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Metallurgical and Materials Transactions B, April 2016

Graphitization of coke and its interaction with slag in the hearth of a blast furnace. K. Li, J. Zhang, Y. Liu, M. Barati, Z. Liu, J. Zhang, B. Su, M. Wei, G. Wang, T. Yang

Coke reaction behavior in the blast furnace hearth has yet to be fully understood due to limited access to the high temperature zone. The graphitization of coke and its interaction with slag in the hearth of blast furnace were investigated with samples obtained from the center of the deadman of a blast furnace during its overhaul period. All hearth coke samples from fines to lumps were confirmed to be highly graphitized, and the graphitization of coke in the high temperature zone was convinced to start from the coke surface and lead to the formation of coke fines. It will be essential to perform further comprehensive investigations on graphite formation and its evolution in a coke as well as its multi-effect on blast furnace performance. The porous hearth cokes were found to be filled up with final slag. Further research is required about the capability of coke to fill final slag and the attack of final slag on the hearth bottom refractories since this might be a new degradation mechanism of refractories located in the hearth bottom.

Insight into the consolidation mechanism of oxidized pellets made from the mixture of magnetite and chromite concentrates. D. Zhu, C. Yang, J. Pan, Q. Zhang, B. Shi, F. Zhang

To produce more competitive stainless steel products, the utilization of low-cost chromite concentrate is of great importance. In a previous study, a high-quality product pellet (CMP) for blast furnace smelting process made from a mixture of 40 wt pct chromite and 60 wt pct magnetite concentrates was manufactured by a high-pressure grinding rollers pretreatment. In this work, an insight into the consolidation mechanism of CMP is taken in comparison with the oxidized pellets (MP) made from 100 pct magnetite concentrate by adopting the scanning electron microscopy, energy-dispersive spectrometer, and X-ray diffractometer. The mineralogy of the pellets and the morphology of the preheated and roasted mineral particles are demonstrated. To gain better understanding of the consolidation mechanism of CMP, the thermodynamics of chromite–magnetite spinel system and hematite–sesquioxide corundum system in air are considered by using FactSage software. It can be found that the solid-state bonding is the dominant form in the consolidation of CMP, which mainly depends on the recrystallization of hematite, the solid solution bonding in adjacent areas of both magnetite–chromite particles and chromite–chromite particles. The latter two bonds rely on the formation of the miscible sesquioxide and spinel solid solution at the contact areas of particles, which is largely affected by the oxidizability of magnetite and chromite spinels. When more chromite concentrate is blended, the weak bonding among the chromite particles gradually becomes the dominant factor, which will lead to the decrease of the mechanical strength of fired pellets. The presence of a small quantity of siliceous liquid phase in CMP is believed to be beneficial to the hardening by accelerating the ion diffusion rate and forming slag bonds.

Modeling of internal state and performance of an ironmaking blast furnace: slot vs sector geometries. Y. Shen, B. Guo, S. Chew, P. Austin, A. Yu
Mathematical modeling is a cost-effective method to understand internal state and predict performance of ironmaking blast furnace (BF) for improving productivity and maintaining stability. In the past studies, both slot and sector geometries were used for BF modeling. In this paper, a mathematical model is described for simulating the complex behaviors of solid, gas and liquid multiphase flow, heat and mass transfers, and chemical reactions in a BF. Then the model is used to compare different model configurations, viz. slot and sector geometries by investigating their effects on predicted behaviors, in terms of two aspects: (i) internal state including cohesive zone, velocity, temperature, components concentration, reduction degree, gas utilization, and (ii) performance indicators including liquid output at the bottom and gas utilization rate at the furnace top. The comparisons show that on one hand, predictions of internal state of the furnace such as fluid flow and thermo-chemical phenomena using the slot and sector geometries are qualitatively comparable but quantitatively different. Both sector and slot geometries give a similar cohesive zone shape but the sector geometry gives a higher cohesive zone near the wall and faster reduction. On the other hand, the two geometries can produce similar performance indicators including gas utilization at the furnace top and liquid output at the bottom. Such a study is useful in selecting geometry for numerically examining BF operation with respect to different needs.

