Influence of mechanically activated hydrogen diffusivity on the toughness of metallic materials for the storage and transport of hydrogen under pressure

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Context

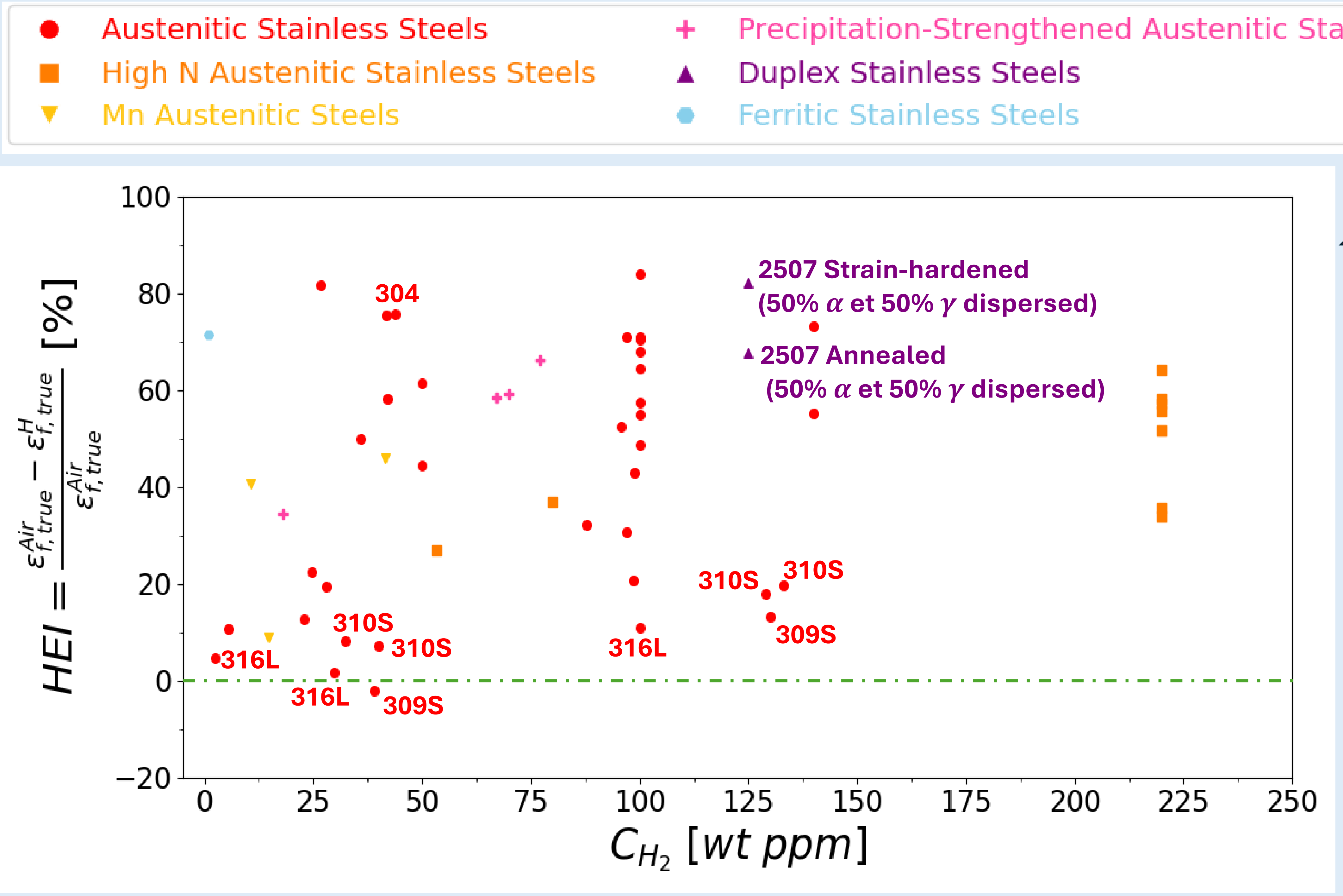
- ❑ Fully metallic (Type I) pressure vessels are limited by hydrogen embrittlement.
- ❑ The problem intensifies at high pressures, requiring new alloys and multilayer solutions, combining:
  - ❖ Low hydrogen permeability
  - ❖ High resistance to hydrogen embrittlement
  - ❖ Excellent mechanical strength
  - ❖ Cost-effectiveness to enable large-scale deployment

