

# 8th International Congress on Science and Technology of Ironmaking - ICSTI 2018

Tuesday 25 September 2018 - Friday 28 September 2018

Schloss Schönbrunn

8<sup>th</sup> ICSTI 2018  
[www.icsti2018.org](http://www.icsti2018.org)

## Book of Abstracts



# Contents

Effects of Change in Blast Furnace Inner Profile on Furnace Performance and Measures to Restore it, a Case Study at JSPL BF-II . . . . .	1
Aiming for Higher Performance Benchmarks at Time of Deteriorating Input Quality : An Experience at JSPL, BF-II (India) . . . . .	1
How iron ore melts in the blast furnace, part 1: ferrous burden . . . . .	1
HOW IRON ORE MELTS, PART 2: ROLE OF COKE AND NUT COKE . . . . .	2
Copper Stave Bending in Blast Furnaces . . . . .	2
Preliminary Results on Mathematical Modelling of Hot Metal Desulphurisation . . . . .	3
High-Temperature Top Combustion Hot Stoves of Kalugin Design for Blast Furnaces . . . . .	3
Energy Saving Technology for Lowering Air Leakage of Sintering Machine . . . . .	4
New Coal blending technique for controlling coal compatibility based on surface tension of semi-coke . . . . .	4
Application of crystallography to the thermodynamic modeling of silico-ferrite of calcium and aluminum . . . . .	5
Rings Growth Behaviors and Forming Mechanism of Rotary Kiln in HIs melt Process . . . . .	5
Size Optimization of Pellets for DRI Process . . . . .	5
Optimization of Sintering Process with Deteriorating Quality of Iron Ore Fines . . . . .	6
Research on the Long Life Blowpipe Liner of BF air supply apparatus . . . . .	6
Fundamental investigation of coke mixed charging using discrete element method . . . . .	7
Present and Perspective of Ironmaking in China . . . . .	7
Impact evaluation of metallization degree of pellets for direct reduction on its value in use . . . . .	7
Study on the mechanism of the flue gas circulation sintering process on sinter properties . . . . .	8
No Return Fine BF Ironmaking Process . . . . .	8
Reduction behavior of high phosphorus iron ore at reducing conditions simulating different zones of blast furnace . . . . .	9

Cooling capacity and thermal deformation analysis of copper steel composite cooling stove . . . . .	9
Characterisation and model fitting kinetic analysis of some carbonaceous material co-combustion . . . . .	10
On-line thickness monitoring system of copper staves in blast furnace in CSC . . . . .	10
The Simulation of Air Lance Design and Its Application for Burning-off the Deposited Carbon in a Coke Oven . . . . .	10
Effect of iron ores on the coking performance of ferro-coke . . . . .	11
A new 3D Characterization technique for Mineralogical Structure of Iron Ore . . . . .	11
Multistep Catalytic Mechanism of Gasification Reaction of Coke by Alkali in Blast Furnace . . . . .	12
Effect of silico and aluminum on the metallogenic and reduction mechanism of the low-quality iron ore sinter . . . . .	12
Reduction behaviors of pellet in hydrogen and carbon monoxide atmospheres . . . . .	12
Reduction behaviors of pellet in hydrogen and carbon monoxide atmospheres . . . . .	13
The improvement of gas combustion in JFE Fukuyama 5D . . . . .	13
A multi-coupled transient model for numerical simulation of blast furnace processes . . . . .	14
Coke Degradation After Reaction with Carbon Oxides In a Blast Furnace conditions using NMR Gas Imaging . . . . .	14
Practice of Low Cost Production in Baosteel Zhanjiang Iron & Steel Plant's Blast Furnace . . . . .	14
Effect of hydrogen content of bosh gas on softening-melting properties of iron-containing burden material . . . . .	15
Experimental Study on Treatment of COREX Dust by Cold Bond Pelletizing . . . . .	15
Effect of Ordinary Magnetite Ratios on Properties, Productivity, and Strength of Hongge High-chromium Vanadium-titanium Magnetite Sinters . . . . .	16
Effect of Ordinary Magnetite Ratios on the Basic Characteristics of Hongge High-chromium Vanadium-titanium Mixed Ores . . . . .	16
Non-isothermal reduction behavior of $\text{CaO}\cdot\text{Fe}_2\text{O}_3$ and $\text{Fe}_2\text{O}_3$ . . . . .	16
Study on preparation of a new biomass sintering fuel . . . . .	17
New understanding and evaluation of coking coal and coke properties . . . . .	17
Simultaneously sulfur removal and recovery of valuable elements from iron ore using hydrometallurgical process under atmospheric conditions . . . . .	18
Desulfurization of Iron Ores: Processes and Challenges . . . . .	18

The distribution of Magnesium in the sintered products and its effect . . . . .	19
Liquidus in the Fe-rich region and MgO partitioning between liquid slag and magnetite on the FeO <sub>x</sub> -CaO-SiO <sub>2</sub> -MgO system at 1573 K under oxygen partial pressure of 10 <sup>-7</sup> atm . . . . .	19
Study on technology of removal of titanium from hot metal in blast furnace . . . . .	20
Relationship between blast system and hearth activity of blast furnace . . . . .	20
Kinetic analysis of coke dissolution in carbon – iron melts . . . . .	20
Strength of Interfaces in Metallurgical Coke and its Influence on Coke Abrasion . . . . .	21
Improvement in blast furnace operational practice through implementation of process models . . . . .	22
Simulation research on spraying steam on sintering bed surface process . . . . .	22
Increase in Production by increasing Double Trough operation through straight campaign of trough repair at G Blast Furnace, Tata Steel Jamshedpur . . . . .	22
Effect of rotating chute shape and its optimization on burden distribution at the upper part of serial type bell-less top blast furnace . . . . .	23
A Cleaner and Efficient Process to Prepare Vanadium Pentoxide from the Converter Vanadium Slag . . . . .	23
Iron & Steel-Chemical Combined Making Technology, The Way of Green Development for Iron & Steel Enterprises In The Future —The carbon recycling and high-efficiency utilization of iron & steel-work off-gases . . . . .	24
Numerical Simulation of Hearth Operating Profile and Its Effect on Campaign Life for Baosteel No.3 Blast Furnace . . . . .	24
Preparation of ZnO/activated semi-coke by hydrothermal and its desulphurization performance . . . . .	24
Application of a new geometric model in estimating densities of ternary molten slags with limited solubility . . . . .	25
The Performance and Application of UCAR Carbon Brick in Blast Furnace . . . . .	25
Influence of CaO/SiO <sub>2</sub> and MgO on properties of blast furnace slag in JISCO and thermodynamic analysis . . . . .	26
Process modelling of ironmaking of blast furnace: developments and applications . . . . .	26
Development of energy recovery system for FINEX® . . . . .	26
Practical study on the flowability and combustion characteristics of pulverized coal for improving PCI operation efficiency . . . . .	27
Development of New Charging Technique of Nut Coke at Blast Furnace with Center Feed Type Bell-less Top . . . . .	27
Magnetite reduction by H <sub>2</sub> during microwave heating . . . . .	28

Effect of Hydrogen Concentration in Blast Furnace Reducing Gas on Reduction Behavior of Iron Ore Sinter . . . . .	28
Influence of Crystal Structure and Chemical Composition of Silico-ferrite of Calcium and Aluminum on its Reducibility . . . . .	29
Application status and investigation of titanium-containing materials in Blast Furnace protection process . . . . .	29
Exploration of Coal Fusibility in the Cokemaking Process and the Links to Coke Quality	30
Applied Fundamental Research of Ferro-coke Production by the Stamped Charging Cokemaking Process . . . . .	30
SEARCH FOR AN ALTERNATIVE PROCESSING OF MAGNETITE CONCENTRATE CONTAINING OXIDES OF VANADIUM AND TITANIUM . . . . .	31
Numerical simulation of blast furnace hearth and bottom erosion . . . . .	31
Blast Furnaces campaign extension and reline planning at CherMK – Severstal . . . . .	31
REGULARITIES OF HIGH INTENSIVE BLAST FURNACE OPERATION . . . . .	32
Thermal control of the blast furnace using instantaneous heat demand calculation method . . . . .	32
Evaluation Straight Grate and Grate Kiln Pelletizing Technologies . . . . .	33
Regularities of heat exchange at modern conditions of intensive blast furnace operation.	33
Modelling of gas and material distribution, raceway conditions and slag mode of operation of blast furnace . . . . .	34
The application practice of prolonging service life of large size BF copper cooling stove	34
Statistic and Thermomechanical Analysis of Titanium Distribution between Hot Metal and BF Slag . . . . .	35
Apparent Softening Viscosity Measurement of Granulated Slag Packed Bed with Softening and Melting Simulator . . . . .	35
Development of a Technique that Adding Iron Ore Micro-Particle Binder Ground by Vertical Wet Ball Mill for Increase of Iron Concentrate at Sintering Process . . . . .	36
Assimilation behavior of MgO source during iron ore sintering . . . . .	36
Model for emission reduction optimization of ironmaking process in blast furnace . . . . .	36
Static model study of the suitable direct reduction degree in COREX process . . . . .	37
Dechlorination effect for alkali liquor spray scrubber after BF dry dust-catch . . . . .	37
Numerical Simulation of Heat Transfer inside the Sintering Bed by Employing Different Cross-section Shapes . . . . .	38
The Development and Application of Blending Ore's Intelligence Heaping Mathematic Model for Large Raw Material Plant . . . . .	38

Discussion and Analysis of Shell Cracking of Large Hot Blast Stove . . . . .	39
Metallurgical Properties and Furnace Protection Practice of Self Produced Titanium Pellets . . . . .	39
Discussion on the influence analysis and migration law of chlorine in blast furnace system	39
Detailed DEM-SPH Simulation of Melt Passing Phenomena in Various Coke Beds . . .	40
Discussion on reasons of refractory material failure of hot blast stove corrugated pipe	40
Influence of thermodynamic melt formation characteristics on liquid phase fluidity of iron ore in sintering process . . . . .	41
A study on the control of porosity and its reduction behavior by using FeCl <sub>2</sub> in FeO .	41
Migration of Organic Sulfur in Nantong and Laigang Coal with Addition of NaOH-H <sub>2</sub> O <sub>2</sub> under Microwave Treatment . . . . .	41
Research on pellets properties prepared with different fineness forsterite . . . . .	42
Factors of influencing the high temperature characteristics of lump ores in blast furnace	42
A review on the ore blending scheme of Zhanjiang pelletizing plant . . . . .	43
Formulation of shrinking behavior of sinter during softening process . . . . .	43
Comprehensive Innovation of flue Gas Purification Facilities and Performance in Ironmaking Plant in Baosteel Zhanjiang Works . . . . .	43
Kinetic analysis of carbon fiber deposition on catalyst iron in CO-H <sub>2</sub> . . . . .	44
Case study of reclaiming Zn containing sludge from settling ponds . . . . .	44
Multiphase modelling of the blast furnace hearth during tapping . . . . .	45
A Successful Endeavor in Developing Long life Tuyere at I Blast Furnace, Tata Steel, Jamshedpur . . . . .	46
Digital Inventory Management System in 'I' Blast Furnace . . . . .	46
Diagnosis model for circumferential balance in burden distribution of blast furnace . .	46
Laboratory Simulation of Direct Reduction Shaft Furnace . . . . .	47
Evolution of coke nanostructure during gasification . . . . .	47
A Thermodynamic Study on the Selective Reduction of Ni in NiFe <sub>2</sub> O <sub>4</sub> . . . . .	48
A Comparison of different tuyere geometries . . . . .	48
Evolution of the structure of analogue sinters and the impact on sinter quality . . . .	49
Effects of operating conditions on the level of size segregation of iron ore granulated mix on a sinter strand . . . . .	49
Development of Granulation and Firing Technology in Using Large Quantity of Magnetite Fine Ore . . . . .	50

A short flow sheet and low carbon ironmaking process by simple raw materials . . . . .	50
Thermal Fluid Analysis in Deforming Packed Bed . . . . .	51
Analysis on the combined form of iron skull on the carbon brick surface used in blast furnace hearth . . . . .	51
Effects of iron coke hot briquette charging on softening-melting and dripping behaviors of blast furnace mixed burden . . . . .	51
Preparation and Application of Blast Furnace Burden from Vanadium Titanomagnetite by Carbon Composite Iron Ore Hot Briquette Process . . . . .	52
A New Method to Separate and Recovery Iron and Alumina from High Iron Bauxite Ore based on Metallized Reduction and Self-disintegrating . . . . .	52
Interaction between Sinter and Lump Ore under Simulated Blast Furnace Conditions . . . . .	53
Function Mechanism of CaO/SiO <sub>2</sub> on Melting Separation of High Chromium Vanadium-bearing Titanomagnetite Metallized Pellet Got from Gas-based Direct Reduction . . . . .	53
APPLICATION OF MODERN INFORMATION TECHNOLOGIES TO CONTROL AND PREDICT BLAST FURNACE OPERATION . . . . .	54
Study on the interaction between high metamorphic coal in Australia and low metamorphic coal . . . . .	54
Reduction behaviors of pellet in hydrogen and carbon monoxide atmospheres . . . . .	55
Modeling inner phenomena of self-reducing agglomerates under external inert gas atmosphere . . . . .	55
Sintering mechanism of self-reducing agglomerates using dilatometric analysis techniques . . . . .	56
Controlling of Fuel Particle Size to Minimize Dust Emission and Improve Productivity in Iron Ore Sintering Process . . . . .	56
Design and Application of Blast Furnace Longevous Copper Cooling Stave . . . . .	57
Construction on Energy Flow Network of Modern Blast Furnace Ironmaking . . . . .	57
Study on the Distribution of Coal(Coke) and DRI(Ore) in the Melter Gasifier of COREX . . . . .	57
Crystal phases in CaO-FeO-Fe <sub>2</sub> O <sub>3</sub> system transformed from CaO-Fe <sub>2</sub> O <sub>3</sub> system under a high cooling rate in air . . . . .	58
Comparing the Results of Acousto Ultrasonic-Echo (AU-E) with Thermal Analysis and Physical Measurements for Several Blast Furnace Hearth Refractory Linings . . . . .	58
Bead - Forming Experiment of Blast Furnace Slag by Gas Quenching . . . . .	59
Factors Influencing Reaction Beginning Temperature of Metallurgical Coke . . . . .	59
The co-liquefaction of low-rank coal/biomass by N-methyl-2-pyrrolidinone at high temperature . . . . .	60

Study on Medium-speed PulverizerCapacity under Non-mainstream Medium Volatile Matter Pulverized Coal Injection of Anthracite in Blast Furnace of Ningbol & S Co.	60
Evaluation of the thermodynamics aspects of Hydrogen Plasma Smelting Reduction (HPSR) of Iron Oxides . . . . .	60
Study on the influence of oxygen content in flue gas on the property of sinter . . . . .	61
Influence of operation parameters on desulfurization of hot metal in COREX Process .	62
Coke texture as coke performance parameter for the blast furnace . . . . .	62
Characterising the interface between IMDC and RMDC using micro-CT imaging . . .	62
Study on BF Hearth Water Accumulation and Influence on Service Life . . . . .	63
Development and Application of New Long Campaign Technology of Blast Furnace .	63
Application of Oxygen-Coal Injection in Shougang Jingtang 5500m <sup>3</sup> Blast Furnace[Pleaseinsertintopreamble] . . . . .	64
Investigation of co-combustion of different kinds of Hydrochar and their blends with anthracite in view of injection into blast furnace . . . . .	64
Reactive wetting of calcium ferrite on TiO <sub>2</sub> substrate at 1523K . . . . .	65
Optimisation of the cokes furnace chamber pressure control system to minimize emissions and damage . . . . .	65
HEARTH RECOVERY – AN EXPERIENCE WITH USIMINAS BLAST FURNACE#1	65
DEM-CFD Modelling of the transient, multiphase flow in the hearth of a blast furnace	66
Effect of Conductivity and Magnetization of Water on Green Mix Granulation Process	66
Comparison of different blast furnace operation modes . . . . .	67
Simulation of burden charging in a blast-furnace equipped with a Bell-less top system using Discrete Element Method . . . . .	67
Technical improvement and operation overview of Chinese Hlsmelt plant . . . . .	68
Recent understandings about the coke behavior in the tuyere zones and hearth of industrial blast furnace . . . . .	68
Research development on utilizing biomass in the blast furnace for CO <sub>2</sub> emission reduction: Experiences from Nordic countries and Canada . . . . .	69
A New Binder and MgO Flux for Pellet Production . . . . .	69
Development of Simulation and Mathematical Model for the Bell-less Top Burden Distribution in BF in Ansteel . . . . .	69
Low MgO Content Slag of Blast Furnace in Anshan Iron and Steel Group Corporation	70
Practice on Improving ANSTEEL'S No.3 BF Hearth Activity . . . . .	70

The Effect of CaF <sub>2</sub> on the Viscosity of Blast Furnace Slag with Low w(MgO)/w(Al <sub>2</sub> O <sub>3</sub> ) Ratio . . . . .	70
The Application of Oxygen Enrich Combustion on Hot Stove . . . . .	71
Research and Practice of CDQ Long campaign Life Technology in Ansteel . . . . .	71
The Experimental Research on Thermal Insulation Agent Made from CDQ Dust on Molten Steel . . . . .	71
Technology and Application on Low Carbon Sintering of Iron Ore . . . . .	72
Research on the rational utilization of iron solid waste in Baiyunebo special ore smelting process . . . . .	72
Pulverized Coal Injection Simulation . . . . .	73
Techno-Economic Analysis of Biocarbon Direct Injection in Blast Furnace Ironmaking	73
Experimental Blast Furnace Operation -Outline of Experimental Blast Furnace-	73
A new method to ensure completion of carbonization cycle through online raw coke oven gas temperature measurement . . . . .	74
Key Technical Challenges in Sinter Making at Tata Steel Kalinganagar – Use of high Alkali ores & control of High temperature properties. . . . .	74
Recycling of the High-zinc Fraction of Upgraded BF Sludge within the Integrated Steelplant . . . . .	75
The Effect of Unburned Pulverized Coal on The Slag Viscosity . . . . .	75
Measurement of activity of Al <sub>2</sub> O <sub>3</sub> in metallurgical slag . . . . .	76
Alkali control in the blast furnace – influence of modified ash composition in coke and charging practice . . . . .	76
CO <sub>2</sub> Ultimate Reduction in Steelmaking Process (COURSE50 Project) . . . . .	77
Study on the Dioxin Emission Reduction in a Commercial Sintering Plant of Shougang Group . . . . .	77
Analysis of Damage Mechanism of Copper Stave Applied in 3200m <sup>3</sup> Blast Furnace of Laiwu Steel . . . . .	78
Effect of ultra-fine iron ores on sinter process and quality . . . . .	78
Strategies Adopted to Reduce Hearth Temperature in High Productivity large Blast Furnace (BF IV) . . . . .	79
The role of mineral phases by sintering of iron ores with biofuel . . . . .	79
Comparison of softening-melting behaviors between Ti-bearing and common high basicity sinter . . . . .	80
Iron Ore Sintering Research at Different Scales . . . . .	80

EXPERIMENTAL STUDY AND FEASIBILITY ANALYSIS ON FLASH REDUCTION IRON MAKING PROCESS . . . . .	80
Using hot blast pressure data for improved detection of raceway blockages and reliable shutdown of PCI branches . . . . .	81
Study on the Sinter distribution in the Circular Cooler Pallet by Three-Dimensional DEM and FEM . . . . .	81
Experimental Research on Effect of unburned coal particles on Coke Properties in Blast Furnace . . . . .	82
Bell Less Top® coupled with advanced material sampling: the only system allowing to know how the BF is really charged . . . . .	82
Control of direct reduction in smelting reduction ironmaking . . . . .	83
Real-time elemental analysis for prompt process control in metallurgy . . . . .	83
Understanding coke formation and quality by analysis of physico-chemical processes . . . . .	83
High Temperature Characteristics of Blast Furnace Ferrous Burdens . . . . .	84
Hot blast superheating – Concept for an industrial trial . . . . .	84
Impact of the gas injection and recycling technology on the powder concentration of the outlet gas of the compact sinter machine . . . . .	85
Modeling the shaft furnace process for producing DRI based on rich hydrogen reducing gas . . . . .	85
Technology Progress for Blast Furnace Slag Granulation Process . . . . .	86
Process visualisation and modelling in ironmaking enabling higher performance . . . . .	86
The Application of Thermal Camera in the 5800m <sup>3</sup> BF at SHAGANG GROUP . . . . .	86
The application of online laser detector of burden surface profile in the 3200m <sup>3</sup> blast furnace at HanSteel . . . . .	87
Wetting behavior of Graphite-Al <sub>2</sub> O <sub>3</sub> Substrates against Molten CaO-SiO <sub>2</sub> -Al <sub>2</sub> O <sub>3</sub> -MgO Slags . . . . .	87
Impact of Altered Coke fraction Distribution Practice and usage of Process Diagnostic Tools on Blast Furnace Performance . . . . .	87
Experimental Blast Furnace Operation for CO <sub>2</sub> reduction . . . . .	88
Calculation model of concentration of quaternary slag system SiO <sub>2</sub> -CaO-Al <sub>2</sub> O <sub>3</sub> -FeO and its application . . . . .	88
The research on blast furnace injection coal evaluation method in industry test . . . . .	89
Recent Progress in Iron Ore Sintering Technologies in AnSteel . . . . .	89
Development of the blast furnace production in Russia . . . . .	89

Direct Reduction: Transition from Natural Gas to Hydrogen? . . . . .	90
The concept of charging different sinter size fractions into the blast furnace. . . . .	90
Dry dedusting system at POSCO Gwangyang No.1 BF . . . . .	91
The relining of Pohang No.3 Blast Furnace . . . . .	91
Impact of transition from Dry to Wet Quenching on Coke Properties and Blast Furnace Performance . . . . .	92
Petrological study of sinter-pellet-coke interaction in Advanced Softening and Melting (ASAM) experiments . . . . .	92
The Possibility of Significant BF-Hearth Lining Life Extension . . . . .	93
Estimation of liquid levels in the blast furnace hearth . . . . .	93
Evolution of Novel Sintering Regime at Tata steel Jamshedpur . . . . .	94
Relevance of Calculated Parameters on Tata Steel Blast Furnace Process Diagnostics	94
Footprints for the future of commercial FINEX plants . . . . .	94
Research on Transfer and its significance of MgO in blast furnace burden from sinter to pellet in Shougang Jingtang . . . . .	95
HIGH PELLETS RATIO BURDEN IN HBIS SERBIA BLAST FURNACE . . . . .	95
A method of micro-fluidized bed for the kinetic characteristics of iron oxide by gas-based direct reduction . . . . .	96
Investigate the optimum proportion for Collocation of Mauritania ore and Sierra Leone ore by Sinter pot . . . . .	96
ILTEC – Highlighting potentials and eliminating concerns regarding the safe and water-free cooling technology . . . . .	97
Influence of MgO on Low Temperature reduction and reduction disintegration of Sinter in COREX Reducing Process . . . . .	97
Recent taphole clay developments focusing on blast furnace preservation . . . . .	97
Towards the Comprehension of Ferrous Burdens Softening and Melting Phenomena in Blast Furnace - Development of a Thermodynamic Approach . . . . .	98
Step wise modifications to BF plants for progressive CO <sub>2</sub> emissions reduction from integrated steel plants . . . . .	98
The impact of iron ore ultra-fines addition on granulation in the sintering process . . .	99
A New Method for Calculating Burning lost Rate of Metallurgical Coke during dry quenching process . . . . .	100
Characterisation of PC char in respect to its consumption in the blast furnace . . . . .	100
Experience of blow-in after long stoppage of BF 2 in JSW Steel, Vidyanagar . . . . .	100

Experience with Continuous Temperature Measurement in a Blast Furnace Runner . . .	101
Study of the Alumina Effects on Iron Making Process through Pilot Scale Test and Numerical Simulation . . . . .	101
High-Temperature Behavior of Self-reducing Composites from BF Flue Dust and Mill Scale . . . . .	102
REFRACTORY CASTABLES FOR BLAST FURNACE MAIN TROUGHS: New developments for severe operating conditions . . . . .	102
Recent Research[Please insert into preamble]Development topics of Iron-making Technologies in NSSMC . . . . .	103
Structural Characterization of Coke from the Tuyere Region of the Blast Furnace . . .	103
Conversion of mill scale waste into high purity pig iron suitable for ductile cast iron production . . . . .	104
Research on the Dropping Mechanism of Iron Raw Material in Process of Blast Furnace Ironmaking . . . . .	104
Increasing the efficiency of biomass product injection into the blast furnace . . . . .	105
Evaluation of Sintering Behavior of Various Iron Ore Types . . . . .	105
Properties and Performance of Tap Hole Clays with Respect to Stable Blast Furnace Operations . . . . .	106
A Green and Sustainable Process of Iron ore Smelting Reduction by Hydrogen Plasma	106
LKAB experimental blast furnace, an important tool in development of products and processes for sustainable ironmaking . . . . .	106
Effects of slag chemistry on liquidus temperatures of high titania slags . . . . .	107
Effect of MgO content in structural and physical properties of iron ore pellets . . . . .	107
How laser based element analysis reduces costs, supports stable processes and increases flexibility in modern iron production . . . . .	108
Phase Transformation and Density Variation Prediction of Hematite Ore Particles in the Flight Melting and Reduction . . . . .	111
Development and Application of Key Process Technology and Equipment for New Generation No-bell Top of Blast Furnace . . . . .	111
Simulation Research on Improving 7.63m Coke Oven High-heating Uniformity in Shougang . . . . .	112
Strategic operation and raw materials planning for integrated steel plants in the process integration platform mSIMTOP . . . . .	112
Energy efficient and low emission sinter cooling . . . . .	113
Microstructural evolution of furnace coke during experimental heating . . . . .	113

New Efficiency in Ironmaking Facilities . . . . .	114
Development of Low thermal expansion Silica bricks for Coke Oven . . . . .	114
Investigation of factors impacting Coke Strength after CO <sub>2</sub> Reaction . . . . .	115
The Next Generation Copper Stave . . . . .	115
Reducing the cost of BF top gas dust handling, with practicable payback . . . . .	115
Prediction of Blast Furnace Hearth Condition: Theory and Practice . . . . .	116
Design and Commissioning of an Experimental Fluidized Bed Reactor for the Hydrogen Reduction of Titanomagnetite Ironsand . . . . .	116
An Assessment of the Effects of Calcia and Calcium Aluminate on the Reactivity of the Coke Analogue . . . . .	117
Characterisation of self-sintering BOS dust for enhanced utilisation of steel plant by- products . . . . .	118
Reduction of Titanohematite Pellets By Hydrogen Gas . . . . .	118
Phase development of titanomagnetite ironsand under oxidising conditions . . . . .	119
Physicochemical behaviour of olivine iron ore pellets mixed with nut coke under simulated blast furnace condition . . . . .	119
Further Possibilities of Competitiveness Improvements of a Midrex Direct Reduction Plant . . . . .	120
The high fluidity of Barro Branco coal (Brazil) and its influence on coke quality . . .	120
The influence of biomass/coal tar blends on the quality of bio-cokes . . . . .	121
Coke microstructure - sample preparation and image analysis via ImageJ . . . . .	121
Improving binding properties of self-reducing briquettes of iron ore and weathered coal	122
SELF-REDUCING AGGLOMERATES FROM LD AND BLAST FURNACE RESIDUES: METALLIZATION AND COOLING EFFECT . . . . .	122
Metallization and Carburization Kinetics in DR Shaft Furnaces. The METCARB Model	122
Advanced Blast Furnace Cooling Technologies . . . . .	123
SUSTAINABLE DECREASE OF CO <sub>2</sub> EMISSIONS IN THE STEELMAKING INDUSTRY BY MEANS OF THE ENERGIRON DIRECT REDUCTION TECHNOLOGY . . .	123
Softening and melting modeling of iron ore particles using a discrete - continuous coupling method . . . . .	124

0

## Effects of Change in Blast Furnace Inner Profile on Furnace Performance and Measures to Restore it, a Case Study at JSPL BF-II

**Author(s):** Mr. UPADHYAY, Hemant<sup>1</sup>

**Co-author(s):** Mr. BHAGAT, Arvind Kumar<sup>1</sup> ; Mr. KHAN, Nadeem<sup>1</sup>

<sup>1</sup> *Jindal Steel & Power Ltd*

**Corresponding Author(s):** hemant\_upd@jspl.com

A stable & productive blast furnace operation greatly depends not only on its design, operator skill or input material but on the profile & shape of its refractory lining also. The blast furnace inner wall profile exerts a large influence on the descent velocity distribution of the burden, the layer structure of the burden and the gas flow across the furnace. Furnace wall brick erosion and the scaffolding make the solid and gas flow unstable in the upper part of the shaft; it also changes the shape of cohesive zone greatly in the lower part of the furnace, thus affecting the heat transfer and melting rates. Conditions within the blast furnace vary widely by region and the refractories used in BF lining, particularly in the stack, belly & bosh are highly susceptible to a variety of wear mechanisms. Due to the very nature of its geometry and the pyro metallurgical process occurring at different stages there are diverse physical and chemical wear mechanisms in play at the different regions of the blast furnace and they are complex in nature but ultimately alter the blast furnace's inner profile by means of eroding / damaging the refractory lining. Here the impact of change in BF inner profile on furnace operations and its performance is studied in context of 1681 m<sup>3</sup> Blast Furnace-II at JSPL, India, after ~10 years of operation and producing ~12.5 million tons of Hot Metal. The extent of erosion, various factors contributing to that and operational actions taken to avoid it are also discussed giving focus on measures to restore the original profile, without necessity of taking long capital shutdowns, and their effect on performance parameters.

1

## Aiming for Higher Performance Benchmarks at Time of Deteriorating Input Quality : An Experience at JSPL, BF-II (India)

**Author(s):** Mr. UPADHYAY, Hemant<sup>1</sup>

**Co-author(s):** Mr. BHAGAT, Arvind Kumar<sup>1</sup> ; Mr. KHAN, Nadeem<sup>1</sup>

<sup>1</sup> *Jindal Steel & Power Ltd*

**Corresponding Author(s):** hemant\_upd@jspl.com

Blast Furnace can be considered as the most important reactor in commercial use in modern time, accounting for a majority of world total steel production through this route. Modern steel making demands superior quality and quantity hot metal at lowest cost. This requires an economic modern blast furnace with consistent, reliable and well-balanced operation of the furnace and all its support systems. Efforts have been continuously made for BF process optimization, to improve the energy efficiency, productivity, cost competitiveness and campaign life of a blast furnace.

The BF2 at JSPL India, over the years has set-up many milestones, surpassing productivity beyond 3.0 t/m<sup>3</sup>WV/day with high hot blast temperature >1200 oC and pulverized coal injection > 200 Kg/tHM, in-spite of not having the best raw materials in industry. This paper deals with the experiences and difficulties faced during the stabilization and operation of that furnace. The various steps taken, process modifications done and parameter tuning like coke quality derivation for different PCI rates, O<sub>2</sub> enrichment stabilization & control, PCI stabilization & control, burden distribution & charging control and raw material quality control are described.

2

## How iron ore melts in the blast furnace, part 1: ferrous burden

**Author(s):** Dr. GEERDES, Maarten<sup>1</sup>

**Co-author(s):** Dr. CHAIGNEAU, Rénard<sup>2</sup>

<sup>1</sup> *Geerdes Advies*

<sup>2</sup> *Rio Tinto*

**Corresponding Author(s):** geerdes@mgeerdes.nl

The present paper describes how the ferrous burden melts in a blast furnace and what consequences it has for blast furnace operation. For high PCI and high productivity operations, gas flow to and hence heat transfer from bosh gas to the solid/cohesive state of the ferrous burden is the rate limiting step in processing the ferrous burden, since the heat requirement of the direct reduction reaction of FeO determines the rate of heating of the primary slag. The processing and drainage of the liquid primary slag is determined by the FeO content of the slag, the slag composition and the voidage available in and below the cohesive zone. The iron fraction of the ferrous burden can only drain to the hearth once the direct reduction reaction is completed, since carbon dissolves in iron only when there is no FeO present. Analysis of operating blast furnaces shows that slag volume per ton is affecting productivity as well as maximum achievable coal injection rates. An estimate is that a decrease of slag volume of 10 kg per ton hot metal increases productivity by about 1,5% and reduces the metallurgical coke rate by 2-4 kg/tHM, while total fuel rate is reduced only by about 0,5 kg/t..

3

## HOW IRON ORE MELTS, PART 2: ROLE OF COKE AND NUT COKE

**Author(s):** Dr. GEERDES, Maarten<sup>1</sup>

**Co-author(s):** Mr. WARREN, Peter<sup>2</sup>

<sup>1</sup> *Geerdes Advies*

<sup>2</sup> *MPI*

**Corresponding Author(s):** geerdes@mgeerdes.nl

The present study was undertaken to find out whether or not there is an optimum distribution for nut coke and metallurgical coke over the ferrous layer and coke layer respectively. To this end a model for degradation of coke in the blast furnace was developed. It was verified with data from tuyere raking experiments. The tuyere raking result can be estimated based on degradation as a consequence of abrasion and direct reduction. Subsequently the model was used to analyze the optimum quantity and size for coke and nut coke. For operation at high PCI rates a large part of char is consumed in the direct reduction of FeO. Therefore, the higher the PCI rate, the lower the “consumable” nut coke rate. At a PCI level of 200 kg/tHM, the direct reduction consumes about 55 kg of coke. Since coke reacts on the surface of the particle, the direct reduction can be expressed as a diameter decrease, which corresponds with about 2 mm decrease of diameter. This means that all particles < 2 mm will be consumed by direct reduction. The model indicates that the voidage available for draining the liquid (“primary”) slag increases if more coke is put in the coke layer and less nut coke is used in the ferrous layer, which means, that at higher PCI rates the coke screen size has to be reduced. A strategy for setting the coke screen size is proposed.

4

## Copper Stave Bending in Blast Furnaces

**Author(s):** Dr. GHORBANI, Hamid<sup>1</sup>

**Co-author(s):** Dr. AL-DOJAYLI, Maher<sup>1</sup> ; Mr. CAMERON, Ian<sup>1</sup>

<sup>1</sup> *Hatch*

**Corresponding Author(s):** hamid.ghorbani@hatch.com

Copper staves are used in blast furnaces to protect the steel shell from process heat loads. Staves have experienced premature failures such as cracks, broken water pipes/water leakage, and abrasion related wear. Relationships between copper stave failure and stave deformation have been reported in literature. A detailed assessment methodology is presented to estimate the

thermomechanical bending in a copper stove. This approach incorporates temperature-dependent copper properties, such as creep and plasticity to more accurately capture stove deformation under transient and cyclic thermal loading. The resulting deformations are compared with commonly reported stove failures. Improvements to stove design and the related anchoring system can be assessed using the assessment methodology presented.

5

## Preliminary Results on Mathematical Modelling of Hot Metal Desulphurisation

**Author(s):** Dr. VISURI, Ville-Valtteri<sup>1</sup>

**Co-author(s):** Mr. VUOLIO, Tero<sup>1</sup>; Dr. SULASALMI, Petri<sup>1</sup>; Prof. FABRITIUS, Timo<sup>1</sup>

<sup>1</sup> *University of Oulu*

**Corresponding Author(s):** ville-valtteri.visuri@oulu.fi

Sulphur is one of the main impurities in steel. In blast furnace based ironmaking, hot metal desulphurisation constitutes the primary desulphurisation step, while secondary desulphurisation is conducted at the melt shop. Hot metal desulphurisation is typically conducted in a ladle or in a torpedo car using pneumatic injection of desulphurisation reagent via an immersed lance.

The ability to predict the course and efficiency of hot metal desulphurisation is important for process control. For this aim, a novel mathematical model was developed based on thermodynamic-kinetic fundamentals associated with hot metal desulphurisation in a ladle. In this model, the system is divided into several reaction interfaces, which have different micro- and macrokinetic characteristics.

The objective of this work is to provide a preliminary validation of the model using plant data collected from a hot metal desulphurisation plant in operation at SSAB Europe Oy in Raahe, Finland. Based on the results obtained, the evolution of the sulphur content and the relative contribution of the different desulphurisation mechanisms to the overall rate are discussed. In particular, the effect of the particle size distribution is estimated. Finally, practical means to improve the overall efficiency are evaluated based on the model predictions.

6

## High-Temperature Top Combustion Hot Stoves of Kalugin Design for Blast Furnaces

**Author(s):** Mr. IVLEV, Sergey<sup>1</sup>

**Co-author(s):** Dr. PROKOFIEV, Boris<sup>1</sup>; Ms. KALUGINA, Marina<sup>1</sup>; Mr. MURZIN, Yury<sup>1</sup>; Mr. SUBBOTIN, Anton<sup>1</sup>

<sup>1</sup> *KALUGIN JSC*

**Corresponding Author(s):** mail@kalugin.biz

Heating of blast has been and remains one of the most important parameters which determine the economic efficiency of blast furnace production. However, for several decades the maximum level of blast temperatures remains unchanged (1200-1250°C). This shows the limited capacity of conventional hot stoves with internal and external combustion chambers. The paper presents a new unique design of top combustion stoves, i.e. Kalugin Shaftless Stove. These stoves make it possible to achieve the hot blast temperature of 1300-1400°C with the use of standard refractory materials (silica, mullite-corundum and fireclay bricks) and provide high economic and environmental performance with the service life of 30 years. In these stoves gas combustion is performed by pre-chamber type burner with jet and vortex supply of gas and air. The burner is installed at the top of the dome and provides full combustion of gas without flame pulsation before its entrance to the checkerwork and uniform distribution of combustion products over the checkerwork. These stoves have small dimensions, which effects a saving of 30-50% on refractory materials. Moreover, they can be used for reconstruction of existing hot stoves and installed instead of old stoves on the same foundation. At present more than 200 Kalugin Shaftless Stoves are successfully operated at iron and steel works in China, Russia, Ukraine, India, Japan, Kazakhstan, Indonesia, Turkey, Brazil, Syria and Czech Republic.

7

## Energy Saving Technology for Lowering Air Leakage of Sintering Machine

**Author(s):** Dr. SHIAU, Jia-Shyan<sup>1</sup>

**Co-author(s):** Mr. HSIEH, Chia-Ming<sup>1</sup>; Mr. HUANG, Kun-Hsiang<sup>2</sup>; Dr. HUANG, Tsung-Yen<sup>1</sup>; Dr. LIU, Shih-Hsien<sup>1</sup>

<sup>1</sup> *China Steel Corporation*

<sup>2</sup> *Dragon Steel Corporation*

**Corresponding Author(s):** jiashyanshiau@gmail.com

In operational practice of the iron ore sintering machine, the increasing air leakage ratio will cause the higher electricity consumption of the suction fan, the higher solid fuel rate, the lower sinter productivity, and the worse sinter quality. In general, more than 50% of the leakage occurs at the pallets themselves and the interfaces between the pallets and the wind boxes. Basically, the sintering strand is comprised of a large number of pallets. And, it leads to the larger number of sealing parts. Consequently, the routine examination of the sealing condition of the pallets for detecting any abnormal air leakage is quite heavy load for the maintenance staffs. Hence, an on-line continuous measurement technology on the air leakage ratio of the sintering machine has been developed in China Steel Corporation (CSC). It has been applied to help the maintenance staffs easily and effectively find out the abnormal air leakage, then to repair or replace the pallets in the very short time. In this technology, the hot-wire type anemometers are fixed on a moving rack for scanning the velocity of the effective air flowing through the sinter bed. Meanwhile, the microphones are installed beside the pathway and close to the outer sidewall of the travelling pallets for monitoring the sound pressure generated by the abnormal air leakage. For identifying the passing pallet, the thermal-resistant type RFID technology is adopted. Based on the data measured from the hardware system mentioned above, the air leakage ratio of the sintering machine can be calculated with the mass balance method and total gas flow rate drawn by the suction fan. And, the pallets with abnormal leakage can be detected and ranked in the severity of leakage according to the measured sound pressure with the relevant criteria. This technology had been implemented in the CSC No. 2 sintering plant since August, 2016. The operation result indicates that it can effectively reduce the air leakage ratio by 5% and further decrease the electricity consumption of the suction fan for the sintering machine. In fact, this technology is very helpful to maintain a low air leakage ratio during the long-term operation of sintering machine.

9

## New Coal blending technique for controlling coal compatibility based on surface tension of semi-coke

**Author(s):** Mr. IGAWA, Daisuke<sup>1</sup>

**Co-author(s):** Dr. FUKADA, Kiyoshi<sup>1</sup>; Mr. MATSUI, Takashi<sup>1</sup>; Dr. FUJIMOTO, Hidekazu<sup>1</sup>; Mr. DOHI, Yusuke<sup>1</sup>; SUMI, Hiroyuki<sup>2</sup>; Mr. NAGAYAMA, Mikiya<sup>1</sup>; Dr. SHIMOYAMA, Izumi<sup>1</sup>

<sup>1</sup> *JFE Steel Corporation*

<sup>2</sup> *Deloitte Tohmatsu Consulting LLC*

**Corresponding Author(s):** d-igawa@jfe-steel.co.jp

Reasonable selection of coal brands and blending them for preparing raw material of coke are important to achieve the effective utilization of caking coal and enhancement of coke strength. Coal compatibility, namely “blending effect” has long been an unresolved problem. The effect is deviation between actual strength of coke made from coal blend and estimated strength which is calculated by averaging single coal properties. To understand the effect and develop a new blending technique which can control coal compatibility, we focused on surface tension of softening coals which probably affects adhesion phenomena between coal particles. However there is no method to measure the surface tension of coal at softening temperature. In this study, to overcome this difficulty, we devised a method to measure surface tension of semi-cokes obtained by heat treatment of coals at 500°C as a substitute for softening coals. First, we investigated the relationship between strength of coke made from binary coal blend and difference in the surface tension of semi-cokes made from these coals. As a result, the larger difference in the surface

tension between two coal brands, the lower strength coke was produced. Next, the finding was extended to multi-coal blend. The strength of coke was deteriorated with an increase in interfacial tension which is a new proposed factor calculated from the surface tensions of single coal brands used in the coal blend. The blending technique based on interfacial tension enables us to evaluate more precisely the coal compatibility and to select the good combination of coals, which can contribute to the production of high strength coke and effective usage of coking coal resources.

10

## Application of crystallography to the thermodynamic modeling of silico-ferrite of calcium and aluminum

**Author(s):** Dr. MURAO, Reiko<sup>1</sup>

**Co-author(s):** Mr. HARANO, Takayuki<sup>2</sup>; Prof. KIMURA, Masao<sup>3</sup>; Prof. JUNG, In-Ho<sup>4</sup>

<sup>1</sup> *Nippon Steel & Sumitomo Metal Corporation*

<sup>2</sup> *Nippon Steel & Sumitomo Metal Corporation*

<sup>3</sup> *High Energy Accelerator Research Organization*

<sup>4</sup> *Seoul National University*

**Corresponding Author(s):** murao.5gg.reiko@jp.nssmc.com

It is important to understand solid-liquid equilibrium of Al<sub>2</sub>O<sub>3</sub>-CaO-Fe<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system to understand the sintering reaction, although the sintering reaction is a non-equilibrium and inhomogeneous. Phase equilibrium calculation of this system has some problems, such as thermodynamic models for some silico-ferrite of aluminum and calcium phases were not present. Thermodynamic modeling of SFCA, Ca<sub>2</sub>(Fe,Ca,Al)<sub>6</sub>(Fe,Al,Si)<sub>6</sub>O<sub>20</sub> was conducted in the framework of the Compound Energy Formalism (CEF). Preferred substitution of Al in tetrahedral site was observed by Fe and Al K-edge X-ray absorption near edge structure. On considering crystallographic information in particular the charge compensation relation in the SFCA solution, the Ca<sub>8</sub>(Fe<sup>3+</sup>)<sub>20</sub>Oct(CaSi<sup>6+</sup>,FeFe<sup>6+</sup>,FeAl<sup>6+</sup>)<sub>3</sub>paired(CaSi<sup>6+</sup>)<sub>1</sub>paired(Fe<sup>3+</sup>,Al<sup>3+</sup>)<sub>20</sub>TetO<sub>80</sub> structure was considered as the SFCA solution model. By using this new model, SFCA single phase region can be well described in the phase diagram of the Ca<sub>4</sub>Si<sub>3</sub>O<sub>10</sub>-CaFe<sub>6</sub>O<sub>10</sub>-CaAl<sub>6</sub>O<sub>10</sub> system.

11

## Rings Growth Behaviors and Forming Mechanism of Rotary Kiln in HIs melt Process

**Author(s):** Mr. WANG, Yao-zu<sup>1</sup>

**Co-author(s):** Prof. LIU, Zheng-jian<sup>1</sup>; Mr. ZHANG, Jian liang<sup>1</sup>

<sup>1</sup> *USTB*

**Corresponding Author(s):** wgyozu@163.com

Recently, the HIs melt process in China has adopted the rotary kiln to achieve the purpose of heating and pre-reduction, which has received good effect compared with fluidized bed in Kwinana. However, ringing in kiln is the biggest problem puzzling relative producers, which wastes raw materials, squanders fuels and even stops production. Therefore, it is of great significance to study the ring mechanism of rotary kiln. In this paper, rings growth behaviors and forming mechanism of rotary kiln in HIs melt process was studied through X-ray diffraction (XRD-Rietveld) and scanning electron microscopy-energy-dispersive X-ray spectroscopy (SEM-EDS). It has been found that the main mineral composition of the rotary kiln ring is Hematite, Magnetite, Spinel, and Diopside. The rotary kiln ring has a very obvious layered structure and can be divided into "dense layer" and "loose layer". Mineral characteristics and consolidation mechanism of "dense layer" and "loose layer" was further studied. A "layer-by-layer" forming mechanism of rotary kiln was proposed based on the structural features and the thermodynamical analysis. Effects of particle size of the mixture, the properties of the coal and alkali metal on the ring forming discussed.

12

## Size Optimization of Pellets for DRI Process

Mr. VERMA, Chandra Shekhar<sup>1</sup><sup>1</sup> *Jindal Steel And Power Limited***Corresponding Author(s):** chandra.verma@jspl.com

The size of pellet plays crucial role in reduction kinetics inside the DRI kilns (Coal based) and most of the DRI plant uses 5-15mm pellet and getting 81-82% Fe(M) in DRI at 92-93% metallization max. which ultimately affects yield of Steel Melting Shop. Study shows +12mm raw pellet has very low Tumbler Index. & high Abrasion Index and reduction behavior also starts decreasing above 10mm size. Study concludes the best size for DRI process is 3-12MM. This size range resulted in reduced retention time of pellet inside the kiln which improved the productivity and quality. It also brought down the sp. energy consumption

13

## Optimization of Sintering Process with Deteriorating Quality of Iron Ore Fines

Mr. VERMA, Chandra Shekhar<sup>1</sup><sup>1</sup> *Jindal Steel And Powe Limited***Corresponding Author(s):** chandra.verma@jspl.com

Strength of the sinter decreases with increasing alumina content as it is a refractory material and required more heat input to fuse. It goes between the grain boundaries of the bond and makes it weaker. The ultimate aim of study is to produce strong sinter even with high Al<sub>2</sub>O<sub>3</sub> without hampering the productivity. Study includes mineralogy test of iron fines and product sinter to find out the distribution of different phases. Study concludes the establishment of B4 and Al<sub>2</sub>O<sub>3</sub>/SiO<sub>2</sub> ratio in between 1.52-1.57 and 0.63- 0.67 respectively and achieved Tumbler Index of 76 plus with the productivity of 1.58-1.6 T/M<sup>2</sup>/Hr.

Keywords: Sinter, B2, B3, B4, Al<sub>2</sub>O<sub>3</sub>/SiO<sub>2</sub> ratio, Productivity,

16

## Research on the Long Life Blowpipe Liner of BF air supply apparatus

**Author(s):** Mr. ZHU, Li<sup>1</sup>

**Co-author(s):** Prof. WU, Keng<sup>1</sup>; Dr. ZHAN, Wenlong<sup>2</sup>; Mr. LIU, Guoyou<sup>3</sup>; Mr. GUO, Yulin<sup>4</sup>; Mr. WANG, Kai<sup>3</sup>; Prof. ZHANG, Junhong<sup>2</sup>; Prof. HE, Zhijun<sup>2</sup>; Dr. PANG, Qinghai<sup>2</sup>

<sup>1</sup> *School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing*<sup>2</sup> *School of Materials and Metallurgy, University of Science and Technology Liaoning*<sup>3</sup> *Shouqin Metal Materials Co.,Ltd.*<sup>4</sup> *Beijing Yaxinda Industry and Trade Co., LTD.***Corresponding Author(s):** zhanwenlong288@163.com

The blowpipe of blast furnace (BF) air supply apparatus is always the weakest link of the hot blast pipe system. The local air leak, high surface temperature and short service life of blowpipe were ubiquity in the air supply apparatus after being used for a period of time. The average service life of No.2 BF tuyere blowpipe with conventional liner in Shouqin Company was 250 days at the initial stage of blowing-in. By improving the lining materials, the tuyere blowpipe adopted the molten silica-based composite refractory as lining material so that the thermal conductivity decreased from 0.812 W/ (m•[U+2103]) to 0.381 W/ (m•[U+2103]). Finally, the average service life of the tuyere blowpipe increased up to 702 days, which was twice times more than before, providing guarantee for the stable production of blast furnace

17

## Fundamental investigation of coke mixed charging using discrete element method

**Author(s):** Mr. TERUI, Koki<sup>1</sup>

**Co-author(s):** Mr. KASHIHARA, Yusuke<sup>1</sup>; Dr. NOUCHI, Taihei<sup>1</sup>; Dr. HIROSAWA, Toshiyuki<sup>1</sup>

<sup>1</sup> *JFE Steel*

**Corresponding Author(s):** k-terui@jfe-steel.co.jp

To achieve stable operation of coke mixed charging, it is essential to control coke segregation behavior in mixed layer. In this study, the effect of charging conditions and burden particle diameter of mixed coke ratio at blast furnace top were analyzed by numerical model based on discrete element method. Parameters necessary for calculation were optimized by experiment and calculation. Then, segregation behavior of coke particle was numerically investigated by using above calculation parameters. As a result, following findings were obtained. 1) At reverse tilting and broad range charging pattern of rotating chute, granular flow to the furnace center was interrupted and mixed coke particle was distributed uniformly for the direction of furnace radius. 2) Coke segregation in mixed layer was decreased by lowering particle diameter ratio between coke and sinter. Therefore, for the improvement of coke mixed ratio in mixed layer, control of particle diameter of coke and sinter is effective.

18

## Present and Perspective of Ironmaking in China

**Author(s):** Prof. YANG, Tianjun<sup>1</sup>

**Co-author(s):** Prof. SHA, Yongzhi<sup>2</sup>; Prof. ZHANG, Jianliang<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

<sup>2</sup> *China Iron and Steel Research Institute*

**Corresponding Author(s):** shayzh17@126.com

During last few years, iron production in China was kept at about 700 million tons annually, which was totally produced from BF process. At same time, a lot of mini BFs have been eliminated, and many big BFs have been built up and put into operation. There are 23 BFs with inner volume equal or over 4000m<sup>3</sup>. Both sinter machines and pellet facilities have been enlarged and upgraded correspondingly. Iron burden constitute has been shifted to 70% of sinter, 15-20% of pellet, and 10-15% of lump in general. Under the conditions of frequent changes in raw material quality and big economic pressure, BF operation controls have been improved in many aspects to maintain stable operation indexes, and to realize low cost production. Many new techniques and facilities have been developed and applied in ironmaking process, including new sealing technique of sinter machines, straight grate pellet process, Ti-Mg bearing pellet, and BF monitoring devices. There is significant progress in cleaning production. Strict emission standards have been imposed on all steel works. Various desulphurization facilities have been installed to treat sinter flue gas. Many open raw material yards have been modified to complete closing ones for dust emission control. Casting areas of blast furnaces have been sealed efficiently. Iron production in China is expected to be reduced gradually in the future, due to overcapacity control of steel production and more recycling of scrap. There is a big room for Chinese ironmaking improvement, including upgrading efficiency of BF ironmaking process, reducing BF fuel rate, extending BF campaign life, and pollution control further. Developing and application of BF smart control systems, by means of various artificial intelligence techniques, are hot points in our industry in the future. CO<sub>2</sub> emission control will be a big challenge for current BF process. New ironmaking processes will be explored continuously.

19

## Impact evaluation of metallization degree of pellets for direct reduction on its value in use

**Author(s):** Mr. LEITE, Michel<sup>1</sup>

**Co-author(s):** Mr. DUTRA, Eider<sup>1</sup>

<sup>1</sup> *Vale***Corresponding Author(s):** michel.leite@vale.com

Direct reduction and electric arc furnace are important routes for steel production in the world. The DRI production in 2016 was 72.8 Mt, from which 64.8% was by Midrex Process, 17.5% by coal-based, 17.4% by Hyl/Energiron and 0.3% by Other processes.

The metallic charge of direct reduction is mainly composed by iron ore agglomerate in the form of pellets and the direct reduction of iron ore occurs without melting and using natural gas as reducing agent. As a consequence, this process is widely used in countries where natural gas cost is low.

Pellets chemical and metallurgical specifications are very important for direct reduction process and steel refining in electric arc furnace. These characteristics impacts on reactor's productivity and consumptions of natural gas, electricity, flux and electrodes and consequently on steel cost production.

The paper presents a discussion about the impacts of metallization degree of pellets for direct reduction on their value in use. Value in use is the maximum price that a particular company is willing to pay for a replacement material without deteriorating economic results. A mathematical model which simulates DRI and steel production by direct reduction and electric arc furnace route was developed using mass and heat balance and also empirical correlations from literature.

20

## Study on the mechanism of the flue gas circulation sintering process on sinter properties

**Author(s):** Dr. LIU, Chao<sup>1</sup>**Co-author(s):** Prof. ZHAO, Kai <sup>2</sup> ; Prof. ZHANG, Yuzhu <sup>1</sup> ; Prof. XING, Hongwei <sup>2</sup> ; Dr. KANG, Yue <sup>1</sup><sup>1</sup> *Northeastern University*<sup>2</sup> *North China University of Science and Technology***Corresponding Author(s):** dbdxlc@126.com

The flue gas circulation sintering process can not only realize the comprehensive utilization of resources, but also can realize clean production which by recycling sintering flue gas to conduct iron ore sintering and significantly reducing the flue gas processing in the terminal treatment. The flue gas directly recycling use in sinter production will affect the sinter properties, because the flue gas oxygen content and temperature in the bellows are different. In order to make rational use of the sintering flue gas, it can be divided into high temperature flue gas, high pollution flue gas and comprehensive circulating flue gas according to the characteristics of sintering flue gas. In this paper, sintering cup experiments are used to study the influence law of the flue gas temperature, the oxygen content, the circulating sintering time and the carbon amount on sintering technical indexes and sintered ore metallurgical properties. The experimental results show that the reasonable amount of carbon reduction is 5% to 10% when the flue gas sintering in the circulation temperature is 423K to 523K [U+2103]. To guarantee the sinter properties, the oxygen content of flue gas should not be less than 18% and the reasonable time of flue gas circulation sintering about 6 min when the circulation flue gas is 473K and the carbon content is 4.05%.

21

## No Return Fine BF Ironmaking Process

**Author(s):** Prof. SHA, Yongzhi<sup>1</sup>**Co-author(s):** Ms. WANG, Zhihua <sup>2</sup> ; Ms. CAO, Jun <sup>2</sup> ; Dr. LI, Guangshen <sup>2</sup><sup>1</sup> *China Iron and Steel Research Institute*<sup>2</sup> *China Iron & Steel Research Institute***Corresponding Author(s):** shayzh17@126.com

A large quantity of return fines recycling is a serious shortage of current sinter + BF ironmaking process, which causes big increases in sintering operation cost and pollutant emissions. No Return Fine (BF) Ironmaking Process (NRIP) is conceived to use return fines in BF directly, after removing minus 1 mm part of dust from it. NRIP could make sinter+BF ironmaking process more efficient and environment friendly. The key point of NRIP application is to enhance capacity of BF granular burden acceptance. The methods are supposed to be dust removing control, separately charging of different size of iron ores, optimum burden distribution, gas flow control, sinter RDI control, smart ironmaking, etc. Industrial practices around the world have demonstrated firm basis and the feasibility of NRIP application.

