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Environmental Management and Rehabilitation

Environmental Management Requirements and Practices in River-Based Artisanal and Small-Scale Sand Mining: A Case Study from the Progo River, Indonesia

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Abstract

Sand is extracted in greater volumes than any other mineral resource, with global consumption reaching approximately 50 billion tonnes annually. In Indonesia, artisanal and small-scale sand mining (ASSM) accounts for 94% of national sand production. However, the implementation of environmental management requirements by formally permitted operations remains poorly understood. This study investigates environmental management and post-mining land rehabilitation in a formally permitted ASSM operation on the Progo River in Yogyakarta Province, Indonesia. Drawing on content analysis of the operation's Environmental Management and Monitoring document, semi-structured interviews with four miners from the same mining group and three environmental consultants, and direct field observations, the study compares documented obligations with on-site practices across all operational stages. Three patterns emerge. First, the Environmental Management and Monitoring document primarily serves as a permit requirement rather than an operational guide: once the permit is issued, miners rarely consult it, and operational decisions revert to miners' own experience and judgment. Second, several requirements are overly generic, drawn from broader mining contexts rather than tailored to the specific conditions of river-based sand extraction, leading to predictable gaps between formal requirements and operational realities. Third, post-mining governance is the weakest stage: a site visit five months after permit expiry found that none of the formal closure requirements had been fulfilled. Despite these gaps, miners demonstrated practical environmental management, including on-site oil containment, topsoil storage and return, and conversion of ex-mining areas into productive fishponds and farmland. These community-driven practices are not captured in the regulatory document. This study concludes that improving governance in river-based ASSM requires technical guidance tailored to on-the-ground conditions, monitoring approaches suited to a dynamic river environment, and stronger post-mining obligations with defined outcomes and timelines.

Keywords: artisanal and small-scale sand mining; environmental governance; environmental compliance; river mining; post-mining rehabilitation

A Multivariate Geostatistical Framework for Environmental Risk Assessment in Mine Tailings

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Abstract

Mine tailings are increasingly recognized as both environmental liabilities and potential secondary sources of critical and valuable metals. Effective management and evaluation of these deposits require reliable spatial models that can quantify the distribution of both economically important and environmentally sensitive elements. Conventional geostatistical methods, such as linear kriging, are often limited in their ability to capture complex non-linear relationships and quantify local uncertainty associated with threshold exceedance. In addition, they are unable to incorporate heterotopically sampled secondary variables, limiting their effectiveness in multivariate estimation problems. These limitations can hinder both environmental risk assessment and resource evaluation in legacy tailings deposits.

This study presents a novel extension of multi-Gaussian kriging (MGK) to a multivariate framework, termed multi-Gaussian cokriging (MGCOK). The approach enables the joint estimation of local recoverable functions, including mean element concentrations, estimated metal quantities, and the volume of material exceeding specified environmental or regulatory thresholds. The methodology was applied to the Haveri tailings deposit in Finland, with a focus on sulphur (S), iron (Fe), and cobalt (Co), elements of environmental and economic relevance. By incorporating cross-variable correlations through a linear model of coregionalization, MGCOK improves the estimation of local recoverable functions, particularly for sparsely sampled variables. Compared with conventional MGK, the proposed approach reduces estimation uncertainty and provides improved delineation of areas with elevated element concentrations. Cross-validation results demonstrate enhanced predictive performance, especially for highly variable and under-sampled elements. The findings highlight the value of multivariate non-linear geostatistical modelling for supporting environmental risk assessment in complex tailings deposits, while also demonstrating its potential applicability to future resource evaluation and reprocessing studies.

Keywords: Multivariate geostatistics, Mine tailings, Environmental risk mapping, Resource Recovery.