Phase equilibrium studies of CaO-SiO2-MgO-Al2O3 system with binary basicity of 1.5 related to blast furnace slag. M. Kou, S. Wu, X. Ma, L. Wang, M. Chen, Q. Cai, B. Zhao
Slags play an important role in blast furnace operation, and their compositions are based on the CaO-SiO2-MgO-Al2O3 quaternary system in many steel companies. The binary basicity (CaO/ SiO2 weight ratio) of blast furnace slags, especially primary slag and bosh slag, can be as high as 1.5 or higher. Phase equilibria and liquidus temperatures in the CaO-SiO2-MgO-Al2O3 system with binary basicity of 1.50 are experimentally determined for temperatures in the range 1723 K to 1823 K (1450 C to 1550 C). High temperature equilibration, quenching, and electron probe X-ray microanalysis techniques have been used in the present study. The isotherms are obtained in the primary phase fields of Ca2SiO4, melilite, spinel, periclase, and merwinite related to blast furnace slags. Effects of Al2O3, MgO, and binary basicity on liquidus temperatures have been discussed. In addition, extensive solid solutions have been measured for different primary phases and will be used for development and optimization of the thermodynamic database.

A structural molar volume model for oxide melts Part II: Li2O-Na2O-K2O-MgO-CaO-MnO-PbO-Al2O3- SiO2 melts—ternary and multicomponent systems. E. Thibodeau, A. Gheribi, I. Jung
A structural molar volume model based on the silicate tetrahedral Q-species has been developed to accurately predict the molar volume of molten oxides. In this study, the molar volumes of ternary and multicomponent melts in the Li2O-Na2O-K2O-MgO-CaO-MnO-PbO-Al2O3-SiO2 system are reviewed and compared with the predicted molar volumes from the newly developed structural model. The model can accurately predict the molar volumes using binary model parameters without any ternary or multicomponent parameters. The nonlinear behavior in the molar volume of silicate melts is well predicted by the present model.

Effect of Al2O3 addition on the precipitated phase transformation in Ti-bearing blast furnace slags. Z. Li, J. Li, Y. Sun, S. Seetharaman, L. Liu, X. Wang, Z. Zhang
The present paper aims to provide a fundamental understanding on phase change of Ti-enriched crystalline phase induced by Al2O3 addition in Ti-bearing blast furnace slags with different basicities using Single Hot Thermocouple Technique and X-ray Diffraction. The results showed that an increase in the Al2O3 content led to phase change from rutile or perovskite to Mg3Al4Ti8O25 and prompted crystallization of the slags with basicity of 0.60 and 0.75, whereas only CaTiO3 was precipitated at a basicity of 0.95.
Both thermodynamic and kinetic analyses were conducted to study the slag crystallization, which would throw light on phase change and enhanced crystallization. To further reveal the relationship with Al2O3 addition on slag structure and crystallization, Fourier transform infrared spectroscopy and magic angle spinning-nuclear magnetic resonance were adopted, with AlO4 tetrahedra and AlO6 octahedra observed in the slag. For slags with the basicity of 0.60 and 0.75, AlO6 octahedron, which was suggested to induce the phase change from TiO2 or CaTiO3 to Mg3Al4Ti8O25, was detected at high Al2O3 content. On the other hand, in slags with the basicity of 0.95, abundant Ca2+ may be connected to TiO6 octahedra, resulting in CaTiO3 formation.

**Iron & Steel Technology, April 2016**

**Co-injection of coal and gas in blast furnaces: are there hidden benefits?** M. Geerdes

This study summarizes the effects of the co-injection of coal and gas on the blast furnace process and attempts to define technical mechanisms and economic evaluations. The study is based on mass and heat balances as well as evaluation of operating furnaces. The technical and economic consequences of replacing coal injection partially by natural gas are described. It was found that, in some furnaces, the amount of coal replaced by natural gas was significantly higher than as calculated from a model.