22

## Reduction behavior of high phosphorus iron ore at reducing conditions simulating different zones of blast furnace

Dr. AL-KELESH, Heba<sup>1</sup>

<sup>1</sup> *Researcher at central metallurgical research and development institute*

**Corresponding Author(s):** hebaakelesh@hotmail.com

The persistently strong global demand for iron and steel has necessitated the utilization of various refractory iron ores, which are not suitable for direct blast furnace processes due to its low grades. In addition, the refractory iron ores cannot be upgraded cost-effectively using the traditional mineral processing methods because of complicated mineral compositions. High phosphorus iron ore is such a refractory mineral resource of great importance due to its vast abundance globally in U.S., Canada, China, Egypt, the former Soviet Union, Pakistan, Italy and Saudi Arabia. The main problem associated with exploiting these deposits is the dissemination of fine silicate minerals and the high level of phosphorus content due to the poor liberation of iron minerals from the gangues. Representative technological samples for iron ore are collected from Eastern South Aswan iron ore mine in Egypt. The principal gangue contents in this ore are SiO<sub>2</sub> 7.76 %, and P<sub>2</sub>O<sub>5</sub> 1.13 %. Iron exists in the form of hematite 78 %. So, it classified as high phosphorus iron ore. Ore was fired at 1000°C for 3 hours, then the green and fired samples was isothermally reduced by different ratios of H<sub>2</sub>/CO/CO<sub>2</sub>/N<sub>2</sub> which closely represent the theoretical reduction conditions in different zones of blast furnace. The influence of reduction conditions on the reduction behaviour and the morphology of the reduced samples were investigated. Green, fired and reduced samples were characterized by X-ray diffraction (XRD), X-ray fluorescence (XRF), Optical microscope and field emission scanning electron microscope (FESEM). The comparative reduction behavior for green and fired iron ore was investigated. At cohesive zone, the effect of firing can hardly be distinguished. But at thermal reserve and top zones conditions, the reduction rate of fired samples is greater than that for the green samples and that was confirmed by morphological examination of the reduced samples.

23

## Cooling capacity and thermal deformation analysis of copper steel composite cooling stave

Mr. HENG, Zhang<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing, USTB*

**Corresponding Author(s):** zh18862611390@126.com

The high heat transfer capacity and deformation resistance of cooling stave are the key to ensure long life of blast furnace and prolong the life of cooling stave. In contrast, temperature field and heat transfer capacity of copper cooling stave and copper steel cooling stave were analyzed through coupled fluid-solid numerical simulation using heat transfer theory. The results show that the difference of heat transfer capacity between copper steel cooling stave and the copper cooling stave is small, the heat transfer efficiency of the copper cooling wall is 78400.416W, and the heat transfer efficiency of cooling copper steel is 77486.611W, the difference between the two only 913.805W. From the analysis of heat transfer model, heat transfer ability of copper steel cooling stave is slightly smaller than the copper cooling stave. Heat convection of cooling water dominated in the cooling system, the 99% heat is taken away through cooling water, the nearest

distance channel in copper surface plays a major role. And deformation resistance of copper steel cooling stave is much better, in the limit working conditions without slag protection, The thermal deformation of copper steel cooling stave is half of that of the copper cooling stave, which indicates the copper steel cooling stave has better anti deformation ability. The stress value in the interface of copper clad steel cooling stave is higher and explosive welding combined with copper and steel materials at the interface to form a wave like interface, which can ensure the interface strength.

25

## Characterisation and model fitting kinetic analysis of some carbonaceous material co-combustion

Mr. WANG, qi<sup>1</sup> ; Mr. ZHANG, j<sup>1</sup> ; Mr. WANG, g<sup>1</sup> ; Mr. WANG, h<sup>2</sup>

<sup>1</sup> +8618811397101

<sup>2</sup> +18811397101

**Corresponding Author(s):** m18811397101@163.com

The combustion behaviors of coal, biomass(Soybean Straw), waste plastic(PVC), waste tires were studied by thermogravimetric analysis. Combustion parameters such as ignition, burnout, peak rate, ignition index, and combustibility index were analyzed. Three representative gas-solid reactivity models, unreacted core model, random pore model, volume model, and were applied to study kinetic parameters of coal, biomass, waste tires. Because the combustion of the PVC was divided into two stages, a double parallel reactions random pore model was used to described the combustion processes of PVC. Results show that random pore model is the most fitting model for simulating the combustion process. The activation energies of coal, biomass and waste tires calculated by this model are 91.6 kJ/mol, 244.1kJ/mol, 101.5kJ/mol, respectively. The combustion of the PVC is divided into two stages, the activation energy of the first stage is 50.7 kJ/mol and second stage is 40.4 kJ/mol, indicating carbon in PVC is easily reacted with oxygen and proving its high combustibility.

26

## On-line thickness monitoring system of copper staves in blast furnace in CSC

**Author(s):** Mr. KO, Yung Chang<sup>1</sup>

**Co-author(s):** Mr. HSU, Kuo-Wei <sup>2</sup> ; Mr. TUNG, Che-Hsiung <sup>1</sup>

<sup>1</sup> *China Steel Corporation*

<sup>2</sup> *National Chengchi University*

**Corresponding Author(s):** ycko1225@gmail.com

Modern blast furnace with long campaign life will install copper stave as its cooling element in bosh, belly and low shaft area. However, copper is not a good material for wear-resistance and deformation-resistance. The wears caused by burden material or high heat load damage make the stave thinning and leakage. Therefore, blast furnace with copper stave has to focus on its thickness. This study describes a new technology to evaluate stave thickness by using body temperature algorithm. It can monitor thickness real time and comprehensive. The system have installed on site in CSC to monitor the thickness of copper stave.

27

## The Simulation of Air Lance Design and Its Application for Burning-off the Deposited Carbon in a Coke Oven

Dr. WANG, Der-Her<sup>1</sup>

<sup>1</sup> *China Steel Corporation*

**Corresponding Author(s):** her111ful@gmail.com

The removal of deposited carbon in a coke oven is a regular task in coke plant. One of the efficient methods is to ventilate the chamber by the air lance for burning the carbon off, especially for the carbon accumulated beneath the oven ceiling or on the upper chamber walls. In this work, the air lance design and its application for burning-off the deposited carbon were performed by the numerical method with the three-dimensional transport equations, turbulent reactive flow and quasi-steady state assumption. In those practices, the adequate discharge air needed to cool the air pipe for sustaining the severe thermal radiation in a coke oven, but not to drop the temperature of chamber wall too low. Furthermore, the charging hole farthest from the ascension pipe was picked for inserting the single air lance, and that the introduced air needed to spread far beneath all charging holes. The simulation results revealed that an asymmetry-nozzle air pipe with the appropriate air outlet areas toward the coke side and pusher side could efficiently improve the carbon burning-off rate in the coke oven. The on-site experimental results showed such an asymmetry air lance could eliminate the carbon adhering to the upper chamber effectively.

28

## Effect of iron ores on the coking performance of ferro-coke

**Author(s):** Dr. XU, Runsheng<sup>1</sup>

**Co-author(s):** Mr. DANG, Han<sup>1</sup>; Mr. HUANG, Jiaqi<sup>1</sup>; Mr. DAI, Bowen<sup>1</sup>; Prof. SCHENK, Johannes<sup>2</sup>; Mr. YU, Lu<sup>3</sup>; Prof. WANG, Wei<sup>4</sup>

<sup>1</sup> Wuhan University of Science and Technology

<sup>2</sup> Montanuniversität Leoben

<sup>3</sup> Wuhan University of Science and Technology

<sup>4</sup> Wuhan university of Science and Technology

**Corresponding Author(s):** xu,unsheng@163.com

Highly-reactive coke can improve the reaction efficiency of blast furnace, as well as decrease the reduction agent ratio and CO<sub>2</sub> emission. Ferro-coke, which is obtained by combining coal with iron ore during coking, has been studied as a novel highly-reactive coke. In this study, effect of three iron ore types (limonite, hematite and oolitic hematite) on the gas generation, volume behavior, and composition evolution during coking were investigated using thermal gravity, high temperature microscope and X-ray diffraction, respectively. The change mechanism of the coking performance of ferro-coke according to the type and content of iron ore were discussed in detail. In addition, the interaction between iron ore and coal was also investigated. The experimental results have guiding significance for the development of the fabrication process of ferro-coke.

29

## A new 3D Characterization technique for Mineralogical Structure of Iron Ore

**Author(s):** Prof. WANG, Wei<sup>1</sup>

**Co-author(s):** Mr. JIA, Bin<sup>2</sup>; Mr. XU, Zhihui<sup>2</sup>; Mr. BAN, Zhaodong<sup>2</sup>; Mr. ZHENG, Heng<sup>3</sup>; Dr. XU, Runsheng<sup>1</sup>; Mr. CHEN, Weilin<sup>2</sup>

<sup>1</sup> Wuhan University of Science and Technology

<sup>2</sup> Wuhan Iron and Steel Co., LTD

<sup>3</sup> Wuhan University of Science and Technology

**Corresponding Author(s):** xu,unsheng@163.com

With the rapid development of iron and steel industry in China, the iron ore pellet as an essential raw material plays an important role in the blast furnace. Due to large-scale production of iron ore pellet, microscopic characterization is an important step in quality control. The structure and distribution of minerals in a pellet and the bonding types at point contacts between the grains strongly affect its metallurgical properties, like mechanical strength and reduction performance. Traditionally, pellets are characterized by 2D Optical Microscopy or Scanning Electron Microscopy. However, these approaches cannot be used to observe inner interconnection crystals in the volume

space. Therefore, the mineral information is incomplete and the 3D morphology and spatial distribution of the minerals are unknown. In this work, a new 3D characterization methodology based on serial sectioning of digital microscopy and image analysis was developed, automating some steps of the characterization. The discrimination of the main solid phases such as hematite, magnetite and silicates, and of pores can be achieved by threshold segmentation in 3D space. This approach enables the acquisition of high-resolution images in a cost-effective manner and greatly assists in the further study of the microstructure of the minerals in an iron ore pellet. The results of this study will contribute to further understanding of the mineral morphology effects on the properties of pellet.

30

## Multistep Catalytic Mechanism of Gasification Reaction of Coke by Alkali in Blast Furnace

**Author(s):** Prof. WANG, Wei<sup>1</sup> ; Dr. XU, Runsheng<sup>1</sup>

**Co-author(s):** Mr. TANG, Hui<sup>1</sup> ; Mr. WU, Yaming<sup>2</sup> ; Mr. LIN, Wenkang<sup>2</sup> ; Mr. GUO, Qing<sup>2</sup> ; Mr. GAN, Xian<sup>2</sup>

<sup>1</sup> Wuhan University of Science and Technology

<sup>2</sup> Pangang Group Xichang steel vanadium Co. Ltd

**Corresponding Author(s):** xu\_runsheng@163.com

Coke plays an irreplaceable role as a combustion agent, a reducing agent, a carburizing agent and a column skeleton in blast furnace. In order to make the production of blast furnace become more stable and efficiency, it needs to study the high temperature performance of coke in the blast furnace. Previous studied found that alkali would cyclic enrichment in the blast furnace, and then could strongly catalyze the coke gasification reaction. However, there are many different views on the catalytic mechanism of alkali on coke gasification reaction, such as oxygen migration theory, interlayer compounds theory, etc. The catalytic mechanism of alkali on the coke gasification reaction may also vary with the reaction temperature. It would be oxygen transfer in lower temperature, whereas that would be the formation of intercalation compounds in higher temperature. In order to verify the catalytic mechanism of alkali on the coke gasification reaction, the DTC analysis, HRSEM, XRD, ketone detection and other meatures was used in this study. This result will help us to understand the catalytic mechanism of alkali on coke gasification, and provide theoretical data for metallurgical production practice.

31

## Effect of silico and aluminum on the metallogenic and reduction mechanism of the low-quality iron ore sinter

**Author(s):** Prof. WANG, Wei<sup>1</sup> ; Dr. XU, Runsheng<sup>1</sup>

**Co-author(s):** Mr. YANG, Daiwei<sup>1</sup> ; Mr. LI, Heping<sup>2</sup>

<sup>1</sup> Wuhan University of Science and Technology

<sup>2</sup> University of Science and Technology Beijing

**Corresponding Author(s):** xu\_runsheng@163.com

Under the pressures of the decreases of high quality iron ore, the iron and steel enterprises in China turn to use low-quality ores which contain elements such as much silicon, aluminum, et al, in sintering. In order to understand the metallogenic and reduction mechanism of the low-quality iron ore sinter, in situ test were used in this study. The sinter samples were analyzed by X-ray diffraction, scanning electron microscopy and mineralogical microscopy to explore the effect of silicon and aluminum on the formation of complex calcium ferrite during sintering. In addition, the characteristics of the gas-soild reduction reaction between complex calcium ferrites and CO gas were studied by thermogravimetric analyzer. The effect of silicon and aluminum on the changes of mineral composition and microstructure of complex calcium ferrite during the isothermal reduction process was also investigated. The results of this study will help to the efficient utilization of low quality iron ore in sintering process.

32

## Reduction behaviors of pellet in hydrogen and carbon monoxide atmospheres

Prof. YU, yaowei<sup>1</sup><sup>1</sup> *shanghai university***Corresponding Author(s):** yaoweiyu@shu.edu.cn

Canadian hematite acid pellet with low magnetite content fluxed and olivine were isothermally reduced with hydrogen and carbon monoxide at 600 to 1000 [U+2103]. The course of reduction was investigated by measuring the oxygen weight loss as a function of time using a thermogravimetric analysis. Macroscopic and microscopic examination, X-ray and carbon analyses were also used to elucidate the mechanisms of reduction of pellet. For CO atmospheres, CO content in mixture can stimulate carbon deposition behaviors in pellet reduction procedure and carbon deposition leads to the fracture of pellet at the low temperature. For H<sub>2</sub> atmospheres, temperature from 600 to 700 and from 900 to 1000 oC have more influence on reduction fraction than one from 700 to 900 oC due to dense microstructures of pellet forming in the latter. Reduction of Fe<sub>2</sub>O<sub>3</sub> to Fe<sub>3</sub>O<sub>4</sub> is fastest and reductions of Fe<sub>3</sub>O<sub>4</sub> to FeO and FeO to Fe happen at the same time. Pellet reduced by CO has porous structures, while pellet reduced by H<sub>2</sub> has a dense product layer on the surface.

33

## Reduction behaviors of pellet in hydrogen and carbon monoxide atmospheres

Prof. YU, yaowei<sup>1</sup><sup>1</sup> *shanghai university***Corresponding Author(s):** yaoweiyu@shu.edu.cn

Canadian hematite acid pellet with low magnetite content fluxed and olivine were isothermally reduced with hydrogen and carbon monoxide at 600 to 1000 [U+2103]. The course of reduction was investigated by measuring the oxygen weight loss as a function of time using a thermogravimetric analysis. Macroscopic and microscopic examination, X-ray and carbon analyses were also used to elucidate the mechanisms of reduction of pellet. For CO atmospheres, CO content in mixture can stimulate carbon deposition behaviors in pellet reduction procedure and carbon deposition leads to the fracture of pellet at the low temperature. For H<sub>2</sub> atmospheres, temperature from 600 to 700 and from 900 to 1000 oC have more influence on reduction fraction than one from 700 to 900 oC due to dense microstructures of pellet forming in the latter. Reduction of Fe<sub>2</sub>O<sub>3</sub> to Fe<sub>3</sub>O<sub>4</sub> is fastest and reductions of Fe<sub>3</sub>O<sub>4</sub> to FeO and FeO to Fe happen at the same time. Pellet reduced by CO has porous structures, while pellet reduced by H<sub>2</sub> has a dense product layer on the surface.

34

## The improvement of gas combustion in JFE Fukuyama 5D

Mr. IKEDA, Norimasa<sup>1</sup><sup>1</sup> *JFE Steel Corporation***Corresponding Author(s):** no-ikeda@jfe-steel.co.jp

JFE Fukuyama No.5 D battery, since this battery started up, we struggle to control the temperatures of center flues and they fall to a low level. We estimated that the amount of air flow in center flues is less than gas flow because of the oven structure. Then, we entertained the way to increase air flow and invented the way we insert air with C ports which are used in only C gas inflammation. In this experiment, we simulated the changes of oven wall temperatures in inserting air and did at the actual equipment. As the result, we made sure of temperature rising nearly similar to our simulation. In this experiment, we put gas concentration meters in target flues and the concentration of CO is extremely less compared with before inserting air. So we

resulted that gas in the center flues was burnt completely. As it is now, we flow air excessively to all flues due to covering the amount of air flow in the center flues. We can modify the air ratio by this improvement. So it attribute to reduce the amount of combustion gas and the heat consumption. Now we are going to conduct the equipment for inserting air to all center flues.

35

## **A multi-coupled transient model for numerical simulation of blast furnace processes**

Dr. HUANG, Jianbo<sup>1</sup>

<sup>1</sup> *Central Research Institute, China BaoWU Iron & Steel Group*

**Corresponding Author(s):** jianbo.huang@baosteel.com

A multi-coupled three-dimensional transient model is proposed for simulation of blast-furnace (BF) iron-making processes. The model couples the whole thermo-fluid flow regions in the BF internal, including shaft, belly, hearth and raceway. Furthermore, the internal fluid flow, heat/mass transfer process is coupled with the heat transfer taking place in the outside refractory walls enclosing the BF internal fluid domain. The coupled simulation of processes in BF upper, middle and bottom parts, and fluid-solid conjugate heat transfer approach adopted in this model allows one to avoid applying artificial boundary conditions between different regions of the BF. The model is validated against the temperature measurements by the embedded thermal-couples, and the cross-sectional temperature measurement at the BF throat. Very good agreement is achieved for temperature at thermal-couple sampling locations, between the measured and calculated temperatures.

The model is capable of predicting transient behaviour of BF processes, such as non-uniform descending velocity of burden, time-varying distribution of different burden materials (coke, pellet, ore and sinter), distribution of porosity, cohesive zone. Distributions of temperature, pressure, velocity and volume fractions of gas mixture, solid particles, liquid iron and slag. The model is applied for detailed analysis of BaoSteel's No. 2 BF in the Baoshan base, Shanghai.

36

## **Coke Degradation After Reaction with Carbon Oxides In a Blast Furnace conditions using NMR Gas Imaging**

Dr. SAITO, Koji<sup>1</sup>

<sup>1</sup> *Nippon Steel & Sumitomo Metals Corporation*

**Corresponding Author(s):** saito.5m5.koji@jp.nssmc.com

Coke degradation by the reaction with carbon dioxide is known to cause the fine particle generation, deteriorating gas and liquid permeability in a blast furnace. Coke degradation must be suppressed or controlled in order to achieve stable operation of blast furnace. In this study, the mechanism of the coke degradation by the reaction with carbon dioxide, i.e. solution loss reaction, was investigated using our developed NMR gas Imaging technique in terms of changes in reactivity of cokes and fine particle generation after mechanical impact by I-drum revolutions when coke qualities were changed. In conclusions, (1) In case that the reaction ratio of coke with CO<sub>2</sub> is changed up to the reactivity of cokes, the reactivity of the cokes strongly affects the fine coke particle generation from reacted cokes. (2) In case that the reaction ratio is adjusted to predetermined value (20mass% in this study) as observed in actual blast-furnace operation, the increase in fine coke particle generation due to the reaction appeared unchanged, regardless of the reactivity of cokes. Instead, the coke abrasive strength appears to significantly affect the fine coke particle generation from reacted cokes.

37

## **Practice of Low Cost Production in Baosteel Zhanjiang Iron & Steel Plant's Blast Furnace**

Mrs. ZHANG, Weiling<sup>1</sup>

<sup>1</sup> Baosteel Zhanjiang iron and Steel Co., Ltd.

**Corresponding Author(s):** wendyzhang1213@163.com

This paper summarizes the low-cost production experience in Baosteel Zhanjiang Iron & Steel Plant's blast furnace. The raw material cost is reduced via optimising the ore blending structure of sinter, pellet and blast furnace, within the quality is assured. It's the key point of low cost economy smelting. Refinement operation level is improved and reasonable operation system is explored to ensure the stability of blast furnace. It's the guarantee of low cost operation. Furthermore, every detail which can reduce the cost should be paid attention to, such as optimising the coke screening system. Through the implementation of these measures, the pig iron cost is reduced efficiently and good economic benefits are obtained.

38

## Effect of hydrogen content of bosh gas on softening-melting properties of iron-containing burden material

**Author(s):** Mr. DU, Chengbo<sup>1</sup>

**Co-author(s):** Prof. ZHANG, Jiangliang<sup>1</sup>; Mr. LIU, Zhengjian<sup>1</sup>; Mr. WANG, Yaozu<sup>1</sup>

<sup>1</sup> University of Science & Technology Beijing

**Corresponding Author(s):** duchengbo<sub>ustb</sub>@163.com

At present, some new blast furnace blowing processes make the blast furnace gas composition changing greatly, especially the increase of hydrogen content. Therefore, it is necessary to study the change process of burden reduction in blast furnace containing hydrogen gas. Under the condition of laboratory, the hot melting performance of iron-containing charges were studied by using droplet furnace and utilizing the principle of phase diagram to analyze the influence of different amount of hydrogen in soft melting zone and the dropping zone. The experimental results show that, with the increase of H<sub>2</sub> content from 0 to 20 [U+FF05], the softening zone of the burden structure shows an upward trend, increasing from 150 to 204 [U+2103]. However, in the process of increasing the content of H<sub>2</sub> from 0% to 30%, the melting range becomes narrow that decreases from 228 to 78 [U+2103]. The maximum pressure difference also declines from 9.44kPa to 3.22kPa. The proper value of furnace burden drops sharply and descends from 1596kPa•[U+2103] to 26.52 kPa•[U+2103], which greatly raises the permeability of the burden column.

39

## Experimental Study on Treatment of COREX Dust by Cold Bond Pelletizing

**Author(s):** Dr. LI, Yang<sup>1</sup>

**Co-author(s):** Prof. ZHANG, Jianliang<sup>1</sup>; Dr. LIU, Zhengjian<sup>1</sup>; Dr. YUAN, Xiang<sup>2</sup>; Dr. WANG, Yaozu<sup>1</sup>; Dr. WANG, Haiyang<sup>1</sup>

<sup>1</sup> University of Science and Technology Beijing

<sup>2</sup> XIANG TAN IRON & STEEL CO., LTD HUNAN VALIN

**Corresponding Author(s):** liyangustb@163.com

COREX shaft furnace dust contains large amounts of valuable elements, such as iron and carbon, and compared with blast furnace dust, it contains more metallic iron. Therefore, take appropriate process to recycle the COREX dust can further achieve efficient utilization of resources. The chemical composition, particle size distribution, microstructure and mineral composition of the dust were characterized by chemical analysis, particle size distribution analyzer, scanning electron microscopy (SEM) and X-ray diffraction (XRD). Carbon-bearing cold-bonded pellet was prepared by COREX dust and further reduced to study the effect of C/O molar ratio, reduction temperature as well as reduction time on the reduction. Results showed that with the increase of C/O, reaction fraction increased first and then decreased; the metallization rate showed a gradual increasing trend with the increase of reduction temperature and reduction time. The optimum process parameters were obtained and as follows: reduction temperature, 1300 [U+2103];

reduction time, 15 minutes and C/O molar ratio, 1.2. Under such conditions, the metallization rate reached to nearly 80%, which showed the feasibility of recycle COREX dust recycling by cold bond pelletizing.

40

## Effect of Ordinary Magnetite Ratios on Properties, Productivity, and Strength of Hongge High-chromium Vanadium-titanium Magnetite Sinters

**Author(s):** Dr. TANG, Weidong<sup>1</sup> ; Prof. XUE, Xiangxin<sup>1</sup>

**Co-author(s):** Dr. YANG, Songtao<sup>1</sup> ; Dr. ZHANG, Liheng<sup>1</sup> ; Mr. HUANG, Zhuang<sup>1</sup>

<sup>1</sup> *Northeastern University*

**Corresponding Author(s):** twdking@163.com

The influence of ordinary magnetite ratios on Hongge high-chromium vanadium-titanium magnetite (HCVTM) sinters was researched through sintering pot tests. The researches including yield, sintering ratio, tumbler index (TI), productivity, solid fuel consumption, reduction degradation index (RDI) and reduction index (RI) were tested and calculated. The addition of ordinary magnetite ore is an adjusting method to affect the chemical content and properties of sinter. In this work, with ordinary magnetite ratio increases, the yield decreases from 90.5% to 84.6%, and sinter ratio decreases slightly from 84.98% to 83.43%. The maximum of productivity is 3.52 t[U+FOD7]m-2[U+FOD7]h-1 with 15% ordinary magnetite and then decreases with increases of ordinary magnetite ratio. The TI decreases and the minimum of TI is 43.65% with 45% ordinary magnetite. The RI increases from 50.7% to 70.9%, and the solid fuel consumption rises from 55.25 kg[U+FOD7]t-1 to 59.10 kg[U+FOD7]t-1 while the RDI deteriorates from 96.7% to 50.7% with increase of ordinary magnetite ratios.

41

## Effect of Ordinary Magnetite Ratios on the Basic Characteristics of Hongge High-chromium Vanadium-titanium Mixed Ores

**Author(s):** Prof. XUE, Xiangxin<sup>1</sup> ; Dr. TANG, Weidong<sup>1</sup>

**Co-author(s):** Dr. YANG, Songtao<sup>1</sup> ; Dr. ZHANG, Liheng<sup>1</sup> ; Mr. HUANG, Zhuang<sup>1</sup>

<sup>1</sup> *Northeastern University*

**Corresponding Author(s):** twdking@163.com

The effect of ordinary magnetite ratios on the basic characteristics of Hongge high-chromium vanadium-titanium mixed ores was investigated through micro-sinter methods. The researches including assimilation characteristic, crystal intensity characteristic, bonding strength characteristic and fluidity characteristic were studied. With increase of ordinary magnetite ratios in Hongge high-chromium vanadium-titanium mixed ores, the lowest assimilation temperature (LAT) of mixed ores decreases slightly from 1395[U+F0B0]C to 1324[U+F0B0]C, the crystal intensity (CI) first decreases and then rises, and the minimum of CI is 4752 N with 30% ordinary magnetite. Meanwhile, the bonding strength (BS) decreases from 4152N to 1781N, and the fluidity index of liquid (FIL) rises from 0.035 to 0.14 with increase of ordinary magnetite ratio. The correlation of FIL with LAT and BC were negative.

42

## Non-isothermal reduction behavior of CaO·Fe<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>

**Author(s):** Mr. LI, Gang<sup>1</sup>

**Co-author(s):** Prof. LV, Xuewei<sup>1</sup> ; Mr. WU, Shanshan<sup>1</sup> ; Dr. DING, Chengyi<sup>1</sup>

<sup>1</sup> *Chongqing University*

**Corresponding Author(s):** cquligang2793@163.com

In the current work, the reduction route of  $\text{CaO}\cdot\text{Fe}_2\text{O}_3$  (CF) was investigated and the comparison of CF and  $\text{Fe}_2\text{O}_3$  (H) on their reduction kinetics was made. Non-isothermal reduction experiments of powdery CF and H heating up to 1123K with a rate of  $10\text{K}\cdot\text{min}^{-1}$  in a continuous stream of 30% CO and 70%  $\text{N}_2$  were conducted through thermo-gravimetric analysis. It found that the reduction processes of CF and H begin at 873 and 623K, respectively. Reduction rate analysis and subsequent X-Ray diffraction measurements at various stages revealed that the reduction of CF can be divided into two steps ( $\text{CF}\rightarrow\text{C}_2\text{F}\rightarrow\text{Fe}$ ), whereas that of H mainly comprises three steps ( $\text{H}\rightarrow\text{M}\rightarrow\text{W}\rightarrow\text{Fe}$ ). Activation energy was calculated by Freeman-Carroll method and the average values of CF and H reduction are 49.88 and 43.74  $\text{kJ}\cdot\text{mol}^{-1}$ , respectively. Model function was calculated by Malek method and the results indicated that the reduction of CF can be described by random instant nucleation and two-dimensional growth of nuclei model, its corresponding model function is Avrami-Erofeev equation with the integral form of  $[-\ln(1-\alpha)]^n$ , whereas the reduction of H was expressed initially by tertiary chemical reaction model ( $\alpha=0.1\sim 0.5$ ) with the integral form of  $1-(1-\alpha)^3$ , and subsequently by two dimensional cylindrical diffusion model ( $\alpha=0.5\sim 0.9$ ) with the integral form of  $\alpha+(1-\alpha)\ln(1-\alpha)$ .

43

## Study on preparation of a new biomass sintering fuel

**Author(s):** Dr. LIU, Chao<sup>1</sup>

**Co-author(s):** Prof. ZHAO, Kai<sup>2</sup>; Prof. ZHANG, Yuzhu<sup>2</sup>; Prof. XING, Hongwei<sup>2</sup>; Dr. KANG, Yue<sup>1</sup>

<sup>1</sup> Northeastern University

<sup>2</sup> North China University of Science and Technology

**Corresponding Author(s):** dbdxlc@126.com

Sintering is an important link of the iron and steel production, through the sintering production process can we improve the quality of raw materials and expand the source of the raw material for ironmaking. However, the sintering process produces a great quantity of particulate matter,  $\text{SO}_2$ ,  $\text{NO}_x$  and dioxins, which leads to damage the atmospheric environment. What's more, the main pollutants come from coke. For controlling sintering pollutants from the sources, this research prepares a new type of biomass fuel to replace numbers of coke. Biomass carbonization, molding and modification experiments to confirm the best experimental conditions. The experimental results show that the new biomass fuel of specific surface area, pore volume, pore diameter and combustion performance approach coke, and it can be used for sintering instead of coke to achieve environmentally friendly production.

44

## New understanding and evaluation of coking coal and coke properties

**Author(s):** Prof. WANG, Qi<sup>1</sup>

**Co-author(s):** Dr. GUO, Rui<sup>2</sup>; Prof. LIANG, Yinghua<sup>3</sup>; Prof. ZHAO, Xuefei<sup>1</sup>

<sup>1</sup> The Key Laboratory of Chemical Metallurgy Engineering of Liaoning Province, University of Science and Technology Liaoning

<sup>2</sup> School of Chemical Engineering, North China University of Science Technology

<sup>3</sup> Hebei Province Coal Chemical-Engineering Technology Research Center, North China University of Science and Technology,

**Corresponding Author(s):** raykuo@126.com

Evaluation of coking coal properties in coking Industry depends on several independent indicators tested in different test conditions for a long time, for example, Gieseler fluidity, Arnu-Audibert's dilatometer, plastometer indice, Roga index, and volatile content. On the other hand, evaluation of coke thermal properties depends on Coke Reactive Index (CRI) and Coke Strength after Reaction (CSR) tested in 1100[U+2103] and lasted in two hours. In view of the fact that there are some shortages of evaluation coking coal properties and coke thermal properties, the evaluation

methods for “the related properties during carbonization of coking coal” and “the comprehensive thermal performance of coke” were developed. The former one was used to measure the relevance between the volatile matter escaping, plastic layer forming, and swelling pressure during single and blending coking coal carbonization process; the latter one was used to detect the initial temperature of coke reaction, the average coke reaction rate and the coke strength after reaction at the coke weight loss up to 25%, the dependence of the coke strength after reaction on the reaction temperature, the coke polycondensation index and coke strength after polycondensation for the coke weight loss up to 25%. These two methods can be used to further identify the performances of coking coal and coke, and establish some new evaluation methods of coking coal and coke quality.

45

## Simultaneously sulfur removal and recovery of valuable elements from iron ore using hydrometallurgical process under atmospheric conditions

**Author(s):** Dr. REZVANIPOUR, Hassan<sup>1</sup>

**Co-author(s):** Prof. MOSTAFAVI, Ali<sup>2</sup> ; Mr. KARIMIMOBARAKABADI, Mohammad<sup>3</sup> ; Mr. EBADIPOUR, Ghobad<sup>4</sup>

<sup>1</sup> *Golegohar Mining and Industrial Co. Sirjan, Iran/Department of Chemistry, Shahid Bahonar University, Kerman, Iran*

<sup>2</sup> *Department of Chemistry, Shahid Bahonar University of Kerman, Kerman 76169-14111 Iran*

<sup>3</sup> *Laboratory and Quality control Manager, GoleGohar Mining & Industrial Company, Sirjan, Iran*

<sup>4</sup> *Head of mineralogy Laboratory, GoleGohar Mining & Industrial Company, Sirjan, Iran*

**Corresponding Author(s):** rezvani.ch@gmail.com

Due to the important effects of sulphur content in iron ore on the technical problems and environmental issues in steel making, a tank leaching process at atmospheric conditions was performed for the desulphurization of the iron ore concentrate and also for the transformation of sulphide minerals into useful by-products. In order to achieve higher sulphur removal rates and efficiency, a central composite design (CCD) was conducted as a response surface methodology for the optimization and evaluation of the process. A full-quadratic polynomial equation between the sulphur removal and the studied parameters was established to assess the behaviour of sulphur removal as a function of the factors and to predict the results at various conditions. After running the experiments, an analysis of the variance tests and response surface plots were used to obtain the optimum conditions. The optimized ranges for each factor resulting in the best response (the highest percentage of desulphurization) were then extracted from these surfaces. The optimum values for the main parameters were found to be 1.39 (mol/dm<sup>3</sup>) for the concentration of nitric acid, 0.88 mol/dm<sup>3</sup> for the concentration of sulphuric acid. The leaching process took 47 hours. The designed process under the optimized condition was applied to extract nickel, cobalt and chromium from the iron ore and tailings. The results obtained showed that more than 75% of the total sulfur was removed and simultaneously more than 50% of valuable metals were extracted by the chemical leaching. In addition to the desulphurization and valuable metals extraction, the conversion of sulphide bearing minerals into useful by-products, phosphorus removal and executing the process under atmospheric conditions are the other advantages of the proposed method.

46

## Desulfurization of Iron Ores: Processes and Challenges

**Author(s):** Dr. REZVANIPOUR, Hassan<sup>1</sup>

**Co-author(s):** Prof. MOSTAFAVI, Ali<sup>2</sup> ; Mr. KARIMIMOBARAKABADI, Mohammad<sup>3</sup> ; Mr. EBADIPOUR, Ghobad<sup>4</sup>

<sup>1</sup> *Golegohar Mining and Industrial Co. Sirjan, Iran/Department of Chemistry, Shahid Bahonar University, Kerman, Iran*

<sup>2</sup> *Department of Chemistry, Shahid Bahonar University of Kerman, Kerman, Iran*

<sup>3</sup> *Laboratory and Quality control Manager, GoleGohar Mining & Industrial Company, Sirjan, Iran*

<sup>4</sup> *Head of mineralogy Laboratory, GoleGohar Mining & Industrial Company, Sirjan, Iran*

**Corresponding Author(s):** rezvani.ch@gmail.com

Various studies have been increasingly performed on the reduction of sulfur content of iron ores and concentrates. The presence of sulfur in these materials causes technical problems in steel and alloys and environmental issues in the roasting of iron ore process. The achievement of higher sulfur removal rates has been an important goal since the development of sulfur removal techniques. In this research, an effort was made to separately introduce the various processes, industrial practices and fundamental research activities to remove sulfur from iron ores, concentrates or roasted iron ores. In this way, the optimized condition and latest innovations in sulfur removal using flotation were reviewed and the development of leaching and bioleaching techniques for sulfur reduction was introduced; following the development of thermal decomposition, physical separation methods and magnetic separation technique were discussed. In each section, a brief introduction of fundamentals for the sulfur removal techniques and their potential advantages for sulfur removal are described and challenges for each technique are presented. Finally, the techniques were compared from technical, economic and environmental viewpoints, and future trends in desulfurization of iron ores are presented.

47

## The distribution of Magnesium in the sintered products and its effect

**Author(s):** Mr. ZHANG, weili<sup>1</sup>

**Co-author(s):** Dr. KOU, Mingyin <sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** zhangweili0408@163.com

Flow and Occurrence of Magnesium in Sintered Products were studied by XRF and SEM-EDS. The results of this research are as follows. The figure shows magnesium content of sintered products in the following decreasing order: blast furnace return fine, sinter return fines, finished ore. Moreover, magnesium content in the 0.5mm-3.15mm size of blast furnace return fine is especially high. Magnesium content of sintered minerals is in the following decreasing order: magnetite, SFCA, silicate, hematite. Magnesium existing in the magnetite will generate magnesia magnetite, which prevents the oxidation of magnetite and then reduces the SFCA liquid phase. Magnesium existing in the SFCA will increase the viscosity of SFCA to reduce the bonding range of the liquid phase and may affect the crystallization state of SFCA, so it will deteriorate the strength index of sinter. The incompletely assimilated dolomites were found in the sintered products and the diffusion range of magnesium is wider than that of calcium, because the chemical reaction ability of calcium oxide is higher than that of magnesium oxide.

48

## Liquidus in the Fe-rich region and MgO partitioning between liquid slag and magnetite on the FeOx-CaO-SiO<sub>2</sub>-MgO system at 1573 K under oxygen partial pressure of 10<sup>-7</sup> atm

**Author(s):** Dr. HAYASHI, Miyuki<sup>1</sup>

**Co-author(s):** Dr. WATANABE, Takashi <sup>1</sup> ; Prof. SUSA, Masahiro <sup>1</sup>

<sup>1</sup> *Tokyo Institute of Technology*

**Corresponding Author(s):** hayashi@mtl.titech.ac.jp

The increment in the impurities of iron ore such as Al<sub>2</sub>O<sub>3</sub> lowers the reducibility of iron ore sinter and increases the gas permeability resistance in a blast furnace. In order to overcome the problems, MgO is often added into sinter by blending dolomite and/or serpentine as a constituent of raw materials of sinters. The role of MgO in sinter at the lower part of a blast furnace depends on the MgO distribution in sinter. In this study, liquidus in equilibrium with iron oxides in the FeOx-CaO-SiO<sub>2</sub>-MgO system has been measured at 1573 K and at oxygen partial pressures of 10<sup>-7</sup> atm and 10<sup>-6</sup> atm which is similar to that of the sintering process. In addition, MgO

concentrations in the liquid and the FeOx phases have also been measured so as to elucidate the compositional dependency of the MgO partitioning between two phases. It has been found that the liquidus region in the FeOx-rich side is decreased by 5 mass% MgO addition over the measurement range of the C/S ratios between 0.32 and 2.28. The liquidus is also divided into two compositional areas of the silicate-based liquid and the calcium ferrite-based liquid, where the C2S phase becomes stable thermodynamically in the range of the C/S ratios between 1.66 and 1.96. The MgO content in magnetite is as large as 14 mass% at C/S = 1.62, and the partitioning of MgO in liquid phase decreases with increasing the C/S ratio.

49

## Study on technology of removal of titanium from hot metal in blast furnace

**Author(s):** Dr. ZHANG, Xuesong<sup>1</sup>

**Co-author(s):** Mr. ZHAO, manxiang<sup>1</sup>; Mr. LIANG, hailong<sup>1</sup>; Mr. ZHAO, tieliang<sup>1</sup>; Dr. ZHOU, jiliang<sup>1</sup>

<sup>1</sup> *ShouGang Group*

**Corresponding Author(s):** zhoujiliang@shougang.com.cn

Laboratory test of removal of titanium from hot metal is developed in different remover, different proportion and different granularity. The suitable remover and parameters for industrial production test are found. At the same time the removable titanium removal device is designed and developed. Industrial test of removal of titanium from hot metal in blast furnace of Shou-gang stock company is developed successful. When the ratio of the remover is 1%, the titanium removal rate of hot metal reaches above 50%. And the temperature drop and slag skimming amount are all within the normal range. There is no effect on the back process. Through this test, the contradiction between high titanium content in hot metal because normal furnace protection and low titanium content in hot metal of silicon steel is solved.

50

## Relationship between blast system and hearth activity of blast furnace

**Author(s):** Dr. DAI, BING<sup>1</sup>

**Co-author(s):** Ms. JIANG, XI<sup>2</sup>; Ms. ZHAO, YI<sup>3</sup>; Mr. LONG, HONG-MING<sup>3</sup>

<sup>1</sup> *Anhui university of technology*

<sup>2</sup> *China Iron and Steel Association*

<sup>3</sup> *Anhui University of Technology*

**Corresponding Author(s):** dbustb@163.com

By analyzing the relationship between the blast system and the hearth activity of blast furnace, the points that tuyere raceway is the link of hearth activity and blast system and reasonable blast system is the important factor to maintain hearth activity were put forward. It was found that the reasonable blast velocity and blast kinetic energy increased with the increase of blast furnace volume and needed reasonable blast volume and tuyere area by studied the theoretical basis and calculation methods. By comparing different blast furnaces, the blast volume ratio and blast volume coefficient were illustrated, what's more, the details of recovering hearth activity by adjusting the tuyere area of BX Steel new No.1 blast furnace were introduced. At the same time, the various phenomena to judge blast velocity and blast kinetic energy whether reasonable or not were clearly shown according to the experience of blast furnace production. In conclusion, maintaining hearth activity needs reasonable raceway position, which needs reasonable blast velocity and blast kinetic energy in order to form reasonable blast system, so that to ensure long-term stability of the blast furnace production.

51

## Kinetic analysis of coke dissolution in carbon – iron melts

**Author(s):** Dr. ZHANG, Wei<sup>1</sup>

**Co-author(s):** Mr. GUO, Peng<sup>1</sup>; Dr. HUA, Fubo<sup>1</sup>; Prof. XUE, Zhengliang<sup>1</sup>; Mr. GONG, Shushan<sup>2</sup>; Mr. ZHANG, Wenhai<sup>2</sup>

<sup>1</sup> Wuhan University of Science and Technology

<sup>2</sup> Science and technology of flash ironmaking of Beijing, Co., Ltd., Beijing

**Corresponding Author(s):** wei\_zhang@wust.edu.cn

Flash ironmaking is a new smelting reduction process. The extent of molten iron carburization is close to saturation in the blast furnace process. However, the extent of carburization in a flash ironmaking process is unexpected because there is no compression of solid charge and no carburization reactions occurred between the deadman bottom and hot metal. To this end, iron powder reduced and chemical pure graphite were used as raw materials, and the iron powder was heated up to 1855K by using a tubular resistance furnace, and the high-purity N<sub>2</sub> was used as the protective gas to study the kinetics of coke dissolution in molten iron. The experimental results show that discarding the change of "k" "t" with dissolution time, the values of "k" "t" were determined under experimental conditions in each group, 4.20×10<sup>-6</sup> m/s (First group), 5.28×10<sup>-6</sup> m/s (Second group) and 6.50×10<sup>-6</sup>m/s (Third group) under natural convection conditions. Considering the change of dissolution rate coefficient with dissolution time, the dissolution rate "k" "t" decreases with the increase of dissolution time and is only controlled by mass transfer, and also decreases with the increase of sulfur content in the iron bath.

52

## Strength of Interfaces in Metallurgical Coke and its Influence on Coke Abrasion

**Author(s):** Dr. LOMAS, Hannah<sup>1</sup>

**Co-author(s):** Dr. ROEST, Richard<sup>1</sup>; Mr. WELLS, Adam<sup>1</sup>; Dr. SAKUROVS, Richard<sup>2</sup>; Prof. JIANG, Zhengyi<sup>3</sup>; Dr. WU, Hui<sup>3</sup>; Mr. STUART, Russell<sup>1</sup>; Ms. THORLEY, Tizshauna<sup>1</sup>; Dr. MAHONEY, Merrick<sup>1</sup>

<sup>1</sup> University of Newcastle, Australia

<sup>2</sup> CSIRO Energy, Australia

<sup>3</sup> University of Wollongong, Australia

**Corresponding Author(s):** hannah.lomas@newcastle.edu.au

Tribological and scratch testing techniques were applied to metallurgical coke samples to determine (1) the abrasive strengths of the coke microtextural constituents, and (2) the strength of the interfaces between the inertinite maceral derived components (IMDC) and the reactive maceral derived components (RMDC), as a function of the properties of the parent coal(s). These parameters were quantified via the application of advanced microscopy techniques and then related to fundamental coal properties, including rank, measure, petrographic composition, and grind characteristics.

During tribological testing, a stationary pin or ball indenter is under a controlled load in contact with a rotating polished block of the material being tested. The wear track is then analysed to determine the degree and nature of the damage to the surface. The wear that occurs in rotational tribology tests is due to the progressive loss of surface material at the points at which the two surfaces (the polished block and the indenter) come into contact as they rub against each other. One of the key measurements that can be obtained from tribological testing is the coefficient of friction (COF). The frictional force between the polished coke block and the indenter shows their resistance to relative motion, and indicates the susceptibility of the coke to tribological wear. The higher the COF, the greater the efficiency in transferring mechanical energy to the coke that can weaken or break it up.

The strength attributes of cokes were related to coal properties, demonstrating that tribological and scratch testing techniques can be used to distinguish between cokes of different coal origin. The key findings were:

(1) IMDC abrasion is insensitive to parent coal rank. (2) RMDC abrasion is sensitive to parent coal rank. (3) RMDC fracture mechanisms are insensitive to parent coal petrographic composition.

(4) Coal blending was found in most circumstances to produce stronger RMDC-IMDC interfaces than were obtained in the cokes formed from the constituent single coals. The essential next step will be to use these findings to identify a path to help improve coke strength prediction and coke resistance to abrasion in the blast furnace. This would help to improve the accuracy of models used by the coal technical marketing industry to predict the value of their coal and coke products.

54

## Improvement in blast furnace operational practice through implementation of process models

**Author(s):** Mr. AGARWAL, MAHESH<sup>1</sup>

**Co-author(s):** Mr. AGRAWAL, ASHISH<sup>1</sup>; Mr. AGNIHOTRI, ANURAG<sup>1</sup>; Mr. SINGH, UTTAM<sup>1</sup>

<sup>1</sup> TATA STEEL LTD

**Corresponding Author(s):** mahesh.agarwal@tatasteel.com

An excellent blast furnace operation requires optimum raw material charging, proper control over liquid drainage from hearth and control over thermal swing occurring in furnace. The preparation of optimum burden recipe facilitates in reduction of additive rate while standardizing the casting practice further enhances the cast house management. To achieve these objectives, the process models act as enabler for stable run of blast furnace to improve the fuel efficiency. This paper demonstrates the effect of using various process models in improving the operational practice in G blast furnace of Tata Steel Jamshedpur works.

55

## Simulation research on spraying steam on sintering bed surface process

**Author(s):** Dr. ZHOU, jiliang<sup>1</sup>

**Co-author(s):** Dr. PEI, yuandong<sup>1</sup>

<sup>1</sup> ShouGang Group

**Corresponding Author(s):** zhoujiliang@shougang.com.cn

The process of spraying steam on surface of sintering bed was studied by using Fluent in this paper. The model was simplified into 2D and only front part of sinter machine was studied. As simulation results show that : (1) average temperature of sintering bed raised 20.3 [U+2103] and temperature of off-gas raised 35.42 [U+2103] after spraying steam; (2) the CO in off-gas became lower and CO<sub>2</sub> in off-gas getting higher when spraying steam and CO<sub>2</sub>/ [U+FF08] CO+CO<sub>2</sub> [U+FF09] of off-gas raised 9.35% compared with spraying nothing; (3) hydrogen (0.14%) was found in off-gas when steam spray on sintering bed surface which means that water may have some reactions with carbon and (or) CO. Some industrial tests were taken after simulation. And the tests results show that sintering speed was accelerated and sinter qualities were improved and solid fuel consumption was reduced about 1.64kg/t by spraying 2t/h steam on sintering bed surface.

56

## Increase in Production by increasing Double Trough operation through straight campaign of trough repair at G Blast Furnace, Tata Steel Jamshedpur

**Author(s):** Mr. AGARWAL, MAHESH<sup>1</sup>

**Co-author(s):** Mr. RAO, K RAMAKRISHNA<sup>2</sup>; Mr. CHOUDHURY, MRIDUAL GHOSH<sup>2</sup>; Mr. RAMNA, R V<sup>2</sup>

<sup>1</sup> TATA STEEL LTD.

<sup>2</sup> TATA STEEL LTD

**Corresponding Author(s):** mahesh.agarwal@tatasteel.com

Non-drainable trough repairs are inevitable in blast furnaces, limiting the drainage facilities. This issue became a bottleneck at G blast furnace leading to a reduction in the production levels. There are two drainable troughs at G Blast furnace with a campaign life of around 160ktons. Two types of repairs are carried out; minor repair after a life of 100ktons and major repair post the trough campaign life. The duration of trough minor repair is around 42 hours and that of trough major repair is around 85hours. As a result a total of 13 major and 13 minor repairs are carried out, thereby resulting in an annual production loss of 17,000 tons. Therefore, to reduce this production loss, various possibilities were explored to lower the frequency of trough repairs, without any compromise in trough health. The paper details out the process followed, resulting in increment in double trough operation by 13 %, which led to an increase in annual production by 17000 tons .Additionally it also helped to reduce specific trough refractory consumption by 13%.

57

## Effect of rotating chute shape and its optimization on burden distribution at the upper part of serial type bell-less top blast furnace

**Author(s):** Dr. KOU, Mingyin<sup>1</sup>

**Co-author(s):** Prof. WU, Shengli <sup>1</sup> ; Mr. GU, Kai <sup>1</sup> ; Mr. YAO, Shun <sup>1</sup> ; Mr. CHANG, Feng <sup>1</sup> ; Dr. ZHOU, Heng <sup>1</sup> ; Dr. XU, Jian <sup>2</sup>

<sup>1</sup> *University of Science and Technology Beijing*

<sup>2</sup> *University of Chongqing University*

**Corresponding Author(s):** koumingyin@ustb.edu.cn

The chute shape determines the particle trajectory on and leaving the chute, and further affects the burden distribution in blast furnace. Therefore, a three dimensional model of the upper part of serial type bell-less top blast furnace is established based on discrete element method. The effects of chute shape and chute angle on the burden distribution on the chute and at the throat of blast furnace. The results show the main striking point is the largest for semicircle shape chute, followed by trapezoidal shape chute, and the smallest for rectangular shape chute. The burden weight maximum position is further than MSP position and the margin between them increases with the increase of chute angle. The burden thickness at blast furnace throat is the smallest at 20 ° chute angle for semicircle shape chute, and at 30 ° chute angle for rectangular shape chute, and at 40 ° chute angle for trapezoidal shape chute. Semicircle shape chute is beneficial to obtain uniform radial size distribution at 20 ° and 30 ° chute angle, while it is trapezoidal shape chute at 40 ° shape chute. Rectangular shape chute helps to form aggregated burden stream at different chute angles, which is beneficial for practical operation to perform precise burden control. Some optimizations of chute shape are also put forward to provide guidance for practical workers.

58

## A Cleaner and Efficient Process to Prepare Vanadium Pentoxide from the Converter Vanadium Slag

**Author(s):** Dr. ZHANG, juhua<sup>1</sup>

**Co-author(s):** Dr. ZHANG, Wei <sup>1</sup> ; Dr. XUE, Zheng <sup>1</sup>

<sup>1</sup> *Wuhan University of Science and Technology*

**Corresponding Author(s):** zhangjuhua@wust.edu.cn

The converter vanadium slag is a byproduct of the iron making process when using the vanadium titanomagnetite as the iron raw material. A cleaner process including calcified roasting, dilute acid leaching, precipitation purification, vanadium precipitation with ammonium salt followed by pyrogenic decomposition was proposed to extract vanadium resource from this slag. And then vanadium pentoxide with purity over 98% was prepared, which can be used as additives for high strength low alloy steel production. A total vanadium recovery beyond 80% was achieved in this whole process. Since no sodium and potassium salt was introduced, waste water generated was closed-circulating after removing the enriched impurities of P, Si, Ti and Cr with adding powder

CaO. The content of V<sub>2</sub>O<sub>5</sub> in residues after vanadium extraction was lower than 1.2wt.%, while other valuable metals like Fe, Mn, Cr and Ti were concentrated. With no alkaline metal salts added in this process, the metals of Fe, Mn, Cr and Ti in the residues were more likely to be recovered with conventional pyrometallurgy processes.

59

## Iron & Steel-Chemical Combined Making Technology, The Way of Green Development for Iron & Steel Enterprises In The Future —The carbon recycling and high-efficiency utilization of iron & steel-work off-gases

**Author(s):** Mr. LI, YANKUI<sup>1</sup>

**Co-author(s):** Mr. JIANG, FENG<sup>2</sup>; Mr. GENG, YUNFENG<sup>1</sup>; Mr. XIE, YOUCHANG<sup>3</sup>

<sup>1</sup> *Peking University Pioneer Technology Co.,Ltd.*

<sup>2</sup> *Peking university Pioneer Technology Co.,Ltd.*

<sup>3</sup> *Peking University*

**Corresponding Author(s):** liyankui@pioneer-pku.com

The iron & steel-work off-gases e.g. blast furnace gas(BFG), basic oxygen furnace gas(BOFG) and coke oven gas(COG) are generally used for heat or power generation, but the efficiency of gases utilization is low. A total solution using PU-1 molecular sieve and vacuum pressure swing adsorption(VPSA) process, gains the carbon monoxide(CO) gas economically which purity can be more than 99%vol., let it be possible that produce chemical product by using the BFG, BOFG or COG efficiently. This solution has been applied in two iron & steel enterprises in China, one is produce formic acid using BOFG, the other is produce ethylene glycol using BOFG and COG. Iron & steel-Chemical Combined Making Technology significantly increase the efficiency of gases utilization, reduce the CO<sub>2</sub> emissions, is one way of green development for iron & steel enterprises in the future.

60

## Numerical Simulation of Hearth Operating Profile and Its Effect on Campaign Life for Baosteel No.3 Blast Furnace

**Author(s):** Dr. WANG, Xunfu<sup>1</sup>

**Co-author(s):** Mr. XIAOMING, Mao<sup>2</sup>

<sup>1</sup> *Baoshan Iron & Steel Co., Ltd(Baosteel)*

<sup>2</sup> *Baoshan iron&steel Co.,Ltd.*

**Corresponding Author(s):** wangxunfu@yahoo.com

The first campaign life of Baosteel No.3 blast furnace is nearly 19 years which is the longest campaign life of large blast furnaces in China so far. The unit furnace capacity iron output was over 15,700t/m<sup>3</sup>. The average utilization coefficient of the first campaign was 2.27t/m<sup>3</sup>·d. After the blast furnace was blown out in September 2013, its hearth was dissected and investigated systematically. According to the hearth design profile, the thermocouple temperature data over the whole campaign life and wear-line that was measured, the different hearth models were built. According to using CFD software, the hot-metal flow characters in the hearth, the sidewall temperature field distribution of fluid-solid coupling and sidewall shear stress were simulated and analyzed in different hearth profiles. The main reasons for long campaign life of No.3 blast furnace are due to the proper design and good operation. Compared with different designs such as the different refractory conductivity and the different height of deadman, and different operation parameters such as taphole depth, angle, diameter and utilization coefficient, the main factors that affect hearth campaign life were concluded.

61

## Preparation of ZnO/activated semi-coke by hydrothermal and its desulphurization performance

**Author(s):** Mrs. SANG, Rong li<sup>1</sup>

**Co-author(s):** Prof. ZHANG, Yu zhu <sup>1</sup> ; Prof. ZHAO, Kai <sup>1</sup> ; Prof. SHI, Yan <sup>1</sup>

<sup>1</sup> *North China University of Science and Technology*

**Corresponding Author(s):** sangrongli@126.com

ZnO/activated semi-coke desulfurizer was synthesized using hydrothermal method. The obtained samples were characterized by X-ray di[U+FB00]raction, scanning electron microscopy, transmission electron microscopy and N<sub>2</sub> adsorption. The effects of the loading amounts of ZnO, reaction time and temperature on the performance of ZnO/activated semi-coke's desulfurization capability were investigated in a fixed-bed reactor. The results showed that the loaded substance on activated semi-coke is pure ZnO with flower-like nanostructures, and the optimum condition for preparing ZnO/semi-coke are as follows: the ratio of loading (mass ratio of ZnO to activated semi-coke) is 1:25, the hydrothermal reaction time is 12h, and the hydrothermal temperature is 150[U+2103]. The pore structure of the as-synthesized desulfurizer changes slightly before and after desulphurization, indicating that the pore structure of the carrier activated semi-coke in is not damaged, which is beneficial to the regeneration of desulfurizer.

62

## Application of a new geometric model in estimating densities of ternary molten slags with limited solubility

**Author(s):** Dr. YU, Zhigang<sup>1</sup>

**Co-author(s):** Prof. LENG, Haiyan <sup>2</sup> ; Prof. CHOU, Kuo-chih <sup>2</sup> ; Mr. LI, Fanbin <sup>2</sup>

<sup>1</sup> *a Shanghai University, State Key Laboratory of Advanced Special Steel & Shanghai Key Laboratory of Advanced Ferrometallurgy & School of Materials Science and Engineering, Shanghai 200072, China*

<sup>2</sup> *Shanghai University, State Key Laboratory of Advanced Special Steel & Shanghai Key Laboratory of Advanced Ferrometallurgy & School of Materials Science and Engineering, Shanghai 200072, China*

**Corresponding Author(s):** zhigangyu.shu@gmail.com

Density is the most essential thermophysical property which reflects the structure correlations of molten slags directly. However, most of the metallurgical melts may have a limited solubility area in the concerned temperature range. In these cases, large errors will be introduced when using traditional geometric models to calculate the properties of melts. We have proposed a new model which can be applied to calculate the densities of this kind of systems. The new model can use limited experimental information to calculate the densities within the isolated homogenous region. The calculated results agree well with experimental data in two ternary systems of CaO-FeO-Fe<sub>2</sub>O<sub>3</sub> and BaO-FeO-Fe<sub>2</sub>O<sub>3</sub> with the mean square root errors being 0.44% and 0.12%, which are within the experimental errors of  $\pm 0.48\%$  and  $\pm 0.35\%$  respectively.

