Reduction and Carburization of Industrial and Biomass-containing Iron Ore Pellets: Effects of Temperature & H_2-CO Ratio

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1. Context

Towards low-CO_2 steelmaking with H_2 Direct Reduction (DR)

- **Current hurdles:**
  - Limited supply of green H_2
  - No carbon in the H_2 stream → affects product quality
- **Opportunity:** Biomass (biochar/biogenic gas) can provide heat and in-situ carbon. Yet, its impact on coupled reduction-carburization kinetics and pellet integrity is poorly documented
- **Why carburization matters (DR → Electric arc furnace):**
  - Enhances slag formation
  - Provides additional heat
  - Reduces residual oxides
- **Drawback:** Excess surface carbon deposition slows reduction and increases dusting/handling issues

2. Objectives

Investigate and quantify the effects of temperature and gas composition (varying H_2/CO ratios) on the reduction kinetics and concurrent carburization in industrial-grade iron ore pellets and biochar composite pellets using TGA and SEM-EDS.

3. Materials, Methods, and Characterization

Material properties		
Pellet type	Industrial-grade	Biomass composite
Fe content	66 wt% (as Fe_2O_3)	89 wt% (as Fe_2O_3)
Other components	Traces of Al_2O_3, SiO_2, and CaO	10 wt% biochar, 1 wt% starch
Diameter	12-13 mm	11-13 mm
Mass	4.0-4.2 g	0.9-1.2 g

Experimental conditions	
Test type	Single-pellet isothermal
Reduction gases	H_2, H_2/CO, and CO
Temperatures	973, 1073, 1173, 1273 K
Gas flow rate	300 mL/min
Test duration	120 min