**Mineral Processing and Extractive Metallurgy, January 2016**

**Studies on parameters affecting sinter strength and prediction through artificial neural network model.** T. Umadevi, D. Naik, R. Sah, A. Brahmacharyulu, K. Marutiram, P. Mahapatra

Bed permeability, rate of reductant and productivity of blast furnace (BF) performance mainly depends on both iron bearing material but also carbonaceous material. Most of the BFs have the sinter being a major burden; hence, in JSW Steel Ltd, four sinter plants are operating to fulfill the four BF’s requirement. For efficient BF operations, sinter plants are key units whose proper performance is vital to produce desired sinter strength. The tumbler index of the sinter is an important property of the sinter, and sinter strength depends on the raw material composition and machine parameters. For smooth sinter plants operation, changes to the operating conditions should be few and precise. To achieve this, a much better understanding of the mechanisms relating control inputs to a sinter production rate and quality needs to be established. In the present work, a neural network based model has been developed and trained relating sinter strength with a set of nine process variables, namely, basicity, Al2O3/SiO2, MgO, MnO, FeO, moisture, coke breeze, burnthrough temperature and machine speed, to predict the tumbler index (26.3 mm) of the sinter. The variables to which strength of the sinter was most sensitive were Al2O3/SiO2, basicity, machine speed, and MgO, MnO and FeO. Tumbler index of the sinter was influenced by sinter porosity, which was itself determined by the firing temperature and green sinter mix carbon content. The predicted results were in good agreement with the actual data with 3.5% error.

**Ironmaking & Steelmaking, January 2016**

**Influence of charcoal replacing coke on microstructure and reduction properties of iron ore sinter.** X. Fan, Z. Ji, M. Gan, X. Chen, Q. Li, T. Jiang

This study was carried out to determine the influence of using charcoal as a supplementary fuel on the microstructure and reduction properties of sinter. The primary fuel was coke breeze with 0, 20, 30 and 40% replacement of weight input with charcoal to produce sinter. Experimental results indicate that when the replacement percentage of charcoal to coke breeze increased from 0 to 40%, the porosity and FeO content of sinter also rose. These changes result in an enhancement from 79.8 to 84.3% for the reducibility index due to the increased reducing surface area. In addition, the
reduction degradation of sinter also improves since degradation during crystalline transformation is restricted. Therefore, replacing coke breeze with charcoal is able to improve the reducing properties of sinter, which is beneficial to small and large blast furnace operation.

**Conversion of injected waste plastics in blast furnace.** A. Babich, D. Senk, M. Knepper, S. Benkert

Operation of several blast furnaces proved that waste plastic (WP) injection makes recycling of industrial and municipal organic wastes and coke saving possible. However, the extent and reaction kinetics of plastic conversion are hardly explored yet. Therefore, a comprehensive study on WP characteristics and conversion behaviour under simulated raceway, bird’s nest and shaft conditions, as well as on its interaction with coke, has been undertaken. Numerous analytical, laboratory and pilot facilities have been used, has shown that despite favourable chemistry, it is hardly possible to reach a high conversion degree of plastics under the raceway conditions. Consumption of unburned residues in coke bed and in shaft is possible. The effect of this phenomenon on coke reactivity has to be considered as well.

**Microstructure evolution during softening and melting process in different reduction degrees.** W. Guo, Q. Xue, Y. Liu, X. She, J. Wang

This paper concerns the degree of indirect reduction in a burden rising substantially in an oxygen blast furnace. It studies the pellet, sinter and a mixture of both in different cases. The paper concerns experiments on single particle load softening to investigate the microstructural evolution of different burdens during the softening and melting process. The results of the experiments show that the degree of reduction impacted the softening and melting behaviour. In the case of a low degree of reduction, a slag phase substrate and a myrmekitic iron structure were formed on the periphery area of the molten burden, whereas slag phase substrate and disperse island wüstite structure were formed in the centre area. Both peripheral and central areas had a slag phase substrate and myrmekitic iron texture. The slag–iron distribution had a structure in which the slag phase was cut in the metal iron phase. The content of $2\text{FeO.SiO}_2$ as a low melting point phase in the slag decreased sharply, and this resulted in the increase in slag–iron separation temperature. The variation of the Ca/Si ratio in the interface between the pellet and the sinter indicated that enhancement of the reduction degree caused the initial temperature of the interaction in the mixed burden to rise and the interaction distance to decrease.