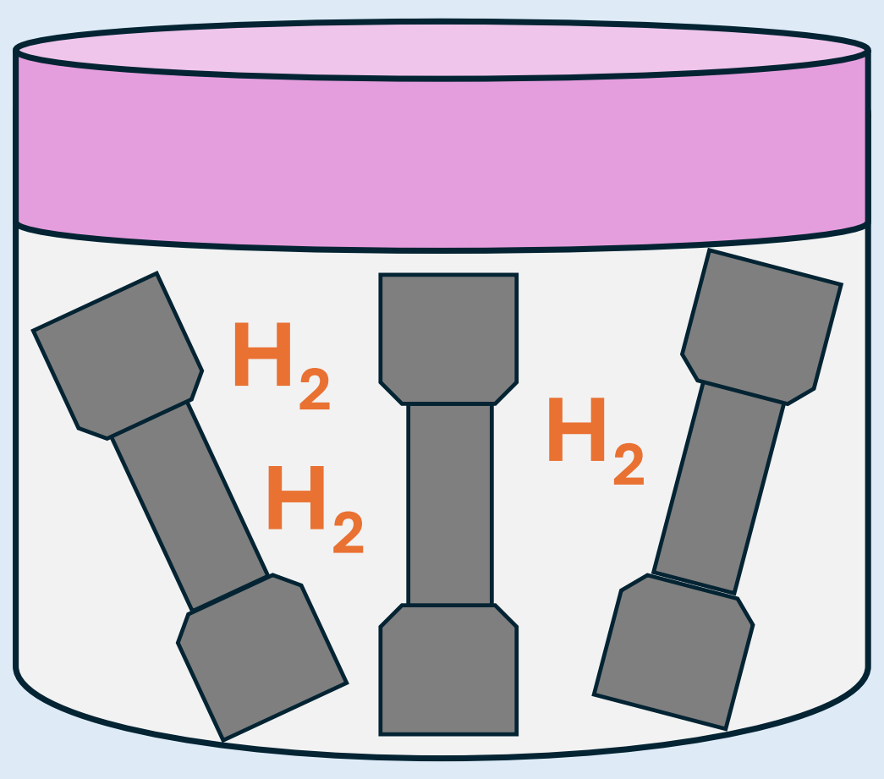
Type I (Fully Metallic)	Type IV (Fully Composite)
Limiting pressure P_{max} = 20-30 MPa	Limiting pressure P_{max} = 70-80 MPa

Goal: Reaching a storage pressure of 70MPa or more with cheaper fully metallic pressure vessels

Hydrogen embrittlement of steels

Hydrogen gaseous pre-charging and tensile testing in air





Higher susceptibility to hydrogen embrittlement

Austenitic stainless steels have the **highest resistance to hydrogen embrittlement** but:

- High amount of Ni: Expensive
- Low yield strength (200-320 MPa)

Need of new alloys

Materials with reduced or no Ni content and high yield strength: Dual-phase steels (Ferrite α/Austenite γ)

