

Dr. Rahul Sarkar

Associate Professor, Department of Materials Science and Engineering (MSE), IIT Kanpur

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Education

University of Utah, Salt Lake City, USA

PhD in Metallurgical Engineering, 2019

Funded by: Department of Energy (DoE) and American Iron and Steel Institute (AISI)

Supervisor: Prof. H.Y.Sohn

Disseration: Interactions of iron, wustite and slags with selected refractory materials under flash ironmaking conditions

IIT Bombay, Mumbai, India,

Masters in Metallurgical Engineering and Materials Science, 2013

Specialisation: Process Engineering

Supervisors: Prof. N.B.Ballal and Prof. S. Basu

Thesis: Dynamic Modleing of LD Converter Steelmaking

Jadavpur University, Kolkata, India

Bachelors in Metallurgical Engineering, 2011

Undergraduate thesis supervisor: Prof. M.K.Mitra

Undergraduate thesis title: Isothermal and non-isothermal kinetics of Magnetite reduction by coking coal

Publications

• Journal Articles

- Aman Nigam, Krishanu Biswas and **Rahul Sarkar**, “Effect of w (CaO)/w (Al₂O₃) Ratio on Crystallization Kinetics of Non-Reactive CaO-Al₂O₃ based Mold Fluxes for Continuous Casting of 3rd Generation AHSS”, *Ceramics International*, Vol. 51 (2025), In press.
- Devendra Nama, Sujan Hazra, Samik Nag and **Rahul Sarkar**, “Intrinsic Kinetics of Reduction of Hematite Concentrates by H₂ at Moderate Temperatures”, *Metallurgical and Materials Transactions B*, Vol.56 (2025), pp. 1380-1398

- Jayaprabhu Karthikeyan and **Rahul Sarkar**, “Kinetics of Oxidation of an Al_2O_3 –SiC–C-Based Blast Furnace Trough Refractory in Air”, *Steel Research International*, Vol. 96 (2025), pp. 2400390.
- **Rahul Sarkar** and Zushu Li “Isothermal and non-isothermal crystallization kinetics of mould fluxes used in continuous casting of steel”, *Metallurgical and Materials Transactions B*, Vol. 52 (2021), pp. 1357–1378.
- **Rahul Sarkar** and H.Y.Sohn, “Interaction of magnesia-carbon refractory with ferrous oxide under the conditions of the novel flash ironmaking technology (FIT)”, *Ceramics International*, Vol. 46 (2020), pp. 7204-7217.
- **Rahul Sarkar** and H.Y.Sohn, “Interaction of magnesia-carbon refractory with metallic iron under flash ironmaking conditions”, *Journal of the European Ceramic Society*, Vol. 40 (2020), pp. 529-541.
- **Rahul Sarkar** and H.Y.Sohn, “Interaction of iron with alumina refractory under flash ironmaking conditions”, *Metallurgical and Materials Transactions B*, Vol.50 (2019), pp. 2063-2076.
- **Rahul Sarkar** and H.Y.Sohn, “Interaction of ferrous oxide with alumina refractory under flash ironmaking conditions”, *Ceramics International*, Vol.45 (2019), pp.15417-15428.
- **Rahul Sarkar** and H.Y.Sohn, “Interactions of alumina refractory with CaO-SiO_2 and CaO-SiO_2 -FeO slags relevant to the novel flash ironmaking technology (FIT)”, *Steel Research International*, Vol. 90 (2019), pp. 1900104-1900116
- **Rahul Sarkar** and H.Y.Sohn, “Interactions of alumina and magnesia based refractories with iron melts and slags-A Review”, *Metallurgical and Materials Transactions B*, Vol.49(2018),pp.1860-1882
- **Rahul Sarkar**, Ushasi Roy and Dinabandhu Ghosh, “A model for dissolution of lime in steelmaking slags”, *Metallurgical and Materials Transactions B*, Vol.47 (2016), No.4, pp. 2651-2665
- M.K.Mishra, A.G.Rao, **Rahul Sarkar**, B.P.Kashyap and N.Prabhu, “Effect of preaging deformation on aging characteristics of 2507 super duplex stainless steels”, *Journal of Materials Engineering and Performance*, Vol.25(2016), pp.374-381
- **Rahul Sarkar**, Arunava Sengupta, Vimal Kumar and S.K.Chaudhury, “Effects of alloying elements on the ferrite potential of Peritectic and Ultra-Low carbon steels”, *Iron and Steel Institute Japan International (ISIJ) International*, Vol. 55(2015), No.4, pp. 781-790
- **Rahul Sarkar**, Pramod Gupta, Somnath Basu and N.B.Ballal, “Dynamic Modeling of LD converter steelmaking: Reaction modelling using Gibb’s free energy minimization”, *Metallurgical and Materials Transactions B*, Vol.46 (2015), No.2, pp. 961-976.