**Effects of MnO on slag viscosity and wetting behaviour between slag and refractory.** H. Zuo, C. Wang, C. Xu2, J. Zhang, T. Zhang

As more and more Mn bearing iron ores are used to decrease steel cost and deal with the problem of hearth deposition, slag regime change and hearth refractory erosion in blast furnace become more often. To address these problems, it is urgent to clarify the effects of MnO upon the ironmaking production. Herein, the viscosities of slags with different MnO contents were measured for the first time, and the influence mechanism of MnO was analysed by infrared spectrum. The wetting behaviours between slags with different MnO contents and alumina–carbon refractory were investigated. The results showed that meltability temperature and viscosity decrease simultaneously with the increasing MnO content from 0 to 2.0 wt-%. Infrared spectrum analysis also proved that the existence of Mn$^{2+}$, Ca$^{2+}$ and Mg$^{2+}$ makes the Si–O bonds peak moving towards high frequency and the asymmetry of Si–O bond increasing, leading to the decrease in viscosity decreasing. In addition, the characteristic temperatures for wetting reaction increased by $40^\circ\text{C}$ with the increasing MnO content from 0 to 3 wt-% (basicity=1.18). The characteristic temperatures decreased by nearly $50^\circ\text{C}$ with the basicity of slag increasing from 1.0 to 1.3 (MnO = 1 wt-%). Therefore, the increasing MnO content in slag
accelerates the erosion rate of BF hearth lining and then decreases the campaign life of blast furnace.

**Numerical simulation on novel blast furnace operation of combining coke oven gas injection with hot burden charging.** Z. Liu, M. Chu, T. Guo, H. Wang, X. Fu

A novel blast furnace operation of coke oven gas (COG) injection simultaneously with hot burden charging has been proposed to solve the problem of insufficient heat in the BF shaft zone under the condition of COG injection and make full use of the abundant sensible heat of high temperature burden. In this paper, the novel process has been simulated with a multifluid blast furnace model. The results show that, in comparison with the operation of COG injection only, under the operation of COG injection together with hot burden charging, the temperature in the upper zone of the shaft increases while that in lower zone decreases. Furthermore, the reduction of iron bearing material is improved in the top zone, and the cohesive zone tends to descend and narrow. The coke ratio, fuel ratio and CO2 emissions of the operation of charging hot pellet and coke with the temperature of 800°C are decreased by 4.0, 4.7 and 5.3% respectively, while the hot metal productivity is increased by 7.14%. Therefore, COG injection combined with hot burden charging operation not only increases temperature in the upper part of the blast furnace but also decreases energy consumption per tonne hot metal.

**Mathematical model for burden distribution in blast furnace.** P. Shi, P. Zhou, D. Fu, C. Zhou

Burden distribution in a blast furnace is vital to its smooth running. However, it is difficult to directly measure the burden distribution for an operating blast furnace. Therefore, mathematical models have been applied to guide the charging process to achieve the desired burden distribution. The accuracies of such models depend on the prediction of falling curve, stockline profile formation, and burden descent mode. In this study, a new stockline profile formation model is proposed in which new equations have been developed for the inner and outer repose angle by considering the influence of the burden flow’s vertical and horizontal velocity at the apex of the stockline profile. Validation of this new stockline profile formation model is provided through comparison between calculated results and experimental data for stockline profile. A stepped burden descending strategy, in which the burden would descend through a specified distance after each ring charging process, is proposed corresponding to the successive charging process. The influence of the burden descending strategy on the falling point, the final burden profile and radial depth ratio of ore to coke is also analyzed. The result shows that the burden descending strategy greatly affects the final burden distribution, especially in the peripheral region.

**METEC & 2nd ESTAD, June 2015**

*The sinter shaft cooler: a highly energy-efficient solution for sinter cooling.* M. Böberl, A. Wegerer