- ❖ **Fe-Cr-Ni duplex stainless steels**
- ❖ **Fe-Mn dual phase steels**

Improving hydrogen embrittlement resistance of dual-phase steels

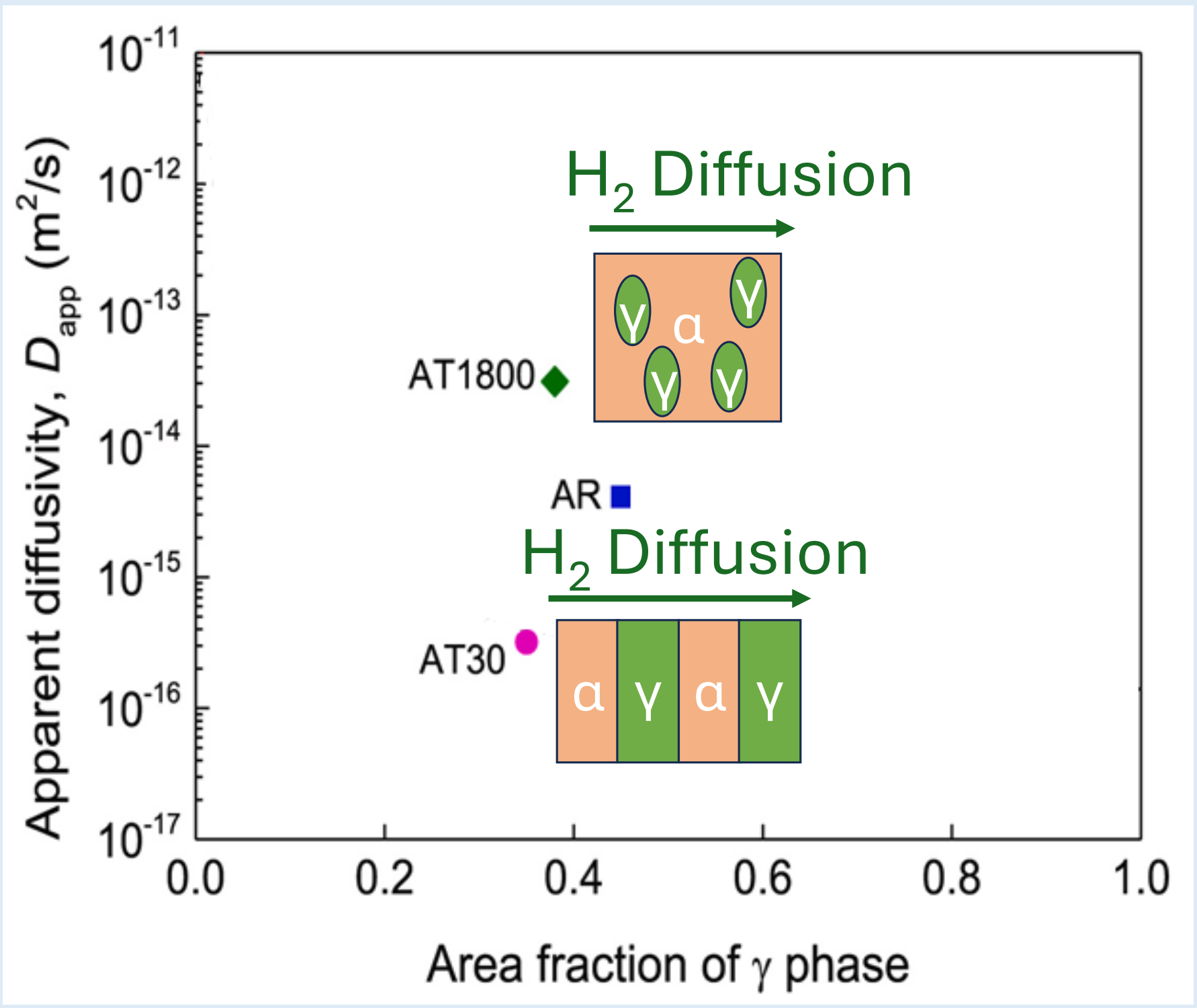
Impact of:

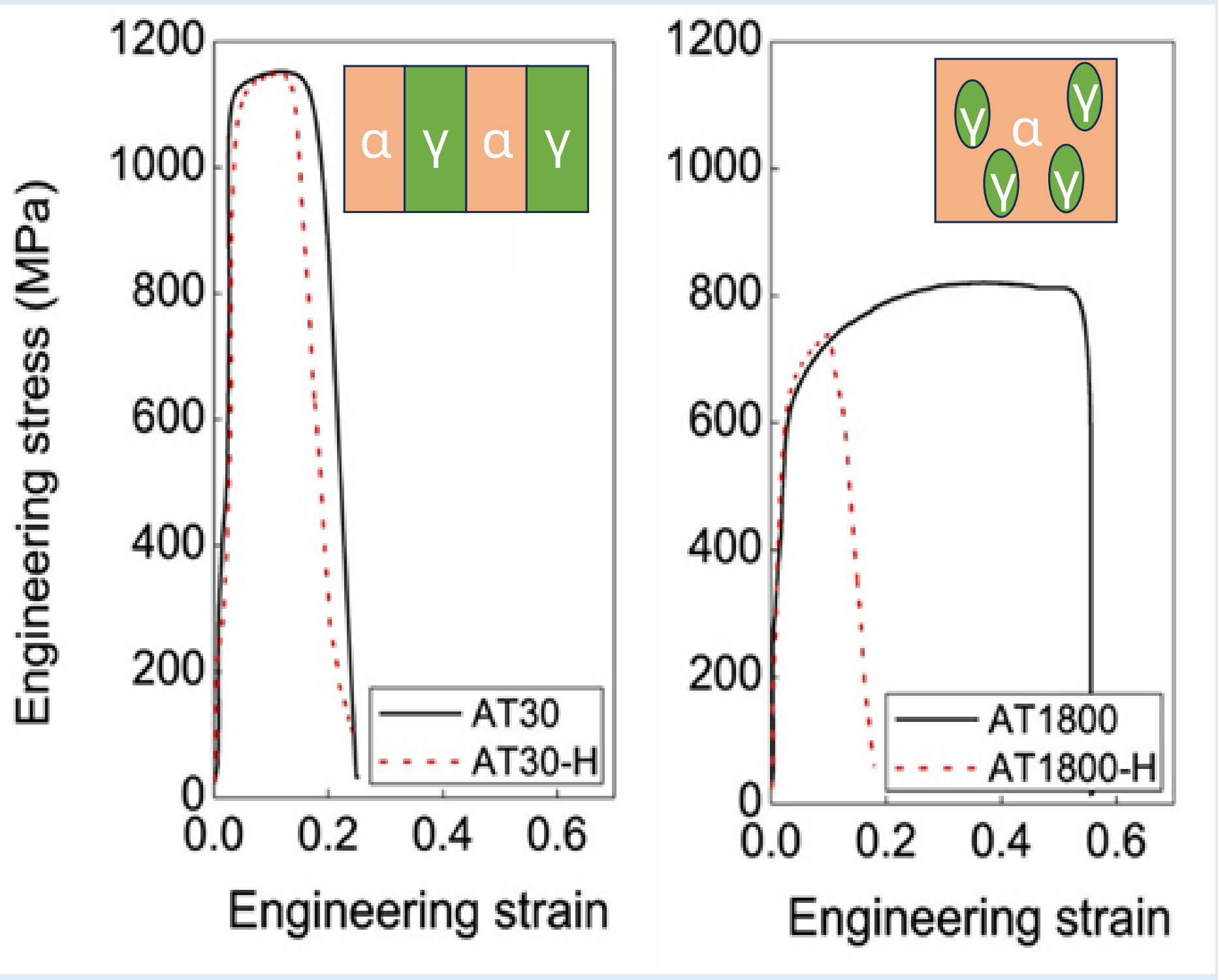
- Austenite phase fraction
- Percolation of austenite
- Phase morphology

Studied through:

- Experimental work:
  - ❖ Electrochemical permeation
  - ❖ Gaseous permeation
  - ❖ Tensile testing after gaseous charging
- Numerical simulations using COMSOL