Rhizosphere-driven Reduction and Organo-mineral Immobilisation of Vanadium During Technosol Formation in Bauxite Residue

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Abstract

Bauxite residue (BR) is a highly alkaline by-product of alumina production that poses significant environmental risks if not effectively remediated. Eco-engineering approaches that use organic matter and fertiliser amendments have successfully transformed BR into soil-like substrates (i.e. Technosol) by promoting mineral weathering and neutralising pH. These transformations facilitate the development of self-sustaining soil systems capable of supporting plant growth. However, the behaviour and mobility of hazardous oxyanions in BR, particularly vanadium (V), during Technosol formation remain poorly understood. This glasshouse study investigated the speciation of V and Fe in early-stage BR Technosol, amended with organic matter and fertilisers, and vegetated with *Atriplex amnicola*. Vanadium K-edge X-ray absorption near edge structure (XANES) spectra revealed a decrease in V oxidation state in amended rhizosphere soils compared to pre-plant soils. Spatially resolved XANES of rhizosphere thin sections showed that V at the soil-root interface was present as V³⁺, whereas V in soil aggregates occurred as mixed V⁴⁺/V⁵⁺ species. Pre-edge spectral analysis suggests that V in soil aggregates was in a distorted octahedral coordination consistent with hematite-associated V(III), while V coordination at the soil-root interface was consistent with organic ligand-associated V. Sequential extractions further indicated that V is primarily associated with organic-bound and Fe-oxide fractions, and less than 0.5% of V is in plant-available forms. Iron K-edge XANES mapping showed a transition from hematite-dominated Fe speciation in outer aggregate regions to predominantly ferrihydrite Fe phases within aggregate interiors, suggesting poorly crystalline ferrihydrites can provide reactive sorption and incorporation sites for V and further stabilisation. Overall, this study demonstrates that Fe-oxide phases and organic matter represent important geochemical sinks for V, effectively reducing its mobility and potential bioavailability, while rhizosphere processes facilitate further reduction and stabilisation at the soil-root interface. These findings support that Technosol formation is an effective strategy for mitigating V-related environmental risks in BR remediation and management

Keywords: bauxite residue, soil formation, vanadium speciation, *Atriplex*, technosol

From Plots to Platforms: A Century of Soil Erosion Monitoring and the Future of Integrated Validation Systems

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Abstract

Over the past century, soil erosion monitoring and assessment have progressed from plot-based experiments to advanced digital and remote sensing platforms. Building on this evolution, this study examines how integrated validation systems can be further developed by leveraging current technological advancements to enhance their applicability and shape the future of erosion assessment. Our analysis draws on an extensive literature review spanning a century of soil erosion monitoring and assessment research, through which we identified five key dimensions that offer a structured characterization of erosion monitoring and assessment methods as well as three major stages of erosion assessment and monitoring, ranging from traditional plot based (500 m²) empirical approaches to contemporary digital, data driven and remote sensing frameworks at landscape scales (1-10 km²). While numerous studies highlight the role of remote sensing and geographic information systems in advancing erosion modelling, their capacity as a direct, standalone monitoring tool has received significantly less focus. Recent technological advancements such as high-resolution LiDAR sensors and their integration with Geographic Information Systems (GIS) demonstrate strong capabilities as a monitoring method by providing substantially higher spatio-temporal coverage and enhanced observational resolution in a cost-effective manner, substantially strengthening the capability of modern erosion monitoring systems. This represents a major improvement over early remote sensing techniques such as early satellite imagery (1970-2000s) which, despite offering broad spatial coverage, were constrained by coarse spatial and temporal resolution. The emergence of airborne and UAV based remote sensing platforms helped to overcome this coarse spatial resolution, while also enabling repeat surveys at user defined intervals, a level of temporal flexibility satellite missions of that era could not offer. Taken together, these findings indicate that integrating ground-based monitoring methods with advanced remote sensing technologies can generate complementary multiscale datasets capable of overcoming long-standing limitations in erosion assessment particularly those constraining robust model calibration and validation.

Keywords: Soil Erosion, Erosion Monitoring, Erosion Modelling, RS and GIS, Model Validation.