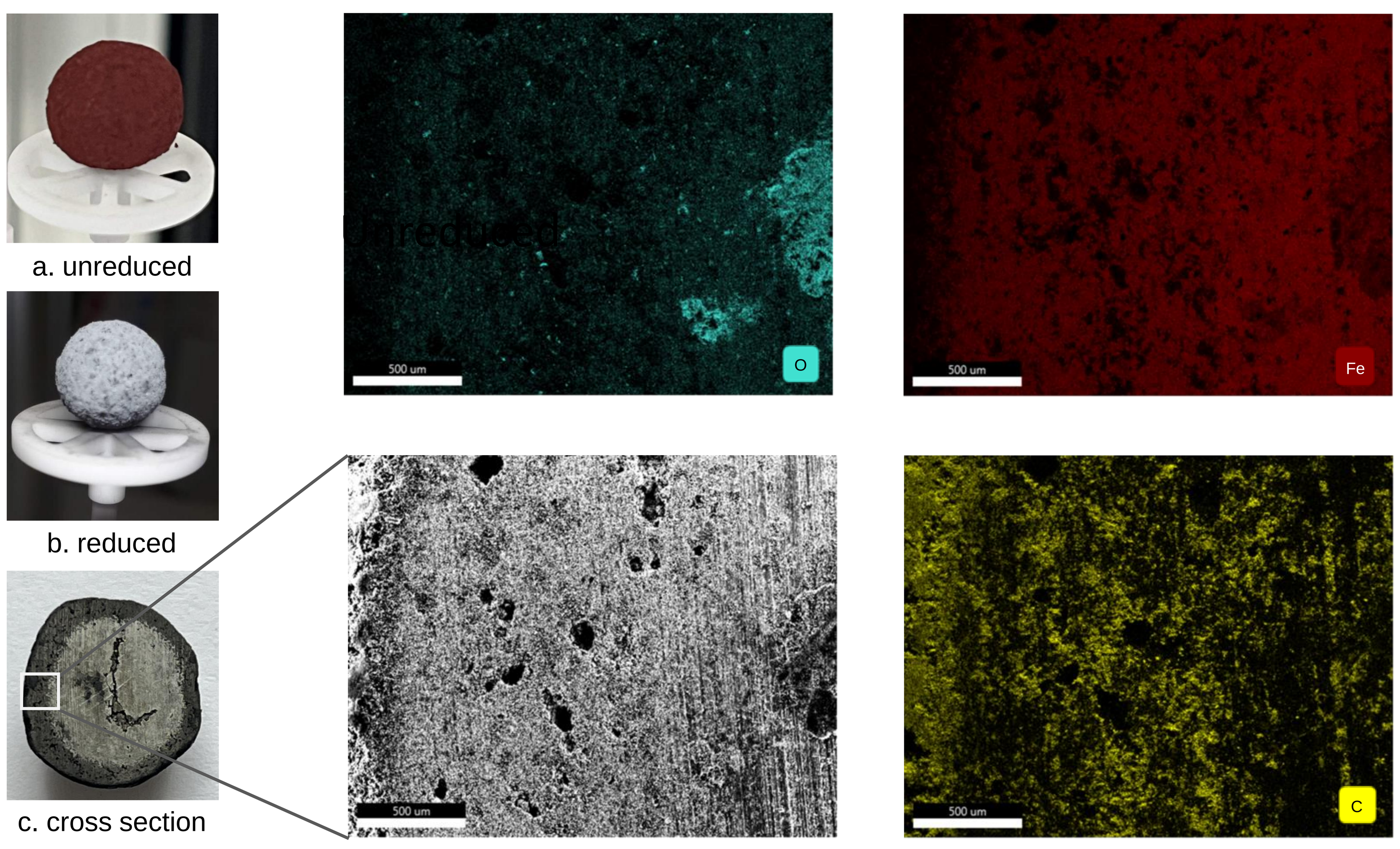


Figure 1. Left: a. and b. composite pellet before and after reduction with H_2. c. cross section of an industrial pellet reduced with a 50/50 H_2/CO mixture at 973 K. Right: SEM-EDS elemental mapping of the industrial pellet reveals a C-rich rim with residual O, indicating surface C uptake and incomplete core reduction.

4. Results

- **Carburization kinetics influenced by:**
  - Gas composition: Maximum at ~25/75% H_2/CO
  - Temperature: Lower temperatures accelerate carburization
- **Overall pellet mass change stems from:**
  - Mass losses: From ore reduction and, in case of composite pellets, also from biomass devolatilization
  - Mass gains: From iron carbide formation and carbon surface deposition, occurring after a certain reduction extent