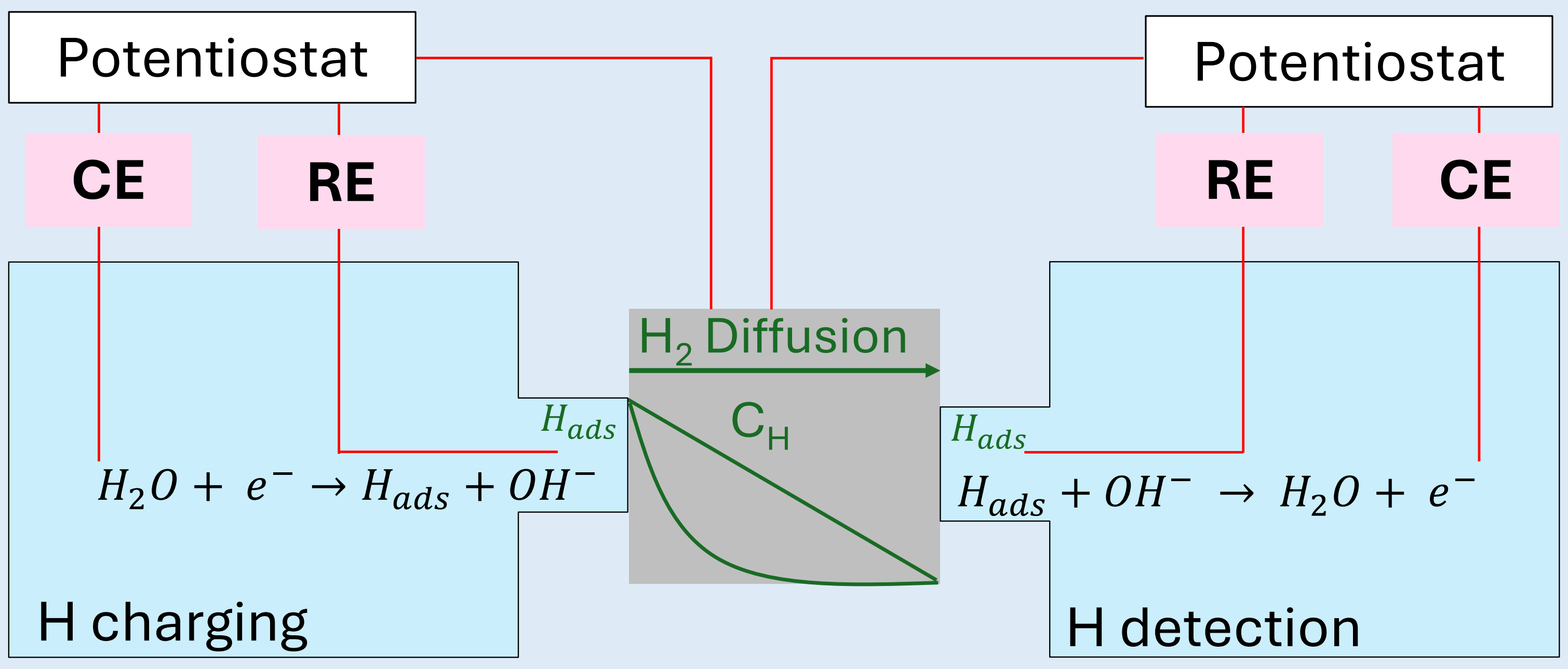
Study on 2205 duplex stainless steel [1]