63

## The Performance and Application of UCAR Carbon Brick in Blast Furnace

**Author(s):** YONG, Deng<sup>1</sup>

**Co-author(s):** JIAN-LIANG, Zhang <sup>1</sup> ; KE-XIN, Jiao <sup>1</sup> ; Mr. MIN-CHUN, Lu <sup>2</sup>

<sup>1</sup> *University of Science and Technology Beijing*

<sup>2</sup> *Tianjin iron and Steel Co., Ltd.*

**Corresponding Author(s):** ustbdy@126.com

In order to evaluate the performance of UCAR carbon brick in blast furnace, the production technology characteristics and the application of UCAR carbon brick in blast furnace were analyzed. Analytic hierarchy process was used to calculate the weight of the performance index for carbon brick, the erosion resistance of carbon brick in molten iron was considered as the

key performance. The erosion resistance of UCAR carbon brick in molten iron was investigated through the experiments, carbon content in molten iron had a great influence on erosion.

64

## Influence of CaO/SiO<sub>2</sub> and MgO on properties of blast furnace slag in JISCO and thermodynamic analysis

**Author(s):** XU, Renze<sup>1</sup>

**Co-author(s):** ZHANG, Jianliang<sup>1</sup>; CHANG, Zhiyu<sup>1</sup>; JIAO, Kexin<sup>1</sup>; HAN, Wangxue<sup>2</sup>; XIE, Qin<sup>2</sup>

<sup>1</sup> *School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing*

<sup>2</sup> *Hongxing Ironworks, Jiuquan Iron and Steel Group Co., Ltd.*

**Corresponding Author(s):** xurenze2010@163.com

In order to clarify the impact mechanism of CaO/SiO<sub>2</sub> and MgO on the performance of Jiusteel blast furnace slag, based on the actual composition of Jiusteel blast furnace slag, the influences of CaO/SiO<sub>2</sub> and MgO on viscosity and melting temperature of slags were investigated. Furthermore, the activity, liquidus temperature, liquid region and phase change of slag from 1600 [U+2103] to 1000 [U+2103] were calculated by using Factsage thermodynamic software. Finally, based on the current raw material conditions in JISCO, the proper CaO/SiO<sub>2</sub> and MgO of slag in Jiusteel blast furnace was discussed.

65

## Process modelling of ironmaking of blast furnace: developments and applications

Prof. SHEN, Yansong<sup>1</sup>

<sup>1</sup> *School of Chemical Engineering, University of New South Wales*

**Corresponding Author(s):** ys.shen@unsw.edu.au

Ironmaking blast furnace accounts for ~80% of energy consumption and emissions in an integrated steel plant. The understanding and optimization of blast furnace process is important in order to be competitive and sustainable under increasingly demanding conditions. Mathematical modelling, facilitated by physical modelling, provides a cost-effective way for process design and control. In particular, CFD and DEM modelling are widely used in academia and industry for their effectiveness. This paper will review our recent CFD and/or DEM-based process models and discuss their roles in the development of new technology for sustainable ironmaking. Three examples are used: CFD-DEM modelling of pulverized coal injection, CFD-DEM modelling of raceway formation, and CFD modelling of the whole blast furnace operation. It is demonstrated that CFD or DEM modelling indeed plays a significant role in process understanding and optimization, vital to sustainable blast furnace ironmaking.

66

## Development of energy recovery system for FINEX®

**Author(s):** Dr. SHIN, MYOUNG KYUN<sup>1</sup>

**Co-author(s):** Mr. KIM, DO-HYUNG<sup>2</sup>; Mr. KIM, DONG-JIN<sup>3</sup>

<sup>1</sup> *Ironmaking research group, Pohang Research Lab., POSCO*

<sup>2</sup> *Technology Development Project, POIST Project Dept., POSCO*

<sup>3</sup> *Plant Engineering Group 1, Investment Planning & Engineering Dept., POSCO*

**Corresponding Author(s):** shinmk@posco.com

The energy recovery system for FINEX® has been developed and adopted with commercial scale to the No.3 FINEX® plant at POSCO's Pohang Works. The energy recovery system is composed

of heat recovery steam generator, dry de-dusting, and expansion turbine-driven power generator, which are optimally configured with adjusting the balance between system efficiency and the process restrictions. For the reliable design, the each components has been selected among the best available technologies, and customized to the FINEX® process conditions through the pilot scale test.

The commercial operation of energy recovery system commenced from July 2017, and demonstrated the satisfactory performance as aimed. At present, the energy recovery system is being stably and reliably operated, and contributes to the cost and energy savings at No.3 FINEX® plant. This paper presents the development progress and operating status of energy recovery system tailored to the current FINEX® plant, and evaluates the change and enhancement in FINEX® process. Also, the further optimization is discussed for the proposal of more efficient and economical adoption to the next FINEX® plant.

67

## Practical study on the flowability and combustion characteristics of pulverized coal for improving PCI operation efficiency

**Author(s):** Mr. SEO, DONGMYUNG<sup>1</sup>

**Co-author(s):** Mr. CHOI, wonseok<sup>1</sup> ; Mr. KANG, Taewoo<sup>1</sup> ; Dr. KIM, Hyuk<sup>1</sup> ; Dr. AN, Jinyoung<sup>1</sup> ; Dr. YOON, Ho Jun<sup>1</sup>

<sup>1</sup> *Hyundai Steel Company*

**Corresponding Author(s):** dmseo@hyundai-steel.com

Pulverized Coal Injection (PCI) into the Blast Furnace (BF) is well-known process for cost saving of the BF. Most of the ironmaking companies are trying to enhance the amount of Pulverized Coal Ratio (PCR) for the purpose of cost reduction. Two key factors, flowability and combustibility, of pulverized coal should be estimated to achieve higher PCR under stable operation condition. The flowability, which depends on characteristic property of coals, influences the even distribution of coal injection across all tuyeres. For Hyundai steel PCI facility (PW type), the flowability of pulverized coal plays more important role for stable injection due to dense phase transfer system. The combustibility also determines permeable and thermal conditions inside raceway through rapid reactions, combustion followed by volatilization. In this study, both of flowability and combustibility were estimated with a powder flow tester and a drop tube furnace, for measuring shear stress and burn-out of pulverized coal, respectively. 10 kinds of coal brands were analyzed to investigate the effect of coal properties, such as volatile matter, H/C ratio, ash composition, inertinite texture, and size distribution, on the two factors. Suitable ranges of those properties obtained from laboratory tests for stable and high efficiency of PCI operation were verified in long period practical operation in actual BF.

68

## Development of New Charging Technique of Nut Coke at Blast Furnace with Center Feed Type Bell-less Top

**Author(s):** Mr. ATSUMI, Hidaka<sup>1</sup>

**Co-author(s):** Mr. KASHIHARA, yusuke<sup>1</sup> ; Mr. IWAI, Yuki<sup>2</sup> ; Mr. HORIKOSHI, Hiroyuki<sup>1</sup> ; Mr. YAMAMOTO, Koji<sup>1</sup>

<sup>1</sup> *JFE Steel*

<sup>2</sup> *JFE steel*

**Corresponding Author(s):** h-atsumi@jfe-steel.co.jp

Improved permeability and increased gas utilization have been desired in order to achieve low coke rate operation of blast furnaces. Coke mixed charging in the ore layer is one measure for realizing these improvements. A new charging technique for mixing nut coke in the ore layer at a blast furnace with a center feed type bell-less top was developed and investigated in an experiment with a 1/18.8 scale model of an actual blast furnace at JFE Steel. The discharge pattern of the mixed nut coke discharged from the bell-less top was improved, and the radial distribution

of the mixed nut coke ratio at the furnace top after the mixed materials were charged in the blast furnace was also improved by the new charging technique in which nut coke was charged in the determined port of the upper bunker before ore was charged in the upper bunker. The new charging technique was applied to an actual blast furnace at JFE Steel, and improvement of gas permeability and a decrease in coke rate were confirmed.

69

## Magnetite reduction by $H_2$ during microwave heating

**Author(s):** Mr. AMINI, Ahmadreza<sup>1</sup>

**Co-author(s):** Prof. OHNO, Ko-ichiro<sup>2</sup>; Prof. MAEDA, Takayuki<sup>3</sup>; Prof. KUNITOMO, Kazuya<sup>3</sup>

<sup>1</sup> *Department of Materials Process Engineering, Graduate School of Engineering, Kyushu University, Japan*

<sup>2</sup> *Kyushu University*

<sup>3</sup> *Department of Materials Science and Engineering, Faculty of Engineering, Kyushu University, Japan*

**Corresponding Author(s):** ahmadreza.amini.ir@gmail.com

Recently, reduction of CO<sub>2</sub> emission and also energy conservation in ironmaking process are serious concerns which persuaded the researchers to look for a cleaner and a more efficient method for iron production. Microwave heating has been considered as a new heating method for iron ore reduction which could decrease the required carbonaceous materials for iron production. However, it would be preferable for low carbon ironmaking if reduction reaction could be conducted by non-carbonaceous materials, such as H<sub>2</sub>, during microwave heating. For this purpose, magnetite would be the best form of iron ore due to its high microwave susceptibility even at room temperature. In the present study, possibility of magnetite reduction by H<sub>2</sub> during microwave heating is investigated using a tablet shape magnetite sample and a microwave generator with a frequency of 2.45 GHz at the output power of 1050 W. The sample was heated to ca. 530°C in 6 minutes under N<sub>2</sub> atmosphere followed by changing the atmosphere from N<sub>2</sub> to H<sub>2</sub> and then heating for a certain time. Results of the weight change measurements showed that a reduction degree of 8, 17.6, 30, 32, 36, 51 and 65% could be achieved after a treatment under H<sub>2</sub> for 2.5, 7.5, 11, 15, 20, 30 and 60 minutes, respectively. Reduction of magnetite to FeO and Fe seems to cause some variations in microwave absorption capability of the sample due to the different magnetic and dielectric properties of the new-formed phases. Also, some changes were observed in the heating pattern of the sample after changing the atmosphere to H<sub>2</sub> confirming the effect of the above-mentioned phase transformations on microwave absorption capability. Furthermore, according to SEM observations of microwave heated sample, some cracks were formed which would be due to the rapid and selective heating characteristics of the microwaves irradiation causing a favorable porous structure for the reduction.

70

## Effect of Hydrogen Concentration in Blast Furnace Reducing Gas on Reduction Behavior of Iron Ore Sinter

**Author(s):** Dr. MURAKAMI, TAICHI<sup>1</sup>

**Co-author(s):** Prof. KASAI, Eiki<sup>1</sup>; Dr. MARUOKA, Daisuke<sup>1</sup>

<sup>1</sup> *Tohoku University*

**Corresponding Author(s):** taichi@material.tohoku.ac.jp

For decreasing CO<sub>2</sub> emission from iron making process, increasing hydrogen concentration in blast furnace is suitable method. However, the property of iron ore agglomerate such as reducibility should be optimized because hydrogen reduction is endothermic reaction and temperature distribution in BF drastically changes by increasing hydrogen concentration. In this study, the effect of hydrogen concentration on the reduction behavior of mineral phases in iron ore sinter is evaluated. Ten sinter samples which were produced by Japanese steel mill were used. The composition of the mineral phases in these samples was analyzed by XRD and image analysis. Sinter sample was reduced under the simulated conditions such as standard (N<sub>2</sub> - 48% (CO+CO<sub>2</sub>) - 5.8% (H<sub>2</sub>+H<sub>2</sub>O)) and high hydrogen (N<sub>2</sub> - 48% (CO+CO<sub>2</sub>) - 13% (H<sub>2</sub>+H<sub>2</sub>O)). After reduction,

microstructure of the sample was observed. Sinter has components of hematite, magnetite, calcium ferrite and slag. Furthermore, calcium ferrite could be divided into four types which were acicular calcium ferrite with primary hematite (1H-ACF), columnar one with secondary hematite (2H-CF), small columnar one with magnetite, and large columnar one with magnetite. Increase in hydrogen concentration accelerates the reduction of hematite, 1H-ACF, and 2H-CF in all sinter samples while the reduction of magnetite, and calcium ferrite with magnetite is not done.

71

## Influence of Crystal Structure and Chemical Composition of Silico-ferrite of Calcium and Aluminum on its Reducibility

**Author(s):** Dr. MARUOKA, Daisuke<sup>1</sup>

**Co-author(s):** Mr. MATAOKA, Shojiro<sup>1</sup> ; Dr. MURAKAMI, Taichi<sup>1</sup> ; Prof. KASAI, Eiki<sup>1</sup>

<sup>1</sup> *Graduate School of Environmental Studies, Tohoku University*

**Corresponding Author(s):** daisuke@material.tohoku.ac.jp

Silico-Ferrite of Calcium and Aluminum (multi-component CF) is one of main minerals in iron ore sinter. Multi-component CF is classified by columnar structure (SFCA) and acicular structure (SFCA-1), which have different crystal structures. It is considered that SFCA-1 has higher reducibility than SFCA, however, the results reported by previous studies have been included factors of adjacent structure such as pores and slag. Moreover, the influence of composition for reducibility has not been clarified while multi-component CF has wide chemical composition. In this study, influence of crystal structure and chemical composition for its own reducibility is investigated on silico-ferrite of calcium and aluminum. Commercial reagents were used to fabricate multi-component CF. Four different chemical composition powder mixtures of SFCA and SFCA-1 were prepared, respectively. These powder mixtures were heated at the range between 1200 and 1400°C, and quenched. Obtained SFCA and SFCA-1 samples were crashed to be powder samples. These powder samples were heated in XRD chamber with heating unit up to 800°C. Atmosphere are N<sub>2</sub>-CO-CO<sub>2</sub> and including two different compositions of H<sub>2</sub>-H<sub>2</sub>O system. These atmospheres were changed to simulate blast furnace process. SFCA samples were not reduced until 800°C in CO-CO<sub>2</sub>, whereas the progress of reduction was shown in CO-CO<sub>2</sub>-H<sub>2</sub>-H<sub>2</sub>O atmosphere. SFCA-1 samples were reduced from 500°C in CO-CO<sub>2</sub> atmosphere. The reduction of SFCA and SFCA-1 are enhanced by high H<sub>2</sub>-H<sub>2</sub>O composition. Reducibility of SFCA is independent with Fe composition, whereas SFCA-1 is enhanced with increasing Fe composition. SFCA-1 on its reducibility is higher than SFCA. It implied that the valence on Fe is affect to its reducibility.

73

## Application status and and investigation of titanium-containing materials in Blast Furnace protection process

Mr. WANG, xiaozhe<sup>1</sup> ; Prof. ZHANG, jianliang<sup>1</sup> ; Dr. LIU, zhengjian<sup>1</sup> ; Dr. LIU, xingle<sup>1</sup> ; Mr. JIANG, chunhe<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** wxz\_u.stb@163.com

The present status of titanium-containing materials from ten steel enterprises in China were investigated in this paper. The conditions of the titanium-containing materials from different blast furnaces were introduced, and the properties of the materials were analyzed as well as their comprehensive properties. Investigation results indicate that the titanium-containing pellet and titanium-containing lump are the main furnace protection materials, and the chemical composition of titanium-containing materials is quite different. The train and the vehicle are the main transportation vehicle. Through the evaluation of the performance and economic indicators of titanium-containing materials, the order of advantages and disadvantages is: titanium-containing core wire, titanium-containing pellet, titanium-containing lump, titanium-containing sinter, and titanium-containing unfired pellets. The way of titanium-containing materials added into furnace is divided into upper addition and lower loading. It is concluded that the use of titanium-containing pellet with the upper addition and taphole clay containing titanium with the lower addition can achieve a better effect.

74

## Exploration of Coal Fusibility in the Cokemaking Process and the Links to Coke Quality

**Author(s):** Ms. NORTH, Lauren<sup>1</sup>

**Co-author(s):** Dr. BLACKMORE, Karen<sup>2</sup>; Dr. NESBITT, Keith<sup>2</sup>; Mr. HOCKINGS, Kim<sup>3</sup>; Dr. MAHONEY, Merrick<sup>1</sup>

<sup>1</sup> *Centre for Ironmaking Materials Research, The University of Newcastle, Australia*

<sup>2</sup> *School of Electrical Engineering and Computing, The University of Newcastle, Australia*

<sup>3</sup> *Coal Technical Marketing, BHP Billiton*

**Corresponding Author(s):** lauren.north@uon.edu.au

Despite the extensive research in the prediction of coke properties from the parent coals, at present, no single model exists to adequately predict coke quality from all coal basins. Whilst heavily used as a feature in early coke quality prediction models, the binding behaviour of the maceral components, termed fusibility, has had limited success in being implemented into a global prediction model. Part of the limitation of existing models is the arbitrarily assumed fixed proportion of fusing macerals within each coal, despite evidence suggesting that the behaviour of macerals varies by coal basin. Current methods of determining coal fusibility rely on manual point count methods on both the coal and coke structures, which is a costly process with significant measurement variability. This study developed a method of predicting the fusibility by using a data mining approach, applied to commonly measured coal quality parameters. The proposed method has implications for determining and interpreting the contributing factors to coal fusibility. Further, as implemented within a coke quality prediction model, this method contributes to the knowledge of the relationship between fusibility and coke quality parameters.

75

## Applied Fundamental Research of Ferro-coke Production by the Stamped Charging Cokemaking Process

**Author(s):** Prof. BI, Xuegong<sup>1</sup>

**Co-author(s):** Prof. SHI, Shizhong<sup>2</sup>; Dr. LI, Peng<sup>1</sup>; Mr. ZHENG, Qi<sup>2</sup>; Ms. ZHANG, Huixuan<sup>1</sup>; Mr. LUO, Yonghui<sup>2</sup>; Mr. LIU, Wei<sup>1</sup>; Dr. ZHOU, Jindong<sup>1</sup>

<sup>1</sup> *State Key Laboratory for Refractory Materials and Metallurgy, Wuhan University of Science and Technology*

<sup>2</sup> *Key Laboratory for Coal Conversion and Advanced Carbon Materials of Hubei Province, Wuhan University of Science and Technology*

**Corresponding Author(s):** bixuegong@wust.edu.cn

Ferro-coke is a highly reactive coke and considered a promising advanced burden material for blast furnace ironmaking due to a potential of decreasing RAR and CO<sub>2</sub> emission. The essential reason is it reacts with CO<sub>2</sub> in BF gases at lower temperatures, which is resulted in by the catalytic effect of metallic iron, and leads to a lower temperature of the thermal reserve zone. However, since iron ores are an inertial material, the mechanical strength of ferro-coke is commonly inferior to the coke prepared without iron ore addition. This violates the requirement for coke in providing mechanical support to the large charge column and in permitting the gases to ascend through the voids. In this work, focused on ferro-coke, a great effort has been made to clarify the influencing factors of reactivity as well as mechanical strength at the room temperature as well higher temperatures after reaction and to determine the quantitative relationship between the quality indices and the productive parameters. Two processes can be applied in the production of ferro-coke, i.e. the traditional battery cokemaking process and the briquetting/shaft process. The briquetting/shaft furnace process is superior to the former in higher iron ores blending ratio, and the traditional battery cokemaking process is superior to the later in higher process maturity, higher production capacity, no need in binders. For this reason, the traditional battery cokemaking process was selected for the preparation of ferro-coke. Further, the stamped coke battery route was tried in this study in order to obtain ferro-coke products with higher mechanical strengths at a same blend ratio of high quality cokemaking coals. It was revealed by this work that the main factors influencing on the reactivity (also the starting gasification temperature) and mechanical strength of ferro-coke are the coking capacity (Vadf, G and Y values) of coal blend,

the quality (gangue materials content, combined water content, size distribution) and blend ratio of iron ores, carbonization conditions (heating speed, carbonizing temperature, soaking time, etc.), and the bulk density of coal charge in particular. A mathematical model has been built up based on the results of a systematical experimental study. This model can be used either for forecasting the reactivity and mechanical strength of ferro-coke under a specified production condition, or for determining the productive conditions for achieving a specified quality standard of ferro-coke. In the 6 kg experimental coke oven of Wuhan University of Science and Technology, a ferro-coke sample with quality indices that are comparable to the industrial coke fed into 2300 m<sup>3</sup> BF has been produced; its declining rate of mechanical strength with the reactivity increasing is as small as that of the formed ferro-coke sample prepared in laboratory by the hot-briquetting/shaft process.

76

## SEARCH FOR AN ALTERNATIVE PROCESSING OF MAGNETITE CONCENTRATE CONTAINING OXIDES OF VANADIUM AND TITANIUM

**Author(s):** Dr. KAPELYUSHIN, Yury<sup>1</sup>

**Co-author(s):** Mr. GAMOV, Pavel<sup>1</sup>; Dr. ROSHCHIN, Vasilij<sup>1</sup>

<sup>1</sup> *South Ural State National Research University*

**Corresponding Author(s):** metallurg.research@gmail.com

**Abstract** An existing scheme of vanadium production from low-titanium magnetite concentrates is energy-consuming and associated with loss of valuable elements, e.g. titanium. The present work investigates the possibility of obtaining products, which are different from the processing using the conventional technological scheme, for further development of an energy-efficient and wasteless technology. A magnetite concentrate containing titanium and vanadium oxides was reduced with coal in a vertical furnace. The effect of temperature was studied at 1000, 1100 and 1200 °C. After reduction the metallized product was melted to separate metallic Fe from slag containing V<sub>2</sub>O<sub>5</sub> and TiO<sub>2</sub>. The phases obtained during reduction and smelting were studied using XRD and SEM analysis. The concentration of V<sub>2</sub>O<sub>5</sub> and TiO<sub>2</sub> in a final product has increased in comparison with the initial magnetite concentrate with minimum transfer to metal. **Keywords:** magnetite coal reduction, vanadium oxide, titanium oxide.

77

## Numerical simulation of blast furnace hearth and bottom erosion

**Author(s):** Prof. LI, Jing<sup>1</sup>

**Co-author(s):** Mr. MA, FangQing<sup>2</sup>

<sup>1</sup> *University of Science & Technology Liaoning*

<sup>2</sup> *Zenith Steel Group Company Limited*

**Corresponding Author(s):** lijing<sub>a</sub>s@163.com

The state of blast furnace (BF) campaign life and the erosion mechanism of BF hearth and bottom are summarized. According to the design and erosion conditions of hearth and bottom of a blast furnace with effective volume of 3200m<sup>3</sup>, a two-dimensional mathematical model was developed using the theory of heat transfer with ANSYS to monitor the erosion state of blast furnace's hearth and bottom. The temperature field distribution of hearth and bottom was obtained at different stages of service, including the early state, the middle state, the mid to late state and the late state. The calculated erosion graph indicates that erosion line at 1150 [U+2103] was located under the iron notch and at the corner of the hearth and bottom, and the "elephant foot wear" was not obvious. Compare with the different situation of the temperature distribution and the location of the erosion line at 1150 [U+2103] of the hearth and bottom at different BF service period, the reason for the change were analyzed, and the influencing factors for hearth lining temperature were discussed.

78

## Blast Furnaces campaign extension and reline planning at CherMK – Severstal

**Author(s):** Dr. GORDON, Yakov<sup>1</sup>

**Co-author(s):** Mr. VINOGRADOV, Evgeniy<sup>2</sup>; Mr. KARIMOV, Mikhail<sup>3</sup>; Mr. SOKOLOV, Aleskandr<sup>4</sup>; Dr. SADRI, Afshin<sup>5</sup>; Mr. CHATAWAY, David<sup>6</sup>

<sup>1</sup> *Technical Director, I & S. Hatch*

<sup>2</sup> *Director, Primary End, CherMK-Severstal*

<sup>3</sup> *Head of BF shop, CherMK, Severstal*

<sup>4</sup> *Deputy Head of BF Shop*

<sup>5</sup> *Director, Hatch*

<sup>6</sup> *Specialist, Hatch*

**Corresponding Author(s):** iakov.gordon@hatch.com

Intensive operation of blast furnace allows increase in production of hot metal. However, furnace life could be sacrificed. CherMK and Hatch systematically monitor conditions of BF lining using Acousto Ultrasonic-Echo (AU-E) non-destructive methodology. Testing of blast furnaces revealed problematic areas with refractory deterioration, formation of elephant foot, extent of accretion and rate of refractory wear, cracks and anomalies. Improvement in coke quality, periodical staves washing, addition of titania, grouting etc. were recommended and implemented to prolong furnace life while maintaining the intensity of furnace operation. Comparison of NDT results and physical measurements showed that they are in a good agreement. Estimated rate of refractory wear allowed to predict the remaining campaign of the blast furnace and start preparation for furnace shutdown and modernization.

79

## REGULARITIES OF HIGH INTENSIVE BLAST FURNACE OPERATION

**Author(s):** Dr. GORDON, Yakov<sup>1</sup>

**Co-author(s):** Mr. FILATOV, Sergei<sup>2</sup>; Prof. ZAGAINOV, Sergei<sup>3</sup>; Mr. LISTOPADOV, Vladislav<sup>4</sup>

<sup>1</sup> *Technical Director, Hatch*

<sup>2</sup> *Managing Director, NLMK*

<sup>3</sup> *Ural Federal University*

<sup>4</sup> *Director, Primary End, NLMK*

**Corresponding Author(s):** iakov.gordon@hatch.com

The influence of the melting intensity, which is defined and estimated as a specific blast-furnace productivity, on the stability of blast furnace operation and conditions of indirect reduction of wustite is evaluated and studied. It is shown that at elevated melting intensity -specific productivity the incremental change in the melting intensity leads to a more modest variation in the efficiency of CO utilization. The increase in the stability of the processes in the wustite indirect reduction zone is accompanied by a decrease in the fluctuation of the chemical composition of the hot metal and slag. The theoretical calculations and production data analysis revealed that the higher intensity of blast furnace process leads to more stable furnace' thermal conditions. This is confirmed by operating data of blast furnaces at NLMK-Russia.

80

## Thermal control of the blast furnace using instantaneous heat demand calculation method

**Author(s):** Dr. ABHALE, Prakash B.<sup>1</sup>

**Co-author(s):** Mr. HAZRA, Sujan<sup>2</sup>; Mr. CHAUDHARI, Ujjwal<sup>2</sup>; Mr. GHOSH, Ujjal<sup>2</sup>; Dr. NAG, Samik<sup>2</sup>; Mr. SINGH, Uttam<sup>2</sup>

<sup>1</sup> *Tata Steel Ltd. Jamshedpur*

<sup>2</sup> *Tata Steel. Ltd. Jamshedpur*

**Corresponding Author(s):** prakash.abhale@tatasteel.com

Maintaining the hot metal temperature (HMT) above target value (e.g.1480 oC) is considered to be a very important for the stable operation of the blast furnace. In extreme conditions, lower thermal level makes tapping of hot metal and slag more difficult and in the event of delayed action, this may lead to chilled or semi-chilled conditions in the hearth. On the other hand, HMT above 1520 oC, is undesirable as the extra heat comes from extra fuel and it also results in undesirable chemistry (e.g. high Si in HM). The blast furnace operator tries to maintain the HMT in a narrow band, by controlling blast parameters and/or coke or injection rate. However, the actions often get delayed, as these are taken by looking at the trends of HMT during every cast. Moreover, blast furnace also responds to the changes in process parameters by a delay varying from 1 to 7 hours depending on the individual parameter, which was modified. Overreactions by the operator to dip or rise in HMT, sometimes results in swings in thermal conditions. This ultimately leads to increase of fuel rate and abnormal furnace behaviour. So, stable blast furnace operation is important to reduce the fuel rate. This is only possible if the operator has an early warning system to indicate the thermal level of the blast furnace at his disposal. A two-stage heat and mass balance model has been developed based on Rist concept for prediction of the thermal level of the blast furnace. Using the top gas composition, oxidation degree of metallic materials and blast conditions as an input, specific fuel rate, and blast rate are calculated. Thereafter by performing heat balance of lower zone, instantaneous heat demand for melting and superheating of iron and slag are obtained. As the heat of melting and superheating of iron and slag is directly proportional to hot metal and slag temperature, it is hypothesized that the former could be used as a thermal level indicator of the blast furnace. Various data handling techniques have been used to filter out the spurious data, perform averages and interpolations to bring all the data to the same frequency. Data reconciliation techniques were used to detect the gross error in the measurements. The reconciled data was used to calculate the thermal level indicator at a frequency of 30 mins. First, the correlation between the thermal indicator and the hot metal temperature was established offline. A prior indication of thermal dip or rise in hot metal temperature by 2-3 hour was observed. After offline validation, the model has been implemented in level 2 systems to help the operator in decision making.

81

## Evaluation Straight Grate and Grate Kiln Pelletizing Technologies

**Author(s):** Mr. HUERTA, Manuel<sup>1</sup>

**Co-author(s):** Dr. GORDON, Yakov <sup>2</sup>

<sup>1</sup> *Specialist, HAtch*

<sup>2</sup> *Technical Director, Hatch*

**Corresponding Author(s):** iakov.gordon@hatch.com

The straight grate and grate kiln indurating processes are the two proven and widely accepted iron ore pelletizing technologies. Hatch performed a technical and economic comparison between the two processes, emphasizing their specific advantages and applicability for selected regional conditions. The technology comparison is based on publicly available literature and our extensive database of iron ore pelletizing operations. Included in the comparison are straight grate and grate kiln plants supplied by long established original equipment manufacturers, as well as grate kiln plants supplied by Chinese equipment manufacturers. A special emphasis is given to limonitic ores, since much growth in pelletizing capacity is expected to occur in coming years for processing of these ores. Advantages and disadvantages of each technology are evaluated. The straight grate and grate kiln technologies are comparable and completely applicable for processing of Indian hematite and limonitic ores. The Chinese grate kiln technology is best applied for smaller capacity pelletizing plants and is less efficient.

82

## Regularities of heat exchange at modern conditions of intensive blast furnace operation.

**Author(s):** Prof. SPIRIN, Nikolai<sup>1</sup>

**Co-author(s):** Dr. GORDON, Yakov<sup>2</sup> ; Prof. YAROSHENKO, Yuriy<sup>1</sup> ; Prof. SHVIDKIY, Vladimir<sup>1</sup> ; Prof. LAVROV, Vladislav<sup>1</sup>

<sup>1</sup> *Ural Federal University*

<sup>2</sup> *Technical Director, Hatch*

**Corresponding Author(s):** iakov.gordon@hatch.com

Changes in heat transfer regularities of blast furnace process in course of this process refinement are considered and evaluated. It is shown that stable and profitable operation of modern intensive blast furnace process with variety of raw materials, combined blast etc. could be achieved only preserving two distinct zones of high intensive heat transfer. Any changes in melting process do not change this fundamental characteristic of blast furnace process. Heat exchange processes in the upper and bottom stages of blast furnace are not completely autonomous since both depends on extend of direct reduction process. Experimental and theoretical investigation of blast furnace process in modern conditions showed the existence of two zones of delayed heat exchange. The upper delayed heat exchange zone is characterized also as delayed mass exchange zone. Therefore, this volume of blast furnace from the heat transfer point of view could be considered as a reserve zone of blast furnace. In the lower zone of delayed heat exchange processes the speed of chemical reactions is comparatively high. Therefore, this zone cannot be considered as a part of reserve zone. From the point of view of heat exchange processes assessment and blast furnace control in modern conditions the furnace still has to be divided by two heat exchange zones – upper and bottom. The boundary between these zones is located at the upper levels of mixed reduction of iron oxide, between elevation of the beginning of carbon gasification reaction and the level, below which reduction of iron oxides characterized only by direct reduction.

83

## Modelling of gas and material distribution, raceway conditions and slag mode of operation of blast furnace

**Author(s):** Mr. IZUMSKIY, Nikolai<sup>1</sup>

**Co-author(s):** Dr. GORDON, Yakov<sup>2</sup> ; Mr. MATVIENKO, Gennadiy<sup>3</sup>

<sup>1</sup> *Metinvest*

<sup>2</sup> *Technical Director, Hatch*

<sup>3</sup> *APIP Ukraine*

**Corresponding Author(s):** iakov.gordon@hatch.com

Any expert system of blast furnace should include the following models: the model to estimate material and gas distribution and their temperatures at the furnace top based on measurements by radioisotope profile scanner (or other type) and industrial IR-camera; conditions and dimensions of the furnace raceway; slag model which allow estimate the viscosity of primary, intermediate and final slags of blast furnace process. Practical realization of these models allows to prolong life of refractory lining, staves and tuyeres, increase in blast furnace productivity and reduction in production cost of hot metal. Reliability of Expert system instrumentation and accuracy of measured data during the long service time of expert system in blast furnace operating environment also discussed in the paper. Case studies of such systems operation are presented for blast furnace #3 at Tulchermet and blast furnace #5 at CherMK-Severstal, Russia for several years of their operation.

84

## The application practice of prolonging service life of large size BF copper cooling stove

**Author(s):** Mr. ZHAO, man xiang<sup>1</sup>

**Co-author(s):** Mr. JIA, Guo li<sup>2</sup>

<sup>1</sup> *Shougang Qian'an Iron & Steel Co.,Ltd.*

<sup>2</sup> *Shougang Qian'an Iron & Steel Co., Ltd.*

**Corresponding Author(s):** zhaomanxiang@sgqg.com

The damage of copper cooling stave in several china's blast furnace is investigated. Furthermore, the damage mechanism has also been analyzed. It's shows that the breakage of copper cooling stave mainly due to unstable slag skull and frequent wearing by furnace burden and gas flow, as well as improper design. Based on which some measures were suggested for prolonging the service life of copper cooling stave. Such as controlling the oxygen content of the copper cooling stave body, ensuring reliability of BF cooling system and maintaining appropriate peripheral gas flow. Most of all, the author believes that long service life of BF copper cooling stave can be achieved by appropriately controlling of peripheral gas flow intensity, protecting the slag skull from frequent peel-off and reducing the thermal shock. Additionally, the operation practice of No.1 BF of Shougang corporation proves that timely spray-lining is effective for handing damage copper stave, Its copper cooling stave life has been more than 13 years. At last, it is pointed out that appropriate use of copper cooling stave can effectively extend the service life of blast furnace.

85

## Statistic and Thermomechanical Analysis of Titanium Distribution between Hot Metal and BF Slag

Mr. SUN, jian<sup>1</sup>

<sup>1</sup> *Shougang Research Institute of Technology*

**Corresponding Author(s):** sunjian771@163.com

A statistic and thermomechanical analysis of about titanium distribution ratio between hot metal and BF slag have been done. The result indicated there is a significant correlation between iron temperature, furnace temperature, and titanium distribution ratio, a negative correlation between sulfur content in iron and titanium distribution ratio, and no correlation between basicity of slag and titanium distribution ratio. Keywords [U+FF1A] Blast furnace; Titanium; Titanium distribution; Statistic;

86

## Apparent Softening Viscosity Measurement of Granulated Slag Packed Bed with Softening and Melting Simulator

**Author(s):** Prof. OHNO, Ko-ichiro<sup>1</sup>

**Co-author(s):** Prof. KUNITOMO, Kazuya<sup>1</sup>; Prof. MAEDA, Takayuki<sup>1</sup>; Dr. SUNAHARA, Kohei<sup>2</sup>; Mr. MORITA, Yusuke<sup>2</sup>; Dr. NISHIMURA, Tsunehisa<sup>2</sup>; Dr. HIGUCHI, Kenichi<sup>2</sup>

<sup>1</sup> *Kyushu University*

<sup>2</sup> *Nippon Steel & Sumitomo Metal Corporation*

**Corresponding Author(s):** ohno@zaiko.kyushu-u.ac.jp

Low carbon operation of blast furnace is important technology for mitigation of CO<sub>2</sub> emission from ironmaking process. This operation means decreasing of coke rate in raw material charging amount into blast furnace. This situation makes severe condition of gas permeability in especially cohesive zone of blast furnace. Therefore, cohesive zone formation behavior should be correctly understood. In this study, slag is focused as the most important melt in cohesive zone because they have higher viscosity and possibility to clogging than molten iron. Using the newly developed softening and melting simulator, effect of the slag behavior in softening and melting process on gas permeability through granulated slag packed sample layer was investigated. In order to evaluate softening behavior of sample packed bed, an apparent softening viscosity is applied. The apparent softening viscosity is estimated from shrinkage resistance of the sample packed bed from 1200-degree C to 1500-degree C under 0.1 MPa load. The slag samples were synthesized in gradual cooling condition to avoid making glassy slag. The slags were crushed and sieved in 4-5mm and then charged into graphite crucible, inner diameter 35 mm, which has holes in bottom. The sample was heated up to 1200-degree C with 1000-degree C/min. After reaching 1200 degree-C, heating rate was changed to 10-degree C/min. During heating experiment, 0.1 MPa load was added to the sample layer from top part through lid and N<sub>2</sub> gas was flowed from bottom side with 1NL/min. Displacement amount of the sample layer thickness and gas pressure

drop were measured for evaluation of softening and melting behavior. From this evaluation, it was found that the apparent softening viscosity at higher shrinkage degree is strongly related with pressure drop in the sample packed bed and surface tension of molten slag has dominant effect on the apparent softening viscosity.

87

## Development of a Technique that Adding Iron Ore Micro-Particle Binder Ground by Vertical Wet Ball Mill for Increase of Iron Concentrate at Sintering Process

**Author(s):** Mr. YAMAGUCHI, Yasuhide<sup>1</sup>

**Co-author(s):** Mr. UMEMOTO, Hironari<sup>1</sup>; Mr. HARA, Masaki<sup>2</sup>; Dr. KAMIJO, Chikashi<sup>1</sup>; Dr. MATSUMURA, Masaru<sup>1</sup>; Dr. HIGUCHI, Kenichi<sup>1</sup>; Dr. NOMURA, Seiji<sup>1</sup>

<sup>1</sup> *Nippon Steel & Sumitomo Metal Corporation*

<sup>2</sup> *Nippon Steel & Sumikin Koutetsu Wakayama*

**Corresponding Author(s):** yamaguchi.3qd.yasuhide@jp.nssmc.com

In order to decrease Reducing Agent Rate (RAR) and CO<sub>2</sub> emission of blast furnaces, it is important to decrease slag volume. In NSSMC, more than 70% of blast furnace burden is sinter ore, so slag volume control is very important. However slag contents of sinter feeds are increasing because of resource deterioration. Therefore, using high amount of iron ore concentrate, which has relatively lower slag contents, is desired. Nevertheless, it causes decreasing of the permeability of the sintering bed and sinter productivity. In order to increase the amount of concentrate, NSSMC has developed the new technique adding micro-particles for binder. In this report, vertical wet ball mill was installed on sub granulation line of Wakayama No.5 sinter plant. In this line, about 0.4% of Australian pisolite ore was ground to -10 micron > 60% and added into intensive mixer with iron concentrate and other sinter feeds. After mixing, they were granulated by a pan-pelletizer. After that, they were charged into sinter machine with other materials granulated in main granulation line with two drum mixers. It was confirmed that up to 13.5wt% of concentrate can be used without decreasing of sinter productivity by adding micro-particles.

88

## Assimilation behavior of MgO source during iron ore sintering

**Author(s):** Mr. OKADA, Kohei<sup>1</sup>

**Co-author(s):** Prof. OKAZAKI, Jun<sup>1</sup>

<sup>1</sup> *Graduate School of Environmental Studies, Tohoku University, Sendai, Japan*

**Corresponding Author(s):** kouhei.okada.t2@dc.tohoku.ac.jp

Improvement of sinter reducibility is necessary for high production rate of blast furnace, involving reduction of the slag component in the sinter. Replacement of peridotite (MgO-SiO<sub>2</sub>) for dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>) is a potent option as dolomite does not contain SiO<sub>2</sub>. However, dolomite is hard to assimilate and deteriorates sinter strength. In this study, assimilation behavior of dolomite has been investigated by means of tablet firing experiments in an electric furnace, where the tablets was compacted with a 2-3mm(?) dolomite particle in the matrix of calcium ferrite reagent. As a result, a reaction layer of a dolomite particle and calcium ferrite was formed by 20μm thickness at 1473K which is the initial melt forming temperature and identified as SFCA by EPMA. At 1527K, the reaction layer thickened to 500μm.

89

## Model for emission reduction optimization of ironmaking process in blast furnace

**Author(s):** Mr. YAO, Shun<sup>1</sup>

**Co-author(s):** Prof. WU, Shengli <sup>1</sup> ; Prof. SONG, Bo <sup>2</sup> ; Dr. KOU, Mingyin <sup>3</sup> ; Dr. ZHOU, Heng <sup>3</sup> ; Mr. GU, Kai <sup>1</sup>

<sup>1</sup> *School of Metallurgical and Ecological Engineering, Beijing University of Science and Technology, Beijing 100083, China*

<sup>2</sup> *University of Science and Technology, Beijing 100083, China*

<sup>3</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** yaoshunapp@163.com

Blast furnace emission reduction optimization model is based on substance conservation and energy conservation of ironmaking process. The mathematical model is established using the multiple-objective optimization method with the cost and CO<sub>2</sub> emission taken as objective functions. The optimization variables and constraints are determined by the characteristics of blast furnace ironmaking process and the objective functions. The optimized results are obtained by using the GRG (Generalized Reduced Gradient) nonlinear solving method. Then, the model is applied to the B# blast furnace in Bayi Steel in China. By comparing the optimized results with the actual production data, the model is verified correct. Meanwhile, the model is applied to analyze the effects of coke ratio, coal ratio, blast temperature and other factors on the cost and CO<sub>2</sub> emission. Then, some measures to cost saving and emission reducing have been proposed.

90

## Static model study of the suitable direct reduction degree in COREX process

**Author(s):** Dr. ZHOU, Heng<sup>1</sup>

**Co-author(s):** Prof. WU, Shengli <sup>1</sup> ; Dr. KOU, Mingyin <sup>1</sup> ; Mr. YAO, Shun <sup>2</sup> ; Ms. WEN, Bingjie <sup>1</sup> ; Mr. SONG, Hekai <sup>1</sup> ; Mr. GU, Kai <sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

<sup>2</sup> *School of Metallurgical and Ecological Engineering, Beijing University of Science and Technology, Beijing 100083, China*

**Corresponding Author(s):** zhouheng@ustb.edu.cn

Direct reduction degree in COREX affects the reducing gas component and effective heat utilization rate. The present work systematically studies the influence of direct reduction degree on these characteristics in COREX through a static model. The model is developed based on mass and heat balances, which can calculate the consumption of iron ores, coal, fluxes, the volume and composition of the slag and the volume and composition of the reducing gas from melter-gasifier. The model is firstly validated by means of comparing calculated values with actual values. Then, the changes of heat flows, volume and component of reducing gas, and effective heat utilization rate in COREX induced by the variation of direct reduction degree are investigated. Finally, the suitable direct reduction degree in COREX is discussed. The findings of this work should be useful for control and optimizing of COREX operation.

92

## Dechlorination effect for alkali liquor spray scrubber after BF dry dust-catch

Dr. CHEN, HUI<sup>1</sup>

<sup>1</sup> *shougang Group Research Institute of Technology*

**Corresponding Author(s):** sunjian771@163.com

In recent years, dry de-dusting technology has been widely used. Alkali liquor spray scrubber was added after dry dust-catch process to removal such the corrosive medium as chlorine. However, the problem of corrosion cracking often occurred in the gas and hot blast pipes. The evaluating method was present through directly measuring the chlorine content in gas before and after alkali liquor spray scrubber. Compared to control PH value in alkali lye, the method above mentioned is more direct and reliable. The results show that the removal rate of chlorine in gas is between 10%~70%, and there is still the risk of corrosion of the equipment in the downstream process.

93

## Numerical Simulation of Heat Transfer inside the Sintering Bed by Employing Different Cross-section Shapes

**Author(s):** Mr. SUN, Chengfeng<sup>1</sup>

**Co-author(s):** Mr. DENG, Junyi<sup>1</sup>; Prof. XU, Jian<sup>1</sup>; Mr. MA, Kaihui<sup>1</sup>; Mr. XU, Yang<sup>1</sup>; Prof. LV, Xuewei<sup>1</sup>; Prof. BAI, Chenguang<sup>1</sup>; Mr. LIAO, Zhehan<sup>1</sup>

<sup>1</sup> *Chongqing University*

**Corresponding Author(s):** xuyang317@163.com

Thick bed technique has been widely used in the sintering plants, because it can save fuel consumption and achieve significant economic benefits. However, when the sintering bed height further increases, the cross-section shape would vary with respect to the inclination angle, and directly affect heat transfer inside sintering bed afterwards. After a two-dimensions(2D) mathematical model is established and validated against the sintering pot test measurements, present work designs four inclination angles, namely 9°, 18°, 26.6°, and 33.7°, in order to investigate the effects of cross-section shapes on heat transfer during the sintering process. The results show that the trapezoid-liked shape of sintering bed cross-section leads to the non-uniform temperature distribution in the width direction, where the temperature close wall is higher than that in the center. Although the increases on the inclination angles from 9° to 33.7° gradually decreases the sinter bed height with the same yield, the temperature difference between wall and center regions increases from 116 K to as great as 292 K.

Key words: sintering; cross-section shape; inclination angle; heat transfer; CFD

94

## The Development and Application of Blending Ore's Intelligence Heaping Mathematic Model for Large Raw Material Plant

**Author(s):** Mr. MA, Futao<sup>1</sup>

**Co-author(s):** Prof. ZHANG, Jianliang<sup>1</sup>; Prof. LIU, Zhengjian<sup>1</sup>; Dr. YAO, Chaoquan<sup>1</sup>; Dr. YAN, Zhiwu<sup>1</sup>; Dr. PAN, Wen<sup>2</sup>; Dr. PEI, Yuandong<sup>2</sup>; Dr. LUO, Yaosheng<sup>3</sup>

<sup>1</sup> *School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing*

<sup>2</sup> *Shougang Institute of Technology, Shijingshan District, Beijing*

<sup>3</sup> *Shougang Jingtang United Iron & Steel Co., Ltd. Caofeidian Industrial Park, Tangshan City, Hebei Province*

**Corresponding Author(s):** fortma214@163.com

**Abstract:** Large-scale blending material plant generally use many kinds of raw materials, including iron raw materials, flux materials, waste materials, etc., but the number of raw material tanks is limited. In view of this production status, "BLOCK" (heaping stage of total blending material pile, namely each layer of total blending material pile) stacking operation is usually applied to solve the problem of production organization. In the past, the composition of each "BLOCK" such as SiO<sub>2</sub> and TFe was adjusted manually, but the artificial experience can hardly ensure the SiO<sub>2</sub> content stability in each "BLOCK", and the TFe content in each BLOCK fluctuated greatly and cannot satisfied the production requirements. In order to satisfy the stability of the blending ore composition, the content precision of SiO<sub>2</sub> and TFe for blending material at each "BLOCK" was chosen as objective function, and the content change of MgO, CaO and Al<sub>2</sub>O<sub>3</sub> was controlled in a small range at the same time. Based on the artificial intelligence algorithm, the mathematical model of intelligence stacking and batching for sintering blending ore was established and fashioned intelligence batching system software was developed to optimally calculate the proportion of iron ore fines in blending material pile. Intelligent optimization results of the software were verified, and optimization effect of the software was obvious, it was ensured that there was almost no difference between the SiO<sub>2</sub> and TFe content of each "BLOCK" and the expected SiO<sub>2</sub> and TFe content of total blending material pile. After the actual application for the software for more than 2 years, the stable rate of TFe content of corresponding sinter ore was

up to 90% or above, it shows that the intelligence batching system software of sintering blending material pile is practical for raw material plant of iron and steel companies, and the system can significantly reduce the request of experience of workers, even for inexperienced workers.

Key Words: Sintering blending material pile; "BLOCK"; SiO<sub>2</sub> and TFe content stability; Artificial intelligence algorithm

95

## Discussion and Analysis of Shell Cracking of Large Hot Blast Stove

Mr. WU, jianlong<sup>1</sup>

<sup>1</sup> *Shougang Group Research Institute of Technology*

**Corresponding Author(s):** sunjian771@163.com

With the progress of iron making technology, the utilization level of air temperature is gradually improved. The temperature increase is conducive to improving production efficiency, increasing coal ratio, reducing coke rate and production cost. In the process of the continuous improvement of the wind temperature, the iron workers must also face the new challenges, such as hot air system, high temperature furnace shell and cracking of the furnace shell. In this paper, the phenomenon of cracking frequently occurred in the hot blast furnace shell of a large blast furnace in China is studied. The sampling of shell, the stain detection and microscopic analysis are carried out, and the cause of cracking of the furnace shell is discussed. Key Word: Hot blast stove; Cracking of furnace shell; Corrosion

96

## Metallurgical Properties and Furnace Protection Practice of Self Produced Titanium Pellets

Mr. MA, zejun<sup>1</sup>

<sup>1</sup> *Shougang Group Research Institute of Technology*

**Corresponding Author(s):** sunjian771@163.com

In recent years, with the increase of the intensity of the blast furnace, the issues of the hearth burn occurs and blast furnace sidewall temperature rapid rise increased significantly. In order to solve the problem that the price of titanium resources is increasing, the cost of furnace is raised, and the variety of titanium resources and the difficulty of adapting the blast furnace with different quality, we developed a titanium ball produced by adding titanium powder in the process of pelletizing production. Compared with the commonly used titanium resources in China, the self made titanium ball has excellent metallurgical properties, and has a very obvious effect on the control of the high temperature point of the hearth.

97

## Discussion on the influence analysis and migration law of chlorine in blast furnace system

Mr. WANG, Wei<sup>1</sup>

<sup>1</sup> *Shougang Group Research Institute of Technology*

**Corresponding Author(s):** sunjian771@163.com

This paper studies the origin and destination of chlorine element in the blast furnace system, the detection of chlorine content in BFG before and after spraying CaCl<sub>2</sub> solution of sinter production, and to explore and put forward some control measures of chlorine corrosion. The study found that sinter is the main source of chlorine of all raw fuel, accounted for 85.89%; 1.288g/m<sup>3</sup> chlorine content of blast furnace gas, is the largest expenditure item of chlorine load of blast furnace, reached more than 80%. The dechlorination efficiency of the dechlorination tower

is less than 60%, and there is still room for further improvement. The technical measures for controlling chlorine corrosion can be carried out from the control of the chlorine loading into the furnace, the heat treatment of the BFG pipeline, the optimization adjustment of the parameters of the dechlorination tower, and the determination of chlorine content in the blast furnace gas. Production practice has proved that chlorine corrosion has serious consequences on the BFG system and its downstream users, and should be paid enough attention to. It is suggested that the chlorine content of raw fuel will be incorporated into the evaluation system of raw fuel cost performance.

98

## Detailed DEM-SPH Simulation of Melt Passing Phenomena in Various Coke Beds

**Author(s):** Dr. NATSUI, Shungo<sup>1</sup>

**Co-author(s):** Mr. SAWADA, Akinori<sup>1</sup>; Dr. KIKUCHI, Tatsuya<sup>1</sup>; Prof. SUZUKI, Ryosuke<sup>2</sup>

<sup>1</sup> *Hokkaido University*

<sup>2</sup> *Hokkaido University*

**Corresponding Author(s):** natsui@eng.hokudai.ac.jp

A state-of-the-art numerical model was developed for analyzing packed bed structures containing non-spherical solids such as cokes and the high-temperature melt trickle flow characteristics of such beds. This enables the direct 3-dimensional analysis of packed beds that are difficult to visualize in experimental tests. The advanced discrete element method with 3D scanning technology is employed as a highly-accurate method for solid-particle motion simulation. It is a method using a contact force model that is expanded to capture the motion of 3-dimensionally freely shaped rigid bodies. Meanwhile, the sophisticated smoothed particle hydrodynamics method can track the motion of liquids without discriminating between continuous and dispersed phases. We used the boundary for the packed bed configured with non-spherical solids to carry out gas-liquid-solid 3-phase dynamic simulation. Based on this model, we carried out the large-scale simulations, and perform case studies and other studies of statistical processing, and investigate the effects of both physical properties and packed bed formed from various types of non-spherical cokes. Even for cokes bed of equal volume, different shapes changed the molten slag passage characteristics and static hold-up amount. Since the size of the hold up site is also influenced by the shape of the void at the top of the neck, the flow characteristics on the upstream side of the packed bed can also have a large influence. And we investigated the influence of melt physical properties on trickle flow, and clarified that an increase in viscosity increases holdup because limiting the effective flow path and suppressing the dispersion of the droplets promoted the enlargement of each stagnant droplet.

99

## Discussion on reasons of refractory material failure of hot blast stove corrugated pipe

Mr. LIANG, hailong<sup>1</sup>

<sup>1</sup> *Shougang Group Research Institute of Technology*

**Corresponding Author(s):** sunjian771@163.com

Hot blast stove corrugated pipe is an important part of hot blast stove pipe system [U+FFOC] for the role of absorption of expansion and contraction caused by the temperature and pressure changes of hot blast pipe and compensation of displacement. Corrugated pipe refractory material structure invalidation [U+FFOC] channeling wind leakage and the high skin temperature is widespread and urgently needs to solve in the domestic iron and steel enterprises. We used dissection of corrugated pipe [U+FFOC] constituent [U+FFOC] properties and micro analysis of refractory materials to study the refractory materials structure failure of hot blast stove corrugated pipe. The results show that refractory material corrosion by harmful elements carried in the hot wind [U+FFOC] air leakage between the hot air valves and corrugated pipe [U+FFOC] air leakage from expansion joint and refractory material itself is the main reason for the refractory material structure

failure of hot blast stove corrugated pipe. Key words: hot blast stove [U+FF0C]corrugated pipe [U+FF0C]failure [U+FF0C]refractory material structure

100

## Influence of thermodynamic melt formation characteristics on liquid phase fluidity of iron ore in sintering process

**Author(s):** Mr. LI, he-ping<sup>1</sup>

**Co-author(s):** Prof. WU, sheng-li<sup>2</sup> ; Dr. KOU, ming-yin<sup>2</sup> ; Dr. SU, Bo<sup>2</sup>

<sup>1</sup> 1) *University of Science and Technology Beijing*; 2) *Meishan Iron and Steel Cooperation*

<sup>2</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** ustb\_subo@163.com

The liquid phase fluidity of iron ore is one of the vital index of sintering characteristic, as the suitable melt fluidity can get a stronger bonding strength of sintered body. In this paper, FactSage thermodynamic calculation software and visible micro-sintering test device were conducted to research liquid phase fluidity and the main influence factors of melt formation characteristics. The results show that the rule of liquid phase fluidity of iron ore is obviously different when the flux is fixed with CaO ratio or fixed alkalinity. The generated liquid content of iron ore powder is the most important melt formation characteristic factor which affects its liquid phase fluidity. The higher the generated liquid content, the greater the liquid phase fluidity index. The content of gangue minerals affect the liquid phase fluidity of iron ore. The liquid fluidity index decreases greatly with increasing SiO<sub>2</sub> content results in lower generated liquid content and the liquid phase viscosity is increased. In contrast, with an increase in the Al<sub>2</sub>O<sub>3</sub> content only slightly increasing the liquid fluidity index.

101

## A study on the control of porosity and its reduction behavior by using FeCl<sub>2</sub> in FeO

Mr. SHIN, Sang Gyun<sup>1</sup> ; Prof. MIN, Dong Joon<sup>1</sup>

<sup>1</sup> *Material science and engineering, Yonsei University*

**Corresponding Author(s):** mang2ca@gmail.com

The Influence of pore on reduction behavior of iron oxide is very important. The pore affects the reduction gas diffusion and thus the reduction behavior is affected. However, in most studies, porosity was used only as a tool for the resultant interpretation of the reduction. There is insufficient studies to identify porosity by artificially changing pore. In this study, we investigate the reduction behavior by changing only pores after fixing other influencing reducing factors. FeCl<sub>2</sub> of high vapor pressure at high temperature, was used to control pores in the sample. FeO and FeCl<sub>2</sub> were physically mixed in a vertical furnace and the FeCl<sub>2</sub> was evaporated at high temperature to form pores. Reduction behavior was investigated by TGA experiment method. By using XRD, SEM, CIC, and BET analysis, the following results were obtained by examining the correlations of compositional equilibrium, morphology, Cl content, porosity and so on. As expected, the amount of pores in the sample was increased in proportion to the amount of FeCl<sub>2</sub> initially added by evaporation of FeCl<sub>2</sub>. The amount of pores in the sample was increased, but the initial rate of reduction was inversely proportional to the pore volume. After the mid-reduction, the rate of reduction tended to increase again in proportion to the initial value of the sample. It was found that not only the amount of pores but also the quality of pores could be an important factor in reduction.