• Conference Proceedings

- Aman Nigam, Krishanu Biswas and **Rahul Sarkar**, “Effect of C/A ratio on the crystallization behavior and structure of calcium-aluminate based alternative mold fluxes for casting medium and high Mn/Al steels”, *Proceedings of the 12th International Conference on Molten Slags, Fluxes and Salts (MOLTEN 2024)*, held in Brisbane (Australia), in June 2024.
- Aman Nigam and **Rahul Sarkar**, “Development of a Low Silica Calcium Aluminate Based Mould Flux for Casting High Al/Mn Steels”, *Proceedings of The International Conference on Metallurgical Engineering and Centenary Celebration (METCENT 2023)*, held in IIT-BHU, Varanasi (India), in October 2023.

- Devendra Nama and **Rahul Sarkar**, “Solid state reduction of Hematite ore using hydrogen at moderate temperatures”, *Proceedings of The International Conference on Metallurgical Engineering and Centenary Celebration (METCENT 2023)*, held in IIT-BHU, Varanasi (India), in October 2023
- **Rahul Sarkar** and H.Y.Sohn, “A model for the interaction of Fe with MgO-14.5 wt. %C refractory under flash ironmaking conditions”, *Proceedings of The Minerals, Metals & Materials Society (TMS) Annual Meeting and Exhibition*, held in San Diego (USA) in February 2020.
- **Rahul Sarkar** and H.Y.Sohn, “A kinetic model for the interaction of FeO with MgO-14.5 wt. %C refractory under the conditions of the novel flash ironmaking technology (FIT)”, *Proceedings of The Minerals, Metals & Materials Society (TMS) Annual Meeting and Exhibition*, held in San Diego (USA) in February 2020.
- **Rahul Sarkar** and H.Y.Sohn, “A kinetic model for interaction of iron powder with alumina refractory relevant to the novel Flash Ironmaking Technology (FIT)”, *Proceedings of Materials Science and Technology (MS&T) Conference*, held in Portland (USA) in September 2019.
- **Rahul Sarkar** and H.Y.Sohn, “A kinetic model for interaction of iron (II) oxide with pure alumina refractory under flash ironmaking conditions”, *Proceedings of Materials Science and Technology (MS&T) Conference*, held in Portland (USA) in September 2019
- **Rahul Sarkar**, Pramod Gupta and N.B.Ballal, “Refining of Metal Droplet in Slag using the concept of Gibbs’ Free Energy Minimization at the Slag-Metal Interface”, *Proceedings of the International Conference on Science and Technology of Ironmaking and Steelmaking (STIS)*, held in Jamshedpur (India) in December 2013, available in CD-ROM.

Professional Experience

- **Assistant Professor, Department of MSE, IIT Kanpur** [Sept 2021-Present]

Sponsored Projects Undertaken

Sl. No.	Project Title	Sponsors	Funding (in INR)	Duration	Role	Status
1.	Development of a Flash Ironmaking Reactor Based on the Direct Reduction of Iron Oxide Fines with H ₂ -CO Mixture	DORA, IIT Kanpur (through Kotak School of Sustainability	50.0 Lakhs	2 years (Started in September 2024, ongoing)	Principal Investigator (Co-PIs: Prof. Laltu Chandra (SEE). Prof. Raghavendra Ragipani (ChE))	Ongoing

2.	Gaseous Reduction of Iron Oxides Using Hydrogen Carbon Monoxide (H ₂ -Co) Mixtures at Low and Moderate Temperatures	ANRF-DST	29.7 Lakhs	2 years and 6 months (started in December 2022, ongoing)	Principal Investigator	Ongoing
3.	Development of alternative mould fluxes for casting high and medium Mn/Al steels	IIT Kanpur (through initiation grant)	25.0 Lakhs	2 years and 9 months (started in March 2022 and completed in December 2024)	Principal Investigator	Completed
4.	Process Modelling and Optimization of Reduction and Distillation Operations of Titanium Sponge Processing	IISRO (through STC-IIT Kanpur)	24.1 Lakhs	2 years and (started in December 2024, ongoing)	Co- Principal Investigator (Principal Investigator: Prof. Amarendra K Singh)	Ongoing