Social Responsibility and Governance



Analysing tailings governance through a human rights lens

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Abstract

The recent history of catastrophic tailings failures in Brazil shows that tailings can violate basic human rights, including the rights to life, safety, and a clean environment. The 2015 Mariana disaster released more than 40 million m³ of mine waste, killed 19 people, contaminated the Doce River basin over hundreds of kilometres, and affected numerous communities and Indigenous territories. Four years later, the Brumadinho tailings dam collapse killed 270 people and released millions of cubic metres of mining waste into the Paraopeba River system, causing extensive and long-lasting socio-environmental impacts. Following these major failures, stricter requirements for transparency, stakeholder engagement, and disaster risk reduction have been introduced in tailings governance worldwide. Yet research shows that Brazil's tailings governance landscape is institutionally complex and fragmented. Ongoing challenges include coordination, capacity, and accountability. Tailings governance, like many socio-environmental phenomena, operates through polycentric systems. These systems are understood as governance arrangements in which multiple centres of authority interact within and across scales to pursue a shared governance goal. In tailings, they involve overlapping responsibilities across government agencies, mining companies, regulators, standards bodies, and stakeholders, including communities. This PhD project analyses multilevel governance systems for tailings management through a human rights lens. The research focuses on three main areas. First, it examines the actors, institutions, and policy instruments that form tailings governance systems in Brazil. Second, it analyses how responsibilities, information flows, and decision-making processes are coordinated within these systems. Third, it explores how communities are positioned within these systems and how they participate in decision-making processes. The presentation will introduce the project's research context, research questions, and emerging methodological framework.

Keywords: tailings governance, polycentric governance, human rights-based approach

Governing Coal Transitions: Exploring Justice and Institutional Dynamics in two mining regions (Saunda, Jharkhand & Latrobe valley, Australia)

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Abstract

Phasing out coal is central to global decarbonisation goals. There is a growing acknowledgment that permanent changes to energy production and use may reproduce or exacerbate injustices for communities that have long depended on coal. The Just Transition literature highlights the need to mitigate job losses, cultivate alternative economic pathways, sustain local services and prevent broader socio-economic decline. While these desired outcomes are well articulated, less is understood about how governance structures embedded in coal regions enable or constrain processes leading to these outcomes. This thesis problematises governance arrangements to examine what role they may play in managing transitions in two diverse coal regions. Drawing on Prno and Slocombe's tripartite model of state-society-market interactions, the study conceptualises governance arrangements as historically situated and continually negotiated relationships among state, company and community actors. Using qualitative data from interviews, focus group discussions, archival material and field observations, the thesis studies these interactions in Saunda, Jharkhand, India, and the Latrobe Valley in Victoria, Australia. In Saunda, decades of paternalistic provision by the Central Coalfields Limited, a state-owned enterprise that historically provided employment, housing, services and welfare, combined with a withdrawn state, have altered local governance dynamics in ways that created a governance vacuum and limited community agency to plan before, during, and after coal mine closures. In contrast, the Latrobe Valley experienced closure under privatised ownership, which prompted substantial state intervention and funding. Yet, anticipated positive outcomes were partially constrained due to fragmented governance and uneven coordination – critical governance failures with lasting impacts for the locals. These cases highlight how historically embedded relationships between state, corporate and community actors continue to shape justice implications for coal-dependent regions as they navigate the uncertainties of closure and transition.

Evaluating Mine Waste Impacts on Local Communities Using Publicly Available Data – An Ore-sand Case Study

