2022 SEAISI Steel Mega Event & Expo (Technology, Sustainability, Construction)

INVESTIGATION OF DRI PHYSICAL PROPERTIES UNDER HYDROGEN REDUCTION CONDITIONS

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Presentation outline

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01 Drive for the expanded use of H_2 in steel industry

02 Viability of using H_2 as reductant

03 Evaluation of H_2-reduced DRI

- Physical strength evaluation - fragmentation
- Clustering behavior

04 Sticking behavior of iron ores

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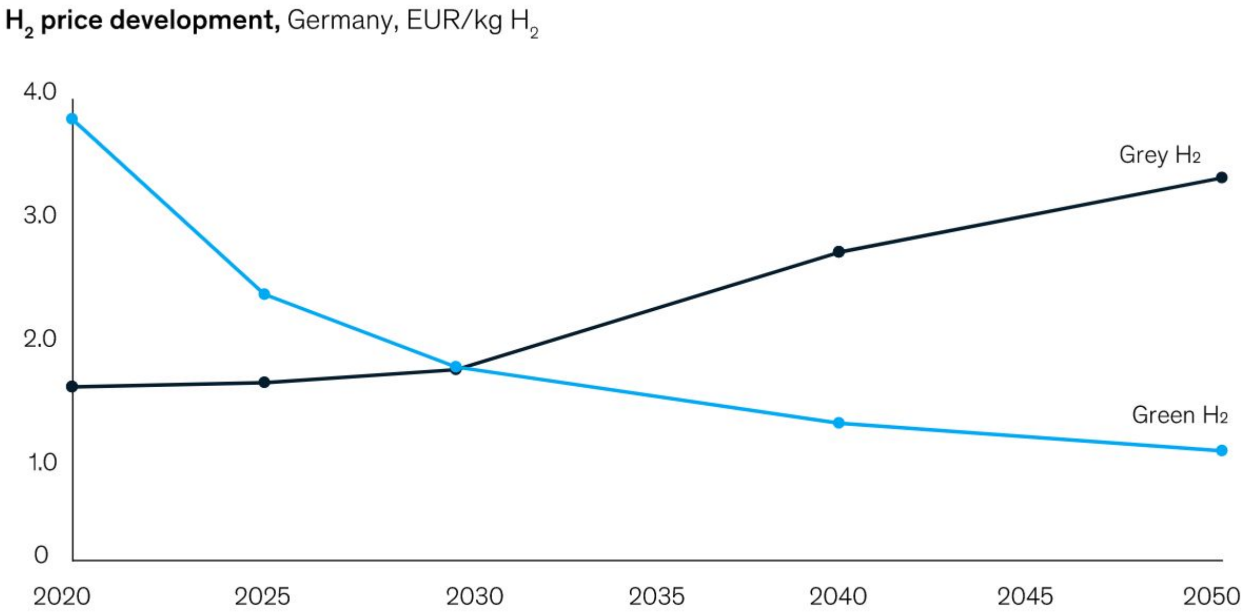
Drive for H_2 use in steelmaking

- Decarbonization challenge – steelmaking accounts for ~8% worldwide CO_2 emission*
  - Changing customer requirements and growing demand for carbon-friendly steel products
  - Tightening of carbon emission regulations
  - Growing investor and public interest in sustainability
- Full decarbonization is possible with MIDREX DRI process using green H_2 plus EAF*

*Decarbonization in steel | McKinsey

Viability of using H_2 as reductant

- Trend of cost of large-scale generation of hydrogen for H_2-based DRI production*.



- *Impact of H_2 reduction process on DRI strength and clustering?*

*https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

Evaluation of H_2-reduced DRI

- Physical characteristics of DRI reduced under Natural Gas (NG) and H_2 reduction conditions.
  - Strength of DRI pellets
  - Clustering behavior of iron oxide pellets and lump ores
- Iron oxides and lump ores for evaluation

Material	T. Fe%	Tumble index +6.73 mm
Lump ore A	54.04	81.8%
Lump ore B	60.41	83.7%
BF grade iron oxide pellet	65.40	95.7%
DR grade iron oxide pellet 1	68.06	95.2%
DR grade iron oxide pellet 2	68.02	94.5%

Physical strength evaluation

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Linder Test (ISO-11257)

