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SMS SUSTAINABLE MATERIALS SCIENCE · SOETE LABORATORY

ROLE OF GASEOUS CHARGING PARAMETERS ON HYDROGEN UPTAKE IN PIPELINE STEELS

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Introduction

Hydrogen transport in repurposed natural gas pipelines faces a key challenge: hydrogen embrittlement (HE). A promising solution is gas-phase inhibition with trace oxygen, which decreases hydrogen absorption at the steel surface.

Objectives

Defining static (no-load) gaseous hydrogen charging conditions.
Effects of charging parameters on hydrogen uptake and distribution.
Oxygen concentration and its long-term inhibition on hydrogen absorption.

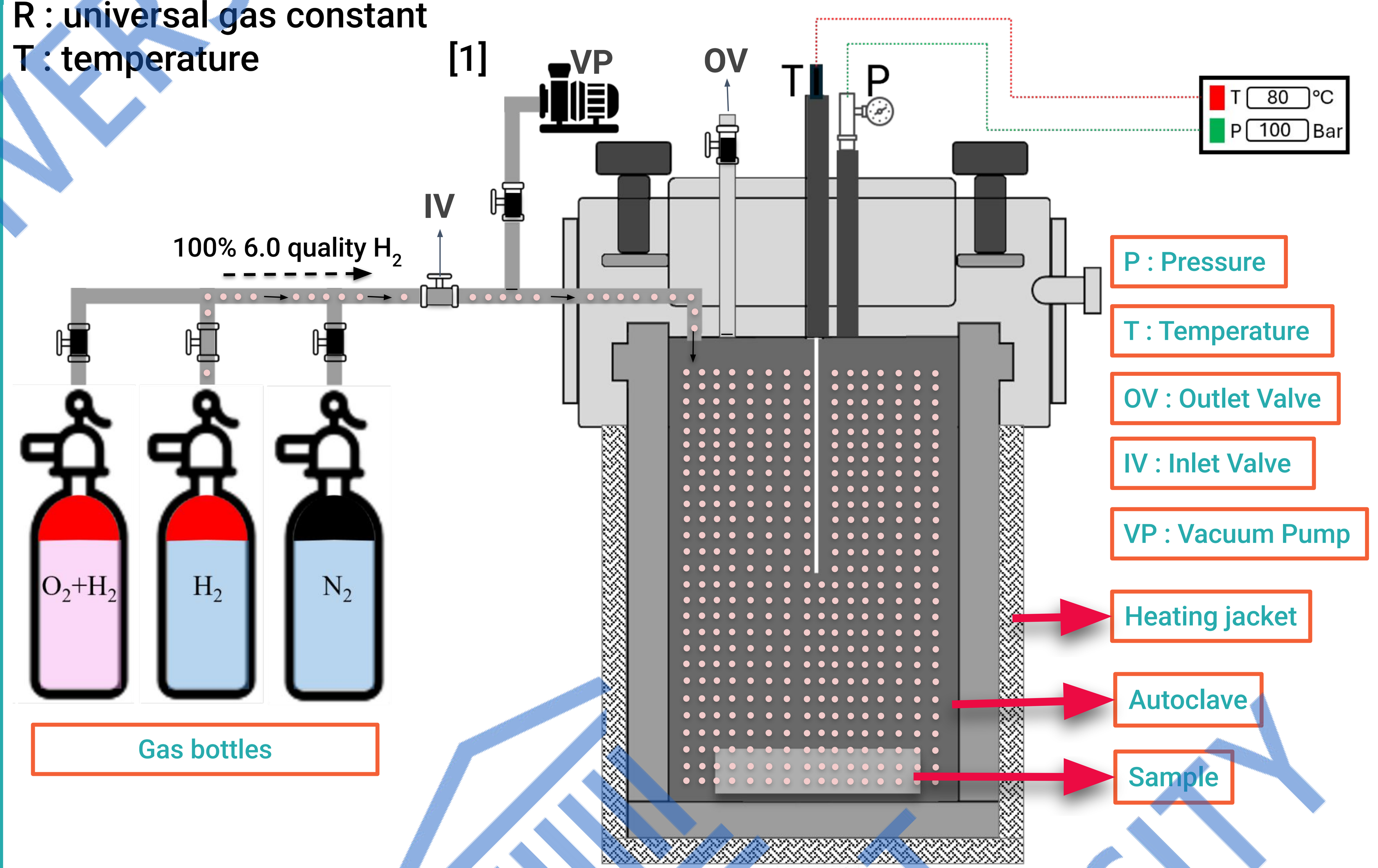
Principle and Equipment

Extended Sieverts' Law

$c_H = K_0\sqrt{f} \cdot \exp(-\Delta H_S / RT)$

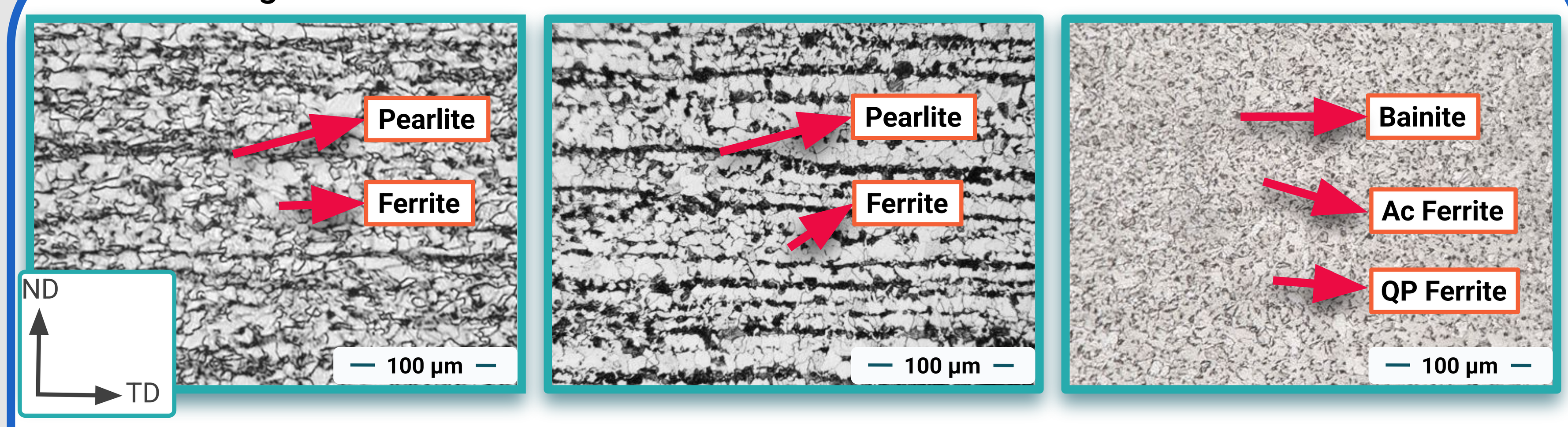
- c_H : hydrogen solubility
- K_0 : solubility coefficient
- f : hydrogen fugacity
- ΔH_s : solution enthalpy
- R : universal gas constant
- T : temperature [1]

Sieverts' law relates the amount of hydrogen absorbed in a metal to its partial pressure. Under non-ideal conditions, partial pressure is replaced by fugacity.