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Abstract

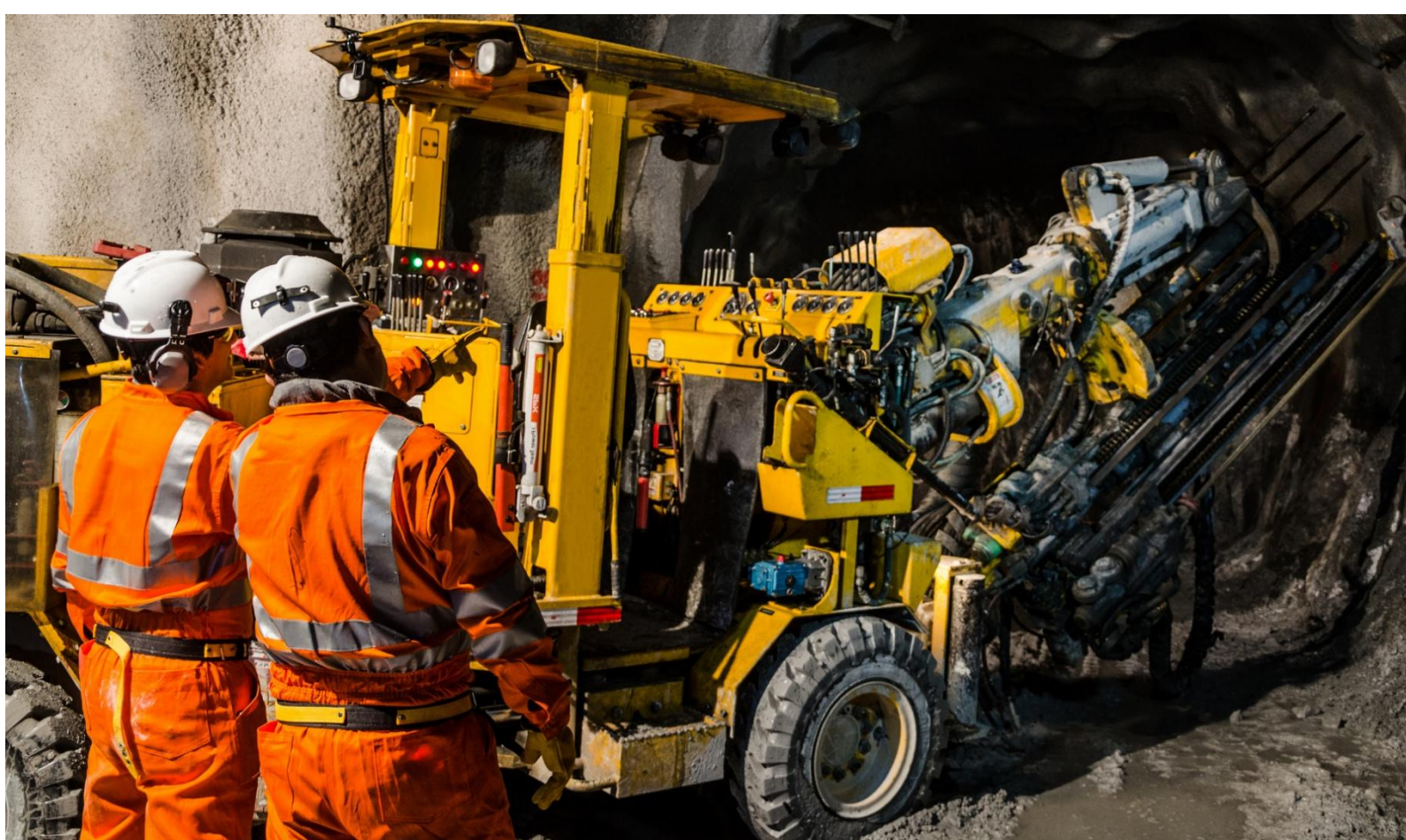
Mine waste can have major health impacts for the environment and local community but is often neglected in life cycle analyses of these operations due to a lack of data on local conditions and few methodological examples of how to transform available data into the format required for social indicators. There is an urgent need to study mining impacts as waste rock is only becoming a larger issue with remaining ore deposits having lower ore grades, meaning less desired mineral and more surrounding rock. Additionally, current management of waste storage systems at mine sites has caused massive damage to mine operations and taken dozens of lives. A mutually beneficial way to reduce mining waste is to make a useful product, such as sand, out of this otherwise wasted rock. The technology to produce ore-sand already exists at pilot sites, but the large-scale impacts of adoption on society and the environment have yet to be explored. To begin a country-wide analysis of the potential impacts of shifting from traditional sand extraction (usually river or terrestrial mining) to ore-sands, I have collected the locations and production levels of sand quarries across Australia. Each of these quarries produces sand with different properties and size distributions, so I am also in the process of quantifying the amount of sand likely consumed by roadworks, building construction, and glass production nationally.

Future work will include a life cycle assessment comparing sand mining and ore-sand production impacts on local communities and environments. I expect the social impacts to be largest in the worker and local community stakeholders, particularly in health and safety (workers), safe and healthy living conditions (local community), and water access (local community). The environmental impacts will likely appear in land use change, energy use, water quality, and air quality indicators.

This data collection and resulting case study analysis will help future researchers use more location specific data on mining impacts as well as demonstrate a method of translating publicly available health, demographic, and governmental data into social life cycle analysis indicators.

Keywords: Waste Management, Life Cycle Assessment, Ore-sand, Social Impacts

Safe and Sustainable Mineral Exploration, Extraction, and Processing



Maintaining the Mine: Linking Asset Productivity, ESG Outcomes, and Sustainable Mining

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Abstract

Mining companies have set ambitious ESG and net-zero targets, yet the link between corporate ambition and operational delivery remains insufficiently defined. This presentation argues that sustainable mining outcomes are linked to the effective performance of interdependent asset systems across exploration, extraction, processing, and mine-to-port operations. Asset availability, utilisation, throughput, safety, and reliability shape not only productivity but also energy efficiency, emissions intensity, and broader operational, safety, and ESG risks. Recent public reporting on decarbonisation challenges at a major Australian miner illustrates a broader sector challenge: public climate commitments are constrained by diesel dependence, delayed renewable deployment, technology readiness, and limitations of existing asset systems ([ABC News](#)).

