

Mitigate Particle Sticking in Hydrogen Fluidized Bed Ironmaking

Erlei Li¹, Zhiming Shi², Geoff Wang¹

¹ School of Chemical Engineering, The University of Queensland, Brisbane, QLD, Australia

² Sustainable Minerals Institute, The University of Queensland, Brisbane, QLD, Australia

Introduction

Iron and steel production contributes approximately 7-9% of global CO₂ emissions, making deep decarbonization of this sector an urgent challenge. Hydrogen-based direct reduction of iron ore offers a promising pathway toward low-carbon steelmaking by replacing carbon-based reductants with hydrogen.

Fluidized bed reactors are attractive because they can directly process fine iron ores and avoid sintering or palletization. However, their industrial deployment is limited by particle sticking and agglomeration during reduction. At high temperatures, iron ore particles may soften, adhere, and form inter-particle bridges, leading to defluidization, unstable reactor operation, and process failure.

This project combines CFD-DEM simulations and laboratory experiments to understand sticking mechanisms and identify stable operating conditions for hydrogen fluidized bed ironmaking.

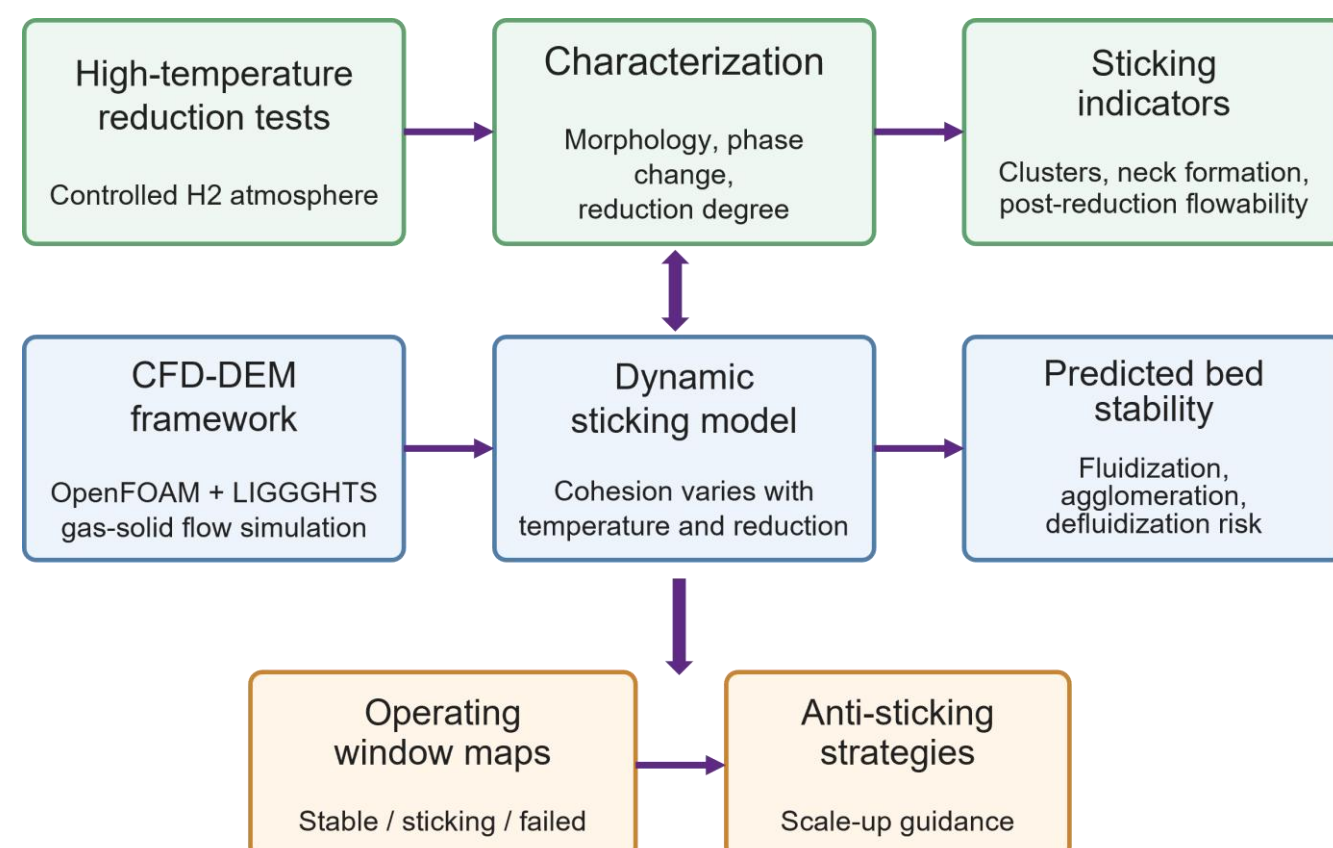


Figure 1: Integrated workflow for investigating particle sticking in hydrogen fluidized bed ironmaking.

Method

A coupled computational and experimental approach will be used to investigate particle sticking during hydrogen reduction of iron ore fines. The methodology combines high-temperature reduction experiments, particle characterization, and CFD-DEM modelling to link particle-scale sticking behavior with predicted fluidized bed stability.

The computational model will be developed using OpenFOAM coupled with LIGGGHTS to simulate gas-solid flow in a fluidized bed reactor. Heat transfer, mass transfer, reaction kinetics, and particle-particle interactions will be incorporated into the CFD-DEM framework. A dynamic sticking model will be implemented to represent temperature- and reduction-degree-dependent cohesion forces, including liquid bridge and solid bridge effects.

Laboratory-scale hydrogen reduction experiments will be conducted using iron ore fines in a high-temperature furnace. The particles will be reduced under controlled H₂/N₂ atmospheres.

Reduced samples will be characterized to examine morphology, phase transformation, and agglomeration behavior. Experimental observations will be used to validate the CFD-DEM model and refine the predicted stable operating windows.