102

## Migration of Organic Sulfur in Nantong and Laigang Coal with Addition of NaOH-H<sub>2</sub>O<sub>2</sub> under Microwave Treatment

**Author(s):** Mr. WU, Yue<sup>1</sup>

**Co-author(s):** Mr. ZHANG, Shengfu<sup>1</sup>; Mr. ZHU, Rongjin<sup>1</sup>; Mr. ZHOU, Xiaohu<sup>1</sup>; Mr. SUO, Guangsheng<sup>1</sup>; Mr. WU, Liang<sup>1</sup>; TAO, Shanlong<sup>1</sup>; Mr. QIU, Shuxing<sup>1</sup>; Mr. ZHANG, Qingyun<sup>1</sup>

<sup>1</sup> *Chongqing University*

**Corresponding Author(s):** wuyue2507@cqu.edu.cn

Nantong coal (NTC) and Laigang coal (LGC), the two typical high-sulfur coking coal in China, were investigated on their desulfurization processes with the addition of NaOH-H<sub>2</sub>O<sub>2</sub> under microwave treatment. X-ray diffraction (XRD), inductively coupled plasma (ICP) and fourier transform infrared (FT-IR) were performed to unravel the migration of organic sulfur in the two coal. In addition, the constituents of organic sulfur and content of functional groups in both two coal were also analyzed. NTC and LGC, with the addition of NaOH/H<sub>2</sub>O<sub>2</sub> at a volume ratio of 1:4 and microwaved at 1000 W for 10 min presented the highest desulfurization rates, that is, 22.3 and 31.75 % respectively. XRD analysis revealed that organic sulfur in the two coal was transformed into inorganic sulfur with the existence of sulfate or FeS, this transformation process inhibited desulfurization rate of the two coal. FT-IR measurement depicted that NaOH/H<sub>2</sub>O<sub>2</sub> ratio below and above 1:4 promoted and inhibited the desulfurization rate of the two coal. Moreover, the three sulfur-bearing functional groups were reserved in the two coal with the order of S=O > -S-H- > -S-S- under the NaOH/H<sub>2</sub>O<sub>2</sub> ratio of 1: 4, therefore, controlling of S=O in NTC and LGC is the key to improve the desulfurization rate.

103

## Research on pellets properties prepared with different fineness forsterite

**Author(s):** Ms. WANG, Rongrong<sup>1</sup>

**Co-author(s):** Prof. ZHANG, Jianliang<sup>1</sup>; Dr. LIU, Zhengjian<sup>1</sup>; Dr. LIU, Xingle<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** banyan8203@163.com

Basic characteristics of forsterite were systematically studied by chemical analysis, XRD, SEM-EDS. A series of experiments were performed to investigate the effect of forsterite fineness on pellets strength and porosity by changing pre-grinding time of olivine. It could be found that prolong the pre-treatment time of forsterite is beneficial to the promotion of pellets strength; there are two kinds of pores in the roasted pellets, which are large circular pores and intergranular pores. With the increase of the pre-grinding time, the shape and distribution of large circular pores become uniform, pore size and quantity of intergranular pores become small, thus pellets compressive strength increases firstly and then decreases slowly, porosity changes in the opposite direction. Optimal pre-grinding time of forsterite is 40~60min, under which condition could the pellets meet requirements of actual production.

104

## Factors of influencing the high temperature characteristics of lump ores in blast furnace

**Author(s):** Ms. DU, Binbin<sup>1</sup>

**Co-author(s):** Ms. LU, Yanan<sup>1</sup>; Dr. KOU, Mingyin<sup>2</sup>; Prof. WU, Shengli<sup>1</sup>; Mr. WANG, Laixin<sup>1</sup>; Mr. GU, Kai<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing, Beijing 100083 China*

<sup>2</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** dubinbin0816@163.com

From the viewpoint of energy conservation and environment protection, it's necessary to promote lump ores proportion in blast furnace burdens adequately. And the lump ore with good high temperature characteristics is conducive to the production of blast furnace. Therefore, in this work, in order to investigate the relation between the high temperature characteristics of lump ore and its primary properties, the reduction disintegration behaviors, reducibility and melting and

dropping characteristics of five lump ores were studied by simulating blast furnace conditions. And it was obviously that there were important differences in behaviors between different lump ores, which were mainly related to the distinct mineral composition, porosity, and chemical composition of various lump ores. Consequently, due to the different high temperature characteristics, each lump ore could match with different types of sinter and pellet so as to obtain a more suitable blast furnace burden and maximize the effective use of iron ores.

106

## A review on the ore blending scheme of Zhanjiang pelletizing plant

**Author(s):** Mr. LI, Xiaobo<sup>1</sup>

**Co-author(s):** Mr. YI, Lujie<sup>1</sup>; Mr. LI, Mengtu<sup>1</sup>; Mr. XIE, Yunjiang<sup>1</sup>; Mr. NIU, Changsheng<sup>1</sup>

<sup>1</sup> Baosteel Zhanjiang iron and Steel Co., Ltd

**Corresponding Author(s):** bobo684879@163.com

The ore blending scheme of Zhanjiang pelletizing plant with grate-kiln-cooler process changes frequently due to the location next to seaside. A complete iron ore blending system for flux pellet has been established to produce high quality pellets with various raw materials. The suitable basicity (CaO/SiO<sub>2</sub>) is 0.8±0.1 to avoid too much CO<sub>2</sub> emission decomposed from calcium carbonate during the pre-heating stage and vicious reduction expansion with basicity of 0.3 - 0.6. By controlling SiO<sub>2</sub> content and limestone content of no more than 3.2% and 4.3%, respectively, appropriate amount of liquid phase is generated to avoid pellets bonding in the cooler and to guarantee the average compressive press above 2500N of pellet.

107

## Formulation of shrinking behavior of sinter during softening process

**Author(s):** Dr. YASUDA, Naoto<sup>1</sup>

**Co-author(s):** Dr. NISHIOKA, Koki<sup>2</sup>; Mr. ORIMOTO, Takashi<sup>2</sup>; Dr. NOMURA, Seiji<sup>2</sup>

<sup>1</sup> Nippon Steel & Sumitomo Metal Corporation

<sup>2</sup> Nippon Steel & Sumitomo Metal Corporation

**Corresponding Author(s):** yasuda.7hz.naoto@jp.nssmc.com

In order to formulate shrinkage behavior of sinter during softening process, the effects of load and reducing gas composition on the shrinkage rate of sinter packed bed has been investigated using a softening-melting furnace. As a result, the shrinkage rate increased with increasing the load on the packed bed in temperature range from 1000 to 1200 °C, and decreased with increasing the reduction degree of sinter in temperature range from 1200 to 1300 °C. The results indicate that shrinkage mechanisms vary depending on temperature. In this study, softening process of sinter was formulated by dividing into two temperature regions. In the region I, the shrinkage rate increased in proportional to the impressed load, and was in inversely proportional to the softening viscosity. In the region II, the shrinkage rate increased in proportion to the generation rate of melt, and decreased with increasing the volume percent of metallic iron in the packed bed. The shrinkage in region II was inhibited with increasing the reduction degree of sinter since formed metallic iron served in the role of aggregate. The shrinkage rate of each region was expressed as functions of initial composition of sinter, load, temperature, and reduction degree. The calculated values were in good agreement with the experimental ones.

108

## Comprehensive Innovation of flue Gas Purification Facilities and Performance in Ironmaking Plant in Baosteel Zhanjiang Works

**Author(s):** Mr. LIANG, LI-SHENG<sup>1</sup>

**Co-author(s):** Mr. ZHOU, QI <sup>1</sup>

<sup>1</sup> Baosteel Zhanjiang Iron&Steel Co.,Ltd, Ironmaking plant

**Corresponding Author(s):** zhouqi120@baosteel.com

Baosteel Zhanjiang Iron&Steel Co.,Ltd., which is a new iron&steel making Works located in southern China, sticks to Baowu Group's "green vision" and driving the development of green steel industry. Ironmaking plant in Zhanjiang Works includes raw materials yard, coking and sintering process and blast furnace. Target of the conventional ironmaking process is going to be a green and low emission ironmaking base. This paper briefly introduced the advanced outdoor dust control of raw materials stock and flue gas purification technologies employed in coking and sintering process in Baosteel Zhanjiang ironmaking plant. Further, the performances of the flue gas purification facilities were discussed. So far, outstanding performances have been achieved.

109

## Kinetic analysis of carbon fiber deposition on catalyst iron in CO-H<sub>2</sub>

**Author(s):** Mr. NISHIHIRO, Kazuto<sup>1</sup>

**Co-author(s):** Prof. OHNO, Ko-ichiro <sup>2</sup> ; Prof. MAEDA, Takayuki <sup>3</sup> ; Prof. KUNITOMO, Kazuya <sup>3</sup>

<sup>1</sup> Department of Materials Process Engineering, Graduate School of Engineering, Kyushu University, Japan

<sup>2</sup> Kyushu University

<sup>3</sup> Department of Materials Science and Engineering, Faculty of Engineering, Kyushu University, Japan

**Corresponding Author(s):** nkazuto36@gmail.com

CO-H<sub>2</sub> mixture gas is often used for gas-based DRI process where carbon deposition reaction and Fe<sub>3</sub>C metal dusting play serious roles for a stable reduction operation. Fe<sub>3</sub>C decomposition leads to the formation of iron particles which is a catalyst for carbon fiber deposition. Because of the parallel occurrence of these reactions, kinetic analysis of them would be complicated. In the present study, to simplify the kinetic analysis, quantitative analysis was conducted by focusing on carbon fiber deposition using thermobalance. A powdery iron sample was prepared by reduction of Fe<sub>2</sub>O<sub>3</sub> at 600 [U+2103] in 100vol%H<sub>2</sub>. Carbon deposition on the iron sample was investigated at 500, 600 and 700 [U+2103] under flowing 100%CO, 90vol%CO-10vol%H<sub>2</sub>, 75vol%CO-25vol%H<sub>2</sub>, 50vol%CO-50vol%H<sub>2</sub>, 25vol%CO-75vol%H<sub>2</sub> and 10vol%CO-90vol%H<sub>2</sub> mixture gases. Results showed that amount of the deposited carbon in the CO-H<sub>2</sub> mixture gas is larger than that in the pure CO gas. The largest amount of deposited carbon was obtained at 600 [U+2103] in the 75vol%CO-25vol%H<sub>2</sub> mixture gas. According to SEM observations and weight change measurements, carbon was deposited in fiber shape on the iron surface and amount of it was increased linearly with an increase in samples' weight change. The rate constant of Carbon fiber deposition was calculated considering Rideal mechanism with focusing on elementary reaction steps. It was found that the rate constant of the hydrogen-oxygen reaction step was the largest indicating a significant effect of hydrogen on promoting carbon deposition. This would be due to the removing oxygen from CO by hydrogen on the iron catalyst.

110

## Case study of reclaiming Zn containing sludge from settling ponds

**Author(s):** Ms. LUNDKVIST, Katarina<sup>1</sup>

**Co-author(s):** Dr. BRÄMMING, Mats <sup>1</sup> ; Ms. HAGEMALM, Jenny <sup>2</sup> ; Mr. LAGERWALL, Per <sup>2</sup> ; Ms. WEDHOLM, Anita <sup>3</sup>

<sup>1</sup> Swerea MEFOS AB, Box 812, SE-97125 Luleå, Sweden

<sup>2</sup> SSAB Europe, SE-97188 Luleå, Sweden

<sup>3</sup> SSAB Merox, SE-97188 Luleå, Sweden

**Corresponding Author(s):** katarina.lundkvist@swerea.se

At SSAB Europe's integrated steel plant in Luleå, Sweden, much effort is directed towards maximising the recycling of in-plant residues. As the blast furnace (BF) operates with a 100 % pellet burden, the main part of all dusts and sludge are recycled via a BF cold bonded briquette and by the BF-injection of its flue dust. However, BF sludge is not presently recycled due to concerns regarding BF zinc load. This has continuously risen with increased recycling, to a current level of 100-120 g/tHM. In order to investigate the possibilities to introduce the recycling of all or parts of the freshly generated BF sludge ([U+F07E]0.8% Zn), or reclaiming previous year's produced BF sludge from settling ponds (0.2-0.5% Zn), a system analysis case study has been performed. The main focus of the case study was to estimate the capacity and economic benefits for BF sludge recycling (back to the BF) via the by-product briquette, based on a set maximum allowed blast furnace zinc load. An increase of the BF zinc load will, of course, raise the zinc level in the total system. Therefore, the developed system analysis tool used in this case study models the influence of the total BF zinc load on all generated residues and, hence, on the zinc content of recycled briquettes and injected flue dust. The establishment of the system zinc balance has been made possible due to good in-plant knowledge of zinc content in input as well as output materials. The system analysis shows that, with a maximum allowed BF Zn-load of 150 g/tHM, a "closed loop" recycling of freshly generated BF sludge is limited to about 40% (or 2 of 5 kg/tHM produced). However, in the case of reclaiming BF sludge from settling ponds the amount of recycled sludge can be considerably larger as the Zn content of recycled sludge will not be affected by the obtained increase in Zn content in the freshly produced BF sludge. At a Zn content of 0.4%, the amount of reclaimed sludge that can be recycled will equal the generated amount (i.e., about 5 kg/tHM). This will result in a reduced need for iron ore pellet and coke (dependent on the sludge Fe and C content) of some 2 kg/tHM, respectively. Hence, recycling of reclaimed BF sludge should be preferred to a "closed loop" recycling. A prerequisite for optimising the recycling of reclaimed sludge is to perform a comprehensive mapping of the zinc distribution in settling ponds.

111

## Multiphase modelling of the blast furnace hearth during tapping

**Author(s):** Mr. VÅNGÖ, Mathias<sup>1</sup>

**Co-author(s):** Dr. LICHTENEGGER, Thomas<sup>1</sup>

<sup>1</sup> *Department of Particulate Flow Modelling, Johannes Kepler University, Linz*

**Corresponding Author(s):** mathias.vangoe@jku.at

The campaign length of a blast furnace is limited by the hearth inner lining lifetime. In order to maximize the campaign length and ensure a good draining of hot metal and slag, a good understanding of the flow in the hearth is essential. Challenges in modeling the flow involve several continuous phases (hot metal, slag and hot blast) as well as the presence of the deadman, a dense bed of coke particles. The shape and position of the deadman is highly dynamic and depend on several conditions, e.g. the weight of the burden, the deadman porosity as well as the liquid iron and slag levels in the hearth.

We present a numerical coupled CFD (Computational Fluid Dynamics) – DEM (Discrete Element Method) model to account for the transient behavior of the deadman. A VOF (Volume of Fluid) method is used to model the multiple continuous phases and the DEM method to model the discrete particles. The VOF and DEM models are coupled together in a 2-way manner, resulting in a complete 4-way coupled CFD-DEM model. Experimental validation was performed on a lab-scale particle filled tank and a demonstration of a small-scale blast furnace hearth is shown. Finally, we present our latest advancements towards modeling industrial scale blast furnaces. Due to the big dimensions, difficulties with long computational times arise as the particle number becomes infeasible. Commonly a parcel approach (coarse graining) is used to handle this problem, where several particles are treated as one large particle. However, in combination with VOF, the amount of coarse graining is limited as the increased particle size impairs the resolution of the fluid interfaces. Additionally, the wide range of time scales (ranging from particle collisions of fractions of a second to several hours of operational times) present in the blast furnace remains a major challenge. With information gathered from several short-term coarse grained DEM simulations for various liquid levels, we performed a long-term fully Eulerian simulation that used

the data to create a dynamic porosity field. By not resolving any particle collisions in the long term simulation, we could simulate a longer process time while still accounting for the dynamic behavior of the deadman.

112

## A Successful Endeavor in Developing Long life Tuyere at I Blast Furnace, Tata Steel, Jamshedpur

**Author(s):** Mr. GHOSH, Ujjal<sup>1</sup>

**Co-author(s):** Mr. SHANMUGASUNDARAM, Subhachandhar<sup>2</sup>; Mr. TRIPATHI, Vineet Ranjan<sup>1</sup>; Mr. PATNAIK, Dhiren<sup>1</sup>; Mr. CHOUDHARY, Daya Shankar<sup>1</sup>; Mr. SINGH, Amit Kumar<sup>1</sup>; Mr. SINGH, Uttam<sup>1</sup>

<sup>1</sup> *Tata Steel*

<sup>2</sup> *Mr*

**Corresponding Author(s):** ujjal.g@tatasteel.com

Tuyere is the equipment which is supposed to sustain one of the most adverse conditions inside the Blast Furnace. Reliability of Tuyere is very important for trouble free safe operation of Blast furnace. Failure of tuyere increases cost of operation in terms of increased fuel rate and production loss as well as create hazard for the process and human. In front of the tuyere almost 2200 – 2300 degree centigrade temperature persists and at the same time tuyere is also subjected to mechanical abrasion from the descending materials. Till now there is no material developed for tuyere which can sustain such adverse conditions. Copper is used to exploit its high conductivity to sustain extreme temperature but it doesn't have abrasion resistance. Thus in almost in all Blast Furnaces of the world, different protective layers have been applied to improve the abrasion resistance but have achieve very limited success. 'I' Blast furnace was also struggling to achieve high tuyere life. Untimely, sudden and frequent failure of Tuyeres was posing serious threat in achieving stable and safe Blast Furnace operation. It was not only causing high copper loss, at the same time it was responsible for other associated problems like high fuel rate, loss of production etc. Apart from predictive modeling to avoid failure at odd hours, other steps were also taken like indigenous development of coating for top surface, measures to reduce heat loss from the inner surface, change in internal and external cooling circuit of tuyere and measures to prolong life even after burning of the tuyere. This paper deals with all scientific and practical measures taken 'I' Blast furnace which aided to achieve a standard tuyere life.

113

## Digital Inventory Management System in 'I' Blast Furnace

**Author(s):** Mr. SHANMUGASUNDARAM, Subhachandhar<sup>1</sup>

**Co-author(s):** Mr. SINGH, Basant Kumar<sup>2</sup>; Mr. GHOSH, Ujjal<sup>2</sup>; Mr. VISHWAKARMA, Raj Kumar<sup>2</sup>; Mr. LAL, Santosh Kumar<sup>2</sup>; Mr. PALIWAL, Lokesh<sup>2</sup>; Mr. TRIPATHI, Vineet<sup>2</sup>

<sup>1</sup> *Mr*

<sup>2</sup> *Tata Steel*

**Corresponding Author(s):** s.subhachandhar@tatasteel.com

Blast furnace forms the heart of integrated steel plant, a capital intensive industry. For sustainable operations of such a capital intensive industry leveraging technology to optimize the process, reduce the cost and provide a safe and clean working environment forms become inevitable. In an endeavor to achieve excellence in the reduction of operational cost of 'I' blast furnace, a confluence of digital technology, namely SAP and theory of constraints were used to develop a self-learning system that optimizes the inventory of the blast furnace. The system calculates the ideal buffer level of different operational consumables and generates the order based on the current inventory, minimum ordering quantity and critical buffer limit. The implementation of the system not only automated the process of ordering but also successfully reduced the inventory of class 'A' consumables by 50% which saved USD 0.5 M in 2017 and has an estimated potential of USD 2.1 M on horizontal deployment.

114

## Diagnosis model for circumferential balance in burden distribution of blast furnace

**Author(s):** Mr. CHAUDHARI, Ujjwal<sup>1</sup> ; Mr. NAG, Samik<sup>1</sup>

**Co-author(s):** Mr. SINGH, Amit<sup>1</sup> ; Mr. SINGH, Uttam<sup>1</sup> ; Mr. SHAH, Devendra<sup>1</sup>

<sup>1</sup> *Tata Steel Ltd. Jamshedpur, India*

**Corresponding Author(s):** ujjwal.chaudhari@tatasteel.com

The iron blast furnace is a complex reaction vessel involving cross-current flows of gas, powder, liquid, and solids. To ensure that blast furnace is operating smoothly, one of the important criteria is to maintain symmetry in burden distributed in this reactor. Blast furnace uses Bell Less Top (BLT) system to distribute the burden in a required pattern. To control distribution, BLT system has its own control logic, but to ensure that BLT system is working according to the set point and gives required symmetry in burden distribution a diagnosis model is developed. It assesses the circumferential balance in burden distribution using parameters such as hopper Wt., tilt angle, vibration signal of hopper and gate opening data to generate decision signal. This model has algorithms like ring completeness, ring start point randomness and uniformity in mass distribution. The algorithm for ring completeness identifies material discharge start and discharge end location based on real-time Wt. of BLT hopper. Complete ring formation is necessary to ensure the material is distributed equally. So this algorithm is designed to counts the real-time rotation angle of the chute and provides visuals for ring completeness status for particular tilt angle. Also, this algorithm generates an index called as ring completeness index, which numerically signifies the status of ring completeness in fraction varying from zero to one for all dumps. There may be a discrepancy in the uniform distribution of burden across the periphery of the blast furnace, to normalize this discrepancy or equally distribute this flaw it is needed to start each dump from a random location across the circumference. The second algorithm for start point randomness generates visuals for coke and metallics start point. It also generates an index which signifies randomness for all dumps. Also, there is a need that mass is uniformly distributed across the circumference of the furnace, the third algorithm generates an index for uniformity in the mass distribution for all dumps. The operator can alter the process parameters to attain the desired value of above-mentioned three indices which ensures circumferential balance in burden distribution across the periphery of the blast furnace.

115

## Laboratory Simulation of Direct Reduction Shaft Furnace

**Author(s):** Mr. FARAHANI, Mahdi<sup>1</sup>

**Co-author(s):** Dr. TSVIK, George<sup>1</sup> ; Mr. COYLE, Thomas<sup>1</sup>

<sup>1</sup> *ArcelorMittal USA*

**Corresponding Author(s):** mahdi.farahani@arcelormittal.com

This article presents a novel experimental procedure that simulates the complicated counter-current DR shaft process. This lab test is recently developed in ArcelorMittal Global R&D and shows good correlation with actual direct reduction process. The method provides a unique tool to study the impact of DR plant operation parameters in the laboratory scale, and enables the study of raw materials evolution from Oxide pellet to DRI.

116

## Evolution of coke nanostructure during gasification

**Author(s):** Dr. GRIGORE, Mihaela<sup>1</sup>

**Co-author(s):** Dr. SAKUROVS, Richard<sup>1</sup> ; Dr. KOVAL, Lukas<sup>2</sup>

<sup>1</sup> *CSIRO Energy*

<sup>2</sup> *CSIRO Minerals*

**Corresponding Author(s):** mihaela.grigore@csiro.au

Coke reactivity is one of the most important parameters that defines coke quality. Although coal parameters such as coal rank, maceral composition and ash chemistry are used as indicators of coke reactivity, they cannot fully predict it. It is well recognized that reactivity of coke is controlled by catalytic mineral matter and its porosity, particularly its nanoporosity (pores of nm in size). Our previous studies on coke gasification under chemically controlled conditions concluded that catalytic mineral matter plays a dominant role on the reaction rate at initial stages whereas nanoporosity controls the reaction rate at the later stages. Porosity in cokes consists of open and closed pores. Recently we found that closed nanoporosity occurs in large proportions in cokes, almost all pores less than 5 nm are closed, and the amount of closed porosity in cokes was influenced by the maceral composition of the parent coals. In this study we examined how the fraction of the closed pores in cokes (as a function of pore size) changes during gasification under chemically controlled conditions. The cokes along with cokes prepared from maceral concentrates have been reacted with CO<sub>2</sub> to different burn-outs, namely 25%, 50% and 75%, using a fixed-bed reactor where the reaction is chemically controlled. The analysis of closed and open porosity in unreacted and reacted cokes was performed using Small Angle Neutron Scattering (SANS). Here we show that closed porosity down to sizes as small as 10 nm open gradually during gasification. Increased pore accessibility rather than pore growth may be the reason surface area of coke increases during the early stages of gasification. The influence of coal maceral composition and coal rank on pore opening in the product coke will be discussed.

117

## A Thermodynamic Study on the Selective Reduction of Ni in NiFe<sub>2</sub>O<sub>4</sub>

Mr. LA, Gi Ho<sup>1</sup> ; Prof. MIN, Dong Joon<sup>1</sup>

<sup>1</sup> Department of MSE, Yonsei Univ., Seoul Korea

**Corresponding Author(s):** ghla0730@gmail.com

Limonitic laterite is an iron ore consisting of a mixture of hydrated iron oxide-hydroxides in varying composition. The generic formula of limonitic laterite is expressed as (Fe, Ni, Mg)O•(OH)•H<sub>2</sub>O. It is possible to obtain high quality ferronickel and iron oxide, which can be used as a blast furnace charge, through selective reduction of Ni using reduction potential difference between Fe and Ni in limonitic laterite. It is reported that the improvement of the quality of ferronickel and iron oxide extracted from limonitic laterite is controlled by optimization of the selective reduction of Ni in NiFe<sub>2</sub>O<sub>4</sub> mineral formed during calcination. In this study, the optimized reduction condition for the selective reduction of Ni in NiFe<sub>2</sub>O<sub>4</sub> is thermodynamically derived, and the effect of oxygen partial pressure and temperature on the grade of ferronickel and iron oxide is evaluated. The NiFe<sub>2</sub>O<sub>4</sub> mineral used in this experiment was synthesized by physical mixing of NiO and Fe<sub>2</sub>O<sub>3</sub> powder, followed by calcining at 1200 [U+2103] for 24 hours in an air atmosphere. The reduction behavior of the synthesized NiFe<sub>2</sub>O<sub>4</sub> is analyzed by TGA and XRD. As a result of the selective reduction of Ni in NiFe<sub>2</sub>O<sub>4</sub>, it is confirmed that the ferronickel and iron oxide (magnetite, wustite) are formed in experimental conditions. Using bromine-methanol leaching method, the composition of ferronickel in leaching solution is quantitatively analyzed by ICO-OES analysis, and the equilibrium phase of coexisting iron oxide was analyzed by XRD.

118

## A Comparison of different tuyere geometries

**Author(s):** Mr. CHATTERJEE, Rajeswar<sup>1</sup>

**Co-author(s):** Dr. NAG, Samik<sup>1</sup> ; Mr. GHOSH, Ujjal<sup>1</sup> ; Mr. KUNDU, Subhashis<sup>1</sup> ; Mr. CHAKRABORTY, Ranjan<sup>1</sup> ; Mr. KISHORE, Kaushal<sup>1</sup>

<sup>1</sup> Tata Steel Ltd.

**Corresponding Author(s):** rajeswar.chatterjee@tatasteel.com

Tuyeres are essential accessories of blast furnace through which hot blast (compressed air and oxygen) & fuels like pulverized coal are injected. By doing so, it gets exposed to the most severe thermal conditions like radiation, convection at temperature of 2200oC & also liquid metal attack &

abrasion. Hence the tuyere failure is a common industrial phenomenon which leads to production loss and increased cost. Improper designing of tuyere, manufacturing defects and improper operational practices can result into this failure. This study therefore comprehensively focuses on comparison of several tuyere models/ geometries based on thermal load, effect of different operating parameters and to identify different coating material suitable for this application based on the failure analysis. Tuyeres are generally casted of pure copper with water cooling channel embedded inside for the purpose of cooling. This work includes conjugate heat transfer with water flow simulation using commercial software FLUENT. Radiative & convective heat transfer has taken into account for thermal boundary conditions. The results include detailed velocity pattern, pressure drop and temperature distribution inside fluid and solid zone. Despite applying radiation at the whole nose surface, hot spot is concentrated only at nose tip revealing insufficient cooling at that zone. Parametric variations like water flow temperature, water flow rate, coating thickness have been simulated to observe their effect on the thermal performance of tuyere. Failure analysis has been conducted to identify the root cause of failure at the tuyere nose. Different coating/ hard facing material has been explored to find out its stability at that extreme thermal environment. This study will result in concluding the better design with respect to thermal load. It will also give a way to modify the better design for enhancing the efficiency of the tuyeres.

119

## Evolution of the structure of analogue sinters and the impact on sinter quality

Mr. HARVEY, Tobin<sup>1</sup>

<sup>1</sup> *The University of Newcastle Australia*

**Corresponding Author(s):** tobin.harvey@uon.edu.au

Typically a large proportion of the ferrous burden charged to the ironmaking blast furnace is iron ore sinter. The quality of iron ore sinter has a strong influence on the productivity and fuel efficiency of the furnace, therefore high quality sinter is desirable. Individual pieces of sinter product from industrial sinter strands and sinter pot test are variable in composition and structure. This is caused by heterogeneous distribution of raw materials and spatial differences sintering conditions (temperature profile and pO<sub>2</sub>), and complicates analysis of sintering mechanisms. To reduce the variability in sinter samples an infra-red rapid heating furnace was used to produce laboratory scale analogue sinter tablets under tightly controlled conditions. The tablets were made from nuclear ore particles (1.0-0.71 mm) and fluxed ore ultra-fines (-0.25 mm). The mechanisms driving changes in sinter structure and mineralogy, and the subsequent impact on sinter quality, were investigated using scanning electron microscopy (SEM), optical microscopy, BET and high resolution X-ray CT. The quality of the laboratory scale sinters was measured using an axial compression strength test and a modified reducibility test.

120

## Effects of operating conditions on the level of size segregation of iron ore granulated mix on a sinter strand

**Author(s):** Mr. LI, Chengzhi<sup>1</sup> ; Prof. HONEYANDS, Tom<sup>1</sup>

**Co-author(s):** Dr. MORENO-ATANASIO, Roberto <sup>2</sup> ; Dr. O'DEA, Damien <sup>3</sup>

<sup>1</sup> *CIMR, Chemical Engineering, University of Newcastle, Australia*

<sup>2</sup> *CAPPT, Chemical Engineering, University of Newcastle, Australia*

<sup>3</sup> *Principal Technical Marketing, Marketing Iron Ore, BHP Billiton, Australia*

**Corresponding Author(s):** c3201028@uon.edu.au

Size segregation of the iron ore granules packed on a sinter strand has a significant influence on both airflow rate and temperature distribution through the bed. Therefore, it is a key factor that governs the efficiency of mass and heat transfer down the sinter bed. For a defined sinter feed and granule size distribution, it is possible to increase the size segregation through optimising the operating parameters in a sintering process. In this paper, a numerical study was carried out using a 3-D model developed by Discrete Element Method (DEM) to investigate the influence of feed rate and the inclination of rill plate on the level of granule size segregation down the

bed. The optimal combination of these two parameters for obtaining a desirable level of size segregation was also studied. These simulation results were validated using a 1/3 scale laboratory sinter strand utilising iron ore granules.

121

## Development of Granulation and Firing Technology in Using Large Quantity of Magnetite Fine Ore

**Author(s):** Mr. OSUGA, Koji<sup>1</sup>

**Co-author(s):** Mr. MATSUMURA, Toshihide<sup>1</sup>; Dr. NOZAWA, Kentaro<sup>2</sup>; Mr. MIYAGAWA, Kazuya<sup>1</sup>

<sup>1</sup> *Kobe Steel, Ltd.*

<sup>2</sup> *Kobe Steel, Ltd*

**Corresponding Author(s):** osuga.koji@kobelco.com

Kakogawa Works of Kobe Steel, Ltd. has a set of sinter and pellet plants for the production of blast furnace raw materials. Recently, the use of magnetite fine ore has attracted attention while deterioration of iron ore grade. We clarified the problem of granulation and firing in using large quantity of magnetite fine ore, and developed countermeasures.

122

## A short flow sheet and low carbon ironmaking process by simple raw materials

Dr. WANG, Guang<sup>1</sup>; Prof. WANG, Jingsong<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** wangguang@ustb.edu.cn

Iron and steel making is one of the most important industrial sectors, which have a great impact on the global growth and economy. By 2050, steel usage is expected to increase to become 1.5 times higher than present levels in order to meet the needs of a growing population. The making of iron and steel consumes lots of energy mainly due to the strong endothermic reaction and high reaction temperature. The steel industry is responsible for approximate 5% of the world-wide energy consumption. The ironmaking process is the highest CO<sub>2</sub> emission part in steel production sector due to the intensive utilization of fossil fuels for heating, melting and reduction of iron ores. Therefore, the main pressure of energy-saving and emission-reduction of steel industry lies in the ironmaking process. In order to reducing the consumption of fossil fuels of ironmaking process, lots of efforts have been done all over the world, such as developing short flow sheet non-blast furnace ironmaking process, utilization of renewable resource (such as biomass and waste plastics) as energy and reducing agents partially in place of some fossil fuels in the ironmaking process. In this paper, fundamental research on a short flow sheet and low carbon ironmaking process by simple raw materials, i.e. iron nugget process, has been presented. A low grade and high Al<sub>2</sub>O<sub>3</sub> and S iron ore was used to produce high grade pig iron nugget for EAF steelmaking. The effect of reduction temperature, carbon content, basicity and additives on the reduction and melting behavior of the high alumina ore/coal composite pellet was investigated. The chemical composition of iron nugget, such as [S] and [C], was further analyzed. The increasing of carbon content could improve the melting separation a little. The reduction rate of the pellet would be improved with the increasing of basicity and the pellet melted better at 1450 [U+2103]. The sulphur content of the iron nugget gradually decreased with basicity increasing from 0.6 to 1.2 and was obviously low when the basicity was 1.2. The sulphur content of the iron nugget was 0.085% and the desulphurization rate was 96.5% when the pellet with basicity of 1.2, 8% Na<sub>2</sub>CO<sub>3</sub> and 4% CaF<sub>2</sub> reduced at 1450 [U+2103]. The obtained iron nugget could meet the requirement of steel making. The results also showed that the carbon content in the iron nugget was as low as 0.80wt.% and much lower than the other iron ore of lower Al<sub>2</sub>O<sub>3</sub> content (2.81wt.%), and increased with the increasing of slag basicity when the Al<sub>2</sub>O<sub>3</sub> content in the iron ore was 4.59wt.%. This process is a possible method for the reducing the coke consumption and CO<sub>2</sub> emission of iron and steel industry.

123

## Thermal Fluid Analysis in Deforming Packed Bed

**Author(s):** Prof. NOGAMI, Hiroshi<sup>1</sup>

**Co-author(s):** Mr. SUZUKI, Shintaro<sup>1</sup> ; Mr. YAMAWAKI, Takuto<sup>1</sup>

<sup>1</sup> *Tohoku University*

**Corresponding Author(s):** nogami@tohoku.ac.jp

The cohesive zone of the blast furnace generates major part of the pressure drop. It is considered that the thickness of the cohesive zone increases with decreasing the reducing agent rate and increasing the usage of the low grade raw materials in future. Thickening the cohesive zone increases the pressure drop and the failure of the blast furnace operation could occur in the extreme condition. Thus the thickness of the cohesive zone should be decreased or permeability of the cohesive zone should be improved. A mathematical simulation technique for the fluid flow and heat transfer in the packed bed of the deforming particles like the cohesive zone was developed. This technique combined the discrete element method for bed deformation and the computational fluid dynamics for the gas flow. Additionally the inter-particle heat exchange in the deforming packed bed was formulated and linked with the discrete element analysis. This mathematical model successfully revealed the variation of the heat transfer mechanism with the deformation of the packed bed. The simulation results could give the useful information for designing the burden distribution under the low carbon operation of the blast furnace.

124

## Analysis on the combined form of iron skull on the carbon brick surface used in blast furnace hearth

**Author(s):** Mr. WEN, Xu<sup>1</sup>

**Co-author(s):** Prof. ZHENG, Shaobo<sup>2</sup> ; Prof. YU, Zhongda<sup>3</sup> ; Dr. JIANG, Hua<sup>4</sup> ; Prof. WANG, Wei<sup>5</sup> ; Dr. XU, Runsheng<sup>5</sup>

<sup>1</sup> *Shanghai University, China*

<sup>2</sup> *Shanghai University, China*

<sup>3</sup> *Shanghai University*

<sup>4</sup> *Baoshan Iron and Steel Co Ltd, China*

<sup>5</sup> *Wuhan University of Science and Technology, China*

**Corresponding Author(s):** xu\_runsheng@163.com

The blast furnace (BF) crucible breakout is not uncommon. More and more attentions have been paid on the penetration of molten iron and hearth lining erosion of BF. The iron skull, which is a layer of iron attached on the inner surface of the lining, provides a barrier between carbon brick and molten iron. Formation of a stable iron skull on the inner surface of the hearth lining could largely protect the carbon brick and extend BF campaign life. In this work, the molten iron in condition of high pressure was simulated to figure out the penetration between carbon brick and molten iron in the BF. The influence on combined form between iron skull and carbon brick during the campaign life of blast furnace was also discussed. The experimental samples were analyzed by X-ray diffraction, scanning electron microscopy to explore the distribution of microstructure between carbon and iron inside the carbon-iron composite material. This work is expected to have a guiding significance for prolonging the campaign life of blast furnace.

125

## Effects of iron coke hot briquette charging on softening-melting and dripping behaviors of blast furnace mixed burden

Dr. WANG, Hongtao<sup>1</sup>

<sup>1</sup> *Noreastern University*

**Corresponding Author(s):** wanghongtao0212@126.com

Reducing CO<sub>2</sub> emission and saving energy consumption in a blast furnace (BF) have become a hot issue all over the world. BF operation with charging ferro coke is considered as an effective countermeasure for mitigating CO<sub>2</sub> emission and energy consumption. In this study, the preparation process of iron coke hot briquette (ICHB) was put forth under laboratory condition. Simultaneously, the effects of ICHB charging on softening-melting and dripping behaviors of blast furnace mixed burden were experimentally investigated. The results showed that, with the increase of ICHB charging ratio, softening interval T<sub>40</sub>-T<sub>4</sub> is increased from 206.3 [U+2103] to 218.9 [U+2103] while melting interval TD-TS is decreased from 171.1 [U+2103] to 124.8 [U+2103]. Additionally, the location of cohesive zone moves downwards slightly and the cohesive zone becomes narrower. Besides, the dripping ratio is increased first and then decreased, whose maximum value comes to 40.58% with 30% ICHB charging into mixed burden. Finally, the softening-melting characteristic value (indexed as S-value) is gradually decreased, which indicates that the permeability of mixed burden is improved. Taking softening-melting and dripping behaviors of mixed burden into consideration, the proper charging ratio of ICHB in mixed burden is about 30%.

126

## Preparation and Application of Blast Furnace Burden from Vanadium Titanomagnetite by Carbon Composite Iron Ore Hot Briquette Process

**Author(s):** Dr. ZHAO, Wei<sup>1</sup>

**Co-author(s):** Prof. CHU, Mansheng<sup>2</sup>; Dr. WANG, Hongtao<sup>2</sup>; Dr. LIU, Zhenggen<sup>2</sup>

<sup>1</sup> *Northeastern university*

<sup>2</sup> *Northeastern University*

**Corresponding Author(s):** zhaowei<sub>ne</sub>u@163.com

For blast furnace smelting vanadium titanomagnetite, which requires increasing the efficiency of blast furnace operation, vanadium titanomagnetite carbon composite hot briquette (VTM-CCB) is promising. As a new type of blast furnace ironmaking burden, VTM-CCB is produced by mixing coal fine and vanadium titanomagnetite fine and densification by hot briquetting, followed by heat treatment of the briquetted material. This paper is aimed to establish the preparation parameters of VTM-CCB firstly, then testing its metallurgical properties and investigating the effects of VTM-CCB on softening, melting and dripping behavior of mixed burden. The integrate preparation parameters include a hot briquetting temperature of 200 °C, a coal added ratio of 31.32% (mass %), a coal particle size of <74 μm, a VTM particle size of <74 μm, a heat treatment temperature of 500 °C, and a heat treatment time of 3 hr. The compressive strength of VTM-CCB based on integrate preparation parameters reaches 2450 N. VTM-CCB exhibits a great reduction disintegration property and its reduction disintegration index is higher than 96% in the temperature range from 500 °C to 900 °C. The swelling of VTM-CCB is not observed during reduction. On the contrary, the shrinking occurs obviously due to the pyrolysis of coal and carbon gasification in VTM-CCB. As carbon-bearing agglomerates, the reducibility of VTM-CCB is evidently better than VTM-pellet. Moreover, the softening-melting behavior and permeability of mixed burden is improved obviously with charging a certain amount of VTM-CCB. Fully considering softening-melting-dripping behavior and permeability, the recommended VTM-CCB charging ratio is 20%.

127

## A New Method to Separate and Recovery Iron and Alumina from High Iron Bauxite Ore based on Metallized Reduction and Self-disintegrating

**Author(s):** Dr. LIU, Zhenggen<sup>1</sup>

**Co-author(s):** Prof. CHU, Mansheng<sup>1</sup>; Mr. WANG, Zheng<sup>1</sup>; Mr. GAO, Lihua<sup>1</sup>; Dr. WANG, Hongtao<sup>2</sup>; Dr. ZHAO, Wei<sup>3</sup>

<sup>1</sup> *Northeastern University*

<sup>2</sup> *Noreastern University*

<sup>3</sup> *Northeastern university*

**Corresponding Author(s):** liuzg@smm.neu.edu.cn

High iron bauxite ore is a complex mineral resource bearing iron and alumina. According to the problem of comprehensive utilization of high iron bauxite, this paper presents a new process of recovering iron and alumina from high iron bauxite by reduction and self-disintegrating based on hot briquette. Through experimental research, the effects of reduction temperature, reduction time and carbon ratio on the recovery ratio of iron and alumina are investigated. The results show that, as the carbon ratio of high iron gibbsite hot briquette 1.0, C/A 1.71, reduction temperature 1425 [U+2103], reduction time 25 min, the iron nuggets and self-disintegrating slag are obtained. The recovery ratio of iron and alumina are 97.42% and 94.62%, respectively. The iron nuggets could be used in the iron and steel production, and the slag could be used to leach alumina.

128

## Interaction between Sinter and Lump Ore under Simulated Blast Furnace Conditions

**Author(s):** Dr. LIU, Xinliang<sup>1</sup>

**Co-author(s):** Prof. HONEYANDS, Tom <sup>1</sup> ; Dr. MITRA, Subhasish <sup>1</sup> ; Prof. EVANS, Geoffrey <sup>1</sup> ; Dr. O'DEA, Damien <sup>2</sup>

<sup>1</sup> *The University of Newcastle Australia*

<sup>2</sup> *BHP Billiton*

**Corresponding Author(s):** xinliang.liu@newcastle.edu.au

Many efforts have been made to investigate the softening-melting (SM) behaviour of ferrous burden material as it governs the formation of the cohesive zone (CZ) inside the ironmaking blast furnace (BF). Usually, the SM property of individual lump ore is thought to be inferior to iron ore sinter, however, it has been demonstrated that results for a mixed burden of  $\approx 80\%$  sinter and  $\approx 20\%$  lump ore are equivalent to the results obtained using only sinter. In this work, the high temperature interaction between a sinter of high basicity and Newman Blend lump ore from Australian is studied through interrupted SM tests at a number of temperatures. The structural and metallurgical aspects of the interaction are examined, e.g., the variation of ferrous burden voidage is tested using synchrotron X-ray CT scanning, and the metallurgical interaction studied using optical and scanning electron microscopy. Furthermore, the mechanism for the interaction between sinter and lump ore is identified, and factors controlling the reaction are discussed.

Key words: softening-melting, interaction, lump ore, ironmaking

129

## Function Mechanism of CaO/SiO<sub>2</sub> on Melting Separation of High Chromium Vanadium-bearing Titanomagnetite Metallized Pellet Got from Gas-based Direct Reduction

**Author(s):** Dr. TANG, Jue<sup>1</sup>

**Co-author(s):** Prof. CHU, Mansheng <sup>2</sup> ; Dr. FENG, Cong <sup>2</sup> ; Dr. LI, Feng <sup>2</sup> ; Dr. TANG, Yating <sup>2</sup> ; Dr. LIU, Zhenggen <sup>2</sup>

<sup>1</sup> *School of Metallurgy, Northeastern University, China*

<sup>2</sup> *School of Metallurgy, Northeastern University*

**Corresponding Author(s):** juetang@126.com

Based on the novel process of gas-based direct reduction followed by melting separation, the function mechanism of CaO/SiO<sub>2</sub> on the melting separation of high chromium vanadium-bearing titanomagnetite metallized pellet had been studied in this work. The experiments along with the calculations by Factsage 7.1 package were done. It was shown that the effect of CaO/SiO<sub>2</sub> on the melting separation kinetic was more considerable than thermodynamic. With the increasing CaO/SiO<sub>2</sub> from 0.6 to 1.1, the slag viscosity decreased, the surface tension increased, and the

melting temperature decreased, which were all attributed to the smooth melting separation and were all good for improving the metallic elements recovery. But further increasing CaO/SiO<sub>2</sub> to 1.2, the amount of CaTiO<sub>3</sub> in the slag increased and the slag melting point increased instead, meanwhile, the amount of slag was relatively excessive, and then all the melting separation indexes showed a decrease tendency. The rational CaO/SiO<sub>2</sub> for high chromium vanadium-bearing titanomagnetite metallized pellet melting separation was around 1.1, when Fe, V, and Cr were enriched in the iron but TiO<sub>2</sub> was in the slag. The recoveries of Fe, V, Cr, and TiO<sub>2</sub> reached 99.78%, 97.02%, 89.93%, and 95.63%, respectively. And the mass fraction of Fe, V, Cr, and TiO<sub>2</sub> are 93.05%, 0.89%, 0.67%, and 36.98%, respectively.

130

## APPLICATION OF MODERN INFORMATION TECHNOLOGIES TO CONTROL AND PREDICT BLAST FURNACE OPERATION

**Author(s):** Prof. SPIRIN, Nikolai<sup>1</sup>

**Co-author(s):** Dr. PAVLOV, Aleksander<sup>2</sup>; Mr. POLINOV, Andrei<sup>2</sup>; Prof. LAVROV, Vyacheslav<sup>1</sup>; Dr. ONORIN, Oleg<sup>1</sup>; Dr. GORDON, Yakov<sup>3</sup>

<sup>1</sup> *Ural Federal University*

<sup>2</sup> *MMK*

<sup>3</sup> *Technical Director, Hatch*

**Corresponding Author(s):** iakov.gordon@hatch.com

Modern Iron & Steel Works as a rule are equipped with powerful distributed control systems (DCS) and databases. Implementation of DSC system solves the problem of storage, control, protection, entry, editing and retrieving of information, as well as creation of the necessary reporting data. At the same time, Russian domestic and international experience shows that improvement in quality, energy efficiency, resource conservation and competitiveness at the global market require further advance of information systems used for process control and production management. The complex of mathematical models is a foundation of information technologies which support decision making process. The user of these technologies has the possibility to obtain the missing information he needs to make a decision by establishing a dialogue with the mathematical model.

Control of blast furnace operation is often classified as poorly structured problem. Because of this the base mathematical models have to be used at automated workstations of engineering and technological staff of blast furnace. The software for computer decision-making support system is a set of information-connected interactive (dialog) program modules integrated into a common environment. Integration of mathematical models is based on the application of both common initial data and the results of calculations performed by individual modules. Software modules implement mathematical models of heat-exchange, slag, cohesive zone, blast and gas-dynamics regimes of blast furnace. This forms the basis of functionality of the decision making support system while the modular structure ensures its extensibility.

As an example, for Magnitogorsk I & S Works (MMK) conditions usage of "cohesive zone" model helped to find the necessity of mixing of basic sinter and acid pellets before charging to the furnace to reduce extend of cohesive zone from 3 m to 1.5 m, which improved gas-dynamics, increased productivity and reduce coke rate at blast furnace.

Solution of the problems of analysis and forecast of blast furnace operating parameters using available actual information on furnace performance requires decomposition of the problem into three main interrelated subsystems: the thermal condition of the furnace, blast and gas-dynamics regimes of blast furnace, slag regime. The basic principle, which underlies the choice of specific mathematical equations to describe the individual subsystems, is to resolve the contradiction between the complexity of the modeled process and the need to resolve the technological problems in real time in course of the process and for a specified time interval using the actual available information.

131

## Study on the interaction between high metamorphic coal in Australia and low metamorphic coal

**Author(s):** Mrs. BAO, junfang<sup>1</sup>

**Co-author(s):** Mrs. JIA, lihui<sup>2</sup>

<sup>1</sup> 02786487686

<sup>2</sup> 02786893166

**Corresponding Author(s):** junfangbao@163.com

In this paper [U+FF0C] through the high metamorphic coking coal and middling metamorphism of coking coal in coking contrast test, the study found high metamorphic coking coal from a mine in Australia measured coarse Mosaic, the Mosaic and incomplete than calculated value of fiber structure, fine particle inlay and complete fiber structure than calculated value decreases, test the coke cold and hot state strength is best; In henan mine middling metamorphism coking coal from the measured optical organization coarse Mosaic structure is lower than the calculated value, the grain and fine grain of Mosaic structure, cold and hot state strength is lower than the high metamorphic coking coal from a mine in Australia. Thus concluded that different metamorphic degree of vitrinite wu with obvious interaction response to coking, large size of anisotropic structure unit and structure unit reaction after the small size of anisotropy anisotropic structure to the middle size unit conversion. Pointed out that the choice of coking coal in consideration of each single coal and coal quality at the same time, should focus on the interaction effect between different types of the influence of the strength of coke.

133

## Reduction behaviors of pellet in hydrogen and carbon monoxide atmospheres

Prof. YU, yaowei<sup>1</sup>

<sup>1</sup> shanghai university

**Corresponding Author(s):** yaoweyu@shu.edu.cn

Canadian hematite acid pellet with low magnetite content fluxed and olivine were isothermally reduced with hydrogen and carbon monoxide at 600 to 1000 [U+2103]. The course of reduction was investigated by measuring the oxygen weight loss as a function of time using a thermogravimetric analysis. Macroscopic and microscopic examination, X-ray and carbon analyses were also used to elucidate the mechanisms of reduction of pellet. For CO atmospheres, CO content in mixture can stimulate carbon deposition behaviors in pellet reduction procedure and carbon deposition leads to the fracture of pellet at the low temperature. For H<sub>2</sub> atmospheres, temperature from 600 to 700 and from 900 to 1000 oC have more influence on reduction fraction than one from 700 to 900 oC due to dense microstructures of pellet forming in the latter. Reduction of Fe<sub>2</sub>O<sub>3</sub> to Fe<sub>3</sub>O<sub>4</sub> is fastest and reductions of Fe<sub>3</sub>O<sub>4</sub> to FeO and FeO to Fe happen at the same time. Pellet reduced by CO has porous structures, while pellet reduced by H<sub>2</sub> has a dense product layer on the surface. CO atmospheres have the products of carbide and the has the phase changes: Fe<sub>2</sub>O<sub>3</sub>→Fe<sub>3</sub>O<sub>4</sub>→FeO→Fe→Fe<sub>3</sub>C. ,while the process of phase changes for H<sub>2</sub> atmospheres is : Fe<sub>2</sub>O<sub>3</sub>→Fe<sub>3</sub>O<sub>4</sub>→FeO→Fe.

134

## Modeling inner phenomena of self-reducing agglomerates under external inert gas atmosphere

**Author(s):** Prof. CASTRO, Jose Adilson<sup>1</sup>

**Co-author(s):** Ms. SOUZA CALDAS, Rayla<sup>1</sup> ; Prof. MENDES DE OLIVEIRA, Elizabeth<sup>2</sup> ; Prof. TAKANO, Cyro<sup>3</sup>

<sup>1</sup> Federal Fluminense University

<sup>2</sup> CEFET - Federal Center for Technological Education Celso Suckow da Fonseca - Angra dos Reis

<sup>3</sup> USP-Poli - University of São Paulo

**Corresponding Author(s):** joseadilsoncastro@id.uff.br

The self-reducing phenomena has been explored with the aim of improving the reducing velocity of agglomerates during hot metal production. The inner phenomena taking place in the agglomerates, however, are still controversial and further studies are demanded. In this paper we proposed a detailed mechanism taking place within the agglomerates during the solid-gas self-reducing step. In order to study the inner phenomena, a comprehensive mathematical model is proposed which takes into account the gas inner flow and chemical species transport, with heat supply using inert external atmosphere. The detailed mechanism taking into account gas and solid reactions are discussed and the controlling mechanisms of heat and mass transport are discussed in light of the coupled reactions mechanism. The results are obtained experimentally using isothermal runs and numerically to fit the experimental data and inversely determine the kinetic parameters of the proposed model. It is found that the heat transfer process is the controlling mechanism for the self-reducing step with deficit of carbon at lower temperatures while at high temperatures the mass controlling mechanism plays important role.

135

## Sintering mechanism of self-reducing agglomerates using dilatometric analysis techniques

**Author(s):** Prof. CASTRO, Jose Adilson<sup>1</sup>

**Co-author(s):** Ms. VIRGOLINO GONÇALVES, Evandro<sup>2</sup>; Ms. CARDIAL, Daiane<sup>3</sup>; Prof. SOARES DA FONSECA, Glaucio<sup>3</sup>

<sup>1</sup> *Federal Fluminense University*

<sup>2</sup> *UFF- Federal Fluminense University*

<sup>3</sup> *UFF - Federal Fluminense University*

**Corresponding Author(s):** joseadilsoncastro@id.uff.br

The technological maturity of the self-reducing process still face challenges due to the complexity of the phenomena involved. During the self-reducing process sintering phenomena of the agglomerates could take place improving the mechanical resistance, in one hand, and slowing the reducing velocity. The inner phenomena in the agglomerates, however, are still controversial and further studies are demanded. In this paper we proposed an experimental procedure based on the dilatometric technique to study the phases and porosities formations during the evolution of the self-reducing process. The samples were dried and submitted to different thermal treatment using heating and isothermal regions. The analysis are carried out using optical microscopy (OM) and scanning electron microscopy (SEM) for image acquisition and quantitative analysis techniques by image analysis pixel quantification. The amount of sintering were estimated and confronted with traditional densification modeling for powder compacts. The results suggested that the amount of initial carbon takes primordial role on the micro pores formation and densification amount.

136

## Controlling of Fuel Particle Size to Minimize Dust Emission and Improve Productivity in Iron Ore Sintering Process

**Author(s):** Mr. WON, SEUNGYEON<sup>1</sup>

**Co-author(s):** Mr. CHOI, Younghyun<sup>1</sup>; Dr. YOON, Hojun<sup>1</sup>; Dr. KIM, Byongchul<sup>1</sup>; Dr. GO, GwangHyun<sup>1</sup>; Mr. LEE, Heungmin<sup>1</sup>

<sup>1</sup> *Hyundai Steel Company*

**Corresponding Author(s):** won\_ssteel@hyundai - steel.com

Recently, steel industry confronts a high risk of deterioration of Iron ore property as well as mitigation of green-house gas and particulate in response to the environmental regulation. For particular, iron ore sintering in the integrated steelmaking process generates a high level of particulate due to use of fine ore. It is impossible to recover energy through by-product gas like BFG and COG in blast furnace and coke oven. In addition, the use of fine coke breeze and anthracite as fuel source for the sintering of iron ore particles is an environmental inferior process. The purpose of this study, therefore, is to figure out the optimal size of the fuel, which

is only controllable parameter except that of the iron ore, in order to achieve the mitigation of environmental issue and improve productivity. First of all, the criteria on optimal particle size of the fuel guaranteeing both minimum amount of fine particles in exhaust gas and maximum productivity has been set up through a lab scale pot test. Secondly, optimized operation condition of rod mill was derived based on the criteria. Lastly, result of lab test was compared with that of plant test. As a result, the optimal fuel size is about  $2.4\pm 0.2$ mm that makes sure to improve the productivity without reducing strength. In order to achieve the purpose of study, it was confirmed that the rod mill must run at charging rate of 45t/h of the fuel with 150 rods. It was shown that the productivity improved by 2% and level of particulate in the exhaust gas reduced by 7% at the operating condition in long term plant test. Consequently, the results of this study might be thought to contribute to partially solving issues on reduction in productivity and increasing fine particulate due to increased fine iron ore.

137

## Design and Application of Blast Furnace Longevous Copper Cooling Stave

Dr. ZHANG, Fuming<sup>1</sup>

<sup>1</sup> *Vice General Engineer*

**Corresponding Author(s):** liaodong12@sina.com

Since 21 century, the application of copper cooling stave has been an important technical measure to prolong the campaign life of modern blast furnace. Combined with the application of blast furnace copper cooling stave at Shougang Qian'an steel plant, the optimum design of copper cooling stave heat transfer research and structure parameters are discussed. The heat transfer parameters, structure design and installation method of the copper cooling stave are introduced in this paper. The blast furnace engineering design and over 13 years operating practice of the copper cooling stave for No. 1 blast furnace at Shougang Qian'an steel plant are expounded.

138

## Construction on Energy Flow Network of Modern Blast Furnace Ironmaking

Prof. ZHANG, Fuming<sup>1</sup>

<sup>1</sup> *vice general engineer of Shougang Group*

**Corresponding Author(s):** liaodong12@sina.com

The modern blast furnace not only is the hot metal generator, but also the important energy conversion process unit. The future direction of technological development of modern blast furnace ironmaking is focused on the energy utilization efficiency improving, energy consumption reducing, pollutant emissions abating. This paper expounds the high efficient energy flow network construction of modern blast furnace ironmaking, researches the energy optimum utilization of ironmaking process and the systematic energy saving in whole ironmaking process, and introduces a new model of energy high efficient conversion for modern blast furnace.