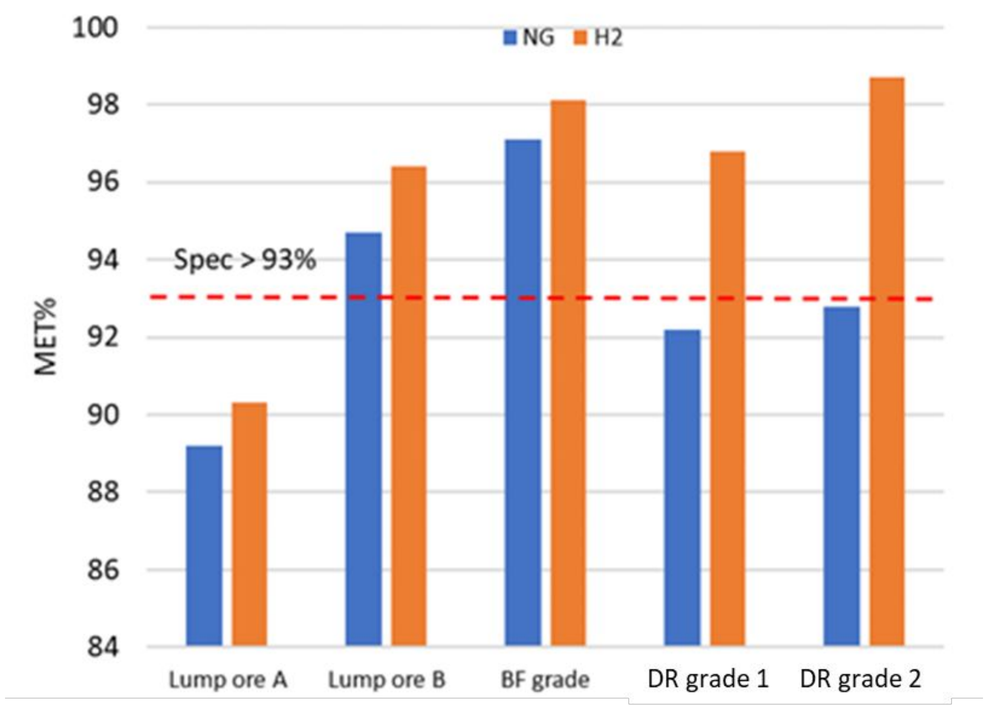
NG conditions: 36% CO, 5% CO_2, 55% H_2, 4% CH_4