Rather than treating maintenance as a support function or cost centre, the presentation positions maintenance, repair, and operations (MRO) capability as an important enabler of ESG performance. Even electrified, automated, and digitally enabled assets have downtime, requiring inspection, servicing, condition monitoring, repair, shutdowns, skilled labour, spares, and restoration time. Improving asset productivity by reducing downtime is therefore critical to reducing waste, lowering exposure to operational, safety, and ESG risks, and strengthening sustainable mineral production.

The presentation introduces an Asset Productivity-to-Net-Zero framework supported by three constructs: Safe Maintenance Asset Restoration Time (SMART), Maintenance Operations Real-Time Asset Loss (MO-REAL), and Asset Throughput Metric (ATM). Together, these constructs connect maintenance execution to ESG-relevant decision-making and provide visibility for asset-specific interventions to achieve ESG goals. The framework positions asset productivity as both an economic measure and an operational mechanism for safer, more sustainable mining performance.

The presentation contributes a conceptual bridge between corporate sustainability ambition and operational mining practice. By reframing maintenance from cost control to ESG enablement, the framework shifts mining sustainability from retrospective reporting toward real-time asset-level visibility, control, and auditable evidence that can be used to guide industry interventions, maintenance decisions, and critical risk governance.

Keywords: asset productivity; ESG; maintenance; net-zero; sustainable mining; asset systems.

Unlock the Secret of Pyrite in Becoming an Alternative Source for Critical Metals via Thermal Decomposition

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Abstract

Pyrite is widely treated as a non-valuable and problematic mineral by environmental and mineral processing sectors (Jefferson et al, 2023). Despite these challenges, pyrite is increasingly recognised as a potentially valuable resource for its ability to host economically important and critical elements (e.g., cobalt (Co), nickel (Ni) and gold (Au); Steadman et al., 2021; Babedi et al., 2022; Li et al., 2025; Erlandsson et al., 2025) across various deposit types (e.g., IOCG, sediment-hosted and epithermal; Keith et al., 2018; Li et al., 2024). In fact, pyrite when oxidised, it is the main contributor for acid and metalliferous drainage (AMD; Xu et al., 2025). To reduce environmental risks associated with pyrite-rich tailings, pyrite could be selectively recovered as part of a rehabilitation measure. Cobalt Blue's patented technology, turning pyrite to pyrrhotite through thermal decomposition (Cobalt Blue Holdings, 2026), followed by leaching critical metals, has shown the potential to deliver benefits throughout the entire life of mine. By reducing the acid-forming potential of mine waste whilst enhancing the recovery of critical metals, this approach makes a meaningful contribution to circular economy principles and the United Nations Sustainable Development Goals (SDGs) (e.g., SDG 12: Responsible Consumption and Production). Despite the successful Co extraction demonstrated by Cobalt Blue, the mechanistic controls governing variability in pyrite-to-pyrrhotite conversion rates remain poorly understood. By investigating the geochemical, textural and mineralogical factors driving these differences, this research aims to establish a predictive framework for the thermal decomposition of pyrite across different deposit types. The resulting framework will drive efforts to optimise the thermal decomposition process and the recovery of critical metals essential to the green energy transition and sulphuric acid production.

Keywords: thermal decomposition; pyrite; critical metals; cobalt; mine wastes

Mapping of Alteration Zones in a Porphyry Copper System Using PRISMA Hyperspectral Imagery

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Abstract

Hyperspectral imagery has been widely used to map alteration zones associated with various ore deposits, particularly those found in porphyry copper systems. The PRISMA hyperspectral satellite, launched in 2018, offers improved spectral coverage (400–2500 nm, 240 bands) and reduced noise, enabling more accurate identification of porphyry copper alteration related minerals, such as sericite, kaolinite, chlorite, and epidote. This study evaluates PRISMA's capability to map phyllic, argillic, and propylitic alteration in the Kuhpanj porphyry copper deposit in southeast Iran. Four techniques were applied: selective principal component analysis (SPCA), mixture-tuned matched filtering (MTMF), linear spectral unmixing (LSU), and novel band ratios, using PRISMA Level 2D data from April 2022, with radiometric corrections and removal of noisy SWIR bands. Results were validated using field samples and geological maps.

