen partial pressures were observed at 1573K by using chemical equilibration technique. The liquid phase area changed with adding Al_2O_3 or MgO. The effect of the Fe^{3+}/Fe^{2+} ratio on the melting mechanism is discussed.

(cf. *ISIJ Int.*, **45** (2005), 506)

Experimental evaluation of chemical composition and viscosity of melts during iron ore sintering

S.MACHIDA et al.

The viscosity of the melts formed in the sintering reaction was measured for evaluating the fluidity of the melts, which play a crucial role in the sintering process. Using the sphere draw-up method carried out the measurements of high temperature viscosity. With low-melting point compositions of the $Fe_2O_3–CaO–SiO_2$ system, the viscosity of high SiO_2 content melts ($Fe_2O_3/CaO/SiO_2$=38.5/34.5/27.0 weight basis) was 5 times higher than that of low SiO_2 content melts (Fe_2O_3/CaO=80/20). The viscosity of low SiO_2 content increased with addition of Al_2O_3 and SiO_2. Similarly, with melt compositions generated from actual ores, viscosity depended on the contents of Al_2O_3 and SiO_2.

Based on the results, the viscosity of the melted liquid was estimated from the chemical composition, and the viscosity of the solid-liquid coexistence phase was also evaluated using a viscosity calculating equation for suspensions. The viscosity distribution of the solid-liquid coexistence phase at 1300°C in the ternary composition system $Fe_2O_3–CaO–SiO_2$ was obtained.

(cf. *ISIJ Int.*, **45** (2005), 513)

Development of a 3-D sinter process mathematical simulation model

H.YAMAOKA et al.

A 3 dimensional sinter process mathematical simulation model has been developed for the purpose to make it possible the designs of sinter process from the stereoscopic viewpoint. This sinter process model can calculate not only the progress of sintering reactions and the resultant changes in the bed structures such as pore ratio and minerals composition but also the qualities of produced sinter.

Through a pot sintering test, this sinter process model was confirmed authentic and able to calculate also the distributions of sinters property such as minerals composition inside sinter cake. This sinter process model was used for the analysis of the effects of gas flow plate on the sintering performance.

(cf. *ISIJ Int.*, **45** (2005), 522)

Properties of core ore in quasi-particle required for large amounts usage of limonitic ores in iron ore sintering process

T.Otomo et al.

The fluidity of melt formed in the sintering process of iron ores is an important factor for producing a high-strength sinter. When using a large amount usage of limonitic ores as core ore of the quasi-particle of sinter mix, it is predicted that the fluidity of formed melt decreases, because the solid ratio in the melt increases by an acceleration of the assimilation of the core ore with the melt.

In order to control the assimilation of limonitic ore, basic researches were conducted using a modeled briquette, which consisted of a disk-shaped iron ore core and a shell layer of fine mixture composed of Fe_2O_3 and $CaCO_3$ reagents. Assimilation rate of various iron ores was measured, and then solid phase ratio in the melt was calculated based on the phase diagram of CaO–Fe_2O_3 system. According to the calculated solid phase ratio in the melt, the fluidity of melt was discussed. The results obtained are summarized as follows:

Fair linear relations were obtained between the porosity of core ore after dehydration and the combined water content of the ore. The assimilation rate of core ore at a specified temperature was represented as a function of the porosity of core ore after dehydration and the holding time at the temperature. The diameter and the apparent density of core ore influenced the calculated solid phase ratio in the melt. It was suggested that an optimal sinter structure was achieved by mixing a large and dense core ore at about 20 mass% in raw mix.

(cf. *ISIJ Int.*, **45** (2005), 532)

Design of bed structure aiming the control of void structure formed in the sinter cake

E.Kasai et al.

Design of bed structure is a promising approach to maintain/increase the productivity of sinter under the condition of increasing use of iron ores having high combined water content. In this paper, a process image of the above proposal, MEBIOS, is illustrated and further *"in situ"* observation of the change in the void structure of the sintering bed by using X-ray CTS and a thermo-fluid dynamic simulation have been conducted in order to preliminary evaluate the possibility of this proposal.

X-ray CTS observation suggests that the existence of pellets of 15 mm in particle size does not significantly affect the formation of macroscopic void network in the sintering bed and not lead to inhomogeneous sintering. A series of the laboratory-scale of sinter pot experiment was also carried out to obtain parameters for the simulation. The gas flow near the pellet surface and the differences in the temperature profiles among the pellet center and surface were simulated by using the numerical model although further studies are necessary, *e.g.*, on the considering ways of structural changes of void in the sintering bed, reduction and oxidation reactions and a mesh generation method properly representing the contraction of bed height.