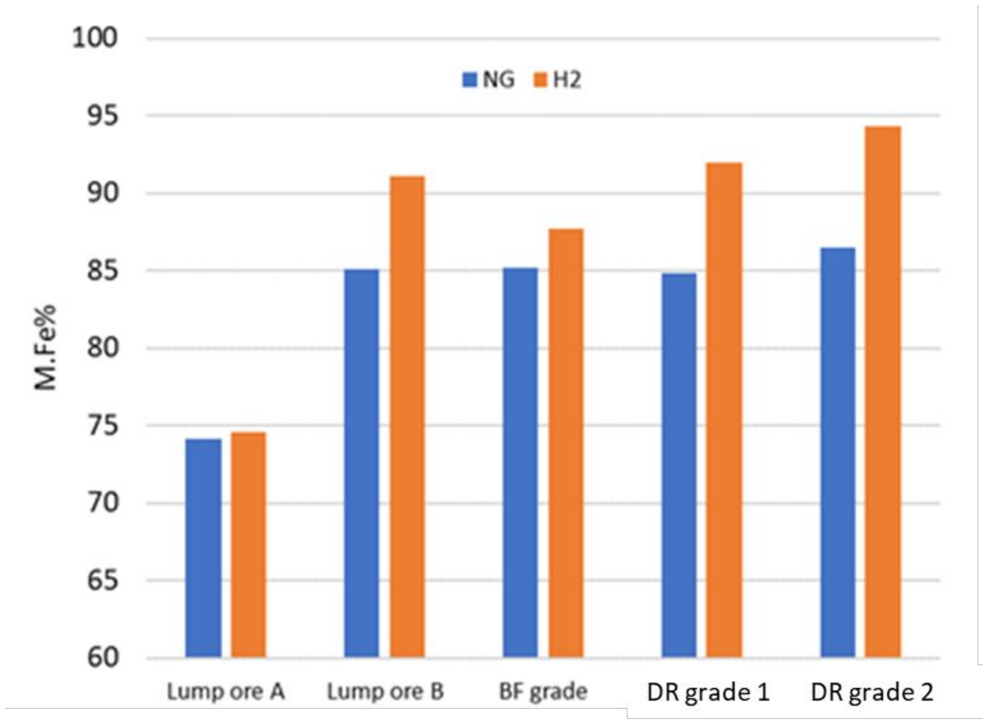
H_2 conditions: 100% H_2

760 °C for 5 hours

DRI is screened to measure degradation

Physical strength evaluation

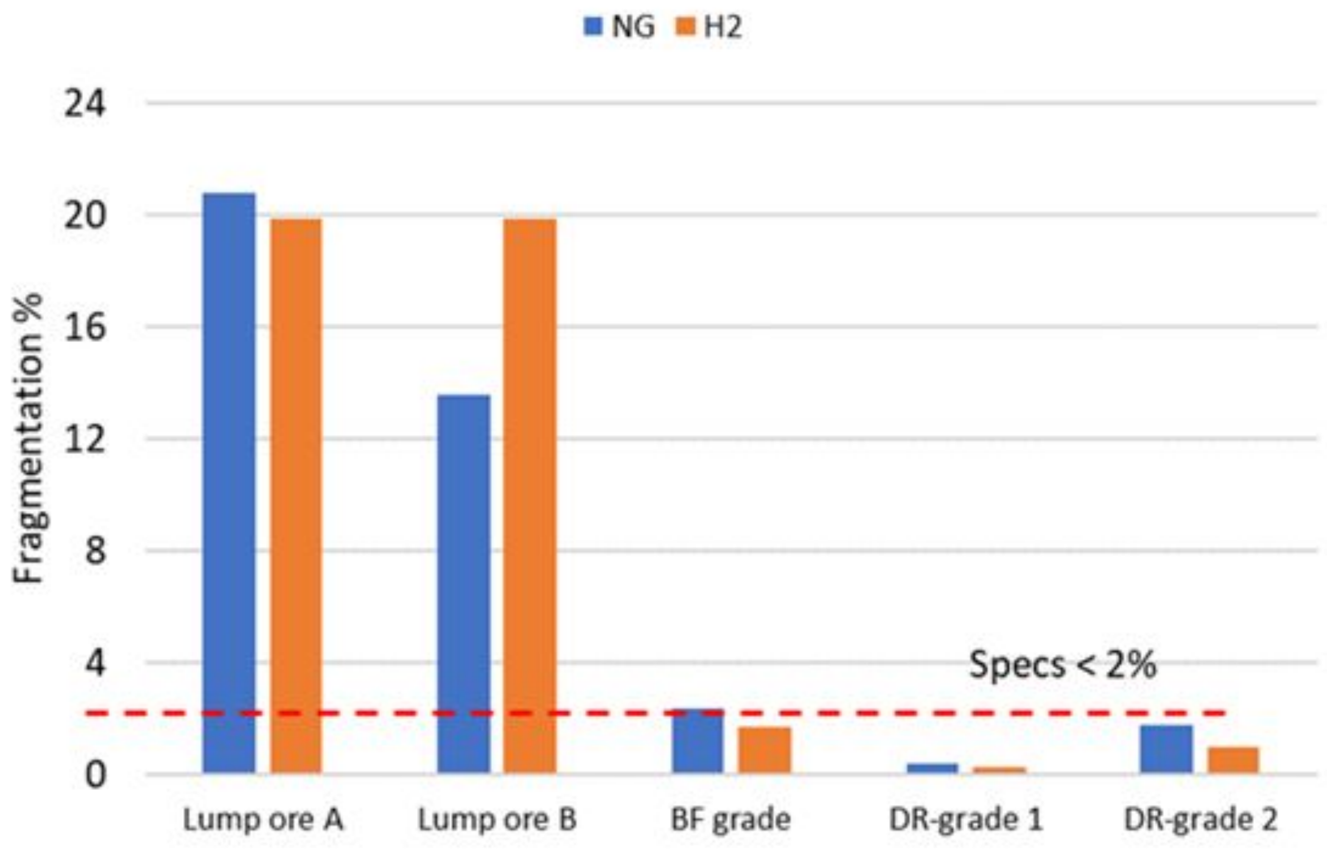




- High metallization (MET%) and metallic iron (M.Fe%) content can be obtained with pure H_2 reduction
- Smaller molecule, higher diffusivity

Physical strength evaluation

- All oxide pellets (BF and DR grades) reduced with H_2 had lower fragmentation than those reduced with NG; lump ores are not indurated.
- Less fines are generated from H2-DRI



Clustering behavior evaluation

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Cluster test (ISO 11256)