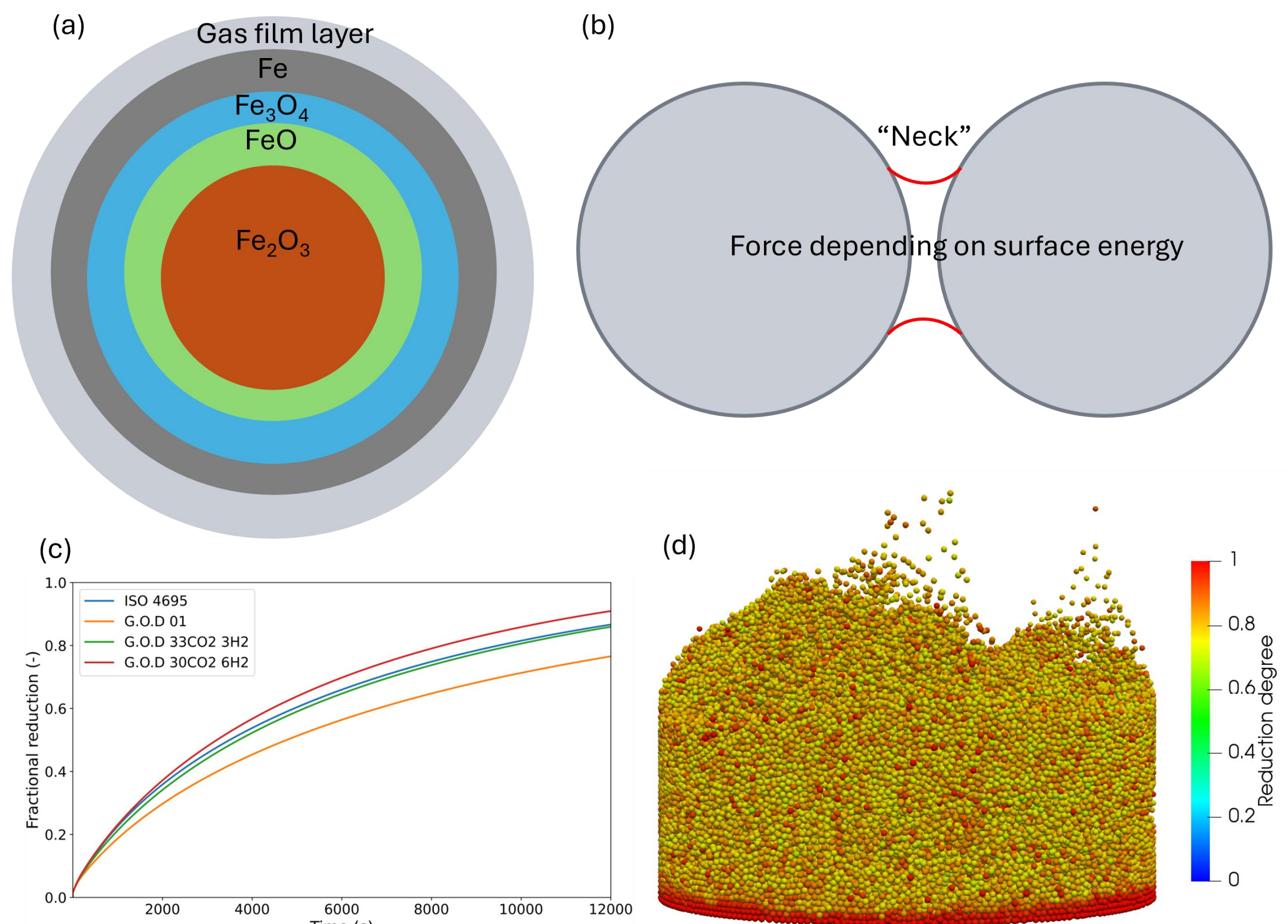


Figure 2: (a) Unreacted shrinking core model for iron ore reduction; (b) JKR model for simulating sticky, cohesive particle contacts; (c) single-particle reduction test showing fractional reduction over time; and (d) CFD-DEM fluidized bed reduction simulation colored by reduction degree.

Results

CFD-DEM model development

A CFD-DEM coupling framework has been developed to simulate hydrogen-based reduction of iron ore particles under gas-solid flow conditions, including

- Unreacted shrinking core model for reduction
- JKR cohesive contact model for particle sticking
- Metallization-dependent and temperature-dependent surface energy

Overall, the developed modelling framework provides a basis for predicting reduction behavior, cohesive contact formation, and potential agglomeration during hydrogen fluidized bed ironmaking.

