SUCCESS STORY

PlasmArc4Green
Simulation, Modelling and Monitoring of Plasma and Arc based Processes for Green Metal Production.

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Programme line: COMET-Module

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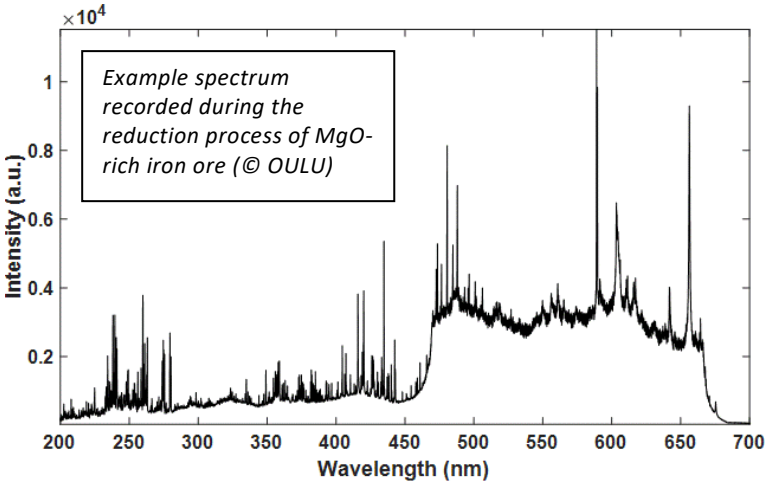

IN-SITU DIAGNOSTICS OF HYDROGEN PLASMA SMELTING REDUCTION

REAL TIME MONITORING OF HYDROGEN PLASMA SMELTING REDUCTION PROCESS BY USING OPTICAL EMISSION SPECTROSCOPY AND VIDEO ANALYSIS

Extensive use of carbon-based reductants in conventional ironmaking routes contributes 7-8% of global anthropogenic CO_2 emissions. Therefore, decarbonization of this process has become an industrial and scientific challenge. Hydrogen Plasma Smelting Reduction (HPSR) has emerged as a promising alternative, combining the use of hydrogen as a reducing agent with plasma technology to enable low-carbon iron production while maintaining flexibility towards lower-grade iron ores and complex raw materials.

In HPSR, a high temperature hydrogen plasma arc is generated between electrodes while an inert gas, such as argon or nitrogen, is supplied as an arc stabilizer. This plasma provides thermal energy for smelting and highly reactive hydrogen species for the reduction of oxides. The plasma exhibits non-equilibrium and dynamic behavior. Numerous physical and chemical phenomena occur including dissociation of hydrogen, evaporation of volatile species, reduction of oxides, and formation of metallic droplets and slag. Thus, advanced in-situ diagnostic tools are needed to observe and understand the process in real time.

To address this challenge, a team from *University of Oulu* (OULU) applied **optical emission spectroscopy (OES)** and **video analysis** during a series of HPSR experiments at *Max Planck Institute for Sustainable Materials* (MPI) using a MgO-rich iron ore. After initial melting of the feed material with an argon plasma, hydrogen was introduced to start the reduction process. Several samples were reduced up to a pre-defined total reduction time after Ar pre-melting. An example OES spectrum, the time evolution of Mg I emissions, and an image captured during the process are shown in the figures. The Mg I emissions increase over time indicating slag becomes rich in Mg as

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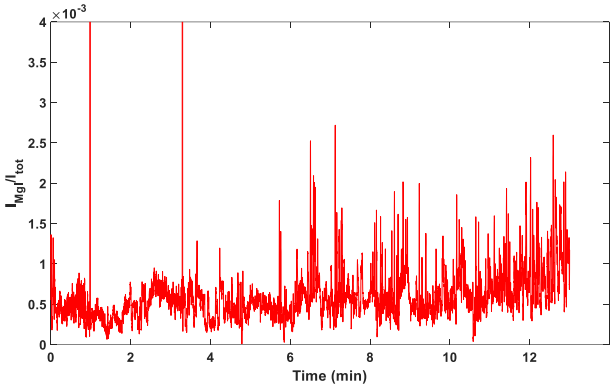
reduction proceeds. After reduction, metallic and slag portions were separated and characterized.



Time evolution of Mg I emissions during HPSR process (© OULU)

The measurements revealed clear changes in the plasma emissions as reduction progressed. In particular, the increasing magnesium-related optical signals indicated the enrichment of Mg-containing phases in the slag, while changes in hydrogen and iron emissions reflected the ongoing reduction of iron oxides. Post-mortem analysis of the samples confirmed successful reduction of the iron ore and demonstrated that magnesium remained predominantly in the slag phase after processing.

Impact and effects

The results highlight the potential of HPSR for the treatment of low-grade and gangue-rich iron ores that are difficult to process via conventional hydrogen-based direct reduction routes. In the long term, HPSR could enable near-zero-emission ironmaking and support future one-step steelmaking concepts, where water vapour is generated instead of CO_2. The developed monitoring approaches will further contribute to improved process control, higher resource efficiency, and accelerated industrial implementation of hydrogen plasma technology for sustainable metal production.

Frame captured from the video recorded during HPSR (© OULU)

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Project partners

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- Max Planck Institute for Sustainable Materials, Germany

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