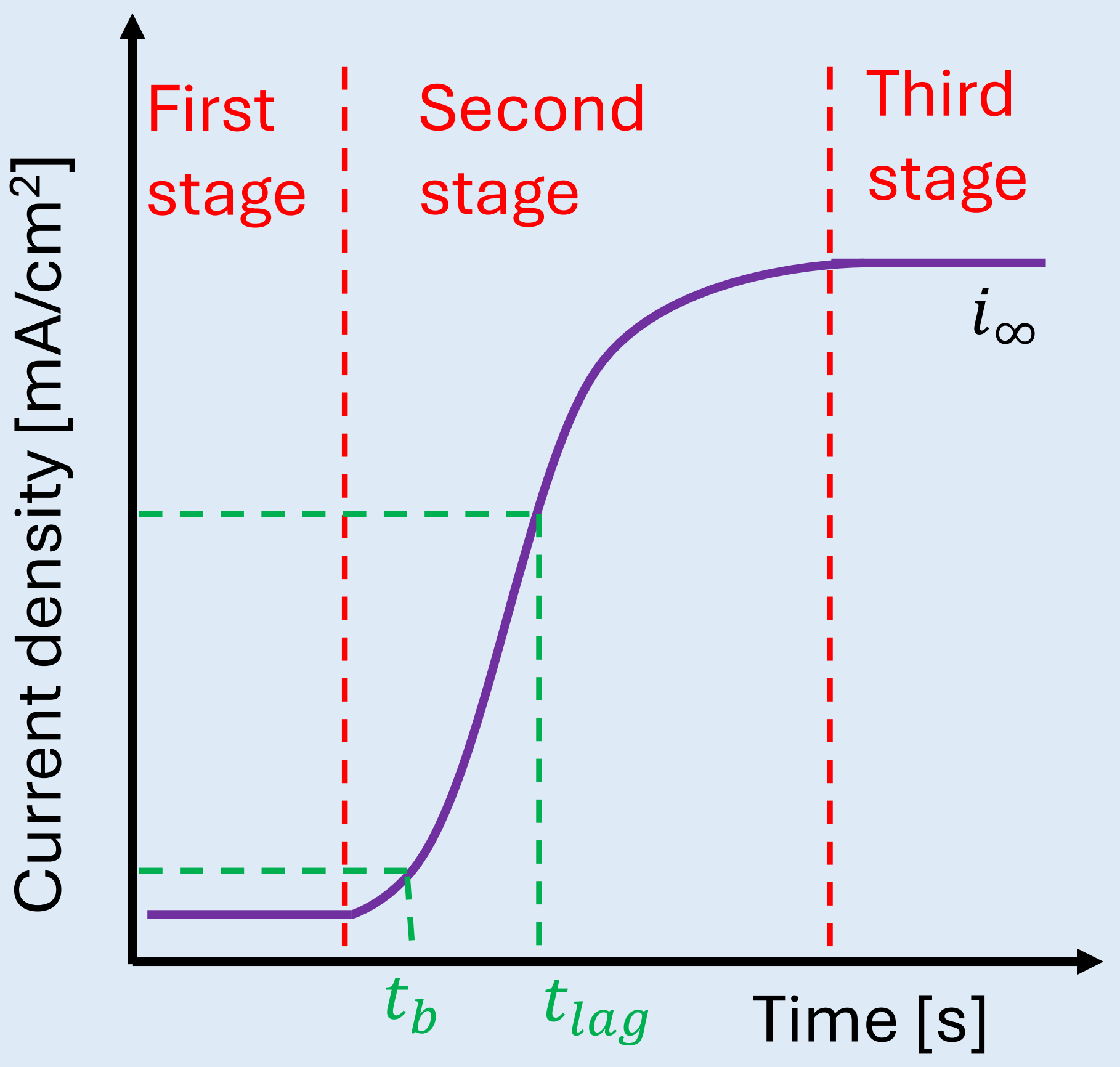




Electrochemical permeation

3-electrode cells:





Diffusivity measurements:

- ❖ Breakthrough time method:

$$D_{eff}(t_b) = \frac{L^2}{7.7\ t_b}$$

- ❖ Time-lag method:

$$D_{eff}(t_{lag}) = \frac{L^2}{2\ t_{lag}}$$

- ❖ Numerical methods

References

[1] Y. Wang et al., Influence of phase morphology on hydrogen embrittlement of type 2205 duplex stainless steel, https://doi.org/10.1016/j.msea.2025.148335

Acknowledgements

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