Primetals Technologies has developed a new sinter shaft cooler that is not only highly energy-efficient but is also much more environmentally friendly than conventional sinter coolers. The shaft cooler design allows the total heat capacity of the hot sinter to be utilized for heating the cooling air that moves in counterflow to the sinter during its descent through the shaft. With this approach, the temperature of the cooling air exiting the shaft can be maximized and more efficiently applied for the generation of steam and electricity in downstream process steps, or used for the preheating and drying of materials or media used in the steelworks. Compared to conventional sinter coolers, the sinter shaft cooler features lower specific investment and production costs, a reduced energy consumption for sinter cooling, a higher throughput, and reduced dust and CO2 emissions due to a closed cooler shaft system. In this paper the features, benefits and challenges of the sinter shaft cooler are presented.
SWGR – selective waste gas recirculation - next generation. M. Mühlböck, G. Naderer
Increasingly stringent global environmental regulations are forcing steel producers to continually improve the efficiency of sinter waste gas treatment. With the Selective Waste Gas Recirculation (SWGR) system from Primetals Technologies, lower production costs can be achieved and the size of downstream waste gas cleaning units can be reduced for investment savings. SWGR features the extraction and reuse of hot sinter off gas from selected wind boxes along the sinter strand, which contributes to improved energy efficiency and off gas treatment in the sintering process. Main emission components in sinter waste gas are CO, CO2, SOx, NOx and dioxins. The level of gaseous emissions depends on the physical and chemical properties of the sinter raw mix, such as grain size distribution and chemical analysis of the raw materials. Additionally, there are typical distribution profiles of the waste gas components emitted along the sinter strand. Therefore, the portion of sinter waste gas used for recirculation has a major impact on the final off gas treatment prior to the release to the environment through the stack. Different recirculation strategies have been established. With the next generation of SWGR, Primetals Technologies can provide an energy optimized, emission optimized and environmentally friendly solution that meet customer requirements and country specific regulations. This paper demonstrates the latest developments in selective waste gas recirculation, particularly the adjustable configuration of waste gas recirculation aligned to specific requirements.

Blast furnace cooling stave design. M. Smith, J. Fletcher, R. Harvey, R. Horwood
Critical to any blast furnace campaign is the quality of the cooling system design. Over the many years of blast furnace history, cooling systems have evolved and changed to give an optimum design that provides long campaign life balanced against cost. In recent years, the latest evolution of the cooling system design, in the shape of the copper stave, has been seen as state of the art and an established feature on a large number of furnaces around the world. When first put forward, the copper stave was marketed as the ultimate cooling element since it not only provided a cooling function but also self-protected by forming an accretion layer. More recently, on some furnaces that have copper staves in their design, significant problems have arisen during operation, causing premature failure of the staves and reduced campaign life. This paper will review the evolution of the copper stave design and illustrate the latest techniques being applied by Primetals in this critical area of blast furnace design.

Primetals Technologies development of the ironmaking furnace hot blast system. M. Geach, M. Fletcher, G. Brown
Since the middle of the first decade of the 21st Century Primetals Technologies have undertaken a number of important developments to the engineering design, supply and installation of the Hot Blast System to meet our customer’s requirements. This Paper (and presentation) will address the numerous developments by Primetals Technologies concerning; the improved external stove cross-over (from the original Krupp Kopper’s design), refractory arrangement of the hot blast system, refractory material supply and quality control, combustion (heating) cycle control, modified combustion cycle (Flue Gas Recycle) for improved efficiency, and refractory chequer design. In the progress of the Hot Blast System developments over the past ten years, Primetals Technologies has consulted with our global network of Ironmaking customers concerning their requirements from operational experience, to provide innovative and tailored engineering solutions which have subsequently been applied across the Primetals Technologies design portfolio. The result of this development of the Hot Blast System being the ability of Primetals Technologies to provide a customer focused and robust engineered solution to the Ironmaking industry.
Use of a PGNAA to minimize standard-deviation of sinter-basicity. B. Kohnen, F. Demirçi, B. Oehling, G. Grabietz, C. Obert, G. Noble

The basicity of the sinter that is used in the blast furnace is a very important factor for the correct operation of the blast furnace. The basicity is defined as the concentration of CaO over SiO2. The common way to determine this value is a chemical analysis from the baked and cooled down sinter. The habit for HKM is the following procedure: taking the sample seven to eight hours after reclaiming the ore blend from the mixing bed and getting it analyzed in the automatic laboratory with XRF after the sintering. Deviations from the target values, leading to, for example, additional limestone dosing to the blend, have a time delay of another five hours for the next evaluation. The Prompt-Gamma-Neutron-Activation-Analysis (PGNAA) can measure the desired elements (Ca and Si) online directly after the mixing line. A neutron source (252Cf) activates the elements on a running conveyor-belt (load capacity of about 1000 t/h) and a detector above the belt measures the gamma rays, which are activated by the neutrons. The system generates six values of the desired elements every minute. A moving average of thirty minutes of the values of CaO and SiO2 is taken to monitor the basicity continuously. If the value of CaO has to be corrected, to get the desired basicity, the results of the chemical analysis are validated much faster, than with the common method. This gains at least five hours instead of waiting for the laboratory analysis. It also lowers the standard-deviation of the sinter-basicity significantly. As already mentioned, this makes the sinter more reliable in the chemical values, which is an improvement for the operation of the blast furnace.