SPCA method enhances alteration detection by maximizing variance linked to minerals in the SWIR bands. MTMF method maps subpixel mineral abundances, while LSU decomposed pixels into endmember fractions but struggled in highly mixed zones. New band ratios for PRISMA imagery, based on mineral absorption features, were further developed to enhance alteration zone discrimination. Accuracy was assessed using 32 ground-truth samples. The band ratio method was the most accurate, achieving 87.50% overall accuracy and a kappa coefficient of 80.54%, followed by MTMF with 81.25% accuracy and a kappa of 70.55%. SPCA and LSU exhibited lower accuracies, both at 71.87%, with kappa coefficients of 58.85% and 57.52%, respectively. All methods delineated major alteration zones consistent with geological data, but the band ratio and MTMF methods proved most reliable. These results confirm that PRISMA's high spectral resolution enables highly accurate detection of alteration zones, and the proposed band ratios are effective tools for mineral exploration and alteration mapping in porphyry copper system

Keywords: PRISMA, alteration mapping, Porphyry system

Effect of High Voltage Pulse Treatment on Mineral Interfacial Properties

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Abstract

The application of High Voltage Pulse (HVP) technology is a promising approach that can reduce energy requirements through enhanced mineral liberation, coarse-waste rejection, pre-weakening, and pre-concentration. There are, however, few studies that examine the influence of HVP treatment on mineral interfaces and downstream processes.

This research investigates the effects of inherent mineral properties on breakage and their impact on the surface chemistry of HVP-treated minerals. Using advanced characterisation and analytical techniques, including X-ray Photoelectron Spectroscopy (XPS), Time-of-Flight Secondary Ion Mass Spectroscopy (TOF-SIMS), and microscopy, the study examines differences between conventional and electrical comminution in terms of breakage, surface chemistry, and potential impact on flotation behaviour.

Recent analytical work comparing electrically and mechanically crushed samples provides evidence of surface-chemistry differences between comminution methods, which may affect how HVP treatment influences flotation behaviour. This research aims to establish the relationship between HVP-induced breakage behaviour and the resulting surface-chemistry modifications, providing insight into how electrical comminution may influence flotation performance.

Keywords: high voltage pulse technology, surface chemistry, XPS, ToF-SIMS

Electrical Conductivity Measurement of Slags for Electric Smelting Ironmaking

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Abstract

In the contemporary global context of carbon neutrality, it is imperative for the ironmaking industry to progressively transition away from the use of fossil fuels. The traditional blast furnace-basic oxygen furnace (BF-BOF) route, which remains the dominant pathway in steel production, is significantly reliant on coal. As a lower-carbon alternative, the direct reduced iron-electric arc furnace (DRI-EAF) route has been increasingly adopted. However, the EAF is highly sensitive to the level of impurities in DRI, which limits its applicability for processing low- to medium-grade iron ores. In contrast, the electric smelting furnace (ESF) exhibits greater flexibility in raw material input and furnace composition adjustments. In the DRI-ESF route, BF grade ores can first be reduced using natural gas or hydrogen in shaft furnaces or fluidised beds to produce DRI, which is subsequently smelted in ESF using electricity. Currently, no commercial-scale ESF process operates using BF grade DRI. Therefore, a comprehensive understanding of the DRI behaviour in the ESF process, especially the properties of the ESF slag where DRI melting and smelting occur, is imperative for ESF design, process optimization and control. Among these properties, the electrical conductivity of slag is of particular importance, as heat in ESF is generated through resistive heating of the slag, thereby directly influencing DRI melting and reaction behaviour.

In this study, the electrical conductivity of DRI smelting slags was systematically investigated as a function of slag composition and temperature using the four-electrode method. The experimental samples were synthesised from CaO, SiO₂, MgO, Al₂O₃, and "FeO". An orthogonal experimental design was employed to evaluate the effects of compositional variations and temperature on slag electrical conductivity. The underlying mechanisms governing slag electrical conductivity are discussed through correlations between the electrical conductivity, slag composition and temperature.

Keywords: Direct reduced iron, electric smelting furnace, smelting slags, electrical conductivity.