139

## Study on the Distribution of Coal(Coke) and DRI(Ore) in the Melter Gasifier of COREX

Mr. XU, Wanren<sup>1</sup>

<sup>1</sup> *Baosteel Group Corporation, China*

**Corresponding Author(s):** wxu@baosteel.com

In order to simulate synchronous distribution of coal (coke) and DRI (ore) in the Melter Gasifier of COREX-3000, with down moving of perimeter zone of char bed, we have studied by laboratory

experiment effect of charging pattern and kind of material on the stock pile shape, distribution of ore/coal ratio, distribution of porosity and particle size segregation on radius direction. The differences of distribution of ore/coal ratio and porosity on radius direction for two typical burden distribution pattern and distribution model had been analyzed based on discrete element method (DEM). The experimental results under different charging pattern and kind of material show that, the stock pile shape presents a steamed bun shape that is the center of stock was higher but the edge of stock was lower; The charging angle range of ore, coal and the particle size of material have important effect on the distribution of ore (pellet, sinter) / coal (coke) ratio on radius direction; The porosity of burden was higher at center and edge area of the stock but lower at middle area of the stock; For the charging pattern that the angle range of ore is the same of coal (coke), the particle size segregation of materials on radius direction was smaller. The DEM simulations results showed that the pellets distributed more at middle area between two adjacent DRI Flap. In addition, under certain distribution pattern, the stock pile shape, distribution of pellets and distribution of ore/coal ratio on radius direction were big difference, for charging model of “in→out” and “out→in”.

140

## Crystal phases in CaO-FeO-Fe<sub>2</sub>O<sub>3</sub> system transformed from CaO-Fe<sub>2</sub>O<sub>3</sub> system under a high cooling rate in air

Prof. KASHIWAYA, Yoshiaki<sup>1</sup>

<sup>1</sup> *Kyoto University, Department of Energy Science and Technology*

**Corresponding Author(s):** kashiwaya@energy.kyoto-u.ac.jp

A CaO-Fe<sub>2</sub>O<sub>3</sub> system is a fundamental binary system for the iron ore sintering process. Although the basic reactions have been investigated since the 1960s, melting and solidification caused by the combustion of coke results in an unstable state owing to extreme temperature variations. In this study, using a hot thermocouple method, samples of 10% CaO-90%Fe<sub>2</sub>O<sub>3</sub> and 20%CaO-80%Fe<sub>2</sub>O<sub>3</sub> were melted on a thermocouple and quenched with several techniques. The obtained samples were precisely examined by XRD. It was found that the sample containing 10% CaO-90% Fe<sub>2</sub>O<sub>3</sub> changed to 10% CaO-13% FeO-77% Fe<sub>2</sub>O<sub>3</sub> under an oxygen partial pressure (PO<sub>2</sub>) of 0.21 during melting. For the 10% CaO sample, the crystal phases found at a low cooling rate (509 K/s) were WF<sub>ss</sub>, C<sub>4</sub>WF<sub>8</sub> (C: CaO, W: FeO, F: Fe<sub>2</sub>O<sub>3</sub>), and C<sub>2</sub>W<sub>4</sub>F<sub>9</sub>. When the sample composition was 20% CaO, the precipitated crystal phases were C<sub>4</sub>WF<sub>4</sub>, C<sub>4</sub>F<sub>7</sub>, and C<sub>4</sub>WF<sub>8</sub>. On the other hand, the crystal phases for high cooling rates (1590 K/s and 7900 K/s) with 10% CaO were WF<sub>ss</sub>, F, C<sub>4</sub>WF<sub>4</sub>, and C<sub>4</sub>WF<sub>8</sub> (solid solution of WF and F), F, and C<sub>2</sub>W<sub>4</sub>F<sub>9</sub>. The formation of the equilibrium phases WF<sub>ss</sub>, F, C<sub>4</sub>WF<sub>4</sub>, and C<sub>4</sub>WF<sub>8</sub> can be understood by examining the isothermal section of the phase diagrams, while the unstable phases C<sub>2</sub>W<sub>4</sub>F<sub>9</sub> and C<sub>4</sub>F<sub>7</sub> are discussed on the basis of the reactions under an equilibrium state.

141

## Comparing the Results of Acousto Ultrasonic-Echo (AU-E) with Thermal Analysis and Physical Measurements for Several Blast Furnace Hearth Refractory Linings

**Author(s):** Dr. SADRI, Afshin<sup>1</sup>

**Co-author(s):** Mr. FLATOV, Sergey <sup>2</sup> ; Mr. SOKOLOV, Alexander <sup>3</sup> ; Dr. GORDON, Yakov <sup>4</sup> ; Mr. CHATAWAY, David <sup>5</sup> ; Dr. YING, Wai Lai <sup>5</sup> ; Mr. SZYPLINSKI, Peter <sup>5</sup>

<sup>1</sup> *Hatch Global Director of Non-Destructive Testing (NDT) Group*

<sup>2</sup> *Managing Director, NLMK*

<sup>3</sup> *Severstal*

<sup>4</sup> *Technical Director, Hatch*

<sup>5</sup> *Hatch*

**Corresponding Author(s):** afshin.sadri@hatch.com

The hearth refractory lining health is the most critical factor affecting the campaign life of a blast furnace. When the hearth refractory lining is severely deteriorated, a blast furnace typically needs

to be shut down for a reline or rebuild. Because of the importance of the hearth refractory lining health, it needs to be monitored at all times. However, this has proven difficult in the past due to the obscurity and inaccessibility of a blast furnace hearth. To date, the most common method of monitoring the hearth lining has been to measure temperatures and corresponding heat fluxes. Temperatures are measured by various types and arrangements of thermocouples imbedded in the hearth refractory lining. Thermos-fluxes from the cooling staves around the hearth are also used by measuring the inlet and outlet water temperatures. Hearth refractory lining monitoring is useful, but is often inaccurate and inconclusive. To accurately measure refractory lining thickness, a technology, Acousto Ultrasonic-Echo (AU-E), was developed in late 1990s based on the stress wave propagation principals. AU-E can detect refractory and skull thicknesses, and can also be used to determine position of the cracks, joints and "brittle zones". The AU-E technique was used for the first time in 1998 to determine a blast furnace lining thickness and has since gone through an evolutionary transformation. In this paper, we present a brief background of the AU-E technique and then describe its application for monitoring the hearth refractory lining thickness in blast furnaces. Included in this are a few case studies comparing the AU-E and temperature measurements with drilling and physical dimensions.

142

## Bead - Forming Experiment of Blast Furnace Slag by Gas Quenching

**Author(s):** Dr. KANG, Yue<sup>1</sup>

**Co-author(s):** Prof. ZHANG, Yuzhu<sup>2</sup>; Dr. LIU, Chao<sup>1</sup>; Prof. XING, Hongwei<sup>2</sup>; Prof. LONG, Yue<sup>2</sup>; Prof. JIANG, Maofa<sup>1</sup>

<sup>1</sup> *Northeastern University*

<sup>2</sup> *North China University of Science and Technology*

**Corresponding Author(s):** kang-kai-yue@163.com

Blast furnace slag(BFS) is the most important by-product in iron and steel industry. Due to its high output and high slag temperature, the BFS is a very good heat source. Recovery of sensible heat from BFS is essential for saving energy, reducing emission and improving energy utilization efficiency in iron and steel industry. The process of bead-forming of BFS by gas quenching can effectively recover the waste heat energy of BFS and improve added- value of the BFS product. This paper studies the influence of slag basicity, nozzle and gas quenching pressure on granules' diameter distribution and bead-forming effect by gas quenching. The experimental results show that the slag granule diameter distribution obeys normal distribution and the peak of BFS granule diameter appears at 1mm-2.5mm; the bead-forming effect by gas quenching is the best when the basicity is controlled at 1.2, the mach number of laval nozzle is 1.6, and gas quenching pressure is 0.3MPa.

143

## Factors Influencing Reaction Beginning Temperature of Metallurgical Coke

**Author(s):** Prof. SHI, Shizhuang<sup>1</sup>

**Co-author(s):** Prof. BI, Xuegong<sup>2</sup>; Mr. MAO, Yangao<sup>3</sup>; Mr. WANG, Gonger<sup>4</sup>; Mr. ZHENG, Qi<sup>2</sup>; Mr. LIU, Wei<sup>2</sup>

<sup>1</sup> *Wuhan University of Science and Technology*

<sup>2</sup> *Wuhan University of Science and Technology*

<sup>3</sup> *BATF Industry Co., Ltd.*

<sup>4</sup> *Jinchang Smeltery of Tongling Nonferrous Metals Group Holdings Co. Ltd*

**Corresponding Author(s):** bixuegong@wust.edu.cn

The influence of various factors, including coal property (single coals and blended coals), cokemaking technological condition (soaking time, fineness and bulk density) and additives (slaked lime and iron ore powder), on the reaction beginning temperature of coke was researched systematically by manufacturing coke under the condition of various factors. The results show that, the coal

property has obvious influence on reaction beginning temperature of coke, both single coals and blended coals, the reaction beginning temperatures of coke increase along with coalification degree of the coals; the technological condition has certain influence on reaction beginning temperature of coke, but different parameters have different influences, the soaking time has obvious influence, the reaction beginning temperature increases substantially along with extension of soaking time, and the fineness of coal charge has a little influence, the reaction beginning temperature increases slightly along with increase of the fineness, and the bulk density of coal charge has little influence; the additive has very obvious influence, the reaction beginning temperature decreases dramatically along with increase of addition ratio, and iron ore powder has more influence than slaked lime, i.e., the reaction beginning temperature of iron coke decreases much more than rich calcium coke in the case of same blending ratio of additive.

145

## The co-liquefaction of low-rank coal/biomass by N-methyl-2-pyrrolidinone at high temperature

**Author(s):** ZHAO, jun<sup>1</sup>

**Co-author(s):** Prof. ZUO, haibin<sup>2</sup>; Prof. WANG, jingsong<sup>2</sup>; Prof. XUE, qingguo<sup>2</sup>

<sup>1</sup> the University of Science and Technology Beijing, china

<sup>2</sup> University of Science and Technology Beijing

**Corresponding Author(s):** zjwitchina@163.com

**Abstract:** In order to effectively use of low rank coal and biomass, the co-liquefied product was extracted from two kinds of low-rank coals and biomass by N-2-methyl-2-pyrrolidinone(NMP) at high temperature and high pressure. The structures of the co-liquefied product and residues were characterized by element analysis, FT-IR spectra. The effects of temperatures, coal rank, solid-liquid ratio and extraction time on the extraction yields of co-liquefied product were studied, respectively. Moreover, the extraction mechanism of the co-liquefied product at mild conditions is proposed. The results show that the ash contents of the co-liquefied product from two raw coals and biomass are significantly lower than that of raw coals, and the volatile contents and H/C are significantly improved. For GD coal, with the increase of temperature, the extraction yield of GD is improved evidently from 20 [U+FF05] to 51.25 [U+FF05] and the ash content is decreased from 0.68 [U+FF05] to 0.33 [U+FF05] at 360 [U+2103].

146

## Study on Medium-speed Pulverizer Capacity under Non-mainstream Medium Volatile Matter Pulverized Coal Injection of Anthracite in Blast Furnace of NingboI & S Co.

**Author(s):** Mr. LIU, Wei Qin<sup>1</sup>

**Co-author(s):** Mr. ZHANG, Dong sheng<sup>1</sup>; Mrs. CHEN, Hong<sup>1</sup>; Mr. SUN, Zhen Xing<sup>1</sup>; Mr. CHEN, Xi Guo<sup>1</sup>; Mr. ZHU, Ji Gen<sup>1</sup>; Mr. ZHAO, Liu Wei<sup>1</sup>; Mr. ZHU, Yue Qing<sup>1</sup>

<sup>1</sup> Ningbo Iron and Steel Co., Ltd China

**Corresponding Author(s):** bluebear714@163.com

The medium-speed pulverizer capacity is directly related to the types of coal. Different origin, different types of pulverized coal injection are used in the same medium-speed pulverizer, the unit-hour output of the pulverizer is different, even in the same origin, different metal point of pulverized coal injection are used in the same medium-speed pulverizer, the differences of unit-hour output of the pulverizer is also very large. In order to meet the market conditions changes in raw materials and meet the needs of blast furnace production, in order to solve the problems in production, the study on medium-speed pulverizer capacity under non-mainstream medium volatile matter pulverized coal injection of anthracite in blast furnace of NingboI & S Co. was carried out by some researchers, the technology of powder production was formed under the condition of special non-mainstream medium volatile matter pulverized coal injection of anthracite in blast furnace of NingboI & S Co.

147

## Evaluation of the thermodynamics aspects of Hydrogen Plasma Smelting Reduction (HPSR) of Iron Oxides

**Author(s):** Mr. NASERI SEFTEJANI, Masab<sup>1</sup>

**Co-author(s):** Prof. SCHENK, Johannes<sup>2</sup>

<sup>1</sup> *Fogh. Lic*

<sup>2</sup> *Chair of Ferrous Metallurgy, Montanuniversitaet Leoben, Leoben, Austria*

**Corresponding Author(s):** naseri.masab@outlook.com

Hydrogen plasma smelting reduction (HPSR) is now an established alternative to be considered for upgrading existing ironmaking process and reducing the emission of greenhouse gases. HPSR offers thermodynamics and kinetics advantages over conventional carbo-thermic reduction of iron ores. This process provides improved reducing conditions by the application of hydrogen in the plasma state and high temperature to intensify the reduction processes, henceforth not only enables the feasibility of producing iron in a one-stage process, but also avoids introducing carbon in the product, which in turn makes the metallurgical equipment smaller. In HPSR process, plasma is generated by passing an electric current through a mixture of argon and hydrogen gases which is injected to the plasma arc zone in the reactor via the hollow graphite electrode. Electrons, which are accelerated particles, are responsible to transfer energy in plasma atmosphere. Electron collision with hydrogen molecules leads to create excited species of hydrogen (H, H<sup>+</sup>, H<sub>2</sub><sup>+</sup>, H<sub>3</sub><sup>+</sup>), therefore the number of free electrons in plasma state, degree of ionization and the lifetime of excited particles should be considered due to their influence on reduction reactions. Moreover, the density of the hydrogen-activated species in plasma, which defines the ionization rate of hydrogen, is a function of temperature and the number of injected molecular hydrogen in the arc zone. This study provides an overview of the following items: 1. Atomic collisions 2. Creating plasma by collisional processes in a plasma arc reactor 3. Degree of ionization 4. The thermodynamic principles of iron oxides reduction by hydrogen 5. Comparison of the reduction ability of hydrogen species in plasma state. As a result, the reduction rate with hydrogen is two orders of magnitude faster than those with other reducing agents. In addition, hydrogen plasma smelting not only provides the most environmental friendly steel making, but also produced steel in this way is cheaper than the conventional steel making routes.

148

## Study on the influence of oxygen content in flue gas on the property of sinter

**Author(s):** Dr. LIU, Chao<sup>1</sup>

**Co-author(s):** Prof. ZHAO, Kai<sup>2</sup>; Prof. ZHANG, Yuzhu<sup>2</sup>; Prof. XING, Hongwei<sup>2</sup>; Dr. KANG, Yue<sup>1</sup>

<sup>1</sup> *Northeastern University*

<sup>2</sup> *North China University of Science and Technology*

**Corresponding Author(s):** dbdxlc@126.com

The flue gas circulation sintering process which by recycling sintering flue gas to conduct iron ore sintering and significantly reducing the flue gas processing in the terminal treatment, can not only realize the comprehensive utilization of resources, and at the same time it can realize clean production. This study which through controlling oxygen content in flue gas to make sintering pot test shows that the influence rule of oxygen content to circulation sintering metallogenic performance by testing vertical burning velocity, particle size distribution, yield, strength, low temperature break-down properties, reduction performance and refractoriness under load on different oxygen content in flue gas. The experimental results show that the reduce of oxygen content in flue gas leads to the slowdown of sintering of vertical burning speed, and the low temperature reduction performance, reduction performance and refractoriness under load all have a different degree slowdown, especially when the flue gas oxygen content reduces to 17%, the metallurgical performance significantly bad. It is worth mentioning that the yield and strength of the sinter are higher than conventional sintering with 21% oxygen content when the flue gas oxygen content reduces to 19%. The oxygen content in the circulation sintering process is not less than 17% by integrating various sinter performance indexes.

149

## Influence of operation parameters on desulfurization of hot metal in COREX Process

**Author(s):** Ms. LU, Yanan<sup>1</sup>

**Co-author(s):** Prof. WU, Shengli<sup>2</sup>; Mr. WANG, Laixin<sup>2</sup>; Mr. GU, Kai<sup>2</sup>; Ms. DU, Binbin<sup>2</sup>; Dr. KOU, Mingyin<sup>2</sup>

<sup>1</sup> *School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing*

<sup>2</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** ynluj12@163.com

COREX process has obvious advantages in environment protection but still has some disadvantages, for example, the content of sulfur in hot metal is high and fluctuant severely. In the present work, the effects of the slag ratio, temperature of hot metal, binary basicity (R2) and the ratio of MgO/Al<sub>2</sub>O<sub>3</sub> of the slag on the sulfur content in hot metal are investigated. Correlation analysis and regression analysis are used to analyze the qualitative and quantitative relationships between operation parameters and sulfur content of hot metal based on actual plant data. Experiments are conducted to verify and develop it. Considering interactions between the slag and hot metal, experimental results shows that the operation parameters that have negative relationships with S content in hot metal are temperature of hot metal, R2, MgO/Al<sub>2</sub>O<sub>3</sub>. On the contrary, slag ratio is positive correlation parameter.

150

## Coke texture as coke performance parameter for the blast furnace

**Author(s):** Mr. GOLS, Bert<sup>1</sup>

**Co-author(s):** Mr. VAN DER VELDEN, Bart<sup>1</sup>; Mr. JAK, Hans<sup>1</sup>

<sup>1</sup> *Tata Steel IJmuiden*

**Corresponding Author(s):** bert.gols@tatasteel.com

Coke quality plays an important role in the blast furnace process. The current coke quality parameters used in Tata Steel, IJmuiden are the I40, I10 and CSR. With the introduction of more different types of coals there is a need for a more detailed characterisation of the coke. Especially for the behaviour of coke in the lower parts of the blast furnace a parameter is lacking. Previous research indicated coke texture as a promising candidate. A project was setup aimed at identifying the value of coke texture as a coke quality parameter for the blast furnace. For this evaluation a set of coke types based on industrial blends were produced with a variation in coke texture, charge density and grain size of inertinite.

The coke texture measurement was evaluated first. One manual and two automated coke texture measurement techniques were used and compared. After the coke texture was established a range of tests were performed with the different coke types. These included the standard coke parameters like strength, CSR and ash chemistry, but also porosity measurements, reactivity test under blast furnace conditions and dissolution tests. In the dissolution tests heat treated samples of all coke types were included. Of these heat treated samples the degree of graphitisation was measured.

Conclusions on the suitability of coke texture as a coke performance indicator for the blast furnace can be drawn based on the results of the various tests. Some interesting conclusions can be drawn from the coke dissolution experiments with heat treated coke samples. And some interesting relations were found between the sulphur level and the final carbon content of the hot metal in the experiments.

151

## Characterising the interface between IMDC and RMDC using micro-CT imaging

**Author(s):** Dr. MAHONEY, Merrick<sup>1</sup>

**Co-author(s):** Ms. CONNELL, Mia<sup>1</sup> ; Dr. JENKINS, David<sup>1</sup> ; Dr. LOMAS, Hannah<sup>2</sup> ; Dr. STEEL, Karen<sup>3</sup> ; Ms. RAYLYN, Tirsha<sup>4</sup>

<sup>1</sup> *University of Newcastle*

<sup>2</sup> *University of Newcastle, Australia*

<sup>3</sup> *University of Queensland*

<sup>4</sup> *CSIRO Mineral Resources*

**Corresponding Author(s):** merrick.mahoney@newcastle.edu.au

In recent years we have conducted integrated mechanistic studies to understand the structures controlling coke strength and how these structures form in the plastic layer. These have involved micro CT studies of coke structures and calculation of the response of these structures to stress as well as fractographic studies of fracture surfaces in coke. A number of studies have identified that the boundary between inert maceral derived components (IMDC) and reactive (fusible) derived maceral components (RMDC) in coke can be a source of weakness in the coke. In particular fractographic studies have identified a number of boundary types, depending on how well the IMDC-RMDC are bonded. This study looks at characterising the IMDC-RMDC boundary in 3 dimensions using micro computed tomography (micro-CT). Hand picked coal inerts (1-2mm) were placed in a bed of hand picked vitrinite (<1mm particle size, 5mm diameter bed) in a graphite crucible, sealed and then heated to 1000oC. Micro CT images were collected at the IMBL (imaging and medical beamline) Australian Synchrotron. The non-fused carbon (IMDC) was identified in the image using standard image analysis and an envelope ~200 microns wide drawn around the IMDC. The pore properties of this region were compared with the bulk region of the sample. By sourcing the vitrinite and inertinite from different coals the interactions between macerals of different rank and geological measures could be studied.

152

## Study on BF Hearth Water Accumulation and Influence on Service Life

**Author(s):** Mr. ZOU, zhongping<sup>1</sup>

**Co-author(s):** Mr. ZHANG, zhenghao<sup>2</sup> ; Mr. JIANG, hua<sup>3</sup> ; Mr. YIN, min<sup>4</sup>

<sup>1</sup> *CISDI Engineering CO.,LTD.*

<sup>2</sup> *meishan plang, baosteel CO.,LTD.*

<sup>3</sup> *Baosteel CO.,LTD.*

<sup>4</sup> *CISDI engineering CO.,LTD.*

**Corresponding Author(s):** zhongping.zou@cisdi.com.cn

This paper sets out analyzing the evolvment of water accumulated in the blast furnace hearth and the influence of water on hearth carbon blocks and skull. With deliberation on the impact of accumulated water on hearth service life, it proposes the measures to prevent water from entering hearth and to discharge water in a regular and effective way. It intends to arouse the attention of blast furnace ironmaking practitioners to the hearth water and hope to useful for improving the blast furnace long-campaign technology.

Keywords: blast furnace; hearth; long service life; water accumulation; skull

153

## Development and Application of New Long Campaign Technology of Blast Furnace

**Author(s):** Mr. WANG, chunlong<sup>1</sup>

**Co-author(s):** Mr. QI, SIQING<sup>1</sup> ; Mr. QUAN, QIANG<sup>1</sup> ; Mrs. ZHAO, YANXIA<sup>1</sup>

<sup>1</sup> *Capital Engineering [U+FF06]Research Incorporation Limited*

**Corresponding Author(s):** wclustb@163.com

Hearth and high heat load region are key factors affecting the campaign life of blast furnace, mainly for the erosion of carbon bricks lined on furnace bottom and hearth and damaged of cooling equipment of high heat load region. In this paper, the long life of high heat load region was studied. And the new furnace longevity technology in the area was developed, which was combined cooling structure of cast iron cooling stove inlaid with copper cooling strips. It puts forward the design concept of bosh region of thin-wall furnace, and introduces the application of the new technology in two domestic 1080m<sup>3</sup> blast furnaces. The practice showed that the technology had the characteristics of large cooling strength and stability of slag skin benefited from special structural design, which can effectively solve the problem of cooling equipment damage in the area of high heat load of the furnace. In addition, it has low investment and wide adaptability. As a new technology of long campaign life of blast furnace, it can effectively prolong the life of blast furnace, and has broad application prospects.

154

## Application of Oxygen-Coal Injection in Shougang Jingtang 5500m<sup>3</sup> Blast Furnace [U+F020]

Mrs. DONG, Xiangjuan<sup>1</sup>

<sup>1</sup> *Shougang Jingtang United & Steel Co., Ltd.*

**Corresponding Author(s):** dongxiangjuan715@163.com

In recent years, Shougang Jingtang has been taking the application of oxygen-coal injection as the breakthrough point in improving ironmaking technology. With tremendous investigations and self-development, Shougang Jingtang successfully applied the oxygen-coal injection in the field of blast furnace in China. The equipment has been put into use in August 6, 2013, in Shougang Jingtang No.1 BF and in good working condition. With the application of this new technology, the coal injection increased, the coke rate reduced, and the carbon content in bag ash lowered. Mover, it was very helpful for prolonging the service life of hot stoves and smoothing operation of the blast furnace.

155

## Investigation of co-combustion of different kinds of Hydrochar and their blends with anthracite in view of injection into blast furnace

**Author(s):** Mr. WANG, Guangwei<sup>1</sup>

**Co-author(s):** Mr. WANG, Chuan<sup>2</sup>; Mr. ZHANG, Jianliang<sup>1</sup>; Mr. WANG, Kaidi<sup>1</sup>; Mr. ZHANG, Nan<sup>3</sup>

<sup>1</sup> *School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing*

<sup>2</sup> *Swerea MEFOS, SE-971 25 Luleå, Sweden*

<sup>3</sup> *School of Metallurgical and Ecological Engineering, University of Science and Technology*

**Corresponding Author(s):** wangkaidi\_u.stb@163.com

Pulverized coal injection (PCI) is one of the major technologies to reduce the coke consumption and the cost of blast furnace ironmaking process. Co-injection of bituminous coal and anthracite has been widely promoted to improve the burning rate in front of the tuyere for blast furnace and to maintain a certain ratio of coal-to-coke replacement. Hydrochar is a kind of clean biomass energy with compositions and properties close to bituminous coal, which will contribute to the CO<sub>2</sub> emission reduction as bituminous coal substitutes. In this study [U+FF0C] the combustion properties of three kinds of Hydrochar, bituminous coal and their blends are investigated systematically by thermogravimetric analysis method. Meanwhile, a laboratory equipment is built to investigate the burnout behavior of Hydrochar and bituminous coal injection in detail. It is founded that the addition of Hydrochar can increase the reaction rate of bituminous coal at lower temperature and can also improve the combustibility of blends. The results of the injection equipment tests show that injection of Hydrochar can enhance the burnout rate of blends, which could reduce the unburnt particles generated in the raceway.

156

## Reactive wetting of calcium ferrite on TiO<sub>2</sub> substrate at 1523K

**Author(s):** Mr. YANG, Mingrui<sup>1</sup>

**Co-author(s):** Mr. LV, Zepeng<sup>2</sup>; Prof. LV, Xuewei<sup>2</sup>; Prof. BAI, Chenguang<sup>2</sup>

<sup>1</sup> *Chongqing University*

<sup>2</sup> *Chongqing University*

**Corresponding Author(s):** ymr@cqu.edu.cn

The wetting behavior of calcium ferrite (CF) slag on TiO<sub>2</sub> substrate at 1523K was investigated using an improved sessile drop method. The initial apparent contact angle was 30°-50°, and the final apparent contact angle was less than 20°. The CF-TiO<sub>2</sub> system is reactive wetting system, and the wetting process was divided into four stages. Stage I: physical spreading; stage II: reaction at the interface controlled spreading; stage III: reaction at the triple phase line controlled spreading (spreading on CaTiO<sub>3</sub>); stage IV: Equilibrium. The interfacial microstructure of residual slag after wetting was roughly divided into three layers. The top layer of residual slag was composed of CaTiO<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>, the middle layer was composed of CaTiO<sub>3</sub> and Fe<sub>2</sub>TiO<sub>5</sub>, and the bottom layer was composed of Fe<sub>2</sub>TiO<sub>5</sub>. The mechanism of interfacial chemical reaction was discussed using the coexistence theory of slag structure, and the results indicating that the formation of CaTiO<sub>3</sub> was mainly in the initial reaction process, then was the formation of Fe<sub>2</sub>TiO<sub>5</sub> in the final reaction process.

157

## Optimisation of the cokes furnace chamber pressure control system to minimize emissions and damage

Dr. SCHUURMANS, Jan<sup>1</sup>

<sup>1</sup> *Dotx Control Solutions*

**Corresponding Author(s):** j.schuurmans@dotxcontrol.com

Optimised control of the pressure in the cokes furnace chambers is essential. This pressure is controlled at only a couple of millibar above ambient air pressure to avoid intake of outside air and emissions. The more this pressure deviates from setpoint, the more emissions occur, and the more outside air enters the furnace, leading to damage of the chamber wall. The chamber control system usually consists of PID controllers that show considerable interactions with each other, and with downstream pressure controllers that adjust the gas ventilators. There have been several publications on the cokes chamber pressure control, but they rarely show measured results of a real-life cokes furnace. This paper presents a systematic method to tune all relevant PID controllers in an optimal way. In addition, it shows how the PID controllers can be extended with sample add-on control loops to improve the pressure control performance considerably. The proposed tuning procedure, and the control add-ons, applied to a cokes furnace, are presented in this paper. The gas pressure peak deviations from setpoint were reduced by more than 50%, while the standard deviation ( $\sigma$ ) of the pressure deviations from setpoint reduced by more than 30%.

158

## HEARTH RECOVERY – AN EXPERIENCE WITH USIMINAS BLAST FURNACE#1

**Author(s):** Mrs. GANDRA, BEATRIZ FAUSTA<sup>1</sup>

**Co-author(s):** Mr. COSTA MANSO, GUSTAVO ALEXANDRE<sup>1</sup>; Mr. VERISSIMO, MARCIO JOSÉ<sup>1</sup>; Mr. PONCE DE LION, EPITACIO PESSOA<sup>2</sup>; Mr. CARVALHO, JOSÉ DE SOUSA<sup>2</sup>

<sup>1</sup> *USIMINAS*

<sup>2</sup> *CONSULTOR*

**Corresponding Author(s):** beatriz.gandra@usiminas.com

In 2008, after the Blast Furnace#1 shut down, was identified an abnormal phenomenon in its hearth which required great team effort for proper recovery of the refractory and resumption of operation. At the time, it was aimed to extend the campaign in five years. In this paper, it is described the general aspects of the equipment, the situation in his hearth, actions taken and the current hearth's condition, after further shut down due to the worsening economic crisis in Brazil. As main conclusions: (i) the abnormal condition found in the Blast Furnace#1's hearth was not associated with the refractories' quality, that had preserved their properties; (ii) the repair done, in order to extend the blast furnace campaign in five years, was extremely efficient; and (iii) the Blast Furnace#1's operation between 2010 and 2015 was properly done contributing to the preservation of the hearth, which did not show brick's wear in that period.

159

## DEM-CFD Modelling of the transient, multiphase flow in the hearth of a blast furnace

**Author(s):** Mr. BAMBAUER, Frederik<sup>1</sup>

**Co-author(s):** Dr. WIRTZ, Siegmar<sup>2</sup>; Prof. SCHERER, Viktor<sup>2</sup>; Dr. BARTUSCH, Hauke<sup>3</sup>; Dr. LIN, Rongshan<sup>4</sup>

<sup>1</sup> Ruhr-Universität Bochum

<sup>2</sup> Ruhr-University Bochum

<sup>3</sup> VDEh-Betriebsforschungsinstitut

<sup>4</sup> Dillinger

**Corresponding Author(s):** bambauer@leat.rub.de

Steelmaking following the blast furnace process route has a share of approximately 75 % of the worldwide steel production and thus is the primary source of steel. Due to the large size of blast furnaces and the extreme process conditions therein, the accessibility for measurements inside the furnace is very limited. Nevertheless, since the campaign life is closely related to the multiphase processes in the lower part of the blast furnace, the hearth, it is important to understand the observed phenomena. Mainly the transient movement of the packed coke bed ("floating" or "sitting" dead man), the shape of the resulting coke free region and their dependence on different operating conditions are of particular interest.

In the past, various (experimental, analytical and numerical) models have been developed to understand and describe the interacting multiphase flow and the thermo-chemical processes inside the blast furnace. These models can be generally subdivided in continuum approaches at the macroscopic and discrete models at the microscopic scale. With increasing computational capabilities the discrete approaches, especially the Discrete Element Method (DEM), have been applied in many fields of research; for instance in geomechanics, physics, pharmacy and (chemical-)engineering. The great advantage of these approaches is the temporal and spatial resolution of the mechanical interaction among individual particles of different size and shape and with their surrounding in granular systems. Furthermore, it is possible to extend these approaches with CFD models to describe the interaction between solid, gaseous and liquid phases in technical, multi-phase systems.

The publication presents a numerical DEM-CFD study of an isothermal blast furnace model of a plant located at the "AG der Dillinger Hüttenwerke" in Dillingen, Germany. The model is calibrated with specifically chosen boundary conditions derived from online measurements and process model calculations. With this calibrated model the impact of different liquid levels on the processes in the hearth is investigated. The results presented focus on particle movement, porosity distribution and the formation of coke free zones in the lower part of the furnace.

160

## Effect of Conductivity and Magnetization of Water on Green Mix Granulation Process

**Author(s):** Mr. AVB, Acharyulu<sup>1</sup>

**Co-author(s):** Mr. SINHA, Abhishek <sup>2</sup> ; Dr. KAZA, Marutiram <sup>3</sup> ; Mr. SINGH, Lokendra Raj <sup>4</sup>

<sup>1</sup> *DGM (Process Optimization)*

<sup>2</sup> *Assistant Manager, R&D and SS*

<sup>3</sup> *General Manager (R&D and SS)*

<sup>4</sup> *Senior Vice President (Iron Zone)*

**Corresponding Author(s):** angalakuditi.brahmacharyulu@jsw.in

Acute crisis of water in the region compelled the usage of recycled water with high conductivity that helped in increasing granulation. However, usage of recycled water beyond 50% has resulted in undesired accretion in the Mixing and Nodulizing Drum. Magnetized water reduced contact angle and improved the granulation of green mix. The effect of magnetization of water was studied by varying magnetic intensity. Contact angle up to 32o was observed against a desired angle of 40-55o for optimum nodulization of the green mix. Conductivity up to 2650 Micro Siemens/sec was found against the normal value of 400. The optimization of contact angle and conductivity of recycled water to control coagulation was mentioned. Anti-coagulant was found to ease the problem, with which the contact angle could be increased to the desired level. The growth of the granules increased with the use of anti-coagulant. Granulation Index in the range of 1.7 could be sustained.

Data of various combinations namely with recycled, without recycled water; with magnetization, without magnetization and with anti-coagulant and without anti-coagulant are presented in this paper. SEM images revealed strengthening of water bond with increasing conductivity. Ultra fines coagulated better with increasing magnetization. Growth was predominantly high with use of anti-coagulant.

161

## Comparison of different blast furnace operation modes

**Author(s):** LÜNGEN, Hans-Bodo<sup>1</sup>

**Co-author(s):** Prof. SCHMÖLE, Peter <sup>2</sup>

<sup>1</sup> *Director Technology VDEh*

<sup>2</sup> *thyssenkrupp steel Europe*

**Corresponding Author(s):** hans-bodo.luengen@vdeh.de

The blast furnace is worldwide the dominant metallic product supplier for crude steel production. It has reached an extreme high technological standard with large efficiency and low reductant rates. Independently from the fact that the blast furnace has nearly reached its theoretical minimum in energy consumption it enables the operators a wide range of operation modes with a high flexibility.

This varies depending on regional and other circumstances in manifold possibilities regarding ferrous burden structure, reductant rates like use and amount of auxiliary reductants and coke rates, productivity levels and oxygen injection rates and the durability in blast furnace campaigns. One aspect are the requirements on the quality of ferrous burden materials and blast furnace coke.

Amongst these items the report also discusses single blast furnace highlights and points out the possible future survival of this process under the given political discussions on CO2 mitigation.

164

## Simulation of burden charging in a blast-furnace equipped with a Bell-less top system using Discrete Element Method

**Author(s):** Dr. CARVALHO, Rodrigo<sup>1</sup>

**Co-author(s):** Mr. SILVA, Bruno <sup>2</sup>

<sup>1</sup> *Universidade Federal do Rio de Janeiro*

<sup>2</sup> *Ternium Brazil*

**Corresponding Author(s):** rodrigo@metalmat.ufrj.br

To achieve a stable and efficient blast furnace operation it is important to have a controlled gas flow inside the furnace with a proper burden distribution, thus a strict control of the particulate material size distribution inside the charge is required to avoid generation of preferential paths of the gas molecules through the burden. This work uses Discrete Element Method (DEM) to simulate raw material loading into a blast furnace equipped with a Bell Less Top (BLT) system. The simulations were based on a real operation of a steelmaking plant in Rio de Janeiro. The simulations allowed the evaluation of the contribution of the physical properties of the raw materials fed into the furnace such as size distribution, shape, density and mechanical resistance, as well as the effect of the rotating chute of the BLT system on the loading of coke and the metallic burden constituted of sinter, iron ore and pellet particles. The effect of wear on the rotating chute were also investigated. Also, a post-processing tool was developed that allowed a qualitative and quantitative analysis of the DEM simulation results in terms of particle size and component segregation at the top of the blast furnace. Thus, this work establishes the foundations of a methodology that allows search for an optimum rotating chute algorithm as function the burden properties.

165

## Technical improvement and operation overview of Chinese HIs melt plant

Prof. ZHANG, Jianliang<sup>1</sup> ; Prof. LI, Kejiang<sup>1</sup> ; Prof. LIU, Zhengjian<sup>1</sup> ; Prof. YANG, Tianjun<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** likejiang@ustb.edu.cn

The only HIs melt process in the world was moved from Kwinana, Australia to Shandong, China in 2013 and all the related copyright has also been transferred from Rio Tinto to a Chinese company in 2017. The Shandong HIs melt plant was put into operation in June, 2016 and it has achieved 70-day continuous operation with the highest daily production being 1876 t/d. This is the first time to achieve continuous industrial and commercial operation of HIs melt process without the utilization of coke and iron ore aggregates. During the construction and operation process in the past 5 years, a lot of technical improvements such as process innovation with rotary kiln furnace, optimization of smelting reduction vessel (SRV) system, adoption of new refractory materials, operation improvement with intermittent tapping, etc., have been made. Meanwhile, the operation indexes were improved compressively compared with the indexes of Kwinana HIs melt plant. An overview of those operation indexes were also introduced in this paper. The successful operation of Chinese HIs melt plant with low cost will promote the advancement of the ironmaking by replace part of blast furnace iron production capacity with sustainable and green HIs melt process.

166

## Recent understandings about the coke behavior in the tuyere zones and hearth of industrial blast furnace

**Author(s):** Prof. LI, Kejiang<sup>1</sup>

**Co-author(s):** Ms. SUN, Minmin<sup>1</sup> ; Prof. ZHANG, Jianliang<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** likejiang@ustb.edu.cn

An in-depth understanding about the coke reactions in the high temperature zone of a blast furnace is significant to optimize both the current and future blast furnace process. Due to the complexity and severity of environment of the BF lower zone, it is impossible to observe phenomena occur inside directly. However, using a tuyere drilling technique, tuyere coke and accompanied samples can be extracted, while hearth coke can be obtained during the overhaul period of blast furnace. By analyzing tuyere samples and hearth coke samples, useful information about various important coke reactions and transformations in the high temperature zone (tuyere level and hearth) were obtained. This paper presents an overview about the recent understandings about the coke behavior in those high temperature zones of industrial blast furnace. The evolution

of coke carbon structural order, coke mineral matters as well as the coke properties and reactions with other materials were analyzed as per the locations and environment in the tuyere zone and hearth. Simulated lab experimental results about coke behaviors in those high temperature zones were also reviewed and compared with industrial results. This review indicates that it is necessary to develop new indexes to evaluate coke heavier in the high temperature zone of blast furnace and provide guidance meaning for coke making.

167

## Research development on utilizing biomass in the blast furnace for CO<sub>2</sub> emission reduction: Experiences from Nordic countries and Canada

**Author(s):** Prof. WANG, Chuan<sup>1</sup>

**Co-author(s):** Dr. SUOPAJÄRVI, Hannu<sup>2</sup>; Dr. NG, Ka Wing<sup>3</sup>; Dr. WETTERLUND, Elisabeth<sup>4</sup>; Ms. NWACHUKWU, Chinedu<sup>4</sup>

<sup>1</sup> Swerea MEFOS

<sup>2</sup> Process Metallurgy, University of Oulu

<sup>3</sup> Natural Resources Canada

<sup>4</sup> Luleå University of Technology

**Corresponding Author(s):** chuan.wang@swerea.se

Within the integrated steel plant, the blast furnace BF is the most energy intensive process with significant amount of CO<sub>2</sub> emission. Switching of fossil fuels to biomass offers an alternative for the natural resources reservation and climate change mitigation. In recent years, lots of efforts have been putting on developing biomass for BF's utilization, especially in regions with abundant forest resources. This paper aims to give a review of research development in Sweden and Finland from North Europe and Canada from North America. Biomass availability, market competition, economic feasibility, and barriers and challenges for the industrial applications are addressed.

168

## A New Binder and MgO Flux for Pellet Production

Mr. ZHOU, Mingshun<sup>1</sup>

<sup>1</sup> Ansteel Group

**Corresponding Author(s):** zhangqianiso@163.com

**Abstract:** In order to ensure an appropriate MgO content in the blast furnace slag, MgO-fluxed pellets are being used in AnSteel to replace the conventional MgO fluxed sinter. In this paper, a new type of pelletizing binder (hereafter referred to as "new binder") was tested together with a new MgO flux to examine their effect on the pelletizing process and the metallurgical properties of pellets. The experimental results showed that the drop strength of green pellets increased with the increased addition of the additives, and no spalling was observed at 350 [U+2103] or below. With the adoption of the new binder, the Fe grade of the pellets increased slightly due to its lower SiO<sub>2</sub> content. The RDI and RSI of the MgO-fluxed pellets were improved as well, which are expected to lower the cohesive zone of BF and improve its permeability. **Key words:** MgO fluxed pellets; metallurgical properties; binder; blast furnace

169

## Development of Simulation and Mathematical Model for the Bell-less Top Burden Distribution in BF in Ansteel

Mr. CHE, Yuman<sup>1</sup>

<sup>1</sup> Ansteel Group

**Corresponding Author(s):** zhangqianiso@163.com

Abstract: The paper presents a brief introduction about the significant work conducted with a scale of physical bell-less burden model for falling curves and burden distribution at any given chute angles. An incidence formula between flow control gate (FCG) and burden flow was established by the actual measurement of charging. The measurement of falling curves using laser trajectory probe at given stockline and any given chute angles was calibrated with the actual measurement data. Based on the above, a burden distribution mathematical model was created in AnSteel. This mathematical model could calculate burden distribution profile and help BF improve operation on thickness of layers, profile and ore/coke distribution on diameter direction. Key words: Bell-less top, Mathematical model, Burden distribution profile

170

## Low MgO Content Slag of Blast Furnace in Anshan Iron and Steel Group Corporation

Mr. LIU, Jie<sup>1</sup>

<sup>1</sup> *Ansteel Group*

**Corresponding Author(s):** zhangqianiso@163.com

Abstract: The metallurgical properties of low MgO content slag were studied and evaluated systematically by laboratory and industrial test in Anshan iron and steel group corporation. The results show that: Under the low Al<sub>2</sub>O<sub>3</sub> load in blast furnace, the MgO content of slag is 4%-7% [U+FFOC] the melting temperature of slag all less than 1350 [U+2103]. When the temperature of slag is 1500 [U+2103], the slag's viscosity can satisfy the need of blast furnace in theory with MgO content over 3%. And the best basicity of slag is about 1.245. Under the condition of industry, the MgO content of slag was controlled in 4.5%-5.0%. The viscosity of slag is about 0.16Pa.s-0.20Pa.s. The capacity of slag's desulfurization may does not fall down when slag's MgO content decreasing by optimizing basicity of slag. The production cost of BF decreasing obviously and the slag ratio almost reduces 17kg/t by adopting new technology. So, it helps to implement green sustainable development.

172

## Practice on Improving ANSTEEL'S No.3 BF Hearth Activity

Mr. ZHANG, Lei<sup>1</sup>

<sup>1</sup> *Ansteel Group*

**Corresponding Author(s):** zhangqianiso@163.com

Abstract: This paper summarizes the practical experience of improving ANSTEEL's No.3BF hearth activity. The author listed the measures that were taken to control the temperature rise of hearth sidewall, and pointed out that the deterioration of the coke quality and continuous lower furnace temperature are the main factors to hearth activity. The hearth activity got ensured and the BF run in stable by taking the following measures: a) strengthening the quality control of the coke; b) optimizing the operational furnace profiles; C) keeping appropriate furnace temperature; d) improving blast kinetic energy; e) strengthening the Organization of HM tapping operation. As a result, the techno-economic indexes were improved greatly.

173

## The Effect of CaF<sub>2</sub> on the Viscosity of Blast Furnace Slag with Low w(MgO)/w(Al<sub>2</sub>O<sub>3</sub>) Ratio

Mr. JIANG, Zhe<sup>1</sup>

<sup>1</sup> *Ansteel Group*

**Corresponding Author(s):** zhangqianiso@163.com

Abstract: The viscosity of CaO–SiO<sub>2</sub>–4.5MgO–CaF<sub>2</sub>–16Al<sub>2</sub>O<sub>3</sub>(wt%) slags(CaO/SiO<sub>2</sub>=1.15, wt%CaF<sub>2</sub>=0~1) were investigated to promote understanding of the effect of CaF<sub>2</sub> on the viscous behaviour of slag containing CaF<sub>2</sub>. In practice, these experimental results are significant for the blast furnace (BF) processing of high Al<sub>2</sub>O<sub>3</sub> ore and for decreasing the content of MgO in high Al<sub>2</sub>O<sub>3</sub> BF slags. The slag viscosity was found to decrease with increasing CaF<sub>2</sub> content at a fixed basicity. The degree of polymerization for [SiO<sub>4</sub>]-tetrahedra was found to decrease with increasing CaF<sub>2</sub> ratio based on the Fourier Transformation-Infrared Spectra (FT-IR) and Raman spectra, which could explain the observed decrease in viscosity.

174

## The Application of Oxygen Enrich Combustion on Hot Stove

Mr. ZHANG, Tianfu<sup>1</sup>

<sup>1</sup> Ansteel Group

**Corresponding Author(s):** zhangqianiso@163.com

Abstract: The unbalance and fluctuation existing in iron and steel making production in steel plants often lead to oxygen excess of its demand and an emission to open air directly. Normally, the emission rate of oxygen is about 3% in a BF/BOF iron and steel production line. In Ansteel, the excess oxygen created in one steel plant is used for oxygen enrich combustion in hot stoves. The results show that energy efficiency was improved, high blast temperature was reached, and the quantity of the emitted oxygen was cut dramatically. Keywords: oxygen enrich combustion, hot stove, the emission rate of oxygen.

175

## Research and Practice of CDQ Long campaign Life Technology in Ansteel

Mr. WANG, Mingguo<sup>1</sup>

<sup>1</sup> Ansteel Group

**Corresponding Author(s):** zhangqianiso@163.com

Abstract: Nowadays, the CDQ technology is widely used in energy-saving and emission reduction for coke-making process to improve coke quality, save energy, and reach environmental protection. To meet the needs of BF operation and environmental protection, improving the longevity of CDQ system has come to a challenge in the steel industry. As the largest coking plant in Asia, Ansteel General Coking Plant started to tackle the tough issue in recent years through well-designed large-scale CDQ devices, high quality refractory material, optimized drying method, daily maintenance and operation and other comprehensive upgraded application. As a result, the maintenance cycle of CDQ system extended from designed one year to two years, and the life expectancy reached to 12 years. At the same time, the average monthly dry quenching rate rised to a higher level of more than 99%. The record of 36 months of continuous running, which is the initial target of CDQ and an advanced level in the world, has been achieved.

176

## The Experimental Research on Thermal Insulation Agent Made from CDQ Dust on Molten Steel

Mr. WANG, Xiangfeng<sup>1</sup>

<sup>1</sup> Ansteel Group

**Corresponding Author(s):** zhangqianiso@163.com

Abstract: In this paper, on the basis of system of CDQ dust block test, thermal insulation performance test of CDQ dust in laboratory and industrial application is studied, the performance

of CDQ dust as thermal insulation agent of molten iron and impact of [S] in iron is comprehensive analyzed, and on the performance of CDQ dust, carbonized rice husk and composite preservation agent etc is comparative tested. The results show that the thermal insulation performance of the CDQ dust as molten iron thermal insulation agent is equivalent to carbonized rice husk, and which is higher than the composite insulation agent, and has no obvious effect on the [S] of molten steel. Compared to carbonized rice husk and composite insulation agent, CDQ dust is directly from the metallurgical enterprises, has stable composition and stable quality, and the quality won't decline by the reason of interference on such as the product cost, raw material source, and other factors. So the CDQ dust has obvious advantages on stable product quality, and have broad application prospect.

177

## Technology and Application on Low Carbon Sintering of Iron Ore

Mr. JIANG, Dajun<sup>1</sup><sup>1</sup> *Anteel Group***Corresponding Author(s):** zhangqianiso@163.com

**Abstract:** Iron ore sintering is a high energy consumption process which accounts for 10-15% of the total energy consumption in iron and steel industry, following the process of iron making. The solid fuel consumption accounts for about 75-80% of sintering process energy consumption. In order to realize low carbon sintering and reduce CO<sub>2</sub> emissions, and based on the analysis of sinter heat balance and the mechanism of solid fuel combustion, some technical measures were taken in sintering experiment and pilot test. The results showed that sinter performance indexes did not get worse but improved a little in case of reducing carbon ratio from 2.61% to 2.16%, the comprehensive effect was improved from 2.91% to 2.40% as well. The practical application showed that sinter solid fuel consumption dropped from 52.03 kgce/t to 36.66kgce/t, sintering machine utilization coefficient changed little, drum index kept stable after a reduction of carbon ratio from 2.85% to 2.24%. The low carbon sintering has made a significant effect on energy saving, emission reduction and benefit. **Keywords** low carbon sintering, energy saving, emission reduction, experimental results, application practice.

178

## Research on the rational utilization of iron solid waste in Baiyunebo special ore smelting process

Dr. WU, Hulin<sup>1</sup> ; Dr. LI, Yuzhu<sup>2</sup><sup>1</sup> *Technical Center of Steel Union Co. Ltd. of BaoTou Steel (Group) Corp*<sup>2</sup> *Technical Center of Steel Union Co. Ltd. of BaoTou Steel (Group) Corp.***Corresponding Author(s):** likejiang@ustb.edu.cn

Baiyunebo special ore has the characteristics of high content of harmful elements such as alkali metals, F and S and P. The iron solid waste also has unique properties in the use of special baiyunebo ore smelting process. Therefore, it is necessary to take special treatment process to realize the recycling of iron solid waste. After the process of water immersion and potassium sodium extraction, the main electric dust ash of sintering machine formed the iron concentrate and potash fertilizer. The sintering process of sintering tail ash is returned to sintering process by preparation of cold consolidation pellets in order to improve the permeability of sintering mixture. Blast furnace gravity dust and cyclone dust can be added directly in the sintering process due to the relatively few harmful element content. After the blast furnace cloth bag ash is removed from zinc, the high zinc product is used as one of the raw materials for electrolyzing zinc and the iron slag is used in sintering process. Some of the converter dust ash can be used in pellets process by replacing some bentonite binder, the rest of them are mixed with sintered tail ash to sintering process by preparation of cold consolidation pellets. The steel slag can be returned to the steel flow in different degree after stuffy slag process. Adoption of the above technical measures, the iron solid waste in Baotou steel has been effectively recycled, which has achieved the purpose of energy conservation and emission reduction, which has realized the green effect of steel production, the economic benefit and social benefit is remarkable.

180

## Pulverized Coal Injection Simulation

**Author(s):** Mr. NG, Ka Wing<sup>1</sup>

**Co-author(s):** Dr. HUANG, Xianai <sup>2</sup> ; Dr. GIROUX, Louis <sup>1</sup>

<sup>1</sup> *Natural Resources Canada*

<sup>2</sup> *Natural Resource Canada*

**Corresponding Author(s):** kawing.ng@canada.ca

Pulverized coal injection is a commonly used practice in modern blast furnace operation. To further increase the PCI rate, a detailed understanding of gasification kinetics behavior of injected coal in tuyere and characteristics of combustion residues is critical. Using the PCI injection simulation rig at CanmetENERGY, the combustion behavior of selected typical PCI coals was examined. The combustion residues collected were analyzed to quantify the contribution of different types of carbon, namely char, coke and soot, using a TGA technique developed recently at CanmetENERGY. Using the information collected, the transformation of coal into different type of carbon materials during heating and combustion is determined. The collected information enables a direct comparison between coals and allows to optimize combustion conditions to further increase PCI rate.

181

## Techno-Economic Analysis of Biocarbon Direct Injection in Blast Furnace Ironmaking

**Author(s):** Mr. NG, Ka Wing<sup>1</sup>

**Co-author(s):** Dr. HUANG, Xianai <sup>2</sup> ; Dr. GIROUX, Louis <sup>1</sup>

<sup>1</sup> *Natural Resources Canada*

<sup>2</sup> *Natural Resource Canada*

**Corresponding Author(s):** kawing.ng@canada.ca

Substitution of pulverized coal injection by solid biocarbon fuel has the potential to achieve substantial reduction in GHG emissions from blast furnace ironmaking. A techno-economic model was developed to evaluate the value-in-use of solid biocarbon to facilitate the selection of solid biocarbon for replacement of pulverized coal injection. The value-in-use of solid biocarbon is strongly influenced by its O/C mass ratio as it dictates the cost of raw materials required to support the blast furnace ironmaking process and potential GHG emissions achievable. The major barrier to industrial-scale implementation is the insufficient solid biocarbon production capacity needed to meet the high demand of the industrial steel sector. In order to overcome this challenge, the entire supply chain of suitable biocarbon needs to be developed and expanded.

182

## Experimental Blast Furnace Operation -Outline of Experimental Blast Furnace-

**Author(s):** Mr. KAKIUCHI, Kazumoto<sup>1</sup>

**Co-author(s):** Dr. UJISAWA, Yutaka <sup>2</sup> ; Dr. KOHEI, Sunahara <sup>2</sup> ; Mr. TOMISAKI, Shin <sup>3</sup> ; Mr. DEMI, Hiroyuki <sup>3</sup> ; Mr. SASAKI, Michiaki <sup>3</sup>

<sup>1</sup> *Nippon Steel & Sumitomo Metal Corporation*

<sup>2</sup> *Nippon Steel & Sumitomo Metal corporation*

<sup>3</sup> *Nippon Steel & Sumikin Engineering corporation*

**Corresponding Author(s):** kakiuchi.858.kazumoto@jp.nssmc.com

In COURSE50 STEP2, integrated verification tests of the mitigation of CO<sub>2</sub> emissions and CO<sub>2</sub> separation from blast furnaces are being conducted using a newly built 12m<sup>3</sup> experimental blast furnace and a 30-t-CO<sub>2</sub>/day chemical absorption process evaluation plant simultaneously. The experimental blast furnace was constructed in Kimitsu Works and the construction was completed

in September 2015. The experimental blast furnace is equipped with 3 tuyeres and 1 taphole. An injection lance is equipped on each tuyere with the ability to inject pulverized coal, oxygen and reducing gases (COG or other gases). For the hot blast production, 2 top combustion hot furnaces were installed. The maximum blast temperature is 1,100 degrees C. The material handling facility has the capacity to charge 1 kind of coke, 2 kinds of ores and 2 kinds of flux. A distributing chute is used to distribute the material into the blast furnace. A hydraulic taphole opener, mud gun and cover traverser are installed in the cast house. The hot metal and slag, produced in the operation, are received in a pot and cooled into solids before removing the metal and slag from the pot. We have performed 4 experimental campaigns with this experimental blast furnace and have had excellent results.

183

### **A new method to ensure completion of carbonization cycle through online raw coke oven gas temperature measurement**

**Author(s):** Mr. BHUSHAN, ashutosh<sup>1</sup>

**Co-author(s):** Mr. KUMAR, ashok<sup>1</sup> ; Mr. REDDY, A.S.<sup>1</sup> ; Ms. GANGULY, adity<sup>1</sup> ; Ms. SEN, Subhadra<sup>1</sup>

<sup>1</sup> *Tata Steel Ltd*

**Corresponding Author(s):** ashutosh.bhushan@tatasteel.com

Carbonization time is an important parameter in coke making which is influenced by several factors. It is very important to ensure completion of carbonization to achieve better coke quality as well as to maintain oven health. Due to wide variations in input parameters e.g. coal blend moisture, flue gas calorific value, gas flow rate etc, the extent of carbonization varies widely which lead to variations in coke quality. Study revealed that Gooseneck temperature( raw coke oven gas temperature measured at the gooseneck part of gas collecting system) can be used for guiding proper carbonization cycle.