(cf. *ISIJ Int.*, **45** (2005), 538)

The sintering behavior of raw material bed placed large particles

C.Kamijo et al.

The pot tests, under the condition that large particles were placed in the sintering bed, were carried out for improvement of permeability. The large particles include green balls made from Marra Mamba ore, fired pellets, dense alumina balls and pisolite lump ore. In the course of pot tests, permeability before ignition and during sintering, bulk density and yield were measured. Also the cross sections of sinter cakes were observed. As a result, the permeability before ignition and during sintering was both increased regardless of the increase in the bulk density of sintering bed. When the large particles were placed, the calculated bulk density of sinter mixture (the rest part of bed excluding the large particles) decreased in inverse proportion to the surface area of large particles. Therefore, the effect of placing large particles was concluded to cause the permeability increase. Placing large particles occasionally decreased yield owing to void formation under the alumina balls in the sinter cake, which was confirmed the visual observation. It is proposed that the increase of coke and/or CaO contents in fine layer and adding carbon in the green balls are effective for yield recovery.

(cf. *ISIJ Int.*, **45** (2005), 544)

Effect of raw material composition on the sintering properties

L.-H.Hsieh

A number of the commercial iron ores were tested in a sinter pot to study the effect of iron ore composition on the sintering properties. In the sintering of individual iron ores, under the sinter controlled at the same levels of basicity, SiO_2 and MgO, the sintering properties varied with iron ore type greatly. The sinters made from the dense low alumina iron ores presented the higher tumbler strength and the lower coke rate, but the RDI was not simply related to the alumina level of iron ore. A high alumina ore may produce the sinter with a very low or very high RDI. The sintering properties of blending ores, including productivity, TI, RI, suitable moisture and coke rate, except for the RDI, were approximately equal to the weighted means of the individual ores.

With an increase in the pisolitic iron ore in sintering, the productivity of sinter decreased by approximately 1.3% on average for each 10 mass% pisolitic ore increased. The decrement varied with the kinds of iron ores replaced by the pisolitic ore. Increasing the pisolitic ore required a higher coke rate and more moisture in raw mix. In the blending ore containing the high ratio of pisolite, reducing the fluxes to decrease the MgO and raise the basicity may improve the productivity, tumbler strength and coke rate in sintering.

(cf. *ISIJ Int.*, **45** (2005), 551)

Sinter Quality

Crystal structure of the SFCAM phase $Ca_2(Ca,Fe,Mg,Al)_6(Fe,Al,Si)_6O_{20}$

K.Sugiyama et al.

The crystal structures of Mg-rich SFCA (SFCAM); $Ca_2(Ca_{0.10}Mg_{1.20}Fe_{5.45}Si_{1.50}Al_{3.65})O_{20}$ (triclinic $P\bar{1}$, a=8.848(1) Å, b=9.812(1) Å, c=10.403(1) Å, α=64.35(1)°, β=84.19(1)°, γ=66.27(1)°, V=742.4(1) Å^3, Z=2) and $Ca_2(Mg_{2.00}Fe_{4.45}Si_{2.15}Al_{3.40})O_{20}$ (triclinic $P\bar{1}$, a=8.928(2) Å, b=9.823(2) Å, c=10.389(1) Å, α=64.41(1)°, β=83.90(1)°, γ=65.69(1)°, V=746.0 (2) Å^3, Z=2) were determined by the single crystal X-ray diffraction. The structure of SFCAM is isostructural with aenigmatite and well demonstrated by an alternating stacking of the tetrahedral and octahedral layers. The tetrahedral sites of oxygen are occupied either by Fe, Al and Si. The octahedral sites of oxygen are occupied either by Fe, Mg and Al and this feature contrasts with that of the Mg-free SFCA phase where Al prefers tetrahedral sites, only. In particular, Si^{4+} and Mg^{2+} prefer the tetrahedral T1, T2 and T4 sites and octahedral M5 and M6 sites, respectively, by producing a structural slab similar to that of aluminous diopside. Such local concentration of divalent Mg^{2+} and tetravalent Si^{4+} in the structure of SFCAM is strongly favored in order to compensate the local charge valance. The SFCAM phase indicates the superior structural flexibility for a variety of cations and this feature is promising for the chemical design of the bonding phase in the sinter ore.

(cf. *ISIJ Int.*, **45** (2005), 560)

Effects of slag content and composition on the reducibility of iron oxide including CaO–SiO_2–Fe_tO slag

H.Ono et al.