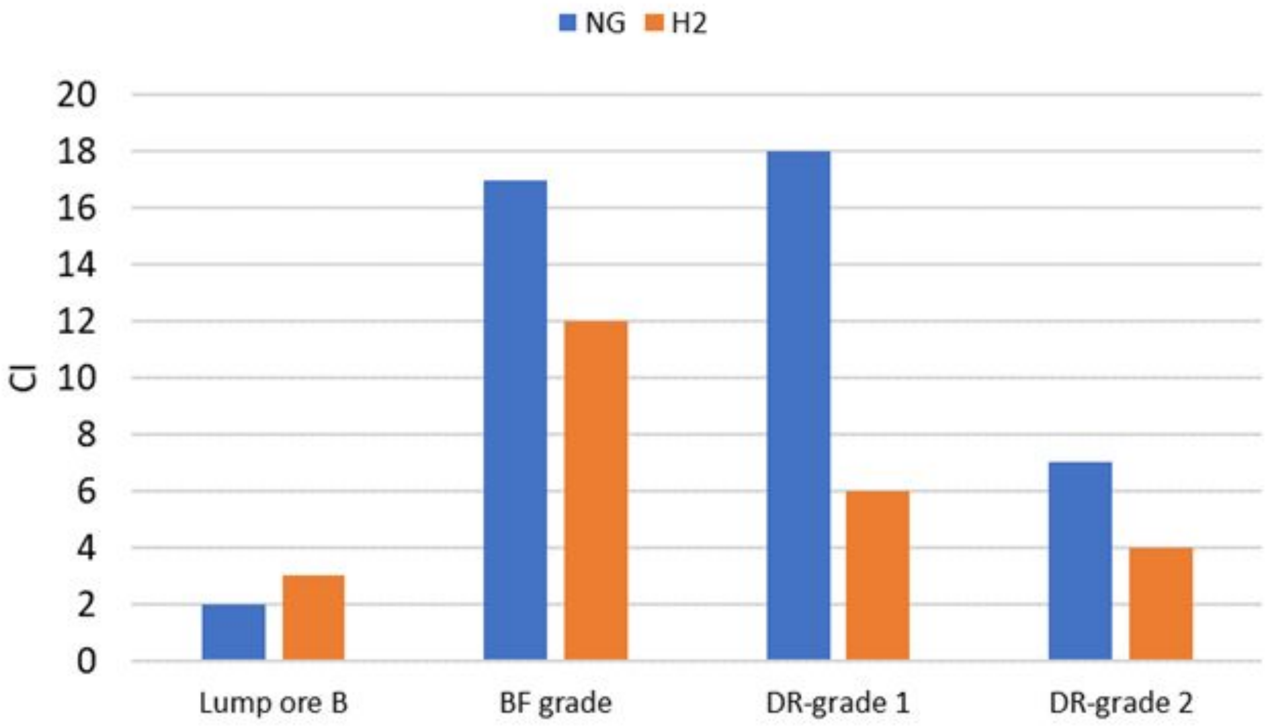
NG conditions: 30% CO, 15% CO_2, 45% H_2, 10% N_2

H_2 conditions: 100% H_2

850 °C until 95% reduction is achieved

Desirable clustering index (CI) is < 20

Clustering behavior



- Sticking/ clustering occurs during metallization of ore and depends on the kind of iron ores
- Midrex CI criterion is < 20
- Lump ore A's CI is 0
- CI of H_2 reduced DRIs is lower than NG reduced DRI

Sticking mechanisms

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1. **Type 1 sticking**[1,2] – formation and interlocking of iron whiskers at temps above 600 °C
   - Reaction controlled conditions trigger formation of iron nuclei whiskers
2. **Type 2 sticking** – bonding effect of newly generated metallic iron.
   - High surface energy and high viscosity of active new metallic iron increased adhesion
3. **Type 3 sticking** – bonding effect due to low melting eutectics at temps above 850 °C
   - Low melting eutectic phase ($CaO\text{-}SiO_2\text{-}FeO$) stick together in an iron ore at high temps.

Sticking behavior of iron ore

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Available literature on the sticking behavior of iron ore shows:

- Interlocking of fibrous iron decreases with H_2 content in reducing gas
- Growth of fibrous iron decreases with small addition of H_2 and stops if the H_2 addition increases greatly
- Sticking of pellets during reduction decreases with H2 content in reducing gas and increases with temperature
- Addition of H_2 transform metallic iron from fibrous to a dense layer; fibrous iron is favored in pure CO and dense iron is dominant in pure H_2

Hypotheses

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Clustering of iron ore reduced under CO (NG-DRI) may be attributed to Type 1 and Type 2 sticking

- Interlocking of iron whiskers
- Bonding effect of high surface energy and high viscosity new metallic iron

Clustering among H2-DRI may be attributed to Type 2 sticking and little to no iron whiskers formed on H2-DRI

Linder Test was conducted at 760 °C, the sticking phenomenon observed in the iron oxide pellets is unlikely to be caused by the formation of low melting eutectica (Type 3 sticking).

Conclusion

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Under H_2 gas, reducibility and physical properties of DRI are improved.

- Reduction in fines generation
- Reduced clustering index

H_2 reduction does not have adverse effects on DRI quality

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Q&A

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Reference

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