Raw gas temperature profiles were analysed and new indices for process monitoring were developed which is useful for plant operation for adjustment of process parameters due to any deviation in input variables. Major parameters like "Time to reach peak Gooseneck temperature( TRPGT) " and "Coking time post peak gooseneck temperature( CTpPGT) were found very useful and correlates well with key process and coke quality parameters. Maintaining these parameters, which was developed based on Gooseneck temperature, ensure consistency in coke quality.

185

### **Key Technical Challenges in Sinter Making at Tata Steel Kalinganagar – Use of high Alkali ores & control of High temperature properties.**

**Author(s):** Mr. MOHANAN, Srijith<sup>1</sup>

**Co-author(s):** Mr. C, Arun Kumar<sup>1</sup> ; Mrs. MOHAPATRA, Prajna<sup>1</sup> ; Mr. KORANNE, Vipul Mohan<sup>1</sup> ; Mr. ASADI, Srinivasa Reddy<sup>1</sup>

<sup>1</sup> *Tata Steel*

**Corresponding Author(s):** srijith.mohanana@tatasteel.com

Tata Steel Kalinganagar is a green field 3MTPA integrated steel plant operating via the BF-BOF route. The sinter plant at Tata Steel Kalinganagar was commissioned in January 2016. The sintering machine area is 496m<sup>2</sup> with state-of-the-art cooler design and advanced high intensity mixing-granulation systems. Among the challenges faced in the ramp up, two key issues that were of major concern in the sinter making process was alkali management due to use of unbeneficiated high alkali ores in pile making and the control of high temperature property of sinter (Reduction Degradation Index, RDI). Due to limited availability and logistic issues of supply to Kalinganagar from Tata Steel's captive iron ore mines at Joda and Noamundi, it was decided to use unbeneficiated iron ore from Khondbond, Odisha. In terms of ore chemistry, Khondbond

ore had high alumina and alkali content (0.3% K<sub>2</sub>O as compared to 0.05% for beneficiated ores from Joda and Noamundi). High alkali content leads to higher coke rate, low productivity and affects the furnace lining in the blast furnace. Studies on alkali flushing capabilities of the blast furnace were carried out and based on this, the permissible limit of sinter alkali was determined and threshold for usage of Khondbond ores in base mix pile was fixed.

Permissible limit of sinter RDI is 30, as desired by blast furnace operators at Tata Steel India. Though commissioning of sinter plant at Kalinganagar was carried out in Jan'16, measurement of sinter RDI began in the month of May'16, and was found to be higher than the specified limit of 30%. Sinter RDI varied between 24 and 46 at different regimes of operating parameters and iron ore fines. Based on data analysis, trials were carried out to control the sintering process – in terms of heat input and burn through temperatures. FeO content of sinter at high alumina input conditions was fixed at 9% minimum to maintain sinter RDI below 30 by considering sinter alumina 2.8% max, with reference to past data at TSK. FeO below 9% needs an action on fuel rate to increase in steps after considering the burn through point and sinter RDI. It was also critical to control the burn through point so as to minimize on strand cooling which is detrimental due to the formation of secondary hematite, known to reduce sinter strength. Crushing fineness of solid fuel and flux also needed improvement for efficiency of solid fuel consumption and consistency in sinter quality.

186

## Recycling of the High-zinc Fraction of Upgraded BF Sludge within the Integrated Steelplant

**Author(s):** Mr. ANDERSSON, Anton<sup>1</sup>

**Co-author(s):** Mr. ANDERSSON, Mats<sup>2</sup>; Ms. KULLERSTEDT, Adeline<sup>3</sup>; Dr. AHMED, Hesham<sup>4</sup>; Prof. SUNDQVIST-ÖKVIST, Lena<sup>5</sup>

<sup>1</sup> *Luleå University of Technology*

<sup>2</sup> *SSAB Europe*

<sup>3</sup> *Swerea MEFOS*

<sup>4</sup> *Luleå University of Technology and Central Metallurgical Research and Development Institute*

<sup>5</sup> *Swerea MEFOS and Luleå University of Technology*

**Corresponding Author(s):** andersson.carl.anton@gmail.com

Ore-based steelmaking generates a variety of residues including dusts, sludges, scales and slags. Recycling of these residues within the process or via other applications is essential for sustainable production from both environmental and economic aspects. In blast furnace (BF) ironmaking, the gas-cleaning equipment recovers the particles in the off-gas as BF dust and sludge. Traditionally, the dry dust is recycled via the sinter, but in the case of pellet based BF, recycling methods utilizing cold bonded briquettes and injection have been developed. Depending on the BF operation, the main output of zinc from the BF is more or less via the top gas. Therefore, as the dust is recycled, the sludge has to be dezincing prior to recycling to prevent accumulation of zinc in the BF. Although dezincing and recycling of the low-zinc fraction via sinter have been reported, research towards recycling of the high-zinc fraction of BF sludge within the integrated steelplant is lacking. In the present paper, the high-zinc fraction of tornado-treated BF sludge was incorporated in self-reducing cold-bonded agglomerates. The agglomerates were subjected to smelting reduction experiments aiming to study the feasibility of recycling the in-plant residues to the desulfurization plant. Difficulties in the melt-in of the agglomerates suggested that cold-bonded pellets were more suitable for recycling than cold-bonded briquettes. However, full-scale trials suggested that cold-bonded briquettes can be used to recycle in-plant residues to the desulfurization plant without affecting the desulfurization process and final steel quality.

187

## The Effect of Unburned Pulverized Coal on The Slag Viscosity

**Author(s):** Dr. XIANG, Dongwen<sup>1</sup>; Prof. SHEN, Fengman<sup>1</sup>

**Co-author(s):** Dr. GAO, Qiangjian<sup>1</sup>; Prof. ZHENG, Haiyan<sup>1</sup>; Mr. DING, Guangen<sup>1</sup>; Prof. JIANG, xin<sup>1</sup>

<sup>1</sup> *School of Metallurgy, Northeastern University, Shenyang, Liaoning, 110004 China*

**Corresponding Author(s):** xiangdongwen1@163.com

**Abstract:** The unburned pulverized coal in the blast furnace has an effect on the slag properties, which affects the quality of the hot metal. The effect of unburned pulverized coal made from Yongcheng anthracite on slag viscosity is studied by means of high temperature melt physical characteristics synthetic test instrument, and the reason of slag viscosity change was illuminated by observing slag surface topography using scanning electron microscope (SEM). The results show that The change of the concentration of complex anions and suspended solids in molten slag is the main reason for the change of slag viscosity. It has a certain dilution effect on the molten slag when the content of unburned coal powder in the slag is 0.2~0.8%, and the slag viscosity increases remarkably when the content of unburned coal powder above 1%.

**Key words:** unburned pulverized coal; slag viscosity; complex anions; surface topography

188

## Measurement of activity of Al<sub>2</sub>O<sub>3</sub> in metallurgical slag

**Author(s):** Prof. SHEN, Fengman<sup>1</sup>; Dr. HU, Xinguang<sup>2</sup>

**Co-author(s):** Mrs. ZHENG, Haiyan<sup>2</sup>; Mr. WEN, Qiulin<sup>2</sup>; Mr. JIANG, Xin<sup>2</sup>; Mr. GAO, Qiangjian<sup>2</sup>

<sup>1</sup> *School of Metallurgy, Northeastern University, Shenyang, Liaoning 110004 China*

<sup>2</sup> *School of Metallurgy, Northeastern University, Shenyang, Liaoning 110004 China*

**Corresponding Author(s):** hxg1982@163.com

**Abstract:** The content of Al<sub>2</sub>O<sub>3</sub> in iron ore is of negative effects on sintering process, metallurgical properties of sinter and smelting of BF, which has a serious influence on the quality of molten iron. So it is very important to study the activity of Al<sub>2</sub>O<sub>3</sub> in metallurgical slag to grasp and control the influence of content of Al<sub>2</sub>O<sub>3</sub> on the quality of molten iron. In this paper, several measurement methods and its present status of Al<sub>2</sub>O<sub>3</sub> activity in different slag systems are reviewed systematically. The achievements of representative studies are introduced and analyzed, both advantage and disadvantage of different methods are explained, and the rationality and accuracy of measurement methods are discussed emphatically. The theoretical analysis shows that the reference slag method can avoid the error caused by thermodynamic data, and has better scientificness and higher precision than other methods. Therefore, the determination of activity of Al<sub>2</sub>O<sub>3</sub> by the reference slag method has important academic value and good application prospect.

**Key words:** activity of Al<sub>2</sub>O<sub>3</sub>; metallurgical slag; measurement method; reference slag method; chemical equilibrium method; e.m.f method

189

## Alkali control in the blast furnace – influence of modified ash composition in coke and charging practice

**Author(s):** Mrs. GULLBERG, Amanda<sup>1</sup>; Mr. ANDERSSON, Anton<sup>2</sup>; Ms. OLOFSSON, Jenny<sup>2</sup>

**Co-author(s):** Prof. SUNDQVIST ÖKVIST, Lena<sup>3</sup>; Prof. BJÖRKMAN, Bo<sup>2</sup>; Mrs. DAHLSTEDT, Anna<sup>4</sup>

<sup>1</sup> *Swerea MEFOS AB*

<sup>2</sup> *Luleå University of Technology*

<sup>3</sup> *Swerea MEFOS AB and Luleå University of Technology*

<sup>4</sup> *LKAB*

**Corresponding Author(s):** amanda.gullberg@swerea.se

In the blast furnace (BF) process, the presence of alkalis (Na, K) is known to have negative influences on the process due to the catalytic effect on coke gasification, destruction of carbon structure by intercalation of alkali, scaffold formation and refractory attack. Alkalis are introduced with the raw materials and due to alkali circulation; alkalis are picked-up on the way to the higher temperature zone in the BF. In the combustion zone, a significant part of alkalis are reduced and vaporized. The formed alkali gas follows the furnace gas to the colder regions in the shaft. Here alkali is condensed on the burden or furnace walls and oxidized to more stable compounds. The rather low temperature and less reducing gas in upper part of the shaft are not favorable for alkali gas output via the top gas. Moreover, the solubility of alkalis in slag is dependent on the slag chemistry and amount while higher temperatures in the raceway region enhance the reduction and vaporization of alkalis which will prevent alkali dissolution in slag. The nature of alkali compounds in the BF combined with the character of the process causes alkalis to recirculate and accumulate in the BF. Within this study, the distribution of alkali at different depths in the shaft and for different charging practices has been studied by examination of excavated coke samples from LKABs Experimental Blast Furnace. A possible way of controlling the alkali load in blast furnace have been investigated by studying if alkali can be bound in stable phases in a modified coke ash and coke coating and thereafter drained out from the BF via the slag.

190

## CO<sub>2</sub> Ultimate Reduction in Steelmaking Process (COURSE50 Project)

**Author(s):** Mr. TONOMURA, Shigeaki<sup>1</sup>

**Co-author(s):** Mr. ARAKI, Kyohichi<sup>1</sup> ; Dr. HASE, Kazukuni<sup>2</sup> ; Mr. UJISAWA, Yutaka<sup>1</sup> ; Dr. NISHIOKA, Koki<sup>1</sup> ; Mr. ISHIWATA, Natsuo<sup>2</sup>

<sup>1</sup> *Nippon Steel & Sumitomo Metal Corporation*

<sup>2</sup> *JFE Steel Corporation*

**Corresponding Author(s):** tonomura.7bf.shigeaki@jp.nssmc.com

Japanese steelmakers have executed “development of technologies for environmentally harmonized steelmaking process, ‘CO<sub>2</sub> ultimate reduction in steelmaking process by innovative technology for Cool Earth 50’ (COURSE50)” since FY 2008. This is a national project commissioned by the New Energy and Industrial Technology Development Organization (NEDO). The target of COURSE50 is the mitigation of approximately 30% of CO<sub>2</sub> emissions in integrated steel plants. For this purpose, two technologies are investigated, which include a) Intensified hydrogen reduction in blast furnace and b) Separation and recovery of CO<sub>2</sub> from the blast furnace gas via chemical absorption and physical adsorption methods by the effective utilization of unused waste heat in steel works. The concept of the intensified hydrogen reduction of iron ore is as follows. Intensified hydrogen reduction must ensure the heat balance by decreasing the carbon direct reduction ratio, which is an endothermic reaction. To verify this concept, the experimental blast furnace is constructed in Kimitsu works, Nippon Steel & Sumitomo Metal Corporation. Main methods of decreasing the carbon direct reduction ratio are blast and raw material control. And reasonability of the results is affirmed by comparison between results of three dimensional mathematical calculation model and actual results of experimental blast furnace. The outline of results of the experimental blast furnace are reported and the basic concept is recognized through the experiment.

191

## Study on the Dioxin Emission Reduction in a Commercial Sintering Plant of Shougang Group

**Author(s):** FAN, Zhengyun<sup>1</sup>

**Co-author(s):** Mr. PEI, yuandong<sup>1</sup> ; Mr. SHI, fengkui<sup>2</sup> ; Mr. SHI, jiangshan<sup>2</sup> ; Mr. YIN, youhao<sup>1</sup> ; Mr. ZHAO, shiqi<sup>1</sup>

<sup>1</sup> *Iron and Steel Research Department of Shougang Research Institute of Technology, Beijing, China*

<sup>2</sup> *Shougang Jingtang Iron&Steel Co.,Ltd, Tangshan, China*

**Corresponding Author(s):** zyfan2004@126.com

Abstract: In this article, several experiments were carried out in a commercial sintering plant of Shougang Group about dioxin emission reduction in sintering process. Effects of chlorine content in raw materials, steam spraying, hot exhausted gas circulation and sintering desulfurization facilities on the dioxin emission in the commercial sintering plant were studied. The results show: (1) when the chlorine content in sinter mixture is decreased by 18.18%, the total dioxin content in sintering exhausted gas is reduced by 49.5%. PCDFs and PCDDs fell by 53.4% and 31.4%, irrespectively. (2) Steam spraying on the sintering bed can reduce remarkably the dioxin emission. when the amount of steam is increased from 0t/h to 4.5t/h, the total dioxin content in sintering exhausted gas is reduced from 0.3661ng/Nm<sup>3</sup> to 0.1282 ng/Nm<sup>3</sup>. PCDFs and PCDDs fell by 69.5% and 40.9%, irrespectively. (3) The application of hot air circulation sintering reduces the dioxin content in the exhaust gas by 21.7%. (4)The effect of dust collector on the reduction of dioxin in exhaust gas can reach by 11.4%.

192

## Analysis of Damage Mechanism of Copper Stave Applied in 3200m<sup>3</sup> Blast Furnace of Laiwu Steel

**Author(s):** Prof. ZUO, Haibin<sup>1</sup>

**Co-author(s):** WANG, Ya-jie<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** melanie.baumgartner@asmet.at

Copper stave has been widely applied in large blast furnaces especially whose inner volume exceed 2000m<sup>3</sup> due to high cooling capacity. In the past years, cooper staves suffered damages in some blast furnace, dwindling the campaign life of blast furnace. For this problem, the damage mechanism of the cooling stave was studied by analyzing the chemical composition, thermal conductivity, metallographic tissue and microstructure in this paper. It was found that the main reason for the damage of the cooling stave was not the cooling stave itself but its working condition. Firstly, the poor quality of the coke and the large furnace angle promoted the development of the marginal airflow, which intensified the erosion of refractory materials, resulting in a large area of slag crust fall-off and the damage of the cooling water pipe. After the remedy, the cooling capacity of the cooling stave was still reduced. And the temperature was easy to rise, especially when the temperature reached 370 [U+2103], the hydrogen embrittlement happened. Those two reasons led to the rapid decrease of the ability of adhering slag. Finally, the erosion of marginal airflow caused the damage of cooling stave.

193

## Effect of ultra-fine iron ores on sinter process and quality

**Author(s):** Mr. STEINDORF, Gabriel<sup>1</sup>

**Co-author(s):** Dr. BABICH, Alexander<sup>2</sup> ; Prof. SENK, Dieter<sup>2</sup>

<sup>1</sup> *Department of Ferrous Metallurgy, RWTH Aachen University*

<sup>2</sup> *RWTH Aachen University*

**Corresponding Author(s):** gabriel.steindorf@iehk.rwth-aachen.de

The iron ore sintering process is essentially influenced by the permeability of the sinter bed. Higher amounts of ultra-fine iron ores lead to a weak granulation behaviour, which causes lower voidage in the sinter bed and therefore a decreasing bed permeability. Due to this, the application of ores with a size lower than 0.2 mm is limited. In this investigation the amount of ultra-fine ores (-0.1 mm) in the sinter mixture is increased stepwise up to 500 kg/t sinter mixture by using an intensive mixer for mixing and granulating and hydrated lime as binder. Trials in a laboratory sinter pot could show that with this method it is possible handle such high amounts of ultra-fines with only a minor loss in productivity and increase of solid fuel. By using about 300 kg ultra-fines per tonne of sinter mixture no negative changes neither in sintering process nor in product yield was observed. The sinter product was investigated regarding its quality. The sinter strength was measured with the shatter test and showed virtually no decrease with increasing amount of ultra-fines in the sinter mixture. The reduction behaviour of sinter produced from

the mixture with 500 kg/t ultra-fines was investigated using a Tammann furnace experimental set and thermo-balance facilities. Isothermal tests were conducted to determine the activation energy; non-isothermal tests were performed under conditions simulating the area of the cohesive zone in the blast furnace; results were compared with those for a reference sinter.

194

## Strategies Adopted to Reduce Hearth Temperature in High Productivity large Blast Furnace (BF IV)

**Author(s):** Mr. KOLLAPUR, NAVEEN SINGH<sup>1</sup>

**Co-author(s):** Mr. SINGH, LOKENDRA RAJ<sup>1</sup>; Mr. RAO, A SRINIVAS<sup>1</sup>; Mr. MOHAMMED, UBAYADULLAH<sup>1</sup>; Mr. JAYAPALAN, VENKATESAN<sup>2</sup>; Mr. MELSIMI, BUSI REDDY<sup>1</sup>

<sup>1</sup> JSW STEEL LTD

<sup>2</sup> JSW STEEL LTD.

**Corresponding Author(s):** naveen.singh@jsw.in

JSW steel limited, Vijayanagar works is an integrated steel plant with an installed crude steel production capacity of 12 MTPA. Blast furnace III & IV are two large furnaces with installed production capacity of ~8000 tons/day. In practice, BF#4 is producing average of 9800 tons/day with slag rate of ~400 kg/thm and has set, a 'Global benchmark in terms of total liquid Production'. This abnormally high liquid production rate, led to proliferation of hearth refractory temperature. In Q3 and Q4 of FY'17, there was temperature raise > 300 deg C in certain sections in hearth side walls. Also, there was an instance of grouted carbon mass excluding out, from hearth shell and bottom plate (cracks). A detail study carried out to understand various forces acting inside the hearth and their net impact on the lining. Based on the understanding from study, strategies were deployed to control hearth temperature without adversely affecting both productivity and efficiency. This paper summarizes the various activities like addition of TiO<sub>2</sub> containing materials, optimizing tuyere diameter, improving casting practices, carbon grouting, hearth anchoring, NDT etc.

As a result, of above countermeasures hearth temperatures were normalized and stabilized. BF IV achieved highest productivity of 2.86 t/m<sup>3</sup>/d (WV) at a slag rate 405 kg/thm (Total liquids – 2965 m<sup>3</sup>/d), surpassing its previous best achieved in Aug-16.

**Key Words:** High Productivity, Hearth refractory temperature, Rutilit injection, Ilmenite sand injection, Hearth Anchoring

195

## The role of mineral phases by sintering of iron ores with biofuel

**Author(s):** Mr. MEŽIBRICKÝ, Roland<sup>1</sup>

**Co-author(s):** Prof. FRÖHLICHOVÁ, Mária<sup>1</sup>

<sup>1</sup> Technical university of Košice

**Corresponding Author(s):** roland.mezibricky@tuke.sk

In recent years, substituting a part of coke breeze with a biomass fuel in the sintering of iron ores has become an attractive research topic, which should help with the minimization of CO<sub>2</sub> released from fossil fuels as well as searching for an alternative for coke in ironmaking. Besides the common process analyses, characterization of sinter properties through the mineralogical composition represents a new challenge. In this study, the mineralogy of iron ore sinters produced with partial fuel substitution with charcoal, milled walnut shells and oak sawdust are described and the basic technical parameters such as the tumble index and temperature are compared. When the fuel substitution is based on the equivalent fixed carbon content, the overall fuel amount in the sintering mixture by using non-pyrolysed biomass increases. Because this is caused by the volatile matter, which cannot be fully utilised, no dramatic increase of the temperature of FeO/magnetite content was observed. On the other hand, energy brought due the non-pyrolysed biomass is distributed much more uniformly and the ore particle assimilation is then more advanced. Also,

higher porosity during the cooling of the hot sinter mass supported the formation of the calcium ferrites. Finally, the tumble index shows that the substitution of the coke breeze in the sintering process generates quality sinters but is limited by pyrolysed or non-pyrolysed biomass.

196

## Comparison of softening-melting behaviors between Ti-bearing and common high basicity sinter

**Author(s):** Mr. LI, Tingle<sup>1</sup>

**Co-author(s):** Mr. SUN, Changyu<sup>1</sup>; Ms. LAN, Dong<sup>1</sup>; Mr. WANG, Qi<sup>1</sup>

<sup>1</sup> *The Key Laboratory of Chemical Metallurgy Engineering of Liaoning Province, University of Science and Technology Liaoning*

**Corresponding Author(s):** litingle1@sina.com

The distinctions of softening-melting properties between Ti-bearing and common high basicity sinter have been investigated and what reasons cause these distinctions have been analyzed by employing X-ray diffraction, scanning electron microscope and energy-dispersive spectroscopy. Results of softening-melting tests show that Ti-bearing high basicity sinter has low softening-melting temperatures compared to common sinter. The Ti-bearing sinter exhibits a unique characteristic during softening-melting process that is the pressure drop curve has a second increase obviously. At softening stage, the slag of common high basicity sinter could be described as FeO-2CaO•SiO<sub>2</sub>-melilite while that of Ti-bearing sinter is FeO-melilite-perovskite. The latter has a low eutectic temperature that could make softening temperatures decreased. After melting completion, the main minerals in the residual slags change from 2CaO•SiO<sub>2</sub>, melilite and merwinite to melilite and perovskite with the addition of TiO<sub>2</sub>. The changes of liquidus temperatures of residual slags correspond to the variation trends of melting end temperatures. The second rise of the pressure drop of Ti-bearing sinter may be because its slag has a great priority over iron to melt and slag/iron separates much earlier.

197

## Iron Ore Sintering Research at Different Scales

**Author(s):** Dr. LU, Liming<sup>1</sup>

**Co-author(s):** Dr. LI, Xianchun<sup>2</sup>

<sup>1</sup> *CSIRO*

<sup>2</sup> *University of Science and Technology Liaoning*

**Corresponding Author(s):** liming.lu@csiro.au

With the rapid change in iron ore supplies and composition, steel mills now have to adjust the composition of the ore mixture to the sinter plant more frequently than ever before. Hence, different scales of test methods have been developed to help sinter plants evaluate new ore types and ore blends in order to optimise their ore mixtures and reduce raw material costs. However, iron ore sintering is very complex with many interdependent variables. For the same ores, the sinter quality and sintering performance may vary significantly with the scale at which the sintering tests are conducted. Therefore it is important to understand the effect of test scale on sintering performance and sinter quality while interpreting the test results. This paper provides an overview of various techniques which have been developed at different scales in order to evaluate iron ore and improve the understanding of the iron ore sintering process. This is followed by the results of two sinter blends tested at different scales.

198

## EXPERIMENTAL STUDY AND FEASIBILITY ANALYSIS ON FLASH REDUCTION IRON MAKING PROCESS

**Author(s):** Dr. GUO, Lei<sup>1</sup>

**Co-author(s):** Dr. BAO, Qipeng<sup>1</sup>; Prof. GUO, zhancheng<sup>1</sup>

<sup>1</sup> *University of Science and Technology Beijing*

**Corresponding Author(s):** leiguo@ustb.edu.cn

Due to the very fast reduction rate and its possibility to get rid of coke and other technical advantages the flash reduction iron making process has drawn a lot of concern by many experts and scholars in recent years. According to relative literatures, the derivative process of flash reduction of iron ore is analyzed. The development of the flash reduction iron making process at home and abroad is introduced. The laboratory research work carried out by the author in terms of flash reduction iron making is mainly introduced in this paper, and the main problems that may be faced in the industrialization of flash reduction iron making process are also discussed.

199

## Using hot blast pressure data for improved detection of raceway blockages and reliable shutdown of PCI branches

**Author(s):** PUTTINGER, Stefan<sup>1</sup>

**Co-author(s):** Mr. STOCKER, Hugo<sup>2</sup>

<sup>1</sup> *Johannes Kepler University Linz*

<sup>2</sup> *voestalpine Stahl Donawitz*

**Corresponding Author(s):** stefan.puttinger@jku.at

The raceway areas in a blast furnace are highly dynamic structures and are subject to collapsing and blockages from time to time. These blockage events result in a reduced voidage of the raceway and suboptimal burning conditions for injected coke substitutes like pulverized coal. Thus, the corresponding PCI branch is shut down until the raceway returns to its normal operation state. Previous studies based on the comparison of tuyere cameras and hot blast pressure data showed that there is a clear correlation between signal dips in the pressure data and erratic raceway behavior. Hence, it is possible to implement a reliable raceway monitoring also without a complete tuyere camera installation.

Several signal processing algorithms have been evaluated on real blast furnace pressure data and a final selection of algorithms is currently being implemented in a first online test installation on a medium size blast furnace with 20 tuyeres. The next weeks will therefore deliver enough data for a reliable long-term statistic on the performance of the algorithms and the blockage frequency. Based on this data a fine tuning of the algorithm settings for the individual tuyeres can be done. The results of the online tests will also deliver the necessary data base to evaluate the correlation of anomalous raceway behavior between the individual tuyeres. In case there is a massive blockage on one raceway it is most likely that the neighboring raceway regions are affected as well. Two extreme scenarios can be expected:

- In case there is an erratic burden movement covering a larger percentage of the blast furnace cross section the neighboring raceways will also show a reduced wind flow rate.
- If there is only a local blockage on one raceway it is more likely that the neighboring tuyeres show an increased wind flow rates due to lower pressure drop compared to the blocked raceway.

The next weeks will hopefully deliver enough data to answer these questions and improve the understanding of raceway behavior and burden movement in blast furnaces.

200

## Study on the Sinter distribution in the Circular Cooler Pallet by Three-Dimensional DEM and FEM

**Author(s):** FAN, Zhengyun<sup>1</sup>

**Co-author(s):** Mr. YUANDONG, pei<sup>1</sup>; Mr. FENGKUI, shi<sup>2</sup>; Mr. JIANGSHAN, shi<sup>2</sup>

<sup>1</sup> *Iron and Steel Research Department of Shougang Research Institute of Technology, Beijing, China*

<sup>2</sup> *Shougang Jingtang Iron&Steel Co.,Ltd,Tangshan, China*

**Corresponding Author(s):** zyfan2004@126.com

**Abstract:** In this article, the sinter distribution in the feed hopper and circular cooler was studied by the three-dimensional discrete element method and finite element method. Some conclusions were drawn: 1) The serious mass segregation on the width direction of the cooler pallet was observed in the conventional feed hopper of the sinter cooling process. After adding Plant A and the 30-degree inclined Plate B in the feed hopper, the mass segregation was reduced from 8% to 2%, remarkably. 2) In order to get the more reasonable size segregation in the height direction of cooler pallet, the blind plate C or the sieved Plate C was fixed in the feed hopper. It was found that the maximum segregation intensity could be obtained by using the sieved Plate C with 45 degrees in the feed hopper. 3) Deformation, stress and strain of the cooler pallet with the novel feed hopper fixing the Plate A, Plate B and the 45 degree-sieved plate C are less than that in the conventional feed hopper by the analysis of FEM.

201

## **Experimental Research on Effect of unburned coal particles on Coke Properties in Blast Furnace**

LI, yanjiang<sup>1</sup> ; Mr. ZHANG, jianliang<sup>2</sup> ; Mr. WANG, gunagwei<sup>3</sup> ; Mr. ZHANG, nan<sup>4</sup>

<sup>1</sup> 18800129511

<sup>2</sup> 13910019986

<sup>3</sup> 13811105467

<sup>4</sup> 17801235135

**Corresponding Author(s):** liyanjiangustb@163.com

**Coke gasification by carbon dioxide in the presence of unburned coal particles(UCP) has been investigated using a self-made high-temperature gasification reactor with precision balance. Experiments have been conducted under different temperatures, gas compositions, and coke properties. Coke strength after reaction has been evaluated by pressure test machine. The results show that with the increase of experimental temperature, coke strength becomes higher compared to results without UCP. Besides, the weight loss rate of coke in the presence of UCP is obviously lower than that of coke without UCP. The reactivity of coke with CO<sub>2</sub> is higher than that of coke with UCP at the same temperature.**

202

## **Bell Less Top® coupled with advanced material sampling: the only system allowing to know how the BF is really charged**

Mr. CASTAGNOLA, Cristiano<sup>1</sup> ; Mr. PONGIGLIONE, Giovanni<sup>1</sup> ; Mr. KAUFMANN, Chris<sup>2</sup> ; Mr. DE GRUITER, Christian<sup>2</sup>

<sup>1</sup> *PW Italia S.P.A*

<sup>2</sup> *Paul Wurth S.A.*

**Corresponding Author(s):** christian.degruiter@paulwurth.com

The Bell Less Top Charging System invented and developed by Paul Wurth, is commonly recognized as Best Available Technology in the domain of blast furnace charging. This paper describes how the 2nd gen Bell Less Top, combined with stockhouse improvements and intelligent sampling devices can be used in order to expand blast furnace charging process know-how and to further optimize Blast Furnace charging, allowing in particular better monitoring and control of material segregation. In a first part, different design characteristics of the Bell Less Top and blast furnace charging will be described, including Discrete Element Method models. The second part will discuss stockhouse improvements. Finally, the summary will show how these improvements

can be combined in order to control the charging process in a way suitable for every segregation requirements.

203

## Control of direct reduction in smelting reduction ironmaking

**Author(s):** Prof. JUNG, Sung-Mo<sup>1</sup>

**Co-author(s):** Mr. SHIM, Yang-Sub<sup>2</sup>

<sup>1</sup> Pohang University of Science and Technology

<sup>2</sup> POSCO

**Corresponding Author(s):** smjung@postech.ac.kr

In two stage-smelting reduction process, it is desirable to decrease the reduction degree of iron ore in a pre-reducing unit by reducing its temperature to avoid any troubles due to stickiness of high reduced iron ore. However, less pre-reduced iron ore can induce direct reduction in a melter-gasifier, which can increase the consumption of coal. In this case, the portion of direct reduction can be determined by the reducibility of Pre-Reduced Iron ore (PRI) and the reactivity of coal with CO<sub>2</sub>. PRI was prepared in the form of pellets, and its reducibility was evaluated at various temperatures in an atmosphere containing H<sub>2</sub>. Coal was carbonized in melter-gasifier condition, and then its reactivity with CO<sub>2</sub> was measured at several temperatures and CO<sub>2</sub>-containing gas mixture. The possibility that direct reduction takes place in a melter-gasifier was high because the PRI pellet was reduced more slowly than unreduced iron ore, and the char reacted more actively than coke. The direct reduction rate in a melter-gasifier was roughly estimated as the product of the CO<sub>2</sub> content in the ascending gas and the reaction rate constant of coal with CO<sub>2</sub>. Based on the diagram, the way of minimizing the portion of direct reduction was discussed.

205

## Real-time elemental analysis for prompt process control in metallurgy

**Author(s):** Mr. BARYSHNIKOV, Alexander<sup>1</sup>

**Co-author(s):** Mr. TIKHONOV, Dmitrii<sup>2</sup>

<sup>1</sup> LDS

<sup>2</sup> DDG cooperation technologies

**Corresponding Author(s):** dmitri\_tikhonov@mail.ru

During mining, beneficiation and processing stages in production it's necessary to know chemistry of materials in real-time for optimal process control and improve final product quality. Using online information about chemistry it's possible correct distribute iron ore and concentrate between stockpiles, optimal dosage fluxes and coke for stabilize sinter basicity before it is too late for a process, provide quality control of iron and steel. In report we will talk about laser elemental analyzers for detection in real-time of all necessary elements, including Fe, Si, Ca, Al, Mg, C without sampling directly in site - on a conveyor belt and in a slurry pipeline. This analyzer eliminates expensive laboratory analysis and some hours delay with potential human errors. This analyzer do not produce any ionized radiation and, thus, are fully safe; operate 24/7/365 in the automatic mode under heavy industrial environment many years in metals and fertilizers industries.

206

## Understanding coke formation and quality by analysis of physico-chemical processes

**Author(s):** Dr. MAHONEY, Merrick<sup>1</sup>

**Co-author(s):** Dr. JENKINS, David<sup>1</sup>

<sup>1</sup> *University of Newcastle*

**Corresponding Author(s):** merrick.mahoney@newcastle.edu.au

The conversion of coal into coke is a complex process, involving interrelated phenomena occurring simultaneously. These include heat transfer, gas evolution, softening and resolidification, evaporation and condensation, bubble growth and coalescence, gas transport, shrinkage and fissuring. Moreover, a key aspect of coke quality is its (cold and hot) strength as well as its reactivity. Knowledge of how these competing processes affect the formation and quality of coke is important for optimal outcomes. This work describes a series of research activities based on models, informed by laboratory and pilot scale experiments, of all the above phenomena. Outcomes of the studies have provided novel mechanistic explanations for internal gas pressure, fissure patterns and spacing, dilatometer measurements, sole heated oven tests, coke microstructure formation and aspects of coke quality. The aim here is to emphasise the value of appropriate models for interpretation and analysis of test results, as well as predicting aspects of coke quality from coal properties and coking parameters.

207

## High Temperature Characteristics of Blast Furnace Ferrous Burdens

Dr. LU, Liming<sup>1</sup>

<sup>1</sup> *CSIRO*

**Corresponding Author(s):** liming.lu@csiro.au

Blast furnace cohesive zone has a profound impact on the hot metal productivity and quality, fuel consumption, operation stability and lining life of the blast furnace. The high temperature properties of ferrous burden materials determine the configuration and location of the cohesive zone, and have therefore attracted increased attention. While numerous standard testing methods are in use to assess the quality of ferrous burden materials for the blast furnace use, these simple tests are generally conducted at fixed conditions, which often represent the extreme situations encountered by the burden materials in the blast furnace. Furthermore none of these simple tests provides information on the high temperature properties of the burden materials, such as the softening and melting properties. CSIRO is equipped with a fully computerised testing facility to characterise the high temperature properties of the ferrous burden materials under the realistic conditions similar to those encountered in the blast furnace. This paper will first review the test methods developed worldwide for evaluating the high temperature characteristics of blast furnace ferrous burdens and then discuss the softening and melting properties of a variety of blast furnace burden materials including sinter, pellets and lumps, and their implications for blast furnace operation.

208

## Hot blast superheating – Concept for an industrial trial

**Author(s):** Mr. CAMERON, Ian<sup>1</sup>

**Co-author(s):** Dr. SUKHRAM, Mitren<sup>1</sup>; Ms. WOLOSHYN, Jennifer<sup>1</sup>; Mr. DEL GOBBO, Matthew<sup>1</sup>; Mr. GORODETSKY, Alex<sup>2</sup>

<sup>1</sup> *Hatch Ltd.*

<sup>2</sup> *Alter NRG Corp.*

**Corresponding Author(s):** mitren.sukhram@hatch.com

Hot blast superheating using a hot mixer equipped with plasma torches promises to reduce the blast furnace coke consumption and carbon footprint while increasing blast furnace productivity. Countermeasures to keep the hot blast refractory below its service temperature limit were developed using computational fluid dynamic (CFD) modeling and evaluated at the pilot plant scale. The operation of the hot blast stoves with a plasma torch equipped hot mixer will be explained. The payback period for hot blast superheating ranges from satisfactory to good based on blast furnace cost savings and the value of the additional steel production.

209

## Impact of the gas injection and recycling technology on the powder concentration of the outlet gas of the compact sinter machine

**Author(s):** Prof. CASTRO, Jose Adilson<sup>1</sup>

**Co-author(s):** Ms. CALDAS, Rayla<sup>2</sup>; Prof. OLIVEIRA, Elizabeth<sup>3</sup>; Prof. NOGAMI, Hiroshi<sup>4</sup>; Prof. YAGI, Jun-ichiro<sup>5</sup>

<sup>1</sup> *Federal Fluminense University*

<sup>2</sup> *UFF-Universidade Federal Fluminense*

<sup>3</sup> *CEFET-Angra dos Reis*

<sup>4</sup> *Tohoku University*

<sup>5</sup> *Emeritus Professor at Tohoku University*

**Corresponding Author(s):** joseadilsoncastro@id.uff.br

The iron ore sintering process is a key technology for the steelmaking. One of the most concern of this process is the amount of particles that is generated during the reacting gas flow. The amount of particles and size distribution incorporated in the gas phase are important parameters for the efficiency and safety operation of the electrostatic precipitators on the sintering plant. This paper deals with the dynamic prediction of the generation and settling phenomena within the sintering bed. The model is based on the conservation equations of the gas and particle transport on the sintering bed of a small compact industrial machine. The model prediction are confronted with the total amount of particles captured at the outlet lines incorporating the electrostatic precipitators. The concentrations of the particles, as well as, their size distributions are predicted by the model. The results indicated that as the amount of recycling gas is increased, the amount of powder generated is increased and the larger particles prevails over the smaller one. This phenomenon is mainly attributed to the effect of drag forces balanced by adhesion of smaller particles on the surface of the granular particles of the sintering bed during liquid formation within the sintering bed.

210

## Modeling the shaft furnace process for producing DRI based on rich hydrogen reducing gas

**Author(s):** Prof. CASTRO, Jose Adilson<sup>1</sup>

**Co-author(s):** Prof. ROCHA, Elisa<sup>2</sup>; Prof. OLIVEIRA, Elizabeth<sup>3</sup>; Prof. NOGAMI, Hiroshi<sup>4</sup>

<sup>1</sup> *Federal Fluminense University*

<sup>2</sup> *UFRJ - Federal University of Rio de Janeiro - Campus Macae*

<sup>3</sup> *CEFET-Angra dos Reis*

<sup>4</sup> *Tohoku University*

**Corresponding Author(s):** joseadilsoncastro@id.uff.br

The ironmaking technology based on hydrogen has becoming viable due to process improvements allied to the available sources of hydrogen rich gas from integrated steelmaking plants. In this paper, a numerical model based on transport equations for momentum, energy and chemical species for the gas and solid phases is proposed to simulate the inner phenomena in the direct reduction of the shaft furnace process for producing directly reduced iron (DRI). The model is verified using industrial data for productivity, raw materials and final composition of the DRI product. The model is used to evaluate operational practices using new raw materials and the composition of the reducing gas in the process. Three cases were considered, which correspond to available raw materials commercialized by different suppliers. The effects on the gas and solid inner temperatures, pressure and phase composition distributions are quantified. The simulation results indicated that good agreement for overall parameters of the process could be achieved and afterwards, detailed features of the inner conditions of the process are predicted. Afterwards, the model is used to propose a technology that use controlled hydrogen injection at the bustle gas and combining small amount of oxygen at the first injection level to improve the energy supply and enhance the temperature distribution within the furnace

211

## Technology Progress for Blast Furnace Slag Granulation Process

**Author(s):** Mr. ZHOU, Fan<sup>1</sup>

**Co-author(s):** Mr. SU, Liwei<sup>2</sup>; Prof. LIN, Yang<sup>2</sup>

<sup>1</sup> *Beijing Engineering Incorporation of Iron & Steel Technology, Beijing, China*

<sup>2</sup> *Beijing Engineering Incorporation of Iron & Steel Technology, Beijing, China*

**Corresponding Author(s):** beist@163.com

According to the comparative analysis of different blast furnace slag granulation methods and water-slag separation processes, we have combined the granulation tank, the innovative filtration process and the heat recovery together to ensure the slag granulation production reliable, energy-saving, environmental friendly, practical, economic and efficient. By the analysis of using grab crane to take out granulated blast furnace slag from the filter tank, we have developed automatic reclaimers for taking out granulated slag. The innovative filtration process has technological advances in technology, equipment research & development, environment technical. The application of the innovative filtration process will provide an innovative technical support, lower running cost & automatic production for iron & steel enterprise.

212

## Process visualisation and modelling in ironmaking enabling higher performance

**Author(s):** Mr. SARAN, GAURAV<sup>1</sup>

**Co-author(s):** Ms. RAJ, SRISTY<sup>1</sup>; Mr. SINGHAL, ANEESH<sup>1</sup>; Ms. GANGULY, ADITY<sup>1</sup>; Mr. KUMAR, ASHOK<sup>1</sup>

<sup>1</sup> *TATA STEEL*

**Corresponding Author(s):** sarangm123@gmail.com

Ironmaking processes, being complex metallurgical phenomena require deep understanding of the process for taking informed decisions well in time. Seeking this information from different measurements, making data flow on continuous basis, subjecting data to analysis of trends and cause effect analyses is needed to assert that one can quantitatively connect causes to effects. This is where process visualisation and empirical modelling plays a major role thereby enabling generation of insights, connecting measurements to phenomena, diagnosis of disturbances, finding improvement opportunities, devising innovative approaches and maximizing value chain. This makes the data acquisition and knowledge accretion more important than ever. Real-time data visibility has been established with coke plant, sinter plant and Blast Furnace to take the relevant data to the central data repository named as iMonitor. Enhanced process visibility has helped in the development of advanced visualisations, statistical and empirical diagnostic models. This paper gives a flavour of some of these models such as 'Blast Furnace Cohesive Zone', 'Sounding O/C', 'Stave visualisation', 'Liquid Level in hearth', 'Sinter Burn through', 'Coke Gooseneck temperature' & 'Pile visibility' and how they contributed to achieve the current level of understanding.

213

## The Application of Thermal Camera in the 5800m<sup>3</sup> BF at SHAGANG GROUP

**Author(s):** Prof. GAO, Zhengkai<sup>1</sup>

**Co-author(s):** Mr. GAO, Tai<sup>2</sup>; Mr. YANG, Yanchao<sup>2</sup>; Mr. ZHU, Hua<sup>3</sup>; Mr. TAN, Tianlei<sup>3</sup>; Dr. DU, Ping<sup>3</sup>; Mr. WEI, Hongchao<sup>3</sup>; Prof. ZHANG, Jianliang<sup>1</sup>

<sup>1</sup> *University of Science & Technology Beijing*

<sup>2</sup> *Shenwang Pioneer Tech. Corporation Beijing*

<sup>3</sup> *SHAGANG GROUP*

**Corresponding Author(s):** okgzk@vip.126.com

Abstract: After the 5800m<sup>3</sup> blast furnace was put into operation in 2009, The Thermal Camera started observing the burden surface and gasflow conditions in the furnace. BF Thermal Camera with high resolution chip was upgraded in 2017. Much clear image of the burden surface and gasflow conditions were obtained. Operators can understand very well the situation inside the vessel all the time. Another dedicated Thermal Camera installed to observe chute movement is used also to watch the condition of around lining board. Thermal Camera is beneficial to assist BF operation and equipment maintenance.

Keywords: BF, Thermal Camera, burden surface, gasflow, chute

214

## The application of online laser detector of burden surface profile in the 3200m<sup>3</sup> blast furnace at HanSteel

**Author(s):** Prof. GAO, Zhengkai<sup>1</sup>

**Co-author(s):** Prof. ZHANG, Jianliang<sup>2</sup>; Prof. YANG, Tianjun<sup>2</sup>; Mr. GAO, Tai<sup>3</sup>; Mr. ZHANG, Fan<sup>3</sup>; Mr. YANG, Zhanhai<sup>4</sup>; Mr. WANG, Changhua<sup>4</sup>; Mr. GAO, Yuan<sup>4</sup>; Mr. LU, Jianguang<sup>4</sup>

<sup>1</sup> *University of Science & Technology Beijing*

<sup>2</sup> *University of Science & Technology Beijing*

<sup>3</sup> *Shenwang Pioneer Tech. Corporation Beijing*

<sup>4</sup> *HBIS Group HanSteel Company*

**Corresponding Author(s):** okgzk@vip.126.com

Abstract: No.8 blast furnace (3200m<sup>3</sup>) of HanSteel is equipped with an online laser detector of burden surface profile. During the furnace running, images of burden surface can be obtained with laser scanning. All data and curves of the burden profile are processed by computer to provide real-time BF information for operators. This system can be used to detect burden surface profile and help improving BF charging operation. Some irregular furnace circumstances such as burden deflection or collapse can be corrected in time to keep the BF running stably and smoothly.

Keywords: blast furnace, online laser detector, burden surface profile

215

## Wetting behavior of Graphite-Al<sub>2</sub>O<sub>3</sub> Substrates against Molten CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>-MgO Slags

**Author(s):** Prof. SAITO, Noritaka<sup>1</sup>

**Co-author(s):** Prof. NAKASHIMA, Kunihiko<sup>1</sup>

<sup>1</sup> *Kyushu University*

**Corresponding Author(s):** saito@zaiko.kyushu-u.ac.jp

Permeability at the cohesive and dripping zones in blast furnace is mainly controlled by the dripping behavior of molten slags in the cokes aggregates layer. Thus, wettability of cokes (graphite) which contains ash minerals should be one of the most important controlling factors on the dripping behavior. In the present study, the wettability of graphite-alumina composites with different alumina contents against molten CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>-MgO slags was investigated at 1873K by sessile drop method. It was found that the composite with the larger alumina content had the better wettability, which is attributed to the intensive interfacial reaction against the molten slags. Moreover, the molten slags with the higher basicity revealed the smaller contact angles on the composite substrate, which is simply due to the higher surface tension of slag. Additionally, with increasing the alumina content in the composite, the longer holding time was required for the equilibrium in interfacial reactions.

216

## Impact of Altered Coke fraction Distribution Practice and usage of Process Diagnostic Tools on Blast Furnace Performance

**Author(s):** Mr. KUMAR, Sanjiv<sup>1</sup>

**Co-author(s):** Mr. HALDER, Sabuj<sup>1</sup> ; Mr. REDDY, A S<sup>1</sup> ; Mr. KUMAR, Ashok<sup>1</sup>

<sup>1</sup> *Tata Steel*

**Corresponding Author(s):** sanjiv.kumar@tatasteel.com

Over the years, improved process visibility enabled by reliable measuring instruments, process practices, models and derived parameters have helped BF operators to stabilize and further improve the efficiency of blast furnace. Several such measurement and diagnostic tools/models were used to improve the process efficiency and reduce carbon rates with higher coal injection rates at Tata Steel Jamshedpur blast furnaces. In addition to offline burden distribution models, use of proflometers and under burden probes to fine-tune the burden distribution logic for improving gas utilization helped in achieving the desired result. A change in the distribution philosophy of the coke fraction inside the furnace for optimizing the coke layer thickness helped to sustain furnace stability during low coke rate operations. It also helped in improving the gas utilization in the central and wall regions of the furnace. Increase in coal injection further enabled a reduction in the humidification steam requirement, which also aided in an improvement in the carbon rates.

217

## Experimental Blast Furnace Operation for CO<sub>2</sub> reduction

**Author(s):** Mr. NAKANO, Kaoru<sup>1</sup>

**Co-author(s):** Mr. SUGITANI, Ryohta<sup>2</sup> ; Dr. UJISAWA, Yutaka<sup>3</sup> ; Dr. NISHIOKA, Koki<sup>3</sup> ; Dr. SUNAHARA, Kohei<sup>2</sup> ; Mr. KAKIUCHI, Kazumoto<sup>2</sup> ; Mr. MATSUKURA, Yoshinori<sup>2</sup> ; Mr. YOKOYAMA, Hirokazu<sup>2</sup> ; Mr. SAKAI, Hiroshi<sup>2</sup>

<sup>1</sup> *Nippon Steel & Sumitomo Metal corporation*

<sup>2</sup> *1) Nippon Steel & Sumitomo Metal corporation*

<sup>3</sup> *Nippon Steel & Sumitomo Metal corporation*

**Corresponding Author(s):** nakano.s6x.kaoru@jp.nssmc.com

In COURSE50 STEP2, integrated verification tests of the reduction of CO<sub>2</sub> emissions and CO<sub>2</sub> separation from the blast furnace are being conducted, using a newly build 12 m<sup>3</sup> experimental blast furnace and a 30-t-CO<sub>2</sub>/day chemical absorption process evaluation plant simultaneously. Tests have been carried out with the experimental blast furnace to establish a reaction-controlling technology to reduce CO<sub>2</sub> emissions from blast furnaces, using hydrogen-based reductants effectively. The aim of this technology is to increase the hydrogen reduction rate by about 10% and to decrease the direct reduction rate by about 10% compared to conventional operations. The results of the experimental blast furnace operation showed positive effect of the reaction-controlling technology on CO<sub>2</sub> emissions reduction.

219

## Calculation model of concentration of quaternary slag system SiO<sub>2</sub>-CaO-Al<sub>2</sub>O<sub>3</sub>-FeO and its application

**Author(s):** Dr. LI, Zhi<sup>1</sup>

**Co-author(s):** Prof. MA, Guojun<sup>1</sup>

<sup>1</sup> *Wuhan University of Science and Technology*

**Corresponding Author(s):** gma@wust.edu.cn

Abstract: According to the coexistence theory of slag structure, a calculation model of concentration of SiO<sub>2</sub>-CaO-Al<sub>2</sub>O<sub>3</sub>-FeO of depleted copper slag was established. The model was used to calculate and analyze the effects of slag composition, temperature (T) and basicity (B) on the activity of FeO (NFeO). The results show that NFeO tends to increase and then decrease with the increase of basicity, due to the fact that CaO is easier to combine with SiO<sub>2</sub> than FeO to

form calcium silicate, which replaces FeO in  $2\text{FeO}\cdot\text{SiO}_2$  and increases NFeO. However, an increase of CaO content leads to the formation of high-viscosity silicate  $2\text{CaO}\cdot\text{SiO}_2$ , which increases the difficulty of combining CaO with  $2\text{FeO}\cdot\text{SiO}_2$  and decreases the NFeO. In the temperature range of 1523-1773K, NFeO decreases with an increase of temperature. In addition, the activity of FeO decreases with the increase of  $\text{Al}_2\text{O}_3$  content. By comparing with the measured values, it is found that the calculated results of this model are close to the actual values, and therefore, it can be used as a theoretical basis to guide the carbon carbothermal reduction of copper slag. Keywords: Quaternary slag system of  $\text{SiO}_2\text{-CaO-Al}_2\text{O}_3\text{-FeO}$ ; Calculation model of concentration; Activity of FeO

220

## The research on blast furnace injection coal evaluation method in industry test

**Author(s):** Mrs. DONGQING, wang<sup>1</sup>

**Co-author(s):** Mr. WEICHUN, zhu<sup>1</sup>; Mrs. JINHUA, wang<sup>1</sup>

<sup>1</sup> *Iron and Steel Research Department of Shougang Research Institute of Technology, Beijing, China*

**Corresponding Author(s):** zyfan2004@126.com

Abstract The blast furnace injection coal evaluation method is developed in this work. This method can be used to reflect the influence of coal injection change on the utilization of coal powder and the blast furnace performance. The smooth operation index and carbon content index are put forward. The smooth operation index represents the effect on blast furnace performance. The carbon content index represents the effect on utilization ratio of pulverized coal. The method considers blast furnace operation parameters (blast volume, pressure difference), gas dust weight of per ton iron and gas dust quality etc. The blast furnace performance and utilization ratio of pulverized coal are evaluated effectively. By the comparative analysis with injecting coal laboratory investigation and industry test in some blast furnace in Shougang, it is well validated. Although the proportion of coal A is up to 35%, the total carbon content in gas dust and carbon content index are reduced in some extent. It shows the unburned coal was not raised with the increase of blast furnace output and coal ratio. The blast furnace gas permeability remained stable and the blast furnace performance improved.

221

## Recent Progress in Iron Ore Sintering Technologies in AnSteel

Mr. ZHOU, Mingshun<sup>1</sup>

<sup>1</sup> *Ansteel Group*

**Corresponding Author(s):** zhangqianiso@163.com

For raising sinter productivity and quality while reducing energy consumption and raw material cost, a new blending method has been created in Ansteel to optimise sintering blends. Traditionally the granulation of sintering blends in Ansteel has been adopted in disc pelletisers, which was recently found to be one of the causes to unstable blast furnace operation due to their low mixing efficiency. Based on above findings, a number of technical innovations at Sintering workshop 3 were conducted to replace its sixteen existing disc pelletisers with one drum granulator. This experience provided valuable data for optimization of sintering process in Ansteel and even in China. In addition, the single lattice method is proposed to improve the particle-size distribution of coke breeze for sinter quality and lower fuel consumption. Considering the negative impact of high MgO content to blast furnace operations, low MgO sintering was, for the first time, proposed in Ansteel, which has significantly reduced the MgO content of blast furnace slag. Efforts have also been made in Ansteel to further optimize the technological parameters in the sintering process such as the changes of basicity and FeO content. Given the international trend on increasing the bed depth, Ansteel has successfully achieved a bed depth of 750 mm or more in case of 75% concentrates. Finally, the perspective of iron ore sintering is discussed in the paper.

222

## Development of the blast furnace production in Russia

**Author(s):** Mr. TIKHONOV, Dmitrii<sup>1</sup>

**Co-author(s):** Dr. GORDON, Yakov<sup>2</sup>

<sup>1</sup> *DDG cooperation technologies*

<sup>2</sup> *Technical Director, Hatch*

**Corresponding Author(s):** dmitri\_tikhonov@mail.ru

Increase in blast furnace useful volume in course of reconstruction projects and increase in intensity of furnace operation is the major trends in hot metal production in Russian Federation. In majority of furnace enlargement projects the supporting structure, furnace foundation and part of the infrastructure remains the same, while furnace proper is completely replaced with installation of the following new modern systems: furnace shell, furnace cooling system comprised from combination of copper staves, plates and cast iron staves, bell-lest top charging devices, high temperature stoves, gas cleaning and aspiration systems, PCI, oxygen and natural gas injection, slag granulation system, modern control and expert system etc. The sinter and coke quality in industry gradually improves and more and better pellets are used in the metallic burden of blast furnace. As the result during last five years the number of blast furnaces in Russia decreases while hot metal production was increased. Although reconstruction of existing blast furnaces is a major way of improvement in production of hot metal, several new blast furnaces are recent built: "Rossiyanka" (BF7) at NLMK, BF 7 at NTMK-Evraz and BF #2 at Sukhaya Gora Iron & Steel Works. As the result of these changes many blast furnaces in Russia, for example BF 7 "Rossiyanka" at NLMK, BF 1, 2 CherMK, BF 5 and 6 at NTMK-Evraz operate with World highest specific productivity (3.5-3.7 t/m<sup>3</sup>/day) and low total fuel and coke rates, while using only domestic coals and iron ore.

223

## Direct Reduction: Transition from Natural Gas to Hydrogen?

**Author(s):** Prof. HÖLLING, Marc<sup>1</sup>

**Co-author(s):** Dr. GELLERT, Sebastian<sup>2</sup>

<sup>1</sup> *Hamburg University of Applied Science, Dept. of Process Engineering*

<sup>2</sup> *ArcelorMittal Hamburg*

**Corresponding Author(s):** marc.hoelling@haw-hamburg.de

The future of the European steel industry demands solutions for carbon free production routes to fulfil the challenging goals of today's climate policies. In terms of CO<sub>2</sub>-emissions, the reduction process is the most relevant process – be it in a blast furnace or in a direct reduction plant. One solution to this issue could be the transition from fossil-based to hydrogen-based reduction of iron ore. If the hydrogen is produced with electrolyzers by means of renewable energies, the new process would be free of carbon dioxide.

In a cooperation of the Hamburg University of Applied Science (Department of Process Engineering) and ArcelorMittal Hamburg, a concept of a new hydrogen-based process is evaluated. ArcelorMittal Hamburg operates the only direct reduction plant in Western Europe, which uses already up to 60% of hydrogen for the reduction of iron ore. It thus has a deep process understanding and experience in low-CO<sub>2</sub>-reduction of iron ore. For the development of a new process, a concept study was conducted with in-house simulation tools. The results show the energy-demand to be in the same range as for today's direct reduction process. Nevertheless, the energy has to be delivered by renewable energies, which will lead to much higher costs compared to natural gas. Though the transition from natural gas to hydrogen is possible from a technical point of view, there are big obstacles concerning the economics of such a new process. The investment costs as well as the operating costs for such a new plant would be much higher than those of a conventional process. On the other hand, the hydrogen-based process has to be tested in a pilot plant to show "proof of concept", for which ArcelorMittal Hamburg would be the ideal location.