Consultancy Projects Undertaken

Sl. No.	Project Title	Sponsors	Funding (in INR)	Duration	Role	Status
1	Optimization of Mould Powder for Continuous of JA69BMQT-05 Grade Slabs	Jindal Steel and Power Limited (JSPL)	20.1 Lakhs	1 year (started in December 2024, ongoing)	Principal Investigator	Ongoing
2.	Development of Al ₂ O ₃ -CaO Based Mould Power For Ce/ La Added 20 Cr-5 Al Grade to Ensure Ingot Casting, Cc Blooms and Cc Slabs	Jindal Stainless Limited (JSL)	18.1 Lakhs	9 Months (started in October 2024, ongoing)	Principal Investigator (Co- Principal Investigator: Prof. Amarendra K Singh)	Ongoing

Teaching Assignments:

Academic Year	Semester	Course(s) Taught	Comments
2024-2025	II	MSE 306: Iron and Steelmaking	-
2024-2025	I	MSE 651A: Advanced Concepts in Ironmaking; MSE 352: Process Metallurgy and Manufacturing Laboratory	Received <u>citation</u> from IIT Kanpur's Senate for teaching performance in MSE 352
2023-2024	II	MSE 202 (Old UG ARC): Rate Processes	-
2023-2024	I	MSE 690-691 (old UG ARC): Seminar Participation and Presentation	-
2022-2023	II	MSE 421A (old UG ARC): Iron and Steelmaking; MSE 314A (old UG ARC): Process Engineering Laboratory	Received <u>citations</u> from IIT Kanpur's Senate for teaching performance in <u>both</u> MSE 421A and MSE 314A
2022-2023	I	MSE 651A: Advanced Concepts in Ironmaking	Received <u>citation</u> from IIT Kanpur's Senate for teaching performance in MSE 651A
2021-2022	II	MSE 421A (old UG ARC): Iron and Steelmaking	Received <u>citation</u> from IIT Kanpur's Senate for teaching performance in MSE 421A

New Course Developed:

1. MSE 651A: Advanced Concepts in Ironmaking.

Student Supervision

PhD Students:

1. Devendra Nama, Thesis Title: Reduction of Iron oxides using gaseous H₂ at low and moderate temperatures, Ongoing (started September 2021), Co-Supervisor: Dr. Samik Nag (Tata Steel Limited)
2. Aman Nigam, Thesis Title: Mould Fluxes for continuous casting of 3rd generation AHSS, Ongoing (started September 2021), Co-Supervisor: Prof. Krishanu Biswas
3. Debanjan Gain, Thesis Title: Reduction of high-alumina Iron ores, Ongoing (started in January 2024)

Master's Students:

1. Anubhab Sahu, Dissertation Title: Reduction behaviour of high-gangue containing Fe-bearing ores, Ongoing (started in August 2023)
2. Aditya Das, Dissertation Title: Flash Reduction of iron Oxides, Ongoing (started in August 2024)
3. J Karthikeyan, Dissertation Title: Oxidation of refractories used in BF trough, Graduated in July 2023.
4. Late Vaibhav Misra, Dissertation Title: Development of DeS simulator for pre-treatment of BF hot metal, Graduated in June 2024

Undergraduate (UG) Students:

1. Nikhil Karamchandani, UG Project Title: A Generalized Shrinking Core Model for Reaction Kinetics of a Pellet by Hydrogen Gas, (Completed in April 2022, started in January 2022)
2. Rishi Verma, UG Project Title: A Dynamic Mixed-Control Model for BOF Steelmaking, (Completed in April 2022, started in January 2022)

• Research Fellow, WMG, University of Warwick, UK

[Nov 2019-May 2021]

Project Worked in:

- **OPTILOCALHT: Optimization of local heat transfer in the continuous casting mould for casting challenging and innovative steel grades**
 - Characterization of mould powders and mould slag samples obtained from industrial trials using conventional techniques such as XRD, SEM and OM.
 - Simulation of industrial slag films in the laboratory using conventional and innovative methods.
 - Use of novel techniques such as confocal scanning laser microscopy (CSLM) and X-ray computed tomography (XCT) for characterization of crystallization, cracking, fracture strength and porosity of industrial and laboratory simulated slag films.