In the sintering with lower slag ratio, the melt quantity decreases, and the agglomeration do not progress sufficiently. It is necessary to secure the melt quantity by silicate melt mainly composed of Fe_xO–SiO_2 system and to control ideally the composition and the generation place of the melt. In the present study, iron ore sinter is simulated by an iron oxide pellet added with (CaO–)SiO_2–Fe_tO slag particles, and the effects of the slag content, the composition, the holding time at 1573K and the slag particle size on the hydrogen reduction behavior of the iron oxide pellet including (CaO–)SiO_2–Fe_tO slag particles have been investigated at 1173K. In the initial stage of reduction, the fractional reduction is higher when the slag content is higher. With proceeding the reduction, the fractional reduction of the sample with the higher slag content becomes lower than the sample with the lower slag content. The reduction rate decreases with the increase of the slag content. The ratio of the pore area with over 100 μm pore size increases with the increase of slag content. On the other hand, the final fractional reduction decreases with the increase of the slag content. From

this fact, it is considered that the increase of macro pore over 100 μm does not affect on the improvement of reducibility, and the microporosity under 100 μm may become an influential factor. On the slag composition, the final fractional reduction of the pellet including Fe_xO–SiO_2 slag is better. This is because that the silicate slag is difficult to permeate nor block up the pore.

(cf. *ISIJ Int.*, **45** (2005), 569)

Influence of artificially induced porosity on strength and reduction behavior of hematite compacts

K.HIGUCHI et al.

With the objective to gain more fundamental understanding of the influence of pore structure on the low-temperature reduction behavior of iron ore agglomerates, laboratory-scale induration experiments were performed using pure hematite compacts doped with naphthalene as a porosity-generating agent. The pore structure was thus controlled up to 60% porosity and 1.4 mm pore diameter, and no mineralogical changes were observed in these ranges after induration. The cold strength of indurated compacts was higher with pores smaller than 0.125 mm in diameter, as well as with pores larger than 1 mm. Changes in the cold crushing behavior of indurated compacts are discussed based on matrix length and distribution theory. Reduction tests in CO–CO_2–N_2 gas at temperatures in the range of 350–800°C revealed high strength after reduction of compacts with fine pores less than 0.125 mm in diameter. Reasons for this high strength were the isotropic stress distribution within the compacts, as well as lower expansion due to development of a complex reduction front.

(cf. *ISIJ Int.*, **45** (2005), 574)

Measuring strains for hematite phase in sinter by electron backscattering diffraction method

Y.SASAKI et al.

Based on the relationship between quantified blurring degree of Kikuchi bands obtained by an electron backscattering diffraction (EBSD) technique and macroscopic strains measured by a strain gauge, the local compression strain S_{EBSD} in sinter ore has been evaluated. There is a good linear relationship between the average of S_{EBSD} (denoted by S_{AVE}) and the strain measured by a strain gauge (S_{MEAS}).

$$S_{AVE}=1.9S_{MEAS}$$

From the variation of S_{EBSD} on the distance from the grain boundary, the local strain is found to be mainly distributed in the volume near grain boundaries. It has been confirmed that the local strain S_{EBSD} evaluated by EBSD patterns can be used as an index of local strains.

(cf. *ISIJ Int.*, **45** (2005), 582)

Meso-porous modeling for theoretical analysis of sinter ores by the phase-field, unit-cell method

T.AIZAWA et al.

A sinter ore has fine pores as well as macro pores and cavities in it. These mesoscopic porosity distributions have close relationship with reduction of loading capacity for sinter ores as well as their strength and stiffness. In addition, since the gaseous reduction reaction is enhanced by open meso-pores, meso-porous configuration becomes very important in the design of sinter ores. Multi-level modeling with use of artificial unit cells is proposed to aim at the meso-porous microstructure design. The phase filed method with finite element modeling provides us a reliable tool to control the size, shape and distribution of meso-pores and to consider their effects on the mechanical and thermal properties of sinter ores. Meso-porous hematite is employed as a targeting sinter ore to describe actual meso-porous microstructure by comparing the experimentally measured Young's moduli with the theoretically predicted elastic properties. Microstructure with uniform distribution of isolated meso-pores provides the upper bound on the Young's modulus. Reduction of Young's moduli in experiments below this upper bound is caused by irregular shaping and coalescence of meso-pores during sintering. Unit-cell modeling with irregularly shaped and inter-connected meso-pores, provides an actual upper bound for measured elastic properties of sinter ores. Variation of thermal conductivity with the average porosity is also estimated as a master curve for optimum sintering process design.

(cf. *ISIJ Int.*, **45** (2005), 587)

Improvement of sinter softening property and reducibility by controlling chemical compositions

M.MATSUMURA et al.