224

## The concept of charging different sinter size fractions into the blast furnace.

**Author(s):** Dr. MITRA, Tamoghna<sup>1</sup>

**Co-author(s):** Dr. KINZEL, Klaus-Peter<sup>1</sup>; Mr. NOUAILLE-DEGORCE, Gilles<sup>1</sup>; Mr. BERMES, Philipp<sup>1</sup>

<sup>1</sup> *Paul Wurth S.A., Luxembourg*

**Corresponding Author(s):** tamoghna.mitra@paulwurth.com

In sinter plants, at the end of the sintering process the product is subjected to high performance screens of 20 mm, 10 mm and 5 mm respectively. This allows part of the middle size fraction to be utilized as a hearth layer in sinter strands. Normally, the screened product is then remixed to be sent to the blast furnace plant, where it is charged into the furnace. In contrast, if the screened material is charged in separate layers in the BF, the overall pressure drop may be decreased, as narrow material distribution results lower pressure drop. In order to verify the concept a set of pressure drop experiments were carried out for each of the different size fractions and coke particle layers along with the combination thereof. In this paper, the results from the experiments are discussed along with a discussion on the implication of such a charging process on blast furnace operation.

225

## Dry dedusting system at POSCO Gwangyang No.1 BF

Mr. YOON, jihong<sup>1</sup>

<sup>1</sup> *POSCO*

**Corresponding Author(s):** sujinlee@posco.com

Gwangyang No.1 blast furnace blowed in 2013 with 6,000 [U+33A5] inner volume (first half in 2017, Po 2.36t/d/[U+33A5], RR 488.0kg/t-p), and dry-type dedusting system is installed at that time. The introduction background is electricity cost saving through TRT power generation and reducing the amount of waste water discharge, compared with wet-type dedusting system. The dedusting system of Gwangyang No.1 BF is consisted of 18 chambers and 240 bag filters. And there is also wet-type dedusting system (bischoff scrubber) in case of emergency. Compared with No.2~5 BF, the power generation has increased and the amount of waste water discharge is 10~20%. The following issues have arisen during operation, and improvement activities are in progress. (1) [Problem] There was clogging bag filter and corrosion of TRT with dust sticking. [Solution] Prevention dust sticking by using steam heating and improving facilities (2) [Problem] Dust can not be transported by vehicle because of high temperature and smoke. [Solution] We changed the method of emitting dust and add the process of lowering the dust temperature. In result, compared with initial operation, TRT power generation (40.2→46.0kwh/t-p) and operation efficiency ( $\eta_{CO}$  46.8→48.8%) have increased in recent. Considering the overall economic feasibility, there is an economic merit.

226

## The relining of Pohang No.3 Blast Furnace

**Author(s):** Mr. KIM, HYUNGWOO<sup>1</sup>

**Co-author(s):** Mr. SON, KIWAN<sup>1</sup>

<sup>1</sup> *POSCO*

**Corresponding Author(s):** hwkim85@posco.com

Pohang No.3 BF has been repaired it from February 24th to June 6th for 102 days. POSCO intend to improve operation efficiency and save costs by enlarging inner volume from 4,350 to 5,600m<sup>3</sup>. The relining criterion are that remaining of hearth refractory, wear of body shell, needs for increasing production and so on. Recently, the most critical point among them is the remaining of hearth refractory considered minimum remaining is 600mm. Although, the

remaining of Pohang No.3BF hearth refractory is about 900mm, relining was needed for wear of body shell by high productivity.

The strategies for extending blast furnace campaign life are described. First, switching body cooling system. The body cooling system is changed from copper stove to dense cooling plate which was adopted design criteria for the thermal and mechanical wear mechanism and applied same to Gwangyang No.1BF and Pohang No.2BF. POSCO's design concept could be minimize the wear of the blast furnace even at the high productivity. Second, the improvement of main shell profile. The main shell profile was changed belly, throat, hearth diameter, bosh and shaft angle, inner volume and so on. Last, change in refractory design. According to the heat load of furnace body, refractory design was adopted to maximize the cooling ability and minimize the cost. In addition, the design of the refractory block of tap hole was changed from 3block to 2block in order to prevent leaking of the molten Iron.

In addition, new measuring instrument were installed in the blast furnace proper to monitor the gas distribution, segregation fines distribution and deformation of body shell. First, We installed Acoustic gas temperature measurement system that monitor the circumferential distribution of gas flow inside the Blast Furnace. We can change the charging mode using that system. Second, We installed Profilemeter. Profilemeter can measure the segregation fines distribution according to the charging mode. Finally, FBG sensor was installed that check the crack on Hearth Shell. Also it is possible to manage to melting iron level.

227

## Impact of transition from Dry to Wet Quenching on Coke Properties and Blast Furnace Performance

**Author(s):** Ms. RUSTAGI, Naina<sup>1</sup>

**Co-author(s):** Mr. KUMAR, Ashok<sup>1</sup> ; Mr. REDDY, A.S.<sup>2</sup> ; Mr. HALDER, Sabuj<sup>2</sup> ; Mr. ROUT, Goutam Kumar<sup>1</sup> ; Mr. BHUSHAN, Ashutosh<sup>1</sup>

<sup>1</sup> TATA STEEL LTD

<sup>2</sup> TATA STEEL

**Corresponding Author(s):** naina.rustagi@tatasteel.com

Coke Dry Quenching (CDQ) technology helps not only in recovering almost 80% of the sensible heat, but also contributes in improving coke quality, thereby enhancing BF productivity. The 'G' blast furnace at Tata Steel uses 100 percent dry quenched coke in the burden. However, during the annual shutdowns of CDQ plant, coke-quenching method shifts to conventional Wet Quenching. An analysis of the furnace operating data is conducted to assess the impact of change from Dry to Wet-quenching on coke properties and key blast furnace parameters. The transition from a fully dry to a fully wet quenched coke was observed to lead to a decrease in the key coke quality parameters such as CSR, CRI and GCQI. Further, an increase in the carbon rate by up to 13 Kg/thm and a decrease in gas utilization ( $\eta_{CO}$ ) at the blast furnace were reported

228

## Petrological study of sinter-pellet-coke interaction in Advanced Softening and Melting (ASAM) experiments

**Author(s):** Dr. SMALL, James<sup>1</sup>

**Co-author(s):** ADEMA, Allert<sup>1</sup> ; ANDREEV, Kirill<sup>1</sup> ; STUURWOLD, Jeroen<sup>1</sup>

<sup>1</sup> Tata Steel, IJmuiden, Netherlands

**Corresponding Author(s):** melanie.baumgartner@asmet.at

Advanced Softening and Melting (ASAM) experiments were performed with mixed sinter-pellet burdens of contrasting compositions, showing large differences in vertical contraction and pressure-drop curves (vs T, time). To understand the mechanisms behind these differences, experiments were interrupted at key stages of the simulated BF trajectory for detailed petrological investigation. Combining multi-scale structural and chemical (micro-)analysis with thermodynamic calculations in Factsage helps explain the contrasting ASAM results in terms of chemical interaction between

sinter and pellets within the ferrous layer, and the processes of metal-slag-solid oxide segregation at the ferrous layer's margins adjacent the coke layer and graphite crucible.

229

## The Possibility of Significant BF-Hearth Lining Life Extension

**Author(s):** BIEROD, Markus<sup>1</sup>

**Co-author(s):** SCHAUB, Eric<sup>1</sup>

<sup>1</sup> *Paul Wurth Deutschland*

**Corresponding Author(s):** melanie.baumgartner@asmet.at

Significant Blast Furnace (BF) hearth lining life extension is the target of the improved BF-hearth lining observation management; provided by Paul Wurth, Germany, (PWDE).

The hearth lining main property modifications occur nonetheless during the running BF-life campaign and influenced the real hearth lining wear profile.

No classical hearth lining temperature and heat flux observation implementation can detect the main physical and chemical property modifications and their alterations during the running BF-campaign.

A number of main measuring disadvantages and poor evaluation results prevents up to this day the necessary true hearth lining wear profile calculation. For example: • Supply of insufficient hearth lining temperature and heat flux data; • Formations of „heat resistances“, like joints, slots, gaps, structure transformations, embrittlements, like „brittle layers“; • Particular variations of the lining grades TC-values and their alterations during the running BF-campaign.

It is very noticeable, that the classical measured value disadvantages and its poor evaluation results take place already in an early stage of the running BF-campaign. The real hearth lining weak points, like accelerated wear, „hot spots“ or critical reduced hearth lining thickness, can't detect in an early stage for appropriate counter measurements.

PWDE has developed and improved in the last decade precise multipoint temperature & heat flux sensor Probes, (MTP-sensor probes). Meanwhile, the well experienced tool is implemented in a number of BF-hearth bottom and side walls, recording excellent performance data results. The new developed chilling device, necessary for safety pilot core probe drillings and core probe extractions in the BF-hearth lining without salamander tapping will be introduced in this paper. The paper highlights the well experienced hearth lining measuring tool (MTP- sensor probe) for an improved lining observation, true lining wear forecasts and an extended BF-hearth lining life campaign; in spite of „heat resistances“ and / or „brittle layer“ formations in the BF-hearth lining.

230

## Estimation of liquid levels in the blast furnace hearth

**Author(s):** Dr. HELLE, Mikko<sup>1</sup>

**Co-author(s):** Prof. SAXÉN, Henrik<sup>1</sup>

<sup>1</sup> *Åbo Akademi University*

**Corresponding Author(s):** mikko.helle@abo.fi

A well operating hearth is a prerequisite for stable and effective blast furnace operation. On-line estimation of the liquid levels in the blast furnace hearth provides an effective means to prevent disturbances and to improve tap management. A mathematical model of the iron and slag levels in the hearth has been developed. The model is based on mass balances using information about the in- and outgoing flows, hearth geometry and dead-man state. Due to measurement errors the estimated liquid levels exhibit drift and must therefore be periodically corrected. The liquid levels also strongly depend on whether the dead man sits or floats. These aspects are considered in the model. Furthermore, regions with lower dead man permeability in the hearth are taken into account by conceptually dividing the hearth into different pools with cross-communication defined by parametric expressions. The paper first presents the model assumptions and equations,

followed by some results from a study where it has been applied to data from a blast furnace. Finally an attempt is made to verify the results by using indirect measurements from the process.

231

## Evolution of Novel Sintering Regime at Tata steel Jamshedpur

**Author(s):** Mr. C, Arun kumar<sup>1</sup>

**Co-author(s):** Mr. MOHANAN, Srijith<sup>1</sup> ; Mr. KORANNE, Vipul Mohan<sup>1</sup> ; Mr. REDDY, A Srinivasa<sup>1</sup>

<sup>1</sup> *Tata Steel Ltd., Jamshedpur*

**Corresponding Author(s):** arunkumar.c@tatasteel.com

Pellets were introduced into the Blast furnaces at Tata Steel Jamshedpur post the commissioning of pellet plant in the year 2012. The new burden mix (sinter, ore and pellet) offered an opportunity to produce sinter using a new flux regime which permitted flexibility in ore mix and resulted in change of sinter properties. A strategic decision was taken to produce pellets at acidic/minimum flux regime implying that major portion of the flux requirements of blast furnace would be met through sinter. The major shift in sinter chemistry was the increase in CaO content in sinter to >12% based on proportion of sinter and pellet in burden mix in the blast furnace. Simultaneously, fine ore mix to sintering was switched over from higher fines from Noamundi source to higher fines from Joda source. Joda ore fines has lesser amount of super-fines size (-0.15 mm) in granulometry and lesser goethite content in lattice structure compared to Noamundi ore fines. These key strategic changes to operate sinter making in new high flux regime and higher use of Joda ore fines resulted in improvement of sinter quality parameters like Reduction degradation index (RDI) and Reducibility index (RI) as well as 15% (approx.) reduction in fuel rate for sintering. The improved sinter properties were correlated with presence of higher amount of calcium ferrites and Silico ferrites of calcium and alumina (SFCA) phases in matrix of sinter microstructure.

232

## Relevance of Calculated Parameters on Tata Steel Blast Furnace Process Diagnostics

**Author(s):** Mr. RAUT, Goutam Kumar<sup>1</sup>

**Co-author(s):** Mr. REDDY, A Srinivas<sup>1</sup> ; Mr. KUMAR, Ashok<sup>1</sup> ; Mr. HALDER, Sabuj<sup>1</sup>

<sup>1</sup> *Tata Steel Limited, Jamshedpur*

**Corresponding Author(s):** goutamk.raut@tatasteel.com

Process fluctuations occurring within a blast furnace strongly affect the operational stability of the furnace and at times, the material flow within an integrated steel plant. Monitoring a blast furnace process is a very challenging task as it often fluctuates frequently, and further, due to the difficulty in obtaining direct measurements. Therefore, to improve process visibility, certain calculated parameters or indices, like sounding Ore/Coke ratio, hearth liquid level, etc., have been developed for blast furnaces at Tata Steel by utilizing measurements like temperature, pressure, material inputs and outputs etc. to gain insights on process phenomena, which are otherwise difficult to visualize. Such indices enable tracking the dynamics of the process, while also serving as a diagnostic tool for the furnace operators to take corrective action in the event of a process disturbance. The paper focuses on the impact of these calculated indices on the blast furnace process.

234

## Footprints for the future of commercial FINEX plants

**Author(s):** Dr. YI, Sang-Ho<sup>1</sup>

**Co-author(s):** Dr. CHO, Min-Young<sup>1</sup> ; Mr. YI, Joon-Giu<sup>1</sup>

<sup>1</sup> *POSCO*

**Corresponding Author(s):** joonyi@posco.com

FINEX® is an alternative iron making process to the blast furnace (BF) route and it is based on the direct use of iron ore fines and non-coking coal, which gives operational flexibility, cost competitiveness and environmental benefits compared to the conventional BF route. Continuous improvements are carried out to increase the process efficiency, including the latest developments of the energy recovery system, changing binders for coal briquettes and the increased production of the hot compacted iron system. Economical benefits are steadily enhanced by the increased use of raw materials with low quality and the recycling of various by-products. The CO<sub>2</sub> removal system working as CCS (carbon capture and storage) in the process brightens the environmental potential. As the core facilities in Pohang Works, two commercial FINEX® plants have already produced over 20 million tons of hot metal and the experience of more than 10 years of commercial operation on the brown field convinces that the equivalent performance will be achieved on green fields. Continuous progress of the FINEX® process promises that the alternative iron making process is now sufficiently competitive with the traditional blast furnace process.

235

## Research on Transfer and its significance of MgO in blast furnace burden from sinter to pellet in Shougang Jingtang

**Author(s):** Dr. PEI, yuandong<sup>1</sup>

**Co-author(s):** Prof. WU, shengli<sup>2</sup>; Dr. ZHAO, zhixing<sup>3</sup>; Dr. AN, gang<sup>1</sup>; QING, gele<sup>1</sup>; Prof. ZHAO, baojun<sup>4</sup>

<sup>1</sup> *shougang*

<sup>2</sup> *USTB*

<sup>3</sup> *shougoang*

<sup>4</sup> *UQ*

**Corresponding Author(s):** peiyuandong@126.com

MgO is one of the main elements of the blast furnace slag, for improving fluidity of slag. Traditionally, MgO is mainly added through the sinter ore. This paper discusses the advantage of transfer of MgO from the sinter to pellet, and this technology is implemented in Shougang jingtang. The study found that reduction swelling index of the pellet improved with increasing MgO content when producing magnesia pellet, and liquid fluidity of sinter ore improves when MgO content decreases, which is beneficial for obtaining SFCA and improving sinter indexes. Finally since 2013 in Jingtang, MgO content of sinter reduced from 1.8-1.9% to 0.7% level, and the MgO content of pellet increased from 0.5% to 1.7% level. MgO not only improves the individual index such as reducibility, at the same time Due to the reduction of difference between sinter and pellet in liquid phase formation temperature, and of the liquid phase viscosity, droplet properties of comprehensive burden of blast furnace was optimized.

236

## HIGH PELLETS RATIO BURDEN IN HBIS SERBIA BLAST FURNACE

**Author(s):** Mr. ANDREJIC, Vladan<sup>1</sup>

**Co-author(s):** Mr. MIHAILOVIC, Vladan<sup>1</sup>; Ms. ZUGIC, Milodarka<sup>1</sup>; Mrs. ZLATOVIC, Vesna<sup>1</sup>; Mr. MILOVANOVIC, Dobrica<sup>1</sup>; Mr. SUSIC, Cedomir<sup>1</sup>

<sup>1</sup> *HBIS GROUP Serbia Iron & Steel*

**Corresponding Author(s):** vladanandrejic@hbisserbia.rs

HBIS GROUP Serbia Iron & Steel is integral Steel plant owned by the HBIS Group that in its composition has 2 Blast furnaces and 3 lines for sinter production. Usual ore burden of the blast furnace is: 35% sinter+62% pellets+3% B-scrap. During January and February 2016, test periods were performed at the Blast Furnace 1, where the ratio of the sinter was gradually reduced to final excluding. Each of these periods wasn't lasting for less than 4-5 days. During all test periods, furnace has not any production issues and productivity was improved. Goal of each test periods was to determine and compare technology and economy parameters of the Blast Furnace

operation. Usage of 100% pellets in the BF ore burden is not usual practice in Europe. This test period is conducted from 20 to 31 January 2016. During the test period were monitored main technical parameters: slag volume and slag basicity, %Fe in the ore burden, usage of fluxes (limestone, quarcite and dolomite), furnace efficiency (EtaCO), total fuel consumption, thermal condition of the blast furnace, cooling system, temperature of BF gases. During this test period, thermal condition of Blast Furnace was normal, without cooling system elements heat overloading. Consumption of fuel was usual or lower. Aimed amount of slag, and basicity was achieved by the usage of fluxes. BF gas utilization was excellent. There were no any irregularities in the Blast Furnace operation. With this is confirmed that Blast Furnace can operate by using 100 % pellets in the burden. During the test period the production cost of the hot metal would be more favorable compared to usual ore burden.

237

### A method of micro-fluidized bed for the kinetic characteristics of iron oxide by gas-based direct reduction

**Author(s):** Dr. KUN, He<sup>1</sup>

**Co-author(s):** Prof. ZHONG, Zheng<sup>1</sup> ; Mr. XU, He<sup>1</sup> ; Prof. XIAOQIANG, Gao<sup>1</sup>

<sup>1</sup> *Chong Qing University*

**Corresponding Author(s):** hekun201124@163.com

The gas-based reduction of iron oxide is one of the important directions in the development of non-blast furnace iron-making process. Mastery of the reaction mechanism of iron oxide with reducing gas is the fundamental task before it is applied. A series of comparative experiment have been designed which were based on the normal thermogravimetry /differential thermal analyzer and the newly achievements of micro-fluidized bed reaction analyzer in reaction mechanism of iron oxide. Under the same situation of reaction, many indexes, such as the time to complete reaction, reduction rate and surface micromorphology of iron oxide reduction by CO or H<sub>2</sub>, are obviously differences between the two ways. As a result, the kinetic parameters from micro-fluidized bed are more similar with the kinetics characteristics of intrinsic reaction. Moreover, micro-fluidized bed reaction analyzer, a new method to study the reaction mechanism of iron oxide, will play a major role in the research of gas-based direct reduction in the future.

**Key words:** Iron oxide, Gas-based reduction, Kinetic characteristics, Micro-fluidized bed, Thermogravimetry /differential thermal analyzer

238

### Investigate the optimum proportion for Collocation of Mauritania ore and Sierra Leone ore by Sinter pot

**Author(s):** Dr. QI, Chenglin<sup>1</sup>

**Co-author(s):** Dr. ZHAO, Xiaohong<sup>2</sup> ; Dr. WANG, Ruozhuo<sup>3</sup> ; Prof. FENG, Gensheng<sup>4</sup>

<sup>1</sup> *University of Science and Technology Beijing, China*

<sup>2</sup> *Cargill Energy, Transportation and Metals, Shanghai*

<sup>3</sup> *Engineering Training Center University of Science and Technology Liaoning*

<sup>4</sup> *School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing, Beijing*

**Corresponding Author(s):** qichenglin@ustb.edu.cn

Sinter pot test was carried out to replace Brazil iron ore with mix of high silicon low aluminum Mauritania ore and low silicon high aluminum Sierra Leone ore, which is 1:1. Through analysis of parameters and characteristics of sintering experiment, following results were concluded: with replaced of Brazil fine by the low quality ores, vertical rate and utilization efficiency of sintering process was increased; without any effect on quality of sinter; quality of sinter is sensitive to fuel rate, which should be controlled in 59kg/t-61kg/t; after replacement, distribution of sinter particle was improved.

239

## ILTEC – Highlighting potentials and eliminating concerns regarding the safe and water-free cooling technology

Dr. HANEL, Martina<sup>1</sup> ; Dr. FILZWIESER, Andreas<sup>2</sup> ; Dr. DEGEL, Rolf<sup>3</sup>

<sup>1</sup> *Mettop GmbH*

<sup>2</sup> *Mettop GmbH/PolyMet Solutions GmbH*

<sup>3</sup> *PolyMet Solutions GmbH/SMS group GmbH*

**Corresponding Author(s):** martina.hanel@mettop.com

It is the increasing demand for an economic and cost saving operation mode that requires effective cooling in order to achieve low refractory wear and good furnace lifetime, which is making cooling technology an important aspect of furnace operation. In addition, the requirements for safety are getting more and more into focus. However, the use of water - today's standard cooling medium - has major drawbacks as it can cause problems both during furnace start up and operation, namely hydration problems, corrosion, and explosion. Not to forget the severe personal as well as economical damage in case of a malfunctioning water cooling system. With this new and patented cooling technology ILTEC and the ionic liquid IL-B2001 as the cooling medium, it is possible to realise a water-free cooling solution and therefore the door is wide open to rethink existing and conventional cooling solutions. Furthermore especially in the area of ironmaking, there is also the chance to recover heat from the process in a more efficient way. However, since the technology is novel and unique there are a lot of concerns and doubts regarding safety for plant operators and employees. Although perfectly unsubstantiated, especially the topic of gaseous hydrogen fluoride formation and the handling and transportation is of great interest and concern. The paper is intended to cover both: highlighting the enormous potential of the technology with special focus on ironmaking but also to eliminate concerns mainly caused by rumour and unawareness.

240

## Influence of MgO on Low Temperature reduction and reduction disintegration of Sinter in COREX Reducing Process

Dr. SHI, Benjing<sup>1</sup> ; Prof. ZHU, Deqing<sup>1</sup> ; Prof. PAN, Jian<sup>1</sup> ; Dr. ZHANG, Feng<sup>1</sup> ; Dr. LI, Siwei<sup>1</sup>

<sup>1</sup> *Central South University*

**Corresponding Author(s):** shi,benjing@126.com

**Abstract:** COREX smelting reduction process provides a sustainable developing way for iron-making industry through being rid of dependence on metallurgical coke. The low temperature reduction disintegration is the main factor that restricts the sinter, which is overcapacity in China, to be massively used in COREX process. In this paper, the influences of MgO content on the reduction and disintegration behavior of sinter were explored in reducing condition simulated COREX shaft furnace, simultaneously the changes of mineral phase, microstructures and cracks in samples were followed using X-ray diffraction (XRD), optical microscopy and scanning electron microscopy for revealing the mechanism of effect of MgO on the reduction and disintegration behavior of sinter. The results show that at low temperature of 500 [U+2103], with increase of MgO from 1.36% to 3.10%, the reduction index shows a trend of decreasing, the RDI+6.3 and RDI+3.15 increase from 24.52% and 61.43% to 47.19% and 76.41% respectively. The formation of cracks in sinter with various MgO contents during low temperature reduction process is influenced by the changes of reduction degree, mineral phase and microstructures of sinter. Appropriate porosity is helpful to reduce the formation of cracks in sinter after low temperature reduction. **Keywords:** Sinter, MgO, low temperature reduction disintegration, COREX

241

## Recent taphole clay developments focusing on blast furnace preservation

**Author(s):** Mr. SIMÕES RIBEIRO, Aloísio<sup>1</sup>

**Co-author(s):** Mr. MOREIRA OLIVEIRA, Tomás<sup>1</sup> ; Mr. CHIARETTI BASSALO, Humberto<sup>1</sup> ; Mr. ALMEIDA ASSIS, César<sup>1</sup> ; Mr. TEIXEIRA BRANDÃO, Luiz Carlos<sup>2</sup>

<sup>1</sup> *RHI Magnesita*<sup>2</sup> *Usiminas Ipatinga***Corresponding Author(s):** aloisio.ribeiro@rhimagnesia.com

One of the main challenges for refractory suppliers is to guarantee the blast furnace's safety and its availability for hot metal production. These needs have led to continuous improvements in the taphole clay technology regarding stable tapping operation and blast furnace hearth preservation. The taphole clay used in blast furnaces with 1 or 2 tapholes during the consecutive tapping should exhibit fast sintering to prevent the splash in the beginning of the tapping providing a safety and stable production. In blast furnaces which presents critical wear (hot spots) in the hearth wall close to taphole region, the taphole clay should be adjusted to form a protective and robust layer in this region. This paper presents the results of the taphole clays adjusted to attend these requirements which significantly improve in performance and blast furnace preservation.

242

## Towards the Comprehension of Ferrous Burdens Softening and Melting Phenomena in Blast Furnace - Development of a Thermodynamic Approach

**Author(s):** Mr. FLORES, Ismael<sup>1</sup>**Co-author(s):** Prof. BAGATINI, Maurício<sup>2</sup>; Prof. LIMA DA SILVA, Aline<sup>2</sup>; Prof. HECK, Nestor<sup>3</sup><sup>1</sup> *Universidade Federal de Minas Gerais*<sup>2</sup> *Federal University of Minas Gerais*<sup>3</sup> *Federal University of Rio Grande do Sul***Corresponding Author(s):** ismael.flores@ufrgs.br

In the blast furnace, the onset of softening and melting of ferrous burdens give origin to the region known as the cohesive zone, which is critical to process stability and performance. The softening and meltdown temperatures of ferrous burdens are usually accessed by high temperature softening melting (HTSM) apparatus, which can, to some extent, simulate the blast furnace reduction, temperature and mechanical conditions. However, such properties are highly dependent on the formation of eutectic points as well as on the *solidus* and *liquidus* temperatures of the slag phases, whose characteristics cannot be accurately measured during conventional tests. In this regard, the present work evaluates the suitability of computational thermodynamics as a tool for enhancing the comprehension of the ferrous burdens softening and melting phenomena. For that, composition, reduction profile and softening-meltdown properties of a lump ore, a pellet and a super-fluxed sinter (basicity from 0.02 to 2.07) were obtained from literature and used for carrying out thermodynamic calculations. An iterative strategy was adopted to realize equilibrium calculations from 800 to 1550°C, with an incremental step of 10°C, using Gibbs energy minimization principle along with thermodynamic databases from the commercial package FactSage 7.1. The simulation results were used to predict the whole curve of reduction degree as a function of temperature for different ferrous burdens; since reduction degree from thermodynamics is greater than the experimental one, a restriction factor in the available amount of reducing gas was introduced in the simulation procedure for taking into account kinetic and diffusional constraints in practical reduction process. In this way, the theoretical curve can accurately reproduce the experimental one, and the amount of liquid and solid oxide phases, as well as their compositions, can be known for the whole curve of reduction degree. The conceived methodology for thermodynamic simulation showed potential to improve understanding of the alterations originated from high-temperature reduction and the onset of softening and meltdown process. The chemical composition of liquid slag phase and its proportion to solid oxide phases were accessed in details during the course of reduction. A correlation was established between the calculated temperatures for first and maximum liquid phase formation and the experimental pressure drop profiles recorded for different samples, which could make it possible to estimate the temperature of formation and thickness of cohesive zone. Finally, the differences in behavior between sinter, pellet and lump ore were discussed from a thermodynamic viewpoint.

243

## Step wise modifications to BF plants for progressive CO<sub>2</sub> emissions reduction from integrated steel plants

**Author(s):** Mr. AGRAWAL, Anand Kumar<sup>1</sup> ; Mr. KINZEL, Klaus-Peter<sup>2</sup>

**Co-author(s):** Mr. BERMES, Philipp<sup>2</sup> ; Mr. CASTAGNOLA, Cristiano<sup>2</sup> ; Mrs. CASANOVA, Francesca<sup>1</sup>

<sup>1</sup> *Paul Wurth*

<sup>2</sup> *Paul Wurth*

**Corresponding Author(s):** anand.agrawal@paulwurth.com

The iron and steel industry is a source of industrial CO<sub>2</sub> emissions. The BF-BOF route of iron and steel making is considered as the most successful and economic route, hence widely employed for the iron and steel production. To comply with the targets set by the latest “conference of the parties” (COP) for climate change significant additional effort is required to achieve the target CO<sub>2</sub> emission reduction for the steel plants in Europe.

Paul Wurth is employing intensive research and development work in order to assure that the BF-BOF route will be compatible with future environmental and economic environment. In this paper a range of innovative solutions are analysed. The approach followed is a stepwise retrofit based allowing to stretch the required investment over the time according to the effective calendar which will be set by governmental authorities for the CO<sub>2</sub> emissions trade and cap system.

The steps include a more efficient utilization of input carbon to the steel works for the purpose of saving of iron reductant, consideration of reducing agents having a lower CO<sub>2</sub> emission factor, reutilisation of gases for metallurgical purposes, as well as new approaches for substitution of fuel with renewable electrical power. The current study estimates the technical and economic potential of energy saving and CO<sub>2</sub> emission reduction for each step and demonstrates that the BF-BOF route can significantly and effectively contribute to meet the CO<sub>2</sub> reduction targets.

244

## The impact of iron ore ultra-fines addition on granulation in the sintering process

**Author(s):** Mr. LOPES JÚNIOR, Rafael<sup>1</sup>

**Co-author(s):** Mr. LINO OLIVEIRA, Arthur<sup>1</sup> ; Prof. BAGATINI, Maurício<sup>2</sup>

<sup>1</sup> *Federal University of Minas Gerais - UFMG*

<sup>2</sup> *Federal University of Minas Gerais*

**Corresponding Author(s):** rafaellopesjr@gmail.com

Iron and steelmaking industry is in demand to utilize ultra-fine iron ores due to changes in its availability and quality worldwide. Sintering plants are adapting to introduce higher ultra-fines percentage on their mixtures, raising concerns over the cold agglomeration step, critical to maintaining process stability and performance. Sintering bed permeability, granules mechanical properties and size distribution are keen factors that must be taken into consideration to produce high-quality sinter. The purpose of the present paper was to investigate the influence of ultra-fines addition on the cold agglomeration process and its impacts on the formed granules. Mixtures were composed of sinter feed, lime and different ratios of two different ultra-fine iron ores: natural pellet feed (−0.15mm) and grinded pellet feed (−0.045mm). Initially, maximum moisture capacity for all tested mixtures was determined by a capillary ascension test. Thereafter the mixtures were submitted to granulation experiments on a laboratory scale granulation route. The granules produced were assessed through its size distribution by the Safe Analysis on Frozen Elements (SAFE) method, by its Granulation Index (GI), Degradation Index (DI) by shatter test and bed permeability by Japanese Permeability Unit (JPU). In order to understand the impact of ultra-fines on granulation, microstructure analysis of the granules was performed by optical microscopy. The results showed that the addition of ultra-fines increased the maximum moisture capacity of the mixture. It was also possible to observe the impact of ultra-fines on the granulation index, degradation index and bed permeability of tested samples. Optical microscopy showed different ultra-fines arrangements throughout the granules structure, which points out to different granulation behaviors. The addition of iron ore ultra-fines on the tested mixtures affects the granulation process, which can indicate limitations to its use in industrial setups.

245

## A New Method for Calculating Burning lost Rate of Metallurgical Coke during dry quenching process

**Author(s):** Dr. ZHANG, dianwei<sup>1</sup>

**Co-author(s):** Mr. XUE, Limin<sup>2</sup>

<sup>1</sup> *shougang group*

<sup>2</sup> *Shougang research institute of technology*

**Corresponding Author(s):** zdw8010@126.com

Reduce the burning lost rate of coke is the focus of the current CDQ industry, and how to accurately calculate burning lost rate of coke is also a hot topic during the CDQ industry. There are many methods for calculating burning lost rate of coke. Currently, the main methods used to calculate the CDQ burn rate are: consumption of coal method, import air volume method, heat balance method, and so on. There are many drawbacks in these calculating methods, such as, additional testing data are needed, wet quenched coke data are needed, calculation process is complicated, causal factors exist, standard is not uniform, and so on. And all existing calculating methods are for the burning rate of all coke, but the burning rate of metallurgical coke is really concerned by Metallurgical users. Therefore, We propose a method for calculating the burn rate of metallurgical coke by using stable production test data. This method is more meaningful and broad application value than the other existing methods.

246

## Characterisation of PC char in respect to its consumption in the blast furnace

**Author(s):** Mr. HO, Hai Thong<sup>1</sup>

**Co-author(s):** Dr. BABICH, Alexander<sup>1</sup>; Prof. SENK, Dieter<sup>1</sup>; Mr. GEYER, Richard<sup>1</sup>

<sup>1</sup> *RWTH Aachen University*

**Corresponding Author(s):** babich@iehk.rwth-aachen.de

The rising amount of injected through the tuyeres pulverised coal makes increasingly difficult its conversion within the raceway zones despite of numerous measures to improve gasification of coal particles. Unburnt particles can nevertheless be partly consumed outside the raceway by so called secondary conversion reactions. From this point of view, properties of char that leaves the raceway were in the focus of current study. Chars from two coals with the same grain size distribution were produced artificially in a laboratory furnace at pre-defined conditions in order to find out differences in char properties depending on reaction temperature and coal type. Next to chemical composition that revealed among others volatile yield, petrographic properties has been determined using an oil-immersion microscope. All char samples showed complete disappearance of liptinite phases whereas a significant increase of inertinite was determined with increasing reaction temperature. This effect was in correlation with volatile yield. Physical properties showed an extreme increase in specific surface area by transformation of coal to char which was determined using BET analysis. Microscopic analysis showed high porous particle whereas the average particle size remained almost unchanged and bulk density decreased. However, changes of physical properties were only immense in comparison to its parent coal. Activation energy was determined for coals and chars. A correlation of volatile matter and specific surface area could be identified. The artificially produced char was compared with char generated by injection trials using the MIRI plant simulation the raceway conditions.

247

## Experience of blow-in after long stoppage of BF 2 in JSW Steel, Vidyanagar

**Author(s):** Mr. NAGARAJAN, Mohanraj<sup>1</sup>

**Co-author(s):** Mr. PANDEY, Shashank kumar<sup>1</sup>; Mr. AKULA, Harikrishan<sup>1</sup>; Mr. SINGH, Naveen<sup>1</sup>; Mr. RAO, Srinivas<sup>1</sup>; Mr. SINGH, Lokendraraj<sup>1</sup>

<sup>1</sup> JSW Steel Limited

**Corresponding Author(s):** mohanraj.nagarajan@jsw.in

JSW Steel Ltd, (Vijayanagar) is 12 MTPA integrated steel plant with 2 COREX (0.8MTPA), and 4 BF's (BF- 1, 2, 3 & 4) with inner volumes of 2300m<sup>3</sup>, 1681m<sup>3</sup>, 4019m<sup>3</sup> and 4019m<sup>3</sup> respectively. Iron Zone unit consist of 4 Sinter Plant, 2 Pellet plant & 4 Coke Ovens to supply raw material to these iron making units. Due to insufficient coke capacities of in-house coke ovens to match the iron making unit's requirement, coke is imported from China & Australia. BF1 & 2 are operating with 60 % imported coke, with fuel rate of 598kg/thm & 594 kg/thm and productivity 2.46 & 2.25 m<sup>3</sup>/t/d (WV) respectively. During the global economic slowdown in October-2016 onwards and increased cost of imported coke, cost of HM production has increased sharply. The Company had to mitigate the production as one of its strategy and to facilitate increased usage of agglomerates in other blast furnaces and in turn the reduction in fuel rate. BF-2 being a smallest with low productivity and high fuel rate, was chosen for longer stoppage of 44 days (Commissioned in Aug -2006). Furnace was blown down on 4th Nov-16 up to the tuyere level without salamander opening. Blow down process took 13 hours to complete. Shotcreting was done from tuyere level to throat before blowing-in on 18th Dec -16 and furnace normalised within 46 hours of un-interrupted operation. This paper shared the practical experience of Blow-down, shotcreting, blow in techniques and quick normalisation.

248

## Experience with Continuous Temperature Measurement in a Blast Furnace Runner

**Author(s):** Mr. YARDY, James<sup>1</sup>

**Co-author(s):** Mr. MARSHALL, Rob <sup>2</sup> ; Mr. PAGDEN, Steve <sup>1</sup> ; Mr. HUGHES-NARBOROUGH, Phil <sup>1</sup>

<sup>1</sup> *Heraeus Electro-Nite (UK) Ltd*

<sup>2</sup> *British Steel, Scunthorpe*

**Corresponding Author(s):** philip.hughes-narborough@heraeus.com

This paper will explain the method of measuring the hot metal temperature in the blast furnace runner continuously. A summary of the recent experience with the implementation of continuous temperature measurement systems at Scunthorpe's Queen Anne and Queen Victoria furnaces is outlined. The hot metal temperature of blast furnace runner to some degree reflects the temperature & conditions within the blast furnace itself and good blast furnace control should result in a constant and stable temperature of the tapped hot metal. However, good control is made more difficult as more demand is made on output, as the blast furnace conditions are more sensitive to variation in inputs. Temperature in the blast furnace is only a part of control, however, it is an important part. With the trend to replace burden coke with injected coal, there are more dynamic means for BF temperature control available than in the past. Individual hot metal casts trend to a maximum temperature value which is easily followed using continuous measurement, but not reliably followed using spot measurement. Trends cycle can vary from (<50h) up to (>90h), and a new trend direction can be readily identified within one cast using continuous measurement. Continuous hot metal temperature trend could feed into the models used for blast furnace control and changes (trends) in hot metal temperatures within each cast. The possible benefits of continuous temperature monitoring include: • Reduce energy input • Address refractory /maintenance issues • Control chemistry, primarily silicon and phosphorus • Avoid emergency corrective actions • Help improve slag output control.

249

## Study of the Alumina Effects on Iron Making Process through Pilot Scale Test and Numerical Simulation

**Author(s):** Dr. PEREIRA, Bruno<sup>1</sup>

**Co-author(s):** Mr. DUTRA, Eider <sup>1</sup> ; Mr. PIMENTA, Felipe <sup>1</sup> ; Dr. NOGUEIRA, Paulo <sup>1</sup> ; Dr. CASTRO, José Adilson <sup>2</sup>

<sup>1</sup> *Vale SA*

<sup>2</sup> *Universidade Federal Fluminense*

**Corresponding Author(s):** bruno.amaral@vale.com

Several efforts have been done to improve the iron making process performance regarding metallic burden. To increase efficiency, reduce fuel consumption and cost of hot metal the reduction of some raw material impurities is needed. In this context, the alumina content of iron ore can be harmful in the Sintering Process, producing sinter with inferior physical properties, decreasing the sinter machine productivity. It also impacts the metallurgical properties of the sinter, that impact the Blast Furnace operational parameters such as pressure drop and productivity. Since industrial tests are very expensive to measure the iron ores performance, pilot-scale pot-grate sinter and numerical simulation is largely used instead. In this work, a pilot-scale test was used to produce sinter with high and low alumina content, with different iron ores. The alumina impact in the Blast Furnace was estimated with a CFD (Computational Fluid Dynamics) model that takes into account the main phenomena inside of the reactor. The pilot-scale test results show that the sinter with higher alumina has lower tumbler index (TI) and reducibility (RI) and higher reduction degradation index (RDI). The numerical simulation results show the RDI and RI impacts on the Blast Furnace process, leading to a higher pressure drop and decreasing the productivity.

250

## High-Temperature Behavior of Self-reducing Composites from BF Flue Dust and Mill Scale

**Author(s):** Prof. BAGATINI, Maurício<sup>1</sup>

**Co-author(s):** ARCEBISPO FERNANDES, Thiago<sup>1</sup>; Mrs. TEODORO SILVA, Rúbia<sup>1</sup>; Mr. FLORES, Ismael<sup>2</sup>

<sup>1</sup> *Federal University of Minas Gerais*

<sup>2</sup> *Universidade Federal de Minas Gerais*

**Corresponding Author(s):** bagatini@demet.ufmg.br

The decreasing quality of the raw materials used for the production of iron and steel and the constantly rising of environmental concerns, strengthen the need to internally recycle the wastes generated by the industry. Due to the rich iron and carbon content of some of those wastes, many researchers suggested their potential for the production of self-reducing agglomerates targeted for reduction reactors. However, to extend and consolidate such application, the agglomerates behavior regarding industrial scenarios such as non-isothermal heating and mechanical requirements must be considered. The present research focus on evaluating the performance of self-reducing agglomerates composed by BF flue dust and mill scale at high temperatures. Initially, agglomerates with varied C/O ratios were produced in a laboratory from different proportions of BF dust and mill scale, using water and cement as binders. The agglomerates were submitted to non-isothermal reduction tests using CO/CO<sub>2</sub> atmosphere in a horizontal tubular furnace. Samples were heated at 10°C/min until maximum temperatures of 300, 600, 900 and 1200°C were reached, followed by rapid cooling. The samples obtained were evaluated by means of mass and mechanical strength variations. The phase composition and microstructure obtained in such conditions were accessed by X-ray diffraction analysis and scanning electron microscopy. To evaluate the agglomerates performance from heating until meltdown softening and melting experiments were carried out. For that, the samples were arranged between coke layers and heated until 1550°C at 5°C/min in a reducing atmosphere (70%N<sub>2</sub>-30%CO) while a vertical load (98kPa) was applied. The contraction and pressure loss over the bed were continually monitored, allowing to access the temperatures where degradation/softening and melting of the agglomerates occurred. The results obtained pointed out the mechanical strength variations and its relationship with the reduction behavior and the different ratios of BF dust/mill scale of the agglomerates. Best proportions between the used wastes into the agglomerates were identified. The monitoring of the chemical and morphological alterations due to the high temperature tests contributed to understand the physicochemical phenomena observed.

251

## REFRACTORY CASTABLES FOR BLAST FURNACE MAIN

## TROUGHS: New developments for severe operating conditions

**Author(s):** Mr. DOMICIANO, Vitor Guarnier<sup>1</sup>

**Co-author(s):** Mr. RIBEIRO, Aloísio Simões<sup>1</sup>; Mr. BASSALO, Humberto Chiaretti<sup>1</sup>; Mr. BRITO, Modestino A. M.<sup>1</sup>

<sup>1</sup> *RHI Magnesita*

**Corresponding Author(s):** vitor.domiciano@rhimaginesita.com

The need to improve the monolithic refractories' properties to endure the increasingly severe and unstable Blast Furnace main troughs operating conditions has been a major challenge for refractory suppliers in order to guarantee the runners' safety and its availability for casting operation. Different main trough's wear profiles have been noticed so far which require optimized adjusts in refractory castable's formulation to meet the customers' needs. This paper presents the main properties of 2 new Al<sub>2</sub>O<sub>3</sub>-SiC-C refractory castables (CBV - cement bonded installed by vibration; SBS - sol-bonded installed by shotcrete) developed to endure the severe corrosion mechanism that occurs at the main troughs slag & metal lines which constantly requires a special attention of casthouse operators. Field tests carried out in large-scale production Blast Furnaces main troughs revealed a decrease of the refractory lining wear speed using these new refractory castables developed leading to a safe and reliable Blast Furnace casthouse operation.

252

## Recent Research [U+FF06] Development topics of Iron-making Technologies in NSSMC

Dr. SAITO, Koji<sup>1</sup>

<sup>1</sup> *Nippon Steel & Sumitomo Metals Corporation*

**Corresponding Author(s):** saito.5m5.koji@jp.nssmc.com

The last decade was a turbulent for the steel industry. The reorganization of steel industry across borders has progressed and the increased demand for steel products has made the price of raw materials such as iron ore and metallurgical coal more volatile than ever. Ironmaking technology division in NSSMC has been exposed to global competition and has tried to cope with these changes and to increase its international competitiveness by developing such technologies as utilization of lower grade raw materials, productivity enhancement, measures for energy conservation and reduction of CO<sub>2</sub> and NO<sub>x</sub> emission and so on. This paper describes the recent progress in ironmaking technologies in NSSMC.

253

## Structural Characterization of Coke from the Tuyere Region of the Blast Furnace

**Author(s):** Dr. BHATTACHARYYA, Anrin<sup>1</sup>

**Co-author(s):** Dr. RANTITSCH, Gerd<sup>1</sup>; Prof. SCHENK, Johannes<sup>1</sup>; Mr. GÜNBATI, Ahmet<sup>2</sup>; Dr. JANHSEN, Urban<sup>2</sup>

<sup>1</sup> *Montanuniversitaet Leoben*

<sup>2</sup> *thyssenkrupp Steel Europe AG*

**Corresponding Author(s):** anrin.bhattacharyya@unileoben.ac.at

Coke, the main fuel of the blast furnace (BF) process, undergoes significant structural changes both in the macro- and microstructural level during its descend through the BF. To investigate some of these properties of coke, samples have been taken by drilling through one of the tuyeres on an actual BF. The aggregate mass has been processed to separate the coke pieces from it. These samples have been characterized using several sophisticated techniques like Raman Spectrometry, BET analysis, X-Ray diffraction etc. The results have been compared to the similar properties of the parent coke. The results from these investigations will not only help us to analyze the changes in the coke structure in a deeper way, but also helps the BF operator to predict its quality during the process, providing in turn the promise of a better operation.

254

## Conversion of mill scale waste into high purity pig iron suitable for ductile cast iron production

**Author(s):** Dr. GHALI, Saeed<sup>1</sup>

**Co-author(s):** Prof. EISSA, Mamdouh<sup>2</sup>; Prof. EL-FARAMAWY, Hoda<sup>2</sup>; Prof. MATTAR, Taha<sup>2</sup>; Prof. AHMED, Azza<sup>2</sup>; Dr. ELEWA, M<sup>3</sup>

<sup>1</sup> *Central Metallurgical Research & Development Institute (CMRDI)*

<sup>2</sup> *CMRDI*

<sup>3</sup> *El Nasr Casting*

**Corresponding Author(s):** a3708052@gmail.com

In Egypt, the crude steel production has increased significantly with higher growth rate in the past years of the 21st century. Furthermore, many mill steel companies have been established for steel processing. With the increase in steel production and steel processing, a large amount of waste materials (slag, dust and mill scale) are produced. Mill scale is one of these waste materials produced during preheating of steel slabs and billets before hot rolling in all iron and steel companies and its specific production is about 20-40 kg/ ton of hot rolled product. The mill scale generated from the hot rolled steel products in Egyptian integrated and processing steel companies is amounted 200000 tons annually. This bi-product mill scale is mainly iron oxides and considered a rich iron source. On the other hand, high purity pig iron is used in the production of ductile cast iron. Its consumption is about 25% of the produced ductile cast iron. All needs of high purity pig iron for Egyptian industry are imported. This work aims at recycling of mill scale by adjusting smelting process to produce high purity pig iron. Different heats of smelting process were carried out at submerged arc furnace using different reductants and different fluxing materials to adapt an economic smelting process for producing high purity pig iron with minimum Mn, P, S and other impurities and attain the highest recovery and output. By using the optimum condition, high purity pig iron is obtained with chemical composition conforming the requirements to be used in the production of ductile cast iron. The industrial application of the produced high purity pig iron revealed good mechanical properties of the cast product conforming the requirements of ductile cast iron and the microstructure observation confirmed the obtained mechanical properties.

255

## Research on the Dropping Mechanism of Iron Raw Material in Process of Blast Furnace Ironmaking

**Author(s):** Dr. YAN, Bingji<sup>1</sup>

**Co-author(s):** Dr. GUO, Hongwei<sup>1</sup>; Dr. LI, Peng<sup>1</sup>; Dr. CHEN, Dong<sup>1</sup>; Mr. LI, Hongwei<sup>1</sup>

<sup>1</sup> *Soochow University*

**Corresponding Author(s):** bjyan@suda.edu.cn

Dropping behavior of ferrous material plays an important role in the liquid and gas permeability of the lower part of blast furnace. Most of the current studies are based on the reduction of soft melt dripping behavior of ferrous materials, failed to elaborate dropping process, especially for the drop zone where the interaction occurs between the coke layer and the falling matter. Therefore, it is of great significance to investigate the behavior of the drop material in the process of iron containing material reduction through the coke process, to clarify the dripping performance of the iron containing material and to analyze the behavior of the lower part of the blast furnace. In this work, the flow behavior of slag and iron in the dropping zone of the lower part of an iron blast furnace was simulated by adding drops to the laboratory scale coke packed bed. In the early stage, different kinds of dripping material containing iron were obtained by droplet experiment, a list of constituents obtained from drops by detecting its components after grinding and screening. Different flow processes and behaviors of different slag and iron drops under the same coke bed condition are compared to measure the parameters such as the drop start temperature, the end drop temperature, the drop amount and the retention rate, and to analyze the coke penetration and dripping behavior of various kinds of iron containing burden and synthetic burden. It is concluded that the retention rate of sinter during coke penetration is higher than other kinds of iron containing material, and it is more difficult to flow through the coke penetration process.

Lump ore and pellet containing titanium stranded more serious than ordinary lump ore and pellets; fluidity of lump ore and pellet containing titanium is also worse than that of ordinary ones and the time through the coke layer is longer. There is a similar rule in the mixing burden, but the dropping behavior with Ti containing composite charge is better than that of single titanium containing charge. The research also explain the function of composite furnace charge in burden optimization.

258

## Increasing the efficiency of biomass product injection into the blast furnace

**Author(s):** Dr. BABICH, Alexander<sup>1</sup>

**Co-author(s):** Mr. HIPPE, Frederik<sup>1</sup> ; Prof. SENK, Dieter<sup>1</sup> ; Mr. SOLAR, Jon<sup>2</sup> ; Prof. DE MARCO, Isabel<sup>2</sup>

<sup>1</sup> RWTH Aachen University

<sup>2</sup> School of Engineering of Bilbao

**Corresponding Author(s):** babich@iehk.rwth-aachen.de

The benefits of biomass usage as renewable energy source and reducing agent in the steel industry, particularly, by its injection into the blast furnace tuyeres is known. This contribution focuses on two aspects, which could increase the economic efficiency of this technology. The first one is related to the thermal treatment of biomass. Woody biomass waste and biomass residues were pyrolysed in a laboratory scale screw continuous reactor at different temperature profiles. Besides charcoal, yields of organic liquid and a gas mixture consisting of carbon oxides, light hydrocarbons and hydrogen were considered. The share and quality of these three fractions can be controlled by the pyrolysis parameters such as temperature, heating rate, residence time or presence of catalysts. The second aspect is related to the optimisation of grain size of injected solids. Different grain size fractions in the range from about 0.1 to 1.8 mm were prepared and tested using a batch injection rig. Furthermore, microstructure of samples were examined. Results were compared with PC. It was concluded that coarser grinding of charcoal than that for coal can be sufficient for its conversion in the blast furnace raceway. The microstructure of charcoals may have a great influence on their conversion behaviour along with the chemistry. The effect of injection rate on conversion rate depends on grain size of charcoal.

259

## Evaluation of Sintering Behavior of Various Iron Ore Types

**Author(s):** Mr. HIGUCHI, Takahide<sup>1</sup>

**Co-author(s):** Dr. LU, Liming<sup>2</sup>

<sup>1</sup> JFE Steel Corporation

<sup>2</sup> CSIRO

**Corresponding Author(s):** liming.lu@csiro.au

The qualities of iron ores have been deteriorating, which has influenced sinter quality and productivity adversely. In the sintering process, iron ore fines, fluxes such as limestone and coke breeze, are granulated, then charged and fired in a sinter machine. Sinter quality and productivity are strongly affected by the formation of initial sinter melt, assimilation and penetration into nucleus particles by the initial melt, and solidification of sinter melt. Especially, the assimilation degree and penetration depth depend on the characteristics of individual ores. However, the effect of ore mineralogy on these sintering reactions has not yet been studied in details. In this study, a simple evaluation method was proposed using mini-tablets consisting of coarse particles from various iron ore fines as nucleus particles and chemical reagents or iron ore fines as matrix forming materials. Iron ores were selected to represent various textures ranging from dense to porous ore types from Australia and Brazil. Tablets were fired under simulated sintering conditions to investigate the penetration and assimilation behavior of different ore types. The assimilation and pore structure of resultant analogue sinters was also evaluated and the role of ore mineralogical texture was further discussed.

260

## Properties and Performance of Tap Hole Clays with Respect to Stable Blast Furnace Operations

**Author(s):** Dr. DEMUS, Thorsten<sup>1</sup> ; Dr. PAWLIG, Oliver<sup>2</sup>

**Co-author(s):** Dr. SCHEPERS, Ansgar<sup>2</sup>

<sup>1</sup> *Beck u. Kaltheuner Feuerfeste Erzeugnisse GmbH & Co. KG*

<sup>2</sup> *Beck u. Kaltheuner Feuerfeste Erzeugnisse GmbH & Co. KG*

**Corresponding Author(s):** oliver.pawlig@beka-feuerfest.de

Blast furnace taphole clays can be extremely sophisticated refractory products. The correct selection is affected by several blast furnace operating factors. The complexity of these formulations mirrors the multitude of often conflicting properties and characteristics that are demanded from the modern day taphole clay, e.g. refractory properties, plasticity, erosion stability and the suitability to form a compact leak-proof plug. However, the taphole clay manufacturer not only has to address these 'service' requirements but increasingly there is pressure to meet demanding health and safety as well as environmental standards. The finished product may not look that impressive when stacked on a pallet but this material represents the culmination of significant knowledge and experience in terms of materials technology design. It is our experience that quite often products need to be modified, even custom designed to adapt to a specific furnace or operating practice. Also it is not always the largest furnaces that represent the biggest challenge. We will report about challenges for the complete product chain from raw material selection, production to final application and how to overcome especially operational difficulties.

261

## A Green and Sustainable Process of Iron ore Smelting Reduction by Hydrogen Plasma

**Author(s):** Mr. BEHERA, Pravas Ranjan<sup>1</sup>

**Co-author(s):** Dr. BHOI, Bhagyadhar<sup>2</sup> ; Dr. PARAMGURU, Raja Kishore<sup>3</sup> ; Prof. MISHRA, Barada Kanta<sup>4</sup>

<sup>1</sup> *Ph.D. candidate, SMaRT Centre, School of Materials Science and Engineering, UNSW, Sydney, New South Wales, Australia*

<sup>2</sup> *Chief Scientist and HOD*

<sup>3</sup> *Professor, School of Mechanical Engineering; Director, Students Research Centre, Kalinga Institute of Industrial Technology, Bhubaneswar, India*

<sup>4</sup> *Director, IIT Goa, India*

**Corresponding Author(s):** p.behera@student.unsw.edu.au

The current work reports successful smelting reduction of iron ore (hematite) in thermal hydrogen plasma for the very first time in 1 to 5kg scale. A state-of-the-art plasma reactor with water cooled copper crucible, an electromagnetic coil underneath the copper crucible for easy agitation of the molten bath, and hydrogen as the reductant were used to demonstrate the process in 1kg scale. Further, the 5kg scale smelting studies indicated the crucial role that the ratio of the height of the molten bath to the diameter of the reactor plays as a determining factor for effective hydrodynamics and the subsequent degree of reduction. It also is a vital factor for further scaling up of this process. Also, the rate of the process is influenced by the stoichiometric requirement of hydrogen in place of time. When combined with the degree of reduction, this number helps determine the degree of hydrogen utilization in the process.

262

## LKAB experimental blast furnace, an important tool in development of products and processes for sustainable iron-making

EKLUND, Nicklas<sup>1</sup> ; PETTERSSON, Mikael<sup>2</sup>

<sup>1</sup> LKAB - Research & Development

<sup>2</sup> LKAB - Sales and Logistics

**Corresponding Author(s):** melanie.baumgartner@asmet.at

Since LKAB decided to invest in a pilot scale blast furnace in 1996, the equipment has over the years produced a significant amount of data and results for improvement of products and processes within ironmaking. The experimental blast furnace has played a vital role in many research projects, producing important results which simplify the decisions whether to move into larger scale or continue development. The Experimental Blast Furnace has not only been an important tool for LKAB product development but also contributed to the continues improvements for ironmaking technology. Since the start, various burden materials has been tested together with different types of injection materials. Larger joint projects like ULCOS and Course50 has been developing and testing ideas in pilot scale in order to evaluate possible routes for a more environmentally friendly production. Also individual customer support projects has been conducted where detailed analysis of burdening materials from blast furnace atmosphere has been sampled and evaluated. For the future, the EBF will hopefully continue to be a part in the strive to minimize environmental impact and increase energy efficiency within the field of ironmaking. It will also continue to be a vital part in the development of LKAB high grade products, ensuring that every new product or development is thoroughly tested before being introduced to customers.