Integrated burden control operation for blast furnaces. H. Fritschek, T. Kronberger, M. Schaler, B. Schürz

A key issue for low cost hot metal production is effective control of the composition and distribution of the raw materials in the blast furnace. The first part of the paper describes the individual process models for exact burden proportioning (burden control model and shaft simulation model) and for burden distribution control (online and offline burden distribution model) as well as the model toolbox for checking the plausibility of mass and energy balances. The second part outlines the integration of these individual models into the Iron Expert BF expert system, which is implemented as a rule-based decision machine. Practical examples of suggested corrective actions are shown. Closed-loop burden control made possible by the expert system has been used by voestalpine Stahl in Linz, Austria, for all blast furnaces during the last campaigns. The final section of the paper presents the financial year 2013/14 operational data for the burden composition, the fuel rates as well as the hot metal production and quality. For Blast Furnace A the total fuel coke equivalent rate below 455 kg/t of hot metal and a productivity above 2.8 t HM per m³ of working volume show the potential of the presented integrated burden control philosophy for low cost, highly efficient ironmaking.

Economic waste heat recovery for different sinter cooler types. G. Strasser, D. Bettinger, M. Moser

In the energy-intensive sintering process, fine iron ore, recycled process materials, additives and fossil fuels are agglomerated to fulfill the requirements for high-performance blast furnace operations. The sintered material is discharged from the sinter strand with a temperature range between 500°C and 700°C and cooled down to less than 100°C on the sinter cooler. The sensible heat of the produced sinter, which amounts to about half of the total energy input, is normally lost to the environment at the sinter cooler. For a typical sinter plant with a capacity of 4.5 million t/a, more than 800,000 MWh/a of thermal energy – equivalent to the average annual heating energy requirements of some 40,000 central European households – is wasted as a result of cooling. To reduce energy costs, plant operators are increasingly looking at solutions to utilize this heat in an economic way. Waste-heat recovery systems have therefore been
developed to meet the specific requirements of different sinter cooler types and on-site conditions. By means of specially designed cooler hoods, the bulk of the thermal energy in hot sinter can be extracted and efficiently used in a waste-heat boiler for steam generation. The steam can then be fed either to the local steam network for various local applications, or applied to produce electricity in a dedicated modular power block. By additional firing of low-calorific blast furnace gas in an external superheating system, the steam temperature and pressure can be further increased to meet local requirements. Technologies to improve the efficiency of heat-recovery during sinter cooling are discussed in this paper.

Influence of intentionally deteriorated coke properties on performance of Blast Furnace #2 Schwelgern. R. Schwalbe, R. Klock, U. Janhsen, P. Schmöle, M. Peters

In view of the current development in the raw material markets, it will become increasingly more difficult to obtain high-quality coking coal for the production of blast furnace coke with excellent properties. Today, such a coke quality is a prerequisite for a high rate of hot metal production with simultaneously high coal injection volume and low coke consumption. It is not yet known how large scale blast furnaces in particular will respond to the use of coke with poorer quality. For this reason an operational test at TKSE plants in Duisburg was conducted in 2011. In this test, a specific quality-reduced coke was produced in the company’s coking plant for use in the large scale Blast Furnace #2 Schwelgern. The effects of coke quality on process performance could be determined by intensive tracking of raw material quality, recording and analysis of all process-relevant data and a comparison with a representative reference period. In early November 2011, coking coal with a higher proportion of inert carbon carriers was deliberately used in coking plant, from which, as expected, only coke with impaired quality was produced. This coke was charged immediately in BF #2 Schwelgern. After a short period, deterioration in the furnace operation was observed. The hot metal production level fell as did other process parameters, thus significantly worsening and complicating process run as well as control. The results of this experiment show that a large blast furnace such as BF #2 Schwelgern requires coke with sufficiently good properties in order to operate economically and in a controlled manner.