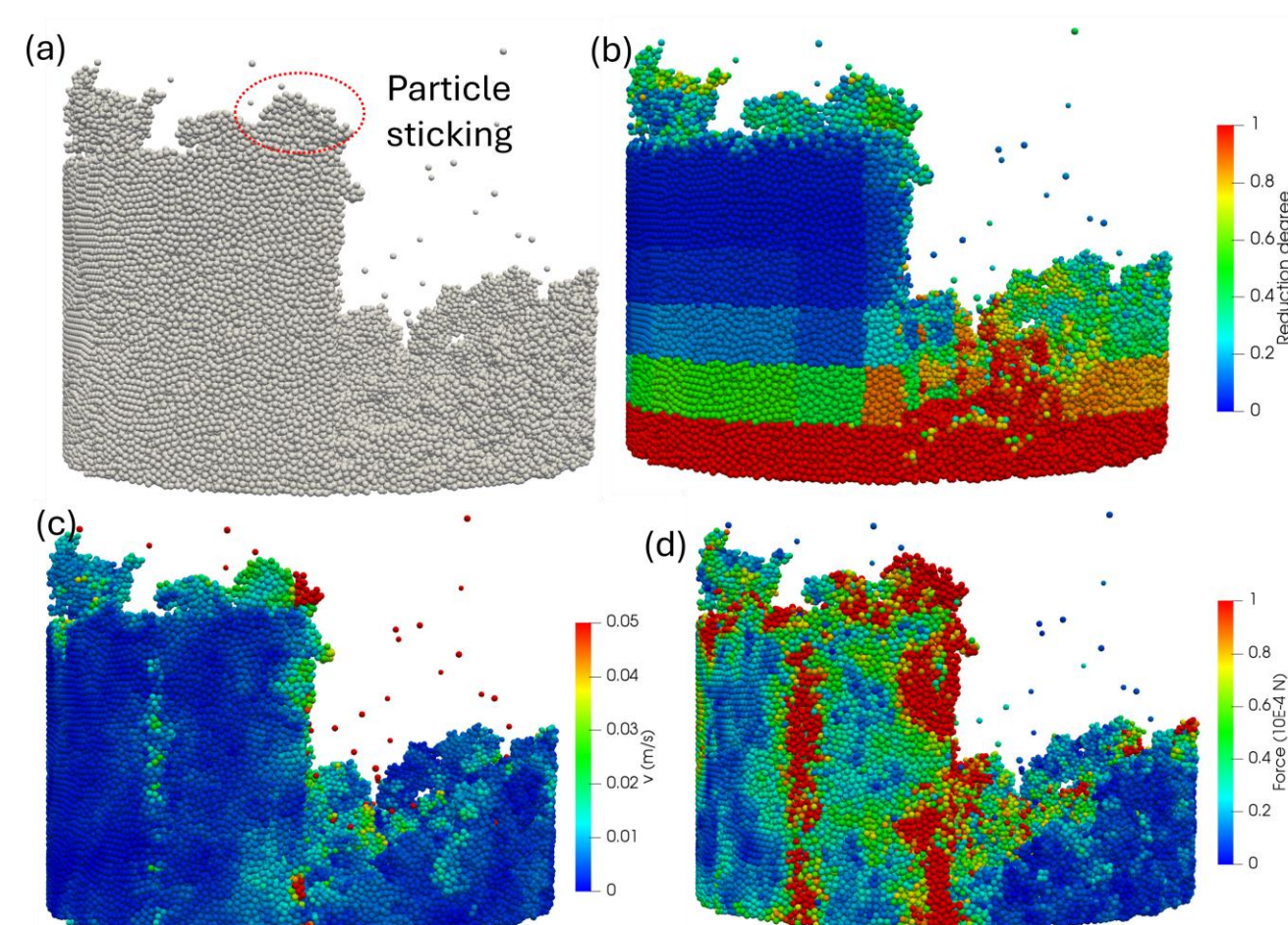


Figure 3: Particle sticking and defluidization : (a) particle sticking and local agglomerate formation; (b) reduction degree distribution; (c) particle velocity distribution; and (d) particle contact force distribution.

Particle sticking & Defluidization

Particle sticking and local agglomeration can be observed in Fig. 3(a), indicating that cohesive contacts form when particles become highly reduced. Fig. 3(b) shows a non-uniform reduction degree across the bed, suggesting that gas flow, residence time, and local mixing strongly affect reaction progress. Fig. 3 (c) and (d) further explain the sticking mechanism. Low-velocity regions indicate local particle stagnation, which increases contact time between particles, while high-force regions show where strong particle-particle interactions occur.

The surface energy, dependent on metallization degree and temperature, will be calibrated using experimental results.

Conclusions

Hydrogen fluidized bed ironmaking is a promising pathway for low-carbon steel production, but particle sticking remains a key barrier to stable operation and industrial scale-up. In this project, a CFD-DEM framework has been developed to couple gas-solid flow, reduction kinetics, coarse-grained particle motion, and JKR-based cohesive contact forces. The model enables particle sticking to be linked with reduction degree, temperature-dependent surface energy.

Future work will focus on process parameter studies to identify stable operating windows. Anti-sticking strategies such as optimizing fluidization velocity, controlling reduction degree, and using surface modification or additives will also be evaluated to support future pilot-scale and industrial hydrogen ironmaking reactors.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the 2026 Accelerating Future Decarbonisation Technologies Seed Grants from UQ Dow Centre for Sustainable Engineering Innovation.