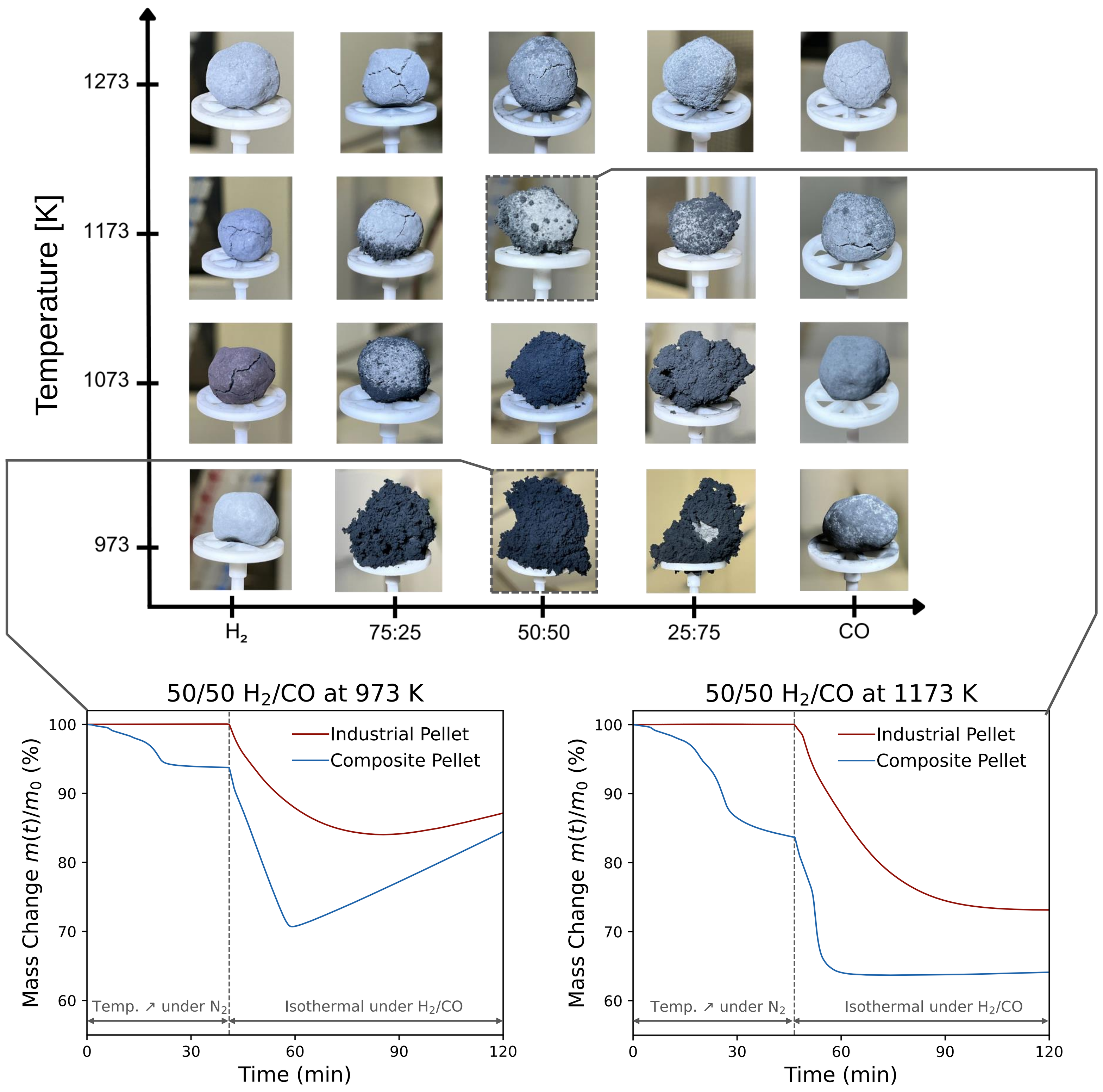
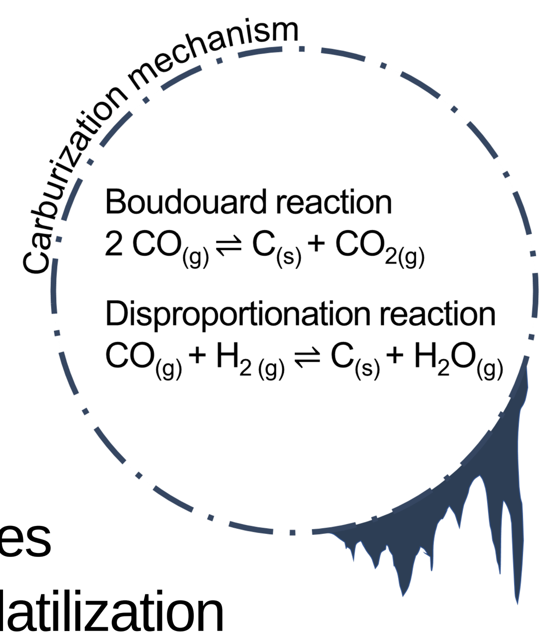


Figure 2. Top: Conversion of industrial iron ore pellets at four temperatures (973–1273 K) under various H_2/CO gas atmospheres. Bottom: Comparison of conversion over time for industrial and composite pellets at 973 and 1273 K with a 50/50 H_2/CO mixture. m_0: Initial pellet mass, $m(t)$: mass at time t

5. Discussion

- **Complex process description:**
  - Off-gas analysis and phase quantification required to decouple devolatilization, reduction, and carburization processes
  - Carbon deposition catalyzed by the presence of reduced iron or iron carbide
  - Hydrogen enhances the rate of reduction but also the rate of carburization through a disproportionation reaction, which can become excessive



- **Comparison industrial/composite pellets:**
  - Faster rates of reduction, as least partly attributable to the smaller initial pellets sizes
  - Significant in-situ reduction from the devolatilization of biomass, fostering reduction throughout the pellets

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