An Advanced Reduction under Load (ARUL) test has been developed to simulate more accurately the conditions prevailing in a blast furnace as the iron burden falls down to the cohesive zone. In the ARUL test the adjustment of reducing gases (CO, CO2, H2 and N2) is carried out stepwise. The test is ended as the pressure difference over the sample increases to 70 mbar. At that stage, the structure of the sample has become so dense that the reducing gases have major difficulties to penetrate through the material layer. Recently, the ARUL test has been further developed by dynamically adjusting the gas composition during the test. The new test program has been named MASSIM. This paper presents a comparative study of the reduction softening behaviour of olivine fluxed pellets and basic sinter. The sinter showed a higher degree of reduction, as the gas impermeable structure was formed, especially with the MASSIM program. At that point, the final reduction degree was 90.2 % for the sinter and 68.7 % for the pellets and the final temperature of the test was 1329°C and 1252°C, respectively. Quaternary FeO-SiO2-CaO-MgO phase diagrams with constant contents of MgO and CaO were calculated using a computational thermodynamic software FactSage to clarify the melt formation phenomena. Experimental results together with computed phase diagrams showed the superior reduction-softening properties for the basic sinter.

Influence of raw material condition on behavior of reactive coke agglomerate. S. Kogure, H. Yokoyama, K. Higuchi, S. Nomura
An increase of carbon gasification rate lowers the thermal reserve zone temperature in blast furnaces and reduces carbon consumption of blast furnaces. To increase the carbon gasification rate, the enhancement of coke reactivity and close arrangement of fine iron ore and carbonaceous materials have been investigated. One of them is “Reactive Coke Agglomerate, RCA”. RCA had high carbon content and showed very high reducibility, and RCA enhanced the reduction of surrounding sinters by mixing RCA in sinter layer. They confirmed a reduction in thermal reserve zone temperature and an increase of gas utilization by mixing RCA in sinter layer with a Blast furnace Inner reaction Simulator. As for the strength after reaction, disintegration of RCA was fairly small in comparison with that of sinters both in a laboratory scale test and in a basket test using a vertical probe of a commercial blast furnace. Long-term plant trials conducted at the Oita Works No.2 Blast Furnace with a maximum use of 54kg/THM of RCA. As a result, RCA lowered the thermal reserve zone temperature, and carbon consumption in the blast furnace. Carbon consumption was decreased along the relationship of 0.36 kgC/THM per 1kgC/THM of input carbon from RCA. Moreover, in order to improve the effect of RCA, the influence of particle size of raw material iron ore on the behavior of RCA was investigated. By lowering the particle size of raw material iron ore, the crushing strength of RCA after reaction was increased, and the thermal reserve zone temperature was lowered, in consequence, the reduction efficiency was increased.

Energy-saving technologies for blast furnaces of Nippon Steel & Sumikin Engineering, T. Shimamura

In steel industry the rate of energy consumption is enormous, particularly the Blast Furnace (BF) iron-making process which has high consumption rate. Unit energy consumption in Japan is lowest in the world. NIPPON STEEL & SUMIKIN ENGINEERING (NSENGI) has significant contribution for reducing the energy consumption of BFs in Japan for over 50 years by design, manufacture, construction technology as well as development and improvement. NSENGI is the only engineering company participating in the Japan government project for reduction of CO2 emission from BF. This paper emphasizes on 3 major energy-saving technologies. The first is large BF. Enlarging of BF can lead to reduce capital and operating cost caused by consolidating of equipment and heat discharge amount from BF shell, etc. Therefore BFs in Japan have been enlarged. And BFs in Korea and China are also enlarged. Generally productivity and gas utilization tend to get lower with enlargement of BF. However NSENGI can realize highly-efficient BF by various technologies based on rich experience which NSENGI has designed approximately 30% of over 5,000m3 BF in the world. Additionally NSENGI have developed relining technology to satisfy the customer’s needs. For example, “Short Relining Technology” enables to reline over 5,000m3 BF in 68 days. The second is hot blast system “Metallic Burner type Top Combustion Hot Stove with high combustion performance and Heat medium circulation type Waste Gas Heat Recovery system with high heat efficiency”. Additionally Solely BFG Operation without usage of high-cost fuel gas can be achieved in combination, resulting in substantial reduction of operating cost. The third is Gas Cleaning System “Multi-Vessel Electrostatic Precipitator (MVEP)”. Pressure and temperature energy of top gas is recovered as electric power from the top-gas pressure recovery turbine (TRT). With MVEP, TRT can generate approx. 30% higher electricity than conventional wet-type.