Increasing permeability of packed materials in a blast furnace and decreasing reducing agent rate at a blast furnace process take an important role to improve productivity. In order to increase permeability and decrease reducing agent rate, sinter softening property during reduction and sinter reducibility are important.

Effects of sinter compositions (CaO, SiO_2, Al_2O_3, MgO, FeO) on the sinter softening property during reduction and sinter reducibility were examined by samples produced from pot scale sintering. These compositions were controlled by lime stone, serpentine, and coke breeze content and varying iron ore source in raw sinter materials. And sinter softening property was estimated by vertical pressure drop of sinter packed bed (70 mmϕ×100 mm) during sinter reduction with raising temperature to 1600°C under vertical loading force (9.8×10^4 N/m^2). This pressure drop is caused by melt formation from slag compositions in sinter above 1000°C. And sinter reducibility was estimated as reduction degree by CO(30%)–N_2 gas under constant temperature conditions (900°C, 1100°C).

Results were obtained as follows.

(1) Low SiO_2 and low CaO sinter had superiority of sinter softening property. That is small pressure drop caused by decreasing SiO_2–CaO–FeO melt.

(2) And low SiO_2 and low CaO sinter had high reducibility at both 900°C and 1100°C. It is considered that decrease of these compositions affects restriction of calcium silicate containing ferrous oxides.

(3) High MgO and high FeO sinter using dolomite instead of serpentine and blended with high coke breeze also had superiority of sinter softening property. Adding MgO to phase of CaO–FeO–SiO_2 raises melting temperature. The raising melting temperature is considered to make high pressure drop region to be narrow.

(4) And high MgO and high FeO sinter had low reduction degree at 900°C but kept high reduction degree at 1100°C. X-ray diffraction pattern for the sinter indicated that it contained much magnetite structure (magnetite and magnesioferrite) instead of hematite. This mineral composition is consistent with low reduction degree at 900°C. On the other hand, keeping high reduction degree at 1100°C is considered to correspond not to promote silicate ($FeO–2SiO_2$, FeO–SiO_2–CaO) formation. By X-ray micro analyzer, it was found that calcium ferrite contained more Si and more Mg ion with increasing MgO in sinter. Increasing Si ion in calcium ferrite is considered to be the cause of restricting silicate formation.

(5) Al_2O_3 content has little effect to sinter softening property.

Summarized these results, low SiO_2, low CaO, high MgO and high FeO sinter has a good softening property and high reducibility. These characteristics indicate good performance as raw material in a blast furnace.

(cf. *ISIJ Int.*, **45** (2005), 594)

Environmental

Research in the reduction of iron ore agglomerates including coal and C-containing dust (Review)

H.WILHELM et al.

The Department of Ferrous Metallurgy (IEHK) since long has been investigating in the conversion of carbonaceous matter and smelting together with the reduction of iron bearing raws and materials. Actual research is being carried out in the development and improvement of self reducing carbonaceous iron bearing agglomerates. It was found that the kinetics of known reduction processes are transferable to the new agglomerates with respect to new phenomena such as alteration of shape and volume. The examined agglomerates are partly charged in new so-called alternative processes, and shaft furnaces, *e.g.* Tecnored and OxiCup process. These processes are currently being transferred from pilot to industrial plant scale. IEHK is partner in the ongoing research of those processes.

(cf. *ISIJ Int.*, **45** (2005), 603)

Observation of behavior of dioxins and some relating elements in iron ore sintering bed by quenching pot test

M.NAKANO et al.

Understanding of the formation mechanism of dioxins in the sintering bed is of importance in developing countermeasures to reduce the emission of dioxins from sintering plants. This research has clarified the behavior and the possible mechanism of dioxin formation and the relation to Cl and Cu com-

ponents in the sintering bed by conducting a series of quenching tests utilizing sintering pots.

The progress of flame front was quenched by terminating the air supply, then introducing N_2 gas in the reverse direction when the sintering process progressed halfway through the test pots, specifically to the position of the thermocouples. The primary specimens were obtained from the raw mixture zone situated beneath the combustion interface for chemical analysis.

Concentrations of dioxins, Cl and Cu were found at the depth of 10–20 mm beneath the combustion interface in raw mixture zone. This was considered to be the site of dioxin synthesis. Slight increase of dioxins in the wet zone was related to dioxin vaporizing from the site of the synthesis, then to be trapped in this zone. Significant amounts of dioxins escaping into the outlet gas at and after burn through point could be explained by both the releasing of trapped dioxins and the acceleration of the synthesizing process attributable to the increased concentration of Cl and Cu.

(cf. *ISIJ Int.*, **45** (2005), 609)