• Graduate Research Assistant, University of Utah

[August 2015-April 2019]

Projects Worked In:

- **PhD Dissertation : Interactions of iron, wustite and slags with selected refractories under Flash Ironmaking conditions**

- High temperature experimentation with iron/iron oxide and slags with selected refractory materials under flash ironmaking conditions.
- Post-mortem analyses of quenched samples using X-ray diffraction and microscopic techniques like Optical Microscopy (OM) and Scanning Electron Microscopy (SEM).
- Mapping of elements on the refractory cross-section using Energy Dispersive X-ray spectroscopy (EDX).
- Development of suitable kinetics models for refractory-iron/iron oxide/slag interactions using solid-state diffusion and its validation using experimental work.
- Calculation of kinetic parameters such as parabolic growth-rate constants, effective diffusivity and interdiffusion coefficient from the experimental data.
- **Large-Scale Laboratory Testing of Flash Ironmaking Technology**
 - Active participation in the cold and hot commissioning of large-scale bench reactor facility for flash ironmaking in the University of Utah.
 - High temperature experimentation with iron/iron oxide and selected refractory materials under flash ironmaking temperatures and gas atmospheres.
 - Participation in all experimental runs on the bench reactor from May 2016-December 2017.
 - Participation in bench reactor maintenance work from May 2016-December 2017.
- **Researcher, Tata Steel Research and development** *[July 2013-Aug 2015]*

Projects Worked In:

- **Development of static model to improve ferro-alloy recovery in LD 2 plant (Leader)**
 - Data collection on the existing amounts of addition of different ferro-alloys and their chill-factors.
 - Development of a comprehensive model using **[O] at turndown** from the **sub-lance measurements**.
 - Extensive plant trials and model implementation in level 2 automation.
- **Reduction of metal losses during raking in the external Desulphurization unit in LD 2 plant (Member)**
 - Data acquisition from the plant on the metal losses during raking over the last 1 year.
 - Extensive plant trials with additions of **glass and/or lime pellet** and subsequent recommendations.
- **Establishing Heat Transfer and Solidification behavior of peritectic and low-carbon steels (Member)**
 - Development of Peritectic range predictor using **ThermoCalc** analyses and heat flux data
 - Measurement of hot ductility of solidified shell using **Gleeble**
 - Determination of shell thickness through actual temperature measurements along the mold length.

- **Masters Dissertation, IIT Bombay** [Jan 2012-June 2013]
Dissertation Title: Dynamic modeling of LD convertor steelmaking
 - **Decarburization kinetics** of high carbon **Fe-C droplets** in slag
 - Effects of the amount of **FeO** in slag, **droplet size** and **temperatures** on **decarburization rate**
 - **Mathematical model** to predict the composition and temperature of the metal and slag
 - **Mixing** characteristics of the bath by diving it into a two- reactor model
 - Effects of **metal exchange rate** and the **reactor size ratio** on mixing properties of bath
- **Undergraduate project, Jadavpur University** [May 2010-May 2011]
Project Title: Isothermal and non-isothermal kinetics of Magnetite reduction by coking coal
 - Generated **kinetic data** for magnetite reduction in the range **900°C-1100°C**.
 - Qualitative interpretation of kinetic data obtained under **isothermal** and **non-isothermal** conditions
 - Predicted the reaction mechanism to be “**Interfacial Reaction Control**” using ‘**reduced time plots**’
 - Calculated an average activation energy of the reaction using **Arrhenius plots**
- **Summer Intern project, NML Jamshedpur, India** [May’2010-July’2010]
Project Title: Examples of process analysis in metal extraction using Factsage
 - Calculated **Standard Gibbs’ Free Energy Changes (ΔG^0 s)** for reactions pertinent to **Mg extraction**
 - Constructed **binary**, **ternary** and **quaternary** phase diagrams for **MgO-CaO-Al₂O₃-SiO₂** system
 - Determined the theoretical **slag-metal equilibrium** composition for **Fe-Mn** production
 - Examined the **common errors** while using **Factsage** and suggested **methods** to get reliable information

Conference Participation

- **AISTech 2019-The Iron and Steel Technology Conference and Exposition** held in Pittsburgh, PA from May 6-9, 2019. [May’2019]
- **Materials Science & Technology (MS&T) 2019** held in Portland, OR from September 29-October 3, 2019. [September’2019]
- Second international conference on “**Science and Technology of Ironmaking and Steelmaking (STIS-2013)**” held in NML, JSR from Dec. 13-16, 2013. [December’ 2013]
- Fourth “**National Symposium for Materials Research Scholars, MR-12**” held in IIT, Bombay from May 3-5, 2012. [May’2012]

Relevant Skills

- High temperature experimentation using *horizontal* and *vertical tubular furnaces and confocal scanning laser microscopy (CSLM)*.
- Experience in the operation of *Large Scale Bench Reactor (LSBR)* for flash ironmaking in *University of Utah*.
- Analytical tools: *XRD, Scanning Electron Microscopy (SEM)* and *Optical Microscopy (OM)*, *thermal analysis techniques such as DSC-TGA, Electron Probe Microanalyzer (EPMA)* and *Nano-indentation*.
- Software Skills: *ThermoCalc, Factsage, Matlab, Avizo*.