264

## Effects of slag chemistry on liquidus temperatures of high titania slags

Prof. ZHAO, Baojun<sup>1</sup>

<sup>1</sup> The University of Queensland

**Corresponding Author(s):** baojun@uq.edu.au

High temperature experiments have been undertaken using equilibration, quenching and EPMA technique to characterise the phase equilibria of high Ti-containing slag systems. The experimental results have been presented in the form of pseudo-binary sections to show the effects of CaO, TiO<sub>2</sub> and oxygen partial pressure on liquidus temperatures.

The primary phases observed in the composition range investigated include pseudobrookite M<sub>3</sub>O<sub>5</sub> (MgO·2TiO<sub>2</sub> – Al<sub>2</sub>O<sub>3</sub>·TiO<sub>2</sub>), spinel MgO·(Al<sub>3+</sub>,Ti<sub>3+</sub>)<sub>2</sub>O<sub>3</sub>, perovskite CaTiO<sub>3</sub> and rutile TiO<sub>2</sub>. The liquidus temperatures were found to decrease in the TiO<sub>2</sub> and M<sub>3</sub>O<sub>5</sub> primary phase fields with increasing CaO concentration and increase in the spinel and CaTiO<sub>3</sub> primary phase fields with increasing CaO concentration.

The experimentally determined liquidus temperatures were found to be in general significantly higher than those predicted by FactSage model. Experimental data and FactSage predictions show that the liquidus temperatures under reducing conditions are higher than those in air.

265

## Effect of MgO content in structural and physical properties of iron ore pellets

**Author(s):** ANDRADE, Roberto<sup>1</sup>

**Co-author(s):** MOURAO, Marcelo <sup>2</sup> ; RIBEIRO, Tiago <sup>1</sup>

<sup>1</sup> Sao Paulo State Institute of Technological Research

<sup>2</sup> University of Sao Paulo

**Corresponding Author(s):** mbmourao@usp.br

Iron ore pellets swelling is a subject that raises concern in metallurgical industry because of the problems it may cause during reduction processes. Several factors can change pellets behavior concerning swelling, such as binary basicity (CaO/SiO<sub>2</sub>) and the MgO content. Experiments were performed to evaluate the effect of MgO content for pellets of several basicities in the physical properties of the pellets, such as compression strength and porosity. Their behavior during

reduction was also evaluated for parameters such as reduction degree and swelling degree. MgO was added up to 5% and basicity varied in a range from 0.61 to 1.5. Addition of MgO increased porosity in about 15% and also reducibility, while swelling decreased about 34% for 1% of MgO and 7,5% for 5% MgO due to sintering of the reduced iron. Strength also decreased about 67% for higher MgO content, from an average of 428 kgf/pellet to 138.6 kgf/pellet.

266

## How laser based element analysis reduces costs, supports stable processes and increases flexibility in modern iron production

**Author(s):** Mr. SCHLEMMINGER, Alexander<sup>1</sup>

**Co-author(s):** Mr. HOFMANN, Karsten<sup>1</sup>

<sup>1</sup> *SECOPTA analytics GmbH*

**Corresponding Author(s):** alexander.schlemminger@secopta.de

### Content

1. Initial situation
2. New requirements lead to innovative analysis methods
3. Applicable applications for LIBS based smart process control
  - 3.1 Applicable applications –LIBS on the feeding side
  - 3.2 Applicable applications –LIBS in the melt shop
  - 3.3 Applicable applications –LIBS in the milling, rolling and processing lines
  - 3.4 Applicable applications –LIBS in the laboratory
4. LIBS capabilities
5. Industry proven even in harsh environments
6. Summary

### 1. Initial situation

In iron making, wet-chemical, spectroscopic and radiometric methods are well established for a long time already. Nonetheless, the industry is struggling with certain shortcomings or disadvantages of these methods and is increasingly asking to overcome such limitations. Some analysis methods are contacting, some may require tedious sample preparation, some are using harmful ionizing radiation, some cannot measure all elements equally, some require a long time until results are available. To make steel production smart a method would be desirable that is universally applicable, provides results continuously, very quick and is easy to use.

That would be too good to be true, would it? Well, as already seen in many other applications, the use of lasers can open up new possibilities.

### 2. New requirements lead to innovative analysis methods

Ever increasing competition and rising demands on timely fault-free shipments of ever smaller lot sizes have already led to continuous process improvements in steel mills, e.g. by use of laser sensors for real-time measurement of physical properties, like thickness, width, flatness, length etc. With those properties being no longer a major concern, tighter control of other material properties is gaining more attention, namely alloy (chemical) composition of feeder materials.

Tackling the challenge of inconsistent raw materials quality in iron making due to global sourcing of input materials, has also increased the need of continuous monitoring of feeding materials. Input streams that need to be analysed permanently are: - the calorific value and acidity, - the ash percentage - the sulphur and volatile contents of coal - the swelling of coal when coking, - the iron content in the iron ore - the basicity of iron ore - the variety of elements introduced by scrap recycling. - ...

By knowing what material quality is on hand, corrective action can be taken by targeted addition of deficient elements before or while charging, or by rejection of certain other material batches.

### **3. Applicable applications for LIBS based smart process control**

Analysis of the elemental composition is required or desirable in multiple steps and locations of steel making and steel rolling.

Let's have a look at some typical iron industry applications requiring elemental analysis to judge how close this technology can come to above mentioned ideal for the metals industry.

1. Continuous monitoring of the raw feeder materials like coal, coke, limestone, iron ore, scrap metals, sinter etc. on conveyors for charging control of sinter plants, blast furnaces and electric arc furnaces
2. Analysis of the slag composition at furnaces and converters, in solidified or even hot liquid state.
3. Analysis of the composition of steel samples, in solidified or even hot liquid state
4. Identification of alloy changes at the cooling bed exit, especially for SBQ mills, for proper allocation of all partial lengths to the initial billet and rolling order
5. Identification of alloy changes at the end of the (cold) finishing line for proper allocation of each individual rod to the proper shipment batch according to the production schedule
6. Analysis and sorting of head, tail and cobble croppings for alloy-true remelting of internal scrap, avoiding contamination of melts with unwanted elements.
7. 100% material identification at the charging side of reheat furnaces to ensure proper loading according to the production scheduling
8. 100% material identification after de-scaling to ensure proper alloy scheduling at the rolling train entrance.

#### **3.1 Applicable applications –LIBS on the feeding side**

Production of the desired steel grade according to Industry 4.0 smart and in the shortest amount of time already begins when charging the (blast or EAF) furnace: Is the proper mix of materials fed to the furnace at the right time, in the right amount? LIBS sensors installed at the charging side allow precise identification and quantification of the currently charged materials, e.g. to avoid charging copper or other detrimental elements, to prevent mishaps in the charging sequence, as well as to charge fluxes in the right composition and basicity range. By ensuring charging of all required elements in the optimum mixture, time consuming analysis and correction phases in the smelting process can be reduced, thus improving the utilization significantly.

#### **3.2 Applicable applications –LIBS in the melt shop**

In melt shops, two different measuring methods are commonly in use. One system is to analyse iron and another one is to analyse slags. With LIBS, just one system can do it all.

In smelting and in ladle metallurgy, LIBS sensors can precisely determine the composition of slag and metal in real-time because they can measure in hot liquid state already. Thus time-delays incurred by conventional analysis methods requiring cooled down solid samples as well as tedious sample preparation are eliminated. E.g. the optimum tapping point can be determined with continuous monitoring of the iron oxide content in the slag almost to the second

Providing immediate results LIBS allows the production process to meet the target slag and alloy compositions much quicker. Hence in these process steps, not only utilization, but also yield can be improved by using LIBS analysis.

### 3.3 Applicable applications –LIBS in the milling, rolling and processing lines

Further downstream, Positive Material Identification (PMI) by LIBS sensors in rolling mills and processing line, starting at the reheat furnace entry, down to the finishing line exit, helps all mills dealing with frequent alloy changes. For this purpose, FiberLIBS Inline systems with a compact, separate sensor head, mounted at a suitable location of the respective conveyor system, are the ideal solution.

Automatically measuring the composition of each work piece as it passes by on the conveyor, and comparing it against the alloy specification given in the production schedule, detects deviations or confusions immediately. By not only eliminating material confusion, but also allowing to cut down on gaps in the rolling sequence (which now seem to be the common practice to keep different alloys separate) mill utilization can be improved, and costly complaints and rejects due to confused alloys can be avoided.

In times of increasing flexibility requirements PMI is a significant improvement especially for SBQ producers dealing with highly customized products.

### 3.4 Applicable applications – LIBS in the laboratory

Last not least, also in metallurgy labs, LIBS systems can help to increase throughput of sample measurements. It can also solve demanding analysis tasks, like penetration of refractories by alloy elements, fast measurement of segregation effects and patterns in metal samples of almost any size, analysis of even smallest inclusions in metal samples, and so forth. LIBS capabilities Compared to other OES (optical emission spectroscopy) methods LIBS can:

- Analyse all known elements, regardless of their atomic weight. There is no limitation regarding „light“ elements.
- Electrically conductive as well as nonconductive materials can be analysed.
- LIBS analysis can be carried out from a distance without any physical contact
- The analysis is very fast, with precise results available within milliseconds
- The measurements can be carried out at a high repetition rate up into the kHz range, making it ideally suitable for moving parts with velocities up to 3 m/s and more
- Due to the very small spot size, the LIBS method provides a very good spatial resolution, which helps especially with the analysis of elemental distribution of heterogeneous materials.
- In LIBS spectroscopy, no harmful ionizing radiation is present.
- LIBS analysis typically does not require any material preparation, but can be carried out without sampling directly in the regular production material flow

## 4. How does LIBS work?

A high-energy laser pulse of very short duration (typically 1 to 40 mJ, 1 to 100 ns duration) is focused on the surface of the material to be inspected, generating a plasma fume of the material surface. In this process, some material is ablated, generating a „crater“ of 15 nm to 5µm depth and 20 to 100 µm diameter, depending on the parameters of the laser in use. Upon recombination of the plasma (also called breakdown), the electrons falling back on their original orbits emit photons (normally visible as light flash) with wavelengths characteristic for the specific elements. („spectral finger print“) A high-resolution spectral analysis of the emitted light (in NIR, VIS and UV, depending on the respective elements) with chemometric methods does not only allow to identify which elements are present, but also a fairly precise computation of their relative amounts.

## 5. Industry proven even in harsh environments

The long stand-off distance, combined with a very fast autofocus system of the MineralLIBS, allows the installation in a safe distance above conveyors, measuring on the unconditioned regular material stream. Due to the high measuring frequency and the small spot size, even small impurity events in the measurement track of the material flow can be registered.

## 6. Summary

LIBS is a versatile measurement method addressing current needs and challenges of a globalized world regarding analysis of elemental composition in the metals industries.

It has a big potential for improvements of yield and utilization in multiple stages of the production processes, thus enabling metal producers and processors to reduce secondary processing (e.g. waiting) times as well as sourcing costs. In addition LIBS helps to increase process stability and product quality.

267

### Phase Transformation and Density Variation Prediction of Hematite Ore Particles in the Flight Melting and Reduction

**Author(s):** Dr. CHEN, Zhiyuan<sup>1</sup>

**Co-author(s):** Dr. QU, Yingxia<sup>2</sup>; Dr. ZEILSTRA, Christiaan<sup>3</sup>; Mr. VAN DER STEL, Jan<sup>3</sup>; Prof. SIETSMA, Jilt<sup>1</sup>; Dr. YANG, Yongxiang<sup>1</sup>

<sup>1</sup> *TU Delft*

<sup>2</sup> *Northeastern University, China*

<sup>3</sup> *Tata Steel, Ijmuiden*

**Corresponding Author(s):** z.chen-5@tudelft.nl

HIsarna is an emerging and promising alternative ironmaking process. Smelting cyclone is used to melt and pre-reduce fine and un-agglomerated iron ore particles in HIsarna reactor. Fine ore and flux are injected in the smelting cyclone together with oxygen. The injected ore is intensely mixed with rising hot reducing gases, undergoes partial reduction and melting. The melt hits the water-cooled sidewalls of the cyclone section and flows down along with the wall and into the liquid bath in the smelting reduction vessel (SRV) where the final reduction takes place. The ore in the cyclone section is pre-reduced to a degree of about 20% through thermal decomposition and reduction by the SRV gas. The temperature of the melt is approximately 1450 °C. Variation of ore particles' state is difficult to observe inside the cyclone. Therefore, theoretical estimation is extremely important under these conditions. Phase transformation is an essential information for reaction analysis. In addition, density of particles is necessary to estimate the residence time of particles in the cyclone. They were investigated in this study. Phase transformation of iron particles were experimentally studied in simulating cyclone conditions and compared with thermodynamic calculation results. During the reaction process, mineralogy of iron ore particles transforms from hematite to sub-oxides sequentially. The density of particles can be predicted in the reduction based on the phase composition. Therefore, previous density models were evaluated with reported experimental data of slag. As a result, a suitable density model has been developed to calculate the density of slag mainly with FeO-Fe<sub>2</sub>O<sub>3</sub> contained. Density of the reduced ore particles was estimated based on this model. The results show that reduction of the ore could lead to about 10 % shrinkage of the particles. On the contrary, melting contributes around 10 % swelling of the ore particles. It would result corresponding variation of reaction time in flight.

268

### Development and Application of Key Process Technology and Equipment for New Generation No-bell Top of Blast Furnace

**Author(s):** Mr. ZHENG, JUN<sup>1</sup>

**Co-author(s):** Mr. LIU, BO<sup>2</sup>; Mr. CHEN, XIAOGUANG<sup>3</sup>; Mr. ZOU, ZHONGPING<sup>1</sup>; Mr. XIONG, SHIGEN<sup>1</sup>

<sup>1</sup> *CISDI Engineering Co. Ltd*

<sup>2</sup> *Baosteel Zhanjiang steel Co. Ltd*

<sup>3</sup> *Qinye Heavy Industry Co. Ltd*

**Corresponding Author(s):** jun.a.zheng@cisdi.com.cn

Abstract: No-bell top is one of the most important and crucial equipments in the blast furnace system. Along with the development of large-scale blast furnace, hot blast stove and PCI technology, the blast furnace top pressure and temperature are constantly increasing. At the same time with varies of intensified smelting method, the top charging system is challenged by more high-standard and more strict demands. A new generation no-bell top key technology and equipment have been developed, which features excellent process characteristics, high control accuracy, high reliability, good temperature adaptability and convenient maintenance, is well satisfied for modern blast furnace production and manipulation demands.

269

## Simulation Research on Improving 7.63m Coke Oven High-heating Uniformity in Shougang

**Author(s):** Mr. MA, Chao<sup>1</sup>

**Co-author(s):** Mr. XUE, Limin<sup>1</sup>; Mr. YAN, LiQiang<sup>2</sup>; Mr. ZHOU, jiliang<sup>3</sup>; Dr. ZHANG, dianwei<sup>4</sup>

<sup>1</sup> *Shougang Group*

<sup>2</sup> *Shanxi Coking Company of Tangshan Shougang Jingtang*

<sup>3</sup> *ShouGang Group*

<sup>4</sup> *shougang group*

**Corresponding Author(s):** superchao1986@126.com

Combustion processes of heating gas for 7.63m coke oven in Shougang were simulated by the adoption of CFD modeling. Through calculation and analysis, the following conclusions were obtained: (1) As the heating gas flow rate decreased, the average velocity of gas inside the combustion chamber was reduced; (2) When the gas flow rate in the vertical flue was reduced by 5m<sup>3</sup>/h, the average temperature in the combustion chamber was decreased by 0.55 [U+2103] and the maximum temperature was decreased by 1 [U+2103]. It meant reducing the gas flow rate in the vertical flue by 5m<sup>3</sup>/h had little effect on the overall oven temperature. (3) The reverse operation of gas can increase the internal temperature of the combustion chamber. (4) Increasing the air flow rate at the bottom of the vertical flue, meanwhile, reducing the air flow rate in the middle and upper part can obviously increase the average temperature of the combustion chamber, decrease the maximum temperature and improve the uniformity of the overall oven temperature.

270

## Strategic operation and raw materials planning for integrated steel plants in the process integration platform mSIM-TOP

**Author(s):** Dr. WEISS, Bernd<sup>1</sup>

**Co-author(s):** Mr. SPANLANG, Andreas<sup>2</sup>; Dr. WUKOVITS, Walter<sup>3</sup>

<sup>1</sup> *Primetals Technologies GmbH*

<sup>2</sup> *K1Met GmbH*

<sup>3</sup> *TU Vienna*

**Corresponding Author(s):** bernd.weiss@primetals.com

Iron and steel making requires a wide range of different raw materials significantly influencing process performance which demands a continuous optimization of process routes also with respect to energy efficiency as well as environmental emissions. Steadily changing raw material prices and qualities, market situations and product variations are challenging integrated steel plant operators in production planning and cost optimization. Primetals decided to develop a comprehensive metallurgical flow sheet model library for simulation and optimization of integrated steel plants. Intensive development efforts were taken in order to migrate existing well established calculation and engineering routines as well as integrate newly developed models. The generated model library enables the setup of mass and energy balances for integrated steel plants, development and

evaluation of new process concepts as well as investigations on impacts of raw material changes and trace material distributions. By using this process integration platform, it is possible to compare different iron and steelmaking routes within one standardized environment. In this publication an insight will be given on the competence of mSIMTOP in depicting integrated steel plant operation, enhance raw material planning, show the effect of new raw materials and new internal recycles on realistic examples.

271

## Energy efficient and low emission sinter cooling

**Author(s):** Mr. HOFFMANN, Mathias<sup>1</sup>

**Co-author(s):** Mr. NOUAILLE-DEGORCE, Gilles<sup>1</sup> ; Mr. HUTMACHER, Patrick<sup>1</sup> ; Mr. RECHER, Charles<sup>1</sup> ; Mr. KASS, Gilles<sup>1</sup>

<sup>1</sup> *Paul Wurth S.A.*

**Corresponding Author(s):** gilles.kass@paulwurth.com

Cooling of hot sinter involves the release of significant quantities of energy and is a source of fugitive dust emissions. The increasing pressure that steel producers are facing in regard to energy consumption, reduction of CO<sub>2</sub> and air emissions, require new processes and technologies to maximise energy recovery of the sinter cooling and to lower its environmental impact. Paul Wurth has been working intensively on the improvement and redesign of sinter coolers and recently finished developing a new type of shaft cooler based on the counter-flow principle, resulting in advanced thermal efficiency and energy recovery rate.

In parallel, the higher amount of energy recovered from the sinter cooling allows boosting the efficiency of the processes that reuse this energy. Examples are the partial recirculation of hot air to ignition hood and/or the sinter strand and the generation of steam that may be combined to the production of electricity. An interesting alternative is to use the steam for driving a turbine which is coupled directly to the main fan, a setup which increases the yield of thermal energy conversion even further. In this regard, Paul Wurth recently joined hands with a renowned turbine manufacturer to be able to propose complete heat recovery solutions specifically adapted to each customer's requirements.

As the new cooler is based on the suction of cooling air through the bed of hot sinter, dust emissions are strongly reduced compared to existing sinter coolers, making this technology fit for upcoming reinforced legislations on dust emissions.

With a very small footprint, the new cooler can be retrofitted in most existing plants even with reduced available space or it can be implemented in greenfield projects in order to reduce the overall plant footprint.

272

## Microstructural evolution of furnace coke during experimental heating

**Author(s):** Dr. RANTITSCH, Gerd<sup>1</sup>

**Co-author(s):** Mr. BHATTACHARYYA, Anrin<sup>2</sup> ; Prof. SCHENK, Johannes<sup>2</sup>

<sup>1</sup> *Montanuniversität Leoben, Austria*

<sup>2</sup> *Montanuniversitaet Leoben*

**Corresponding Author(s):** gerd.rantitsch@unileoben.ac.at

Furnace coke was experimental heated between 850°C and 1100°C by varying the gas composition and the alkali content of the raw coke. Raman spectroscopy (Iterative Fitting of Raman Spectra) evaluates the microstructural change of coke during the experiments. The obtained results indicate a significant microstructural variation within a bulk sample. This variation controls significantly the coke quality as estimated from standard experiments (CRI 23.9 - 38.3). A bulk sample with a CRI value <30 is composed dominantly of lumps showing a relatively low structural ordering. During experimental heating, the structural ordering of such lumps increases. A bulk sample with a CRI value >30 is composed dominantly of lumps showing a relatively high structural ordering.

During experimental heating, the structural state of such lumps remains unchanged unless a strong reaction is induced by adding alkaline elements. It is suggested that under laboratory conditions, thermal and chemical energy, affecting a microstructurally low-ordered coke, first reorganizes the structural state of the individual coke lumps, retarding the onset of the Boudouard Reaction.

273

## New Efficiency in Ironmaking Facilities

**Author(s):** Mr. STEINWANDTER, Andreas<sup>1</sup>

**Co-author(s):** Mr. BRUNNER, Christian<sup>2</sup>; Mr. VARGA, Andras<sup>2</sup>

<sup>1</sup> *Primetals Technology Austria GmbH*

<sup>2</sup> *Primetals Technologies Austria GmbH*

**Corresponding Author(s):** andreas.steinwandter@primetals.com

The demand for increasing energy efficiency is one of the global megatrends of our time. Although the steel industry suffers from a volatile economic environment, steel plant operators are interested to find opportunities for sustainable cost reduction. Steel mills are trying to cut electrical power and energy costs as these are among the biggest cost factors that can be influenced. The product cooler of sinter plants offers an excellent possibility to recover up to 50 - 80 kWh thermal energy per ton of sinter by using either a steam or hot water boiler. The recovered energy can be used to produce electrical energy or be used for instance for the SCR (Selective Catalytic Reduction) – Technology, which is applied to reduce the nitrous oxides in the primary sinter off-gas in conjunction with Primetals' MEROS® technology. The SCR technology requires typically an elevated reaction temperature and can be therefore an efficient consumer for the generated waste heat and contributes to the efficient gas cleaning of the sinter off gas. Furthermore significant proportion of the generated blast furnace (top-) gas with the inherent pressure/thermal energy is unutilized since the blast furnace gas is just throttled by means a throttling element to reach the pressure of low pressure gas network. In order to recover this energy, Primetals Technologies offers its TRT (Top-Gas Recovery Turbine) solution that includes a gas expander and the required auxiliaries downstream of a widely used wet or innovative dry dedusting technology (MERIM®). In the energy generation process from blast furnace gas approximately 30 – 40 kWh of electrical energy per ton of hot metal is possible with low maintenance costs. This electricity can be used for internal usage within the steelworks or for external sales to the power grid thereby reducing CO<sub>2</sub> emissions. One of the global trends that are constantly challenging the iron and steel industry is related to the generation of fines, slurry, sludge and scales, summed up as ferrous by-products. The recycling of those by-products is commonly practiced in many steel plants. These materials normally cannot be used directly in the primary processes. The most common application is to add ferrous by-products which are suitable concerning chemical composition and grain size distribution to the sinter mix. Primetals will present latest developments in the field of cold briquetting of ferrous by-products and of coal briquetting. Giving examples and results of executed project(s) of cold briquettes directly fed to the DR shaft, and other solutions for integrated steel mills. Coal briquetting on the other hand is based on coal fines which often originate from wear during coal transport from mine to plant. These fines can be used to produce briquettes designed either for the use in a smelting reduction process (COREX®/FINEX®) or for enhanced coke oven operation in the traditional blast furnace route.

274

## Development of Low thermal expansion Silica bricks for Coke Oven

**Author(s):** Mr. PRASAD, Birendra<sup>1</sup>

**Co-author(s):** Mr. PANDA, Bharati Krushna<sup>1</sup>; Mr. GRUBER, Ingo<sup>1</sup>; Mr. SWAIN, Suvash Chandra<sup>1</sup>

<sup>1</sup> *DALMIA OCL*

**Corresponding Author(s):** prasad.birendra@dalmiaoel.com

Silica Bricks are made from Quartzite which mostly contents quartz phase. During making, the quartz is converted into phases like Tridymite and Cristobalite along with some amorphous phases.

This polymorphic transformation in Silica brick is governed by the impurities present in parent quartzite and also with the addition of mineralizers. However in this process very little amount (<1%) of quartz may remain unaltered. The behaviour/ properties of silica bricks is governed by its physical properties (AP/BD/CCS), thermal and thermo-mechanical properties. Out of these, thermal expansion is considered to be one of the major criterion. Thermal expansion plays a vital role in designing and lining of coke ovens. Consistency in thermal expansion of silica bricks is controlled by the quantity of different phases (Tridymite, Cristobalite, Residual quartz etc) present in bricks. In our conventional silica bricks the thermal expansion ranges between 1.28-1.34% at 1000 deg C and these bricks are widely used in Indian coke ovens in normal and tall batteries. Extensive research has been carried out in Dalmia-OCL to develop low thermal expansion bricks ranging between 1.12 -1.25% by controlling the mineralogical phases during manufacturing with available quartzite. In this paper the authors are trying to highlight how the thermal expansion of silica bricks can be reduced by increasing Tridymite content in the brick and then how content of Tridymite formation is linked with the composition and production process like chemistry of mineralizers, firing cycles and quality of quartzite.

275

## Investigation of factors impacting Coke Strength after CO<sub>2</sub> Reaction

**Author(s):** Mr. NAGASHIMA, Yoshihiro<sup>1</sup>

**Co-author(s):** Mr. NANGO, Keigo<sup>1</sup> ; Mr. ANRAKU, Daisuke<sup>1</sup>

<sup>1</sup> *Mitsubishi Chemical Corporation*

**Corresponding Author(s):** nango.keigo.ma@m-chemical.co.jp

Coke Strength after CO<sub>2</sub> Reaction (CSR) is the most important index for metallurgical coke production, however, dominant factors of CSR have not been clarified. Therefore, CSR of produced coke is estimated by statistical methods or experiences. We have been investigating dominant factors of CSR in respect of both matrix and pore of coke. In the result, some factors impacting CSR were found. This technology enables us to estimate CSR more accurately and to supply metallurgical coke which has higher CSR steadily.

276

## The Next Generation Copper Stave

**Author(s):** Mr. OSBORNE, David<sup>1</sup>

**Co-author(s):** Mr. HORWOOD, Robert<sup>2</sup>

<sup>1</sup> *Primetals Technologies Ltd*

<sup>2</sup> *Primetals*

**Corresponding Author(s):** dave.osborne@primetals.com

Primarily used in the high heat zones of the furnace the copper stave has proved to be a hugely popular choice for blast furnace cooling. Despite its many successes, some plants have suffered with copper stave problems in two particular areas: stave bending (leading to water leaks at back of the stave) and stave wear (erosion on the hot face). The root causes of these failures can be defined by a number of factors including the furnace profile, the design and fixing of the stave, and the operation of the furnace. Primetals has had great success with copper staves, but understands the need to develop solutions for those plants with problems, and to provide a more robust solution to take copper staves to the next generation. This paper will describe the technology that Primetals' blast furnace technology team have developed.

277

## Reducing the cost of BF top gas dust handling, with practicable payback

**Author(s):** Mr. OSBORNE, David<sup>1</sup>

**Co-author(s):** Mr. MAWER, robert<sup>2</sup>

<sup>1</sup> *Primetals Technologies Ltd*

<sup>2</sup> *Primetals*

**Corresponding Author(s):** dave.osborne@primetals.com

The majority of existing blast furnaces plants use a dustcatcher as the primary process for removal of the process dust from the top gas. In recent years, there has been a trend to replace the dustcatcher with a cyclone: increasing the efficiency of dust removal, increasing the dry dust recycle to (for example) the sinter plant, and reducing the sludge volume generated from wet gas cleaning. This change provides a reduction in operation expenditure, but with the cost of installing a new cyclone with the necessary plant modifications – changes which can take considerable time and cost within the arrangement of an operating blast furnace. In order to reduce these problems of capital cost and shutdown time, Primetals have developed a solution to convert a dustcatcher into a cyclone, retaining the OPEX advantage at significantly reduced CAPEX. The paper will describe the technology that Primetals have developed.

278

## Prediction of Blast Furnace Hearth Condition: Theory and Practice

Dr. DONG, xuefeng<sup>1</sup> ; Dr. ZULLI, Paul<sup>2</sup> ; Mr. BIASUTTI, Mark<sup>3</sup>

<sup>1</sup> *Associate Research Fellow*

<sup>2</sup> *University of Wollongong*

<sup>3</sup> *Technology Engineer*

**Corresponding Author(s):** xuefengdong@uow.edu.au

In a modern blast furnace (BF) operation, the hearth is a critical area influencing both the routine casting performance and campaign life, where the liquid flow distribution, coke bed structure and condition, and the in-service refractory profile are all contributing factors. However, direct measurement is nearly impossible because of the high temperature conditions in the hearth. In practice, the refractory temperature distribution is a valuable measurement for assessing the hearth condition, e.g. the coke bed state and/or refractory erosion. However, for both normal furnace operations and long maintenance shutdown periods, the refractory temperature cannot fully provide a comprehensive and necessary assessment of this condition. In this regard, mathematical modelling, often coupled with physical modelling, has played an important role in interpreting the refractory temperature distribution in terms of liquid flow distribution, coke bed properties, hearth wear condition, and so forth. One aspect of the present investigation involved using a new, improved conjugate heat transfer model to describe the flow of liquid iron coupled with liquid-refractory heat transfer in the hearth of Port Kembla No. 5 Blast Furnace, under normal operating conditions. The model was carefully validated through a comparison between measured refractory data and model predictions. Results show that the actual range in measured pad temperature fluctuation over the course of the present campaign were well within the temperature difference expected for the float/sink movement of the coke bed. In the second aspect involved the development and application of a new transient numerical model developed to simulate hearth cooling during an extended maintenance shutdown period. In this model, the mushy zone was tracked so as to predict the temporal variation of refractory temperatures and critically, the extent of liquid bath cooling during extended shutdowns of several days duration. During the course of the shutdown, these results proved to be a very useful guide for furnace and maintenance engineers.

279

## Design and Commissioning of an Experimental Fluidized Bed Reactor for the Hydrogen Reduction of Titanomagnetite Ironsand

**Author(s):** Mr. PRABOWO, Sigit<sup>1</sup>

**Co-author(s):** Dr. BUMBY, Chris<sup>1</sup>; Prof. MONAGHAN, Brian<sup>2</sup>; Mr. DEL PUERTO, Diego<sup>3</sup>; Mr. RYAN, Martin<sup>3</sup>; Dr. LONGBOTTOM, Raymond<sup>2</sup>

<sup>1</sup> *Robinson Research Institute, Victoria University of Wellington, PO Box 33436, Lower Hutt 5046, New Zealand*

<sup>2</sup> *Pyrometallurgy Research Group, School of Mechanical, Materials and Mechatronic Engineering University of Wollongong, NSW 2522 Australia*

<sup>3</sup> *Callaghan Innovation, PO Box 31-310, Lower Hutt 5040, New Zealand*

**Corresponding Author(s):** sigit.prabowo@vuw.ac.nz

Substantial deposits of titanomagnetite ironsand are found throughout the west coast of the North Island of New Zealand (NZ). This titaniferous iron ore contains approximately 8% TiO<sub>2</sub> equivalent, which prevents its use as a feedstock concentrate for conventional blast furnace (BF) processes. However, at present ~1.5 Mt pa is utilized in the rotary-kiln production of direct reduced iron (DRI), and a further > 1 Mt is exported for blending as a minority component within BF sinters. However, the increased focus on reduced CO<sub>2</sub> emissions is now promoting renewed interest in alternatives to existing carbo-thermic DRI approaches. Here, we report initial investigative work into the production of DRI from NZ ironsand via hydrogen-reduction in an experimental fluidized bed reactor.

NZ ironsand exhibits a naturally-occurring particle size distribution in the range 100-250 μm, making it potentially well-suited to fluidized bed processing. Fluidized bed processing provides potential advantage for direct use of ironsand powder without pre-treatment of material such as pelletizing and sintering. In the current project, we have determined fluidization parameters for ironsand powder through theoretical calculation and experimental validation. We have then designed and commissioned a small-scale experimental reactor that enables fluidized bed reduction in Ar-H<sub>2</sub> atmospheres at up to 1050 °C. This experimental reactor includes a novel in-situ sampling system which utilizes a micro-cyclone to extract small amount of samples (< 5 g) of partially reduced material at specific time intervals during a batch reduction. We present initial results from this reactor, and compare metallization degree measurements of partially reduced ironsand powder using both quantitative X-ray diffraction (q-XRD) and titration techniques respectively. We show that q-XRD is a useful high-throughput approach to characterize reduction kinetics in this experiment. Finally, we discuss the onset of 'sticking' phenomena within this fluidized bed system, and the limitations this imposes on high-temperature rapid reduction of NZ ironsand in a fluidized bed reactor.

280

## An Assessment of the Effects of Calcia and Calcium Aluminate on the Reactivity of the Coke Analogue

**Author(s):** Mrs. JAYASEKARA, Apsara<sup>1</sup>

**Co-author(s):** Prof. MONAGHAN, Brian<sup>2</sup>; Dr. LONGBOTTOM, Raymond<sup>2</sup>

<sup>1</sup> *Pyrometallurgical research group, and School of Mechanical, Materials, Mechatronic and Biomedical Engineering, University of Wollongong*

<sup>2</sup> *Pyrometallurgical research group and School of Mechanical, Materials, Mechatronic and Biomedical Engineering, University of Wollongong*

**Corresponding Author(s):** rayl@uow.edu.au

Coke is a key reagent in the iron blast furnace process. To enhance its performance in the blast furnace a better understanding of the kinetics of coke reactions in the blast furnace is necessary. Using a synthetic coke (coke analogue) the gasification rate in CO<sub>2</sub> of a coke containing calcia and calcium aluminates (CA6, CA, C3A) was studied. The coke analogue is a laboratory material with simplified carbon structure that has a mineral component with a particle size, size distribution and mineral dispersion that can be controlled. The analogues were reacted isothermally with CO<sub>2</sub> in the temperature range of 1173 – 1623 K. It was found that the reaction rate increased with increasing CaO activity/number of moles of Ca in the mineral. The relative reaction rates (from lowest to highest) of the analogues doped were alumina, CA6, CA, C3A and lime. The relative apparent activation energies of the gasification from lowest to highest was lime, C3A, CA, CA6 and alumina.

281

## Characterisation of self-sintering BOS dust for enhanced utilisation of steel plant by-products

**Author(s):** Dr. LONGBOTTOM, Raymond<sup>1</sup>

**Co-author(s):** Prof. MONAGHAN, Brian<sup>1</sup>; Dr. ZHANG, Guangqing<sup>1</sup>; Dr. PINSON, David<sup>2</sup>; Dr. CHEW, Sheng<sup>3</sup>

<sup>1</sup> *School of Mechanical, Materials, Mechatronic and Biomedical Engineering and ARC Research Hub for Australian Steel Manufacturing, University of Wollongong*

<sup>2</sup> *BlueScope Iron & Steelmaking Technology*

<sup>3</sup> *BlueScope Iron and Steelmaking Technology*

**Corresponding Author(s):** rayl@uow.edu.au

The recycling of steel plant by-products is a key issue for all steelmakers. For these materials to be fully utilised without incurring environmental and economical penalties they need to be better understood with respect to their composition (morphology, phases and phase distribution). Research is being undertaken that aims to realise the value of steel plant by-products to the Australian steel industry and minimise the amount of by-product going to long-term stockpile. Basic oxygen steelmaking (BOS) dust, is a major steel plant by-product stream that has been characterised. This characterisation will inform the assessment of reactivity of the material so that its potential use on plant or elsewhere can be evaluated. While BOS dust contains useful components such as iron units and fluxes, other components, such as zinc, can limit the amount of possible recycling within the steel manufacturing process, causing both process and/or occupational health and safety issues.

BOS dust has been found to undergo a self-sintering process, improving its mechanical properties to allow easier recycling and utilisation on plant. It contains components including iron, flux and zinc units which have value on plant and elsewhere. Better understanding of the self-sintering process will allow better utilisation of this resource and help to minimise emissions and reduce costs by replacement of raw materials. In this paper, BOS dust characterisation by scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), thermo-gravimetric analysis (TGA) and differential calorimetry (DSC) is presented and discussed.

282

## Reduction of Titanohematite Pellets By Hydrogen Gas

**Author(s):** Mr. ZHANG, Ao<sup>1</sup>

**Co-author(s):** Dr. NUSHEH, Mohammad<sup>1</sup>; Dr. LONGBOTTOM, Raymond<sup>2</sup>; Dr. BUMBY, Chris<sup>1</sup>; Prof. MONAGHAN, Brian<sup>3</sup>

<sup>1</sup> *Robinson Research Institute, Victoria University of Wellington*

<sup>2</sup> *Pyrometallurgical Research Group, School of Mechanical, Materials, Mechatronic and Biomedical Engineering, University of Wollongong*

<sup>3</sup> *Pyrometallurgical Research Group, School of Mechanical, Materials, Mechatronic and Biomedical Engineering, University of Wollongong*

**Corresponding Author(s):** rayl@uow.edu.au

Ironsand is a potential cheap source of iron with possible other values such as titania and vanadium oxide. Direct reduction is regarded as one of the promising processes to deal with ironsand in both an economically and environmentally sustainable manner. In this study, the reduction characteristics of pelletised ironsand ore by hydrogen gas were investigated. The pelletising and sintering of the ore is an oxidation process and results in the ironsand transforming to titanohematite (TTH).

A thermogravimetric technique has been used to evaluate the kinetics and X-ray diffraction used to establish the phase distribution before and after the reduction experiments. The experiments were carried out isothermally between 800-1200°C under pure hydrogen. As expected the reduction rate increased with temperature and metallic iron and ilmenite were found in the reduced pellets

at all temperatures. At 900°C and below Ti was also present as rutile, while at temperatures >900°C the second Ti bearing phase was pseudobrookite.

Attempts to use a simple single interface shrinking core model (SCM) to represent the kinetics proved problematic and did not represent the experimental results well. It is likely that this is a result of the reduction process being more complex than this single interface model. Future work is focused developing a more rigorous approach to the kinetics and establishing the reaction interfaces and composition gradients within the pellet.

283

## Phase development of titanomagnetite ironsand under oxidising conditions

Mr. BJAREBORN, Oscar<sup>1</sup> ; Dr. BUMBY, Chris<sup>1</sup> ; Dr. RYAN, Martin<sup>2</sup> ; Dr. LONGBOTTOM, Raymond<sup>3</sup> ; Prof. MONAGHAN, Brian<sup>3</sup>

<sup>1</sup> *Victoria University of Wellington, New Zealand*

<sup>2</sup> *Callaghan Innovation, New Zealand*

<sup>3</sup> *University of Wollongong, Australia*

**Corresponding Author(s):** chris.bumby@vuw.ac.nz

New Zealand ironsand is an unconventional titaniferous ore (typically ~8% TiO<sub>2</sub> by mass) which is commercially utilised to produce DRI, and as a blending component within BF sinters. Oxidative sintering of this titanomagnetite sand enables high-strength porous pellets to be formed, and such pre-oxidation is known to significantly enhance the gas-solid reduction rate compared to unoxidised ironsand. This is attributed to the increase in available surface area which results from cracking of individual grains during oxidation. However, the fate of titanium during oxidation has not been extensively studied, despite titanium playing an important role in the overall kinetics and yield of subsequent direct-reduction processes.

In this work we report a detailed study of the evolution of titanium-bearing phases during the controlled oxidation of NZ ironsand pellets. Samples were oxidised in air at temperatures between 800 °C and 1300 °C, and then characterised using FEG-SEM, EDS, EBSD and XRD. Electron microscopy shows localised regions of titanium enrichment within the oxidised grains, and we observe the emergence of pseudo-brookite and ilmenite phases during the oxidation process. Our results indicate that titanium is highly mobile within individual oxidised grains, and that the final phase composition is strongly affected by both oxidising temperature and time.

284

## Physicochemical behaviour of olivine iron ore pellets mixed with nut coke under simulated blast furnace condition

**Author(s):** Mr. GAVEL, Dharm Jeet<sup>1</sup>

**Co-author(s):** Prof. YANG, Yongxiang<sup>1</sup> ; Dr. ADEMA, Allert<sup>2</sup> ; Mr. STEL, Jan van der<sup>2</sup> ; Prof. SIETSMA, Jilt<sup>1</sup> ; Prof. BOOM, Rob<sup>3</sup>

<sup>1</sup> *TU Delft*

<sup>2</sup> *Tata Steel Europe*

<sup>3</sup> *TU Delft*

**Corresponding Author(s):** dj.gavel10@gmail.com

Blast furnace productivity is limited by the resistance offered to the gas flow in the cohesive zone. Mixed use of nut coke with iron ore proved beneficial for decreasing this resistance. In present study effect of nut coke addition on the olivine iron ore pellet bed was studied under simulated blast furnace condition. Nut coke mixing degree (replacement of regular coke) varied from 0 to 40 wt% to study the physicochemical changes that it brings on pellet bed. The difference between the softening and melting temperature decreases with the nut coke addition. The softening temperature increases due to increase in reduction degree of the pellets. The melting temperature decreases due to the higher carbonisation degree of iron shell. During melting, the magnitude of the pressure drop peak decreases with the increase in nut coke concentration

285

## Further Possibilities of Competitiveness Improvements of a Midrex Direct Reduction Plant

**Author(s):** Mr. MILLNER, Robert<sup>1</sup>

**Co-author(s):** Mr. ROTHBERGER, Johannes<sup>2</sup>; Mr. OFNER, Hanspeter<sup>1</sup>; Mr. RAVENSCROFT, Christopher<sup>3</sup>

<sup>1</sup> *Primetals Technologies Austria GmbH*

<sup>2</sup> *+43 732 6592 4709*

<sup>3</sup> *MIDREX Technologies Inc.*

**Corresponding Author(s):** hanspeter.ofner@primetals.com

Midrex and Primetals Technologies have successfully completed their latest HBI projects for voestalpine Texas LLC/USA and LGOK/Russia. This paper discusses some further possibilities for improvements of Direct reduction plants in order to increase the plant competitiveness and/or flexibility. Such plant improvements have been either already implemented in the latest projects for the first time or were recently developed by Midrex and/or Primetals Technologies. Some of this plant improvements are:

- Waste Heat Recovery for Top gas and Reformer Flue Gas – Production of steam or electricity based on framework conditions
- Bottom Seal Gas Hot Dry Dedusting System – Recovery of hot DRI dust for increase of product yield
- Slurry Treatment by Chamber Filter Presses – Efficient dewatering of slurry from clarifier with low operating and maintenance cost
- Process Water Degasser – Degassing of process water from CO<sub>2</sub> to improve water quality and operation/maintenance cost
- Adjustable Carbon Technology (ACT) – Increase of carbon content depending on HBI off-taker/user requirements
- DRIPAX Carbon and Metallization Prediction – Improvement of plant operation by stable operation
- Level-2 Expert System Improvements – Increased support of operation team

Such improvements either reduce the OPEX costs, increase the yield, improve the operation/maintenance and/or increase the availability of a Midrex plant and can be implemented for new direct reduction plants or retrofitted for existing plants.

286

## The high fluidity of Barro Branco coal (Brazil) and its influence on coke quality

Mr. FLORES, Bruno<sup>1</sup>; Mr. AGRA, Anderson<sup>1</sup>; Prof. OSÓRIO, Eduardo<sup>1</sup>; Prof. VILELA, Antônio<sup>1</sup>; Dr. SILVA, Guilherme<sup>2</sup>

<sup>1</sup> *Federal University of Rio Grande do Sul - Brazil (UFRGS)*

<sup>2</sup> *Gerdau Ouro Branco*

**Corresponding Author(s):** bruno.flores@ufrgs.br

Brazil has a large coal reserve, which is mainly located in the Parana Basin, southern region of the country. Despite that, the steel sector, which is the largest coal consumer in Brazil, needs to import 100% of its demand. The coal from Barro Branco seam in Santa Catarina-Brazil is a potential raw material for coke production due to its well-known coking properties. Thus, the present study aimed to evaluate and justify the thermoplastic behavior of Barro Branco coal, as well as to investigate its influence on the metallurgical coke quality. The results indicated that the Barro Branco coal presents extremely developed thermoplastic properties when compared to

imported coking coals. This characteristic seems to be associated with possible impregnation of bitumen in petrographic components of the vitrinite group. Barro Branco coal promoted an important increase of the thermoplastic properties of coal blends. In general, it was observed that Barro Branco coal caused a decrease on coke quality. However, the use of this coal is favored in coal blends containing high inert content.

287

## The influence of biomass/coal tar blends on the quality of bio-cokes

Mr. FRAGA, Matheus<sup>1</sup> ; Mr. FLORES, Bruno<sup>2</sup> ; Mr. AGRA, Anderson<sup>1</sup> ; Prof. OSORIO, Eduardo<sup>1</sup> ; Prof. VILELA, Antonio<sup>1</sup>

<sup>1</sup> UFRGS

<sup>2</sup> Fedral University of Rio Grande do Sul - Brazil (UFRGS)

**Corresponding Author(s):** matheus.fraga@ufrgs.br

Today global warming has been a major concern, as the average level of atmospheric carbon dioxide (CO<sub>2</sub>) has increased by 5.9% in the last 10 years. According to the International Energy Agency, the steel industry represents approximately 6.7% of total global CO<sub>2</sub> emissions, with 1.8 tons of CO<sub>2</sub> per ton of steel produced. Therefore, the steel industry is facing an increasing pressure to reduce the environmental impact of its production processes. In integrated plants coke consumption corresponds to more than 80% of CO<sub>2</sub> emissions in the production of primary iron. The partial substitution of coking coal for biomass in the steel industry is one of the main ideas to contribute to the mitigation of CO<sub>2</sub> emissions. Previous studies have reported that the production of coke with biomass (bio-coke) resulted in the degradation of coke quality. Thus, this study aimed to evaluate the addition of tar as a way to mitigate the deleterious effects related to the addition of biomass in the coke. The interaction of coal/biomass (charcoal)/coal tar blends has been investigated during pyrolysis. The thermoplastic properties of such blends have been characterized and the quality of the produced bio-cokes was assessed. The results indicated that coal tar impregnated on the surface of charcoal improve the caking properties of the blends and reduces the deleterious effects of biomass on the quality of coke.

288

## Coke microstructure - sample preparation and image analysis via ImageJ

Mr. AGRA, Anderson<sup>1</sup> ; Mr. FLORES, Bruno<sup>2</sup> ; Prof. OSÓRIO, Eduardo<sup>3</sup> ; Prof. VILELA, Antônio<sup>3</sup> ; Dr. LIZIERO, Guilherme<sup>4</sup>

<sup>1</sup> Federal University of Rio Grande do Sul

<sup>2</sup> Federal University of Rio Grande do Sul - Brazil (UFRGS)

<sup>3</sup> UFRGS

<sup>4</sup> Gerdau

**Corresponding Author(s):** anderson.agra@ufrgs.br

Metallurgical coke remains an irreplaceable material in the production of hot metal in blast furnaces, providing the heat and the reducible gases necessary for the process. Coke also play an important structural role in the blast furnace, providing a permeable bed for the passage of gases and liquids. Coke mechanical strength is a key factor for the performance of blast furnace and is essentially governed by coke microstructure. The microstructure of metallurgical coke can be defined as the spatial distribution of the coke carbonaceous matrix and its porosity. In this work, a methodology was developed to perform a representative characterization of coke microstructure. Cokes were produced from individual coals and coal blends in laboratory and pilot scale. Particles of these cokes were prepared and observed under an optical microscope to obtain images that were later analyzed in open source software (ImageJ) using a sequence of commands to obtain the microstructure parameters, such as porosity, average pore size, pore size distribution, wall thickness and pore shape. The influence of variables such as coke particle size, number of coke particles and number of images per sample on coke microstructure parameters was investigated.

In addition, this work will present the step by step commands performed in the image analysis software to obtain the coke microstructure parameters. The geometric parameters, together with a porosity, form the set of data that can be correlated with mechanical strength of coke.

289

## Improving binding properties of self-reducing briquettes of iron ore and weathered coal

**Author(s):** Mr. NARITA, Cesar<sup>1</sup>

**Co-author(s):** Prof. MOURAO, Marcelo <sup>1</sup> ; Prof. TAKANO, Cyro <sup>1</sup>

<sup>1</sup> *University of Sao Paulo*

**Corresponding Author(s):** cesar.narita@usp.br

Coal weathering is a mild air oxidation that causes deterioration on coking coal properties. It starts happening after the coal is mined and exposed to the atmosphere and affects the coking properties of the coal, especially those related to thermoplastic behavior, leading to a more fragile coke. The present investigation studies the addition of petroleum pitch and charcoal tar in mixtures of iron ore and weathered coal. This paper is a continuation of a previous study where, relying in the thermal plasticity of a fresh coking coal, self-reducing briquettes of pellet feed iron ore and coal were produced. The results were then compared and it was found that the addition of both materials helped the binding properties of the mixture, but not to the original state of the fresh coking coal.

290

## SELF-REDUCING AGGLOMERATES FROM LD AND BLAST FURNACE RESIDUES: METALLIZATION AND COOLING EFFECT

**Author(s):** ALVARADO QUINTANILLA, Jerson Edwin<sup>1</sup>

**Co-author(s):** D'ABREU, Jose Carlos <sup>1</sup> ; TINOCO FALERO, Edelink Efrain <sup>1</sup> ; PINTO OLIVEIRA, Luiz Claudio <sup>2</sup>

<sup>1</sup> *Departamento de Engenharia Química e de Materiais (DEQM), Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)*

<sup>2</sup> *ENSORES Consultoria e Projetos, Rio de Janeiro*

**Corresponding Author(s):** melanie.baumgartner@asmet.at

In the integrated steel industry several types of by-products are generated, such as blast furnace slag, wet or dry residues from LD dedusting systems and particulate and slurry generated in the blast furnace cleaning devices. They typically present in their compositions mainly iron and carbon units and in some cases also zinc. Due to this content, the iron and steelmaking residues have become target of various researches and technological initiatives, aiming to recover those elements. In this work the fine-F and coarser-G residues generated in a dry LD dedusting system, in the proportions 50-50 and 70-30, respectively, were mixed with blast furnace dust and ARI-cement type, and the final mixtures mechanically agglomerated to produce the self-reducing briquettes. The compression strength and the metallization degree, obtained at 1100 and 1150°C temperatures, were evaluated. Additionally, in order to know the briquettes cooling effect when added in liquid steel, an energy balance for the briquette-steel bath system was calculated, taking into account a thermodynamic sequence for reactions and the typical oxygen potentials of the LD process. The self-reducing agglomerate cooling effect was experimentally obtained and, by comparison of the cooling indexes, the self-reducing briquettes showed to be an effective alternative material to the scraps and iron ore pellets

291

## Metallization and Carburization Kinetics in DR Shaft Furnaces. The METCARB Model

**Author(s):** TINOCO FALERO, Edelink Efrain<sup>1</sup>

**Co-author(s):** D'ABREU, Jose Carlos <sup>1</sup> ; OTAVIANO, Mauricio Marcos <sup>2</sup>

<sup>1</sup> *Department of Materials Engineering of the Pontifical Catholic University of Rio de Janeiro*

<sup>2</sup> *SAMARCO*

**Corresponding Author(s):** melanie.baumgartner@asmet.at

The production and consumption of Direct Reduced Iron (DRI) remain optimistic in the years to come, mainly as a consequence of the natural and shale gases market. Considering this context, it has an effective potential to improve the productivity and competitiveness of Blast Furnaces, Electric Arc Furnaces and LD/BOF converters. In this work the results of a cooperative research conducted by PUC-Rio University and a Brazilian mining company, are presented. Pilot-scale simulation tests, using DR commercial pellets and typical industrial operational parameters of a benchmarked DR shaft furnace, were planned and conducted using statistical and factorial analysis. In the simulated experiments, the three main regions of a DR shaft furnace were kinetically studied, such as the Reduction (RZ), Transition (TZ) and Cooling zones (CZ). Three steps were considered in this development: (i) to obtain the kinetic equations concerning pellet metallization and Carbon precipitation; (ii) to measure the DRI carburization occurring in the Transition and Cooling zones, and, (iii) to conceive a computational program to simulate mathematically, along the furnace height, the metallization and carburization reactions. Finally, In order to validate the "METCARB" model, two industrial plant operational parameters were utilized.

292

## Advanced Blast Furnace Cooling Technologies

**Author(s):** Mr. VICKRESS, DUSTIN<sup>1</sup>

**Co-author(s):** Mr. RUDGE, David <sup>1</sup>

<sup>1</sup> *HATCH*

**Corresponding Author(s):** melanie.baumgartner@asmet.at

Copper stave failure is a major cause for interim blast furnace repairs, at great cost to the blast furnace owner, primarily due to: a) abrasive wear on the exposed hot-face; b) cracking of welded pipe connections; and c) low cooling density resulting from ineffective cooling layout. Under these damaging conditions, traditional staves often begin to leak water, overheat and exhibit cascading wear around the furnace. Hatch has developed a new and novel stave design to address premature failures that have plagued the industry. These staves feature a metallurgically-bonded abrasion-resistant composite hot-face, providing superior abrasion resistance compared to traditional copper staves, as verified by third-party testing. The metallurgical bond allows for a high level of heat extraction through the hardened layer, maintaining a cold surface conducive to the formation of protective accretions not achievable by traditional mechanically-fixed refractory bricks. Advanced blast furnace cooling technologies and applications for managing premature stave wear will be presented, including specific discussion around imminent stave failure diagnosis, new blast furnace cooling technology (i.e. abrasion-resistant staves) and applications implemented on operating blast furnaces.

293

## SUSTAINABLE DECREASE OF CO<sub>2</sub> EMISSIONS IN THE STEELMAKING INDUSTRY BY MEANS OF THE EN- ERGIRON DIRECT REDUCTION TECHNOLOGY

**Author(s):** PAULUZZI, Dario<sup>1</sup>

**Co-author(s):** MARTINIS, Alessandro <sup>1</sup> ; PICCOLI, Alberto <sup>1</sup>

<sup>1</sup> *Danieli & Officine Meccaniche*

**Corresponding Author(s):** melanie.baumgartner@asmet.at

Compared to the traditional Blast Furnace – Basic Oxygen Furnace way of producing steel, more than 50% of CO<sub>2</sub> emissions can be saved if steel is produced by means of the Energiron Direct Reduction – Electric Arc Furnace way. This target is achieved partly thanks to the use of reducing sources cleaner than coal, and partly thanks to the selective capture of up to 90% of the CO<sub>2</sub>

produced, that can be possibly commercialized as a valuable by-product for several different industries. The investment cost of a DR-EAF minimills is lower than the BF-BOF configuration, therefore in principle this is a sustainable solution to decrease CO<sub>2</sub> emissions in the steel industry. Operating costs are competitive provided that the reducing agent is available at reasonable price: the Energiron process can use either natural gas, syngas and BF off-gas, whichever is locally available at the cheapest price. Further than this, even Hydrogen can be used as reducing gas, without any modification to the original Energiron process scheme. This allows further reductions in CO<sub>2</sub> emissions, as many technologies are being developed to exploit renewable energy sources for production of Hydrogen, which is generally considered to be the fundamental element for the future global energy system.

294

## Softening and melting modeling of iron ore particles using a discrete - continuous coupling method

**Author(s):** BANIASADI, Mehdi<sup>1</sup>

**Co-author(s):** BANIASADI, Maryam<sup>1</sup> ; PETERS, Bernhard<sup>1</sup>

<sup>1</sup> *University of Luxembourg*

**Corresponding Author(s):** melanie.baumgartner@asmet.at

The blast furnace iron making is the main method to produce liquid iron. A blast furnace is charged with ore and coke from the top along with a preheated gas introduced to the furnace through the tuyeres in the lower part. The combustion of coke generates reducing gas ascending through the blast furnace to reduce iron-bearing materials. The reduced iron-bearing particles start softening and melting because of the weight of burden above and the high temperature in the middle of the blast furnace so-called cohesive zone. In this region, as particles are softened, the void space between particles decreases. As the temperature increases further, the softened particles start melting and generate two different liquids: molten iron and slag. Then the generated liquids trickle down to the lower part of the blast furnace. The softening and melting process forms the impermeable ferrous layers forcing gas to flow horizontally through the permeable coke windows. This causes a high-pressure drop. Softening and melting has a big effect on the operation of the blast furnace and since it is not possible to interrupt the blast furnace to investigate details of the phenomena occurring inside, the numerical simulation becomes more practical. In this contribution, the eXtended Discrete Element Method (XDEM) [1,2] as an advanced numerical tool based on the Eulerian-Lagrangian framework, is used. Within this platform, the gas and liquid phases are described by computational fluid dynamics (CFD) and the soft-sphere discrete element approach (DEM) is used for the coke and iron ore particles. Continuous phases are coupled to the discrete entities through mass, momentum, and energy exchange. Moreover, the internal temperature distribution of the particles is described. Therefore, the XDEM is able to model multiphase and multiscale phenomena as can occur in the cohesive zone. The particle's deformation, temperature, melting, and shrinking along with gas and liquids pressure, temperature and velocity patterns are examined using the XDEM method.