Materials

Mid wall region

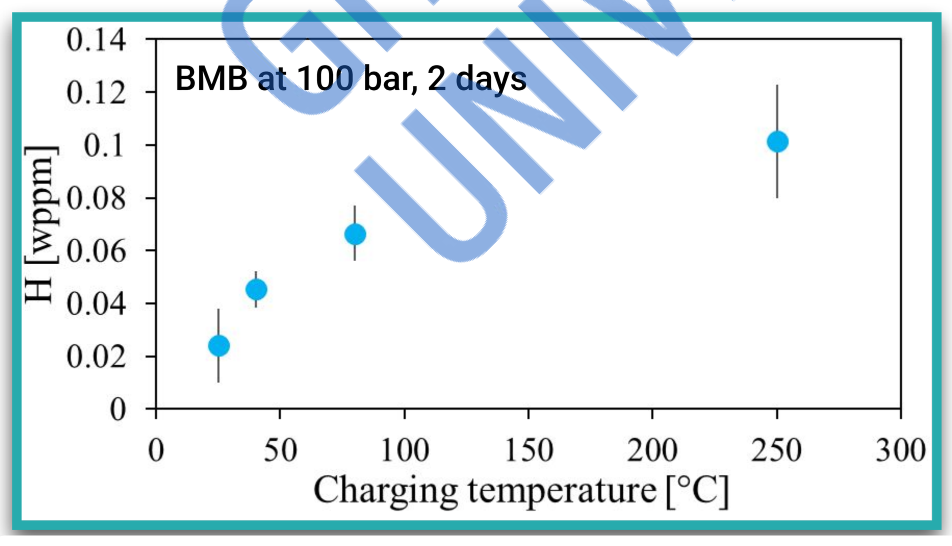


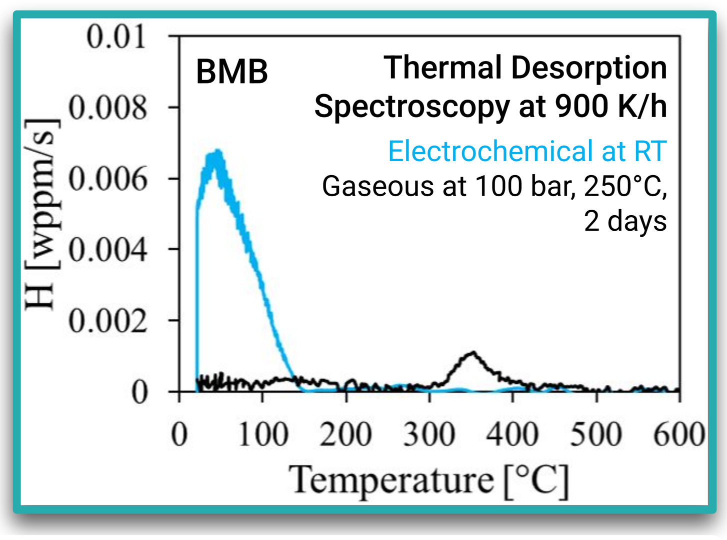
BMA [In-stock] ≈ BMB [In-service] BMC [In-service] BMD [Hot bend before service]
Ac: acicular ; QP: Quasi-polygonal

Methodology development

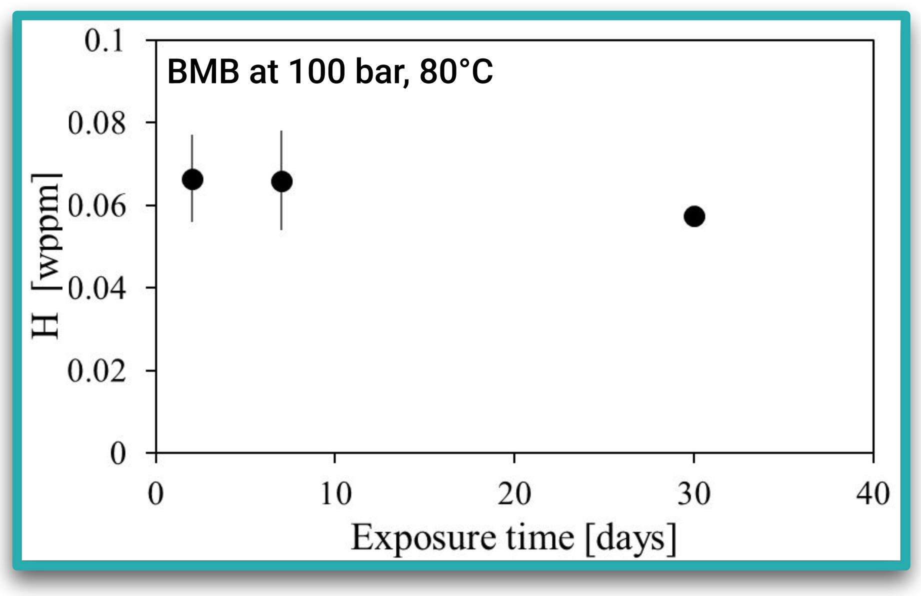
Under laboratory conditions, hydrogen uptake was limited, when industrially relevant conditions of RT and 84 bar were used in 100% 6.0 quality H_2. Hence, 100 bar was chosen to define the gaseous charging parameters.

Effect of temperature

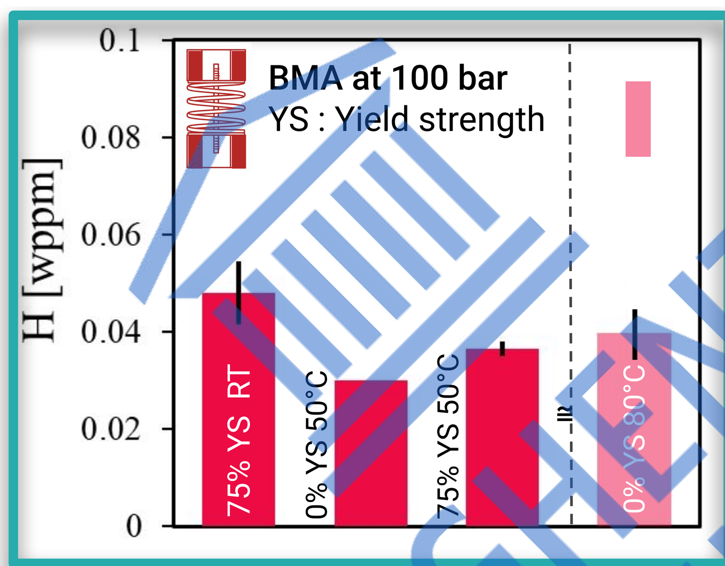




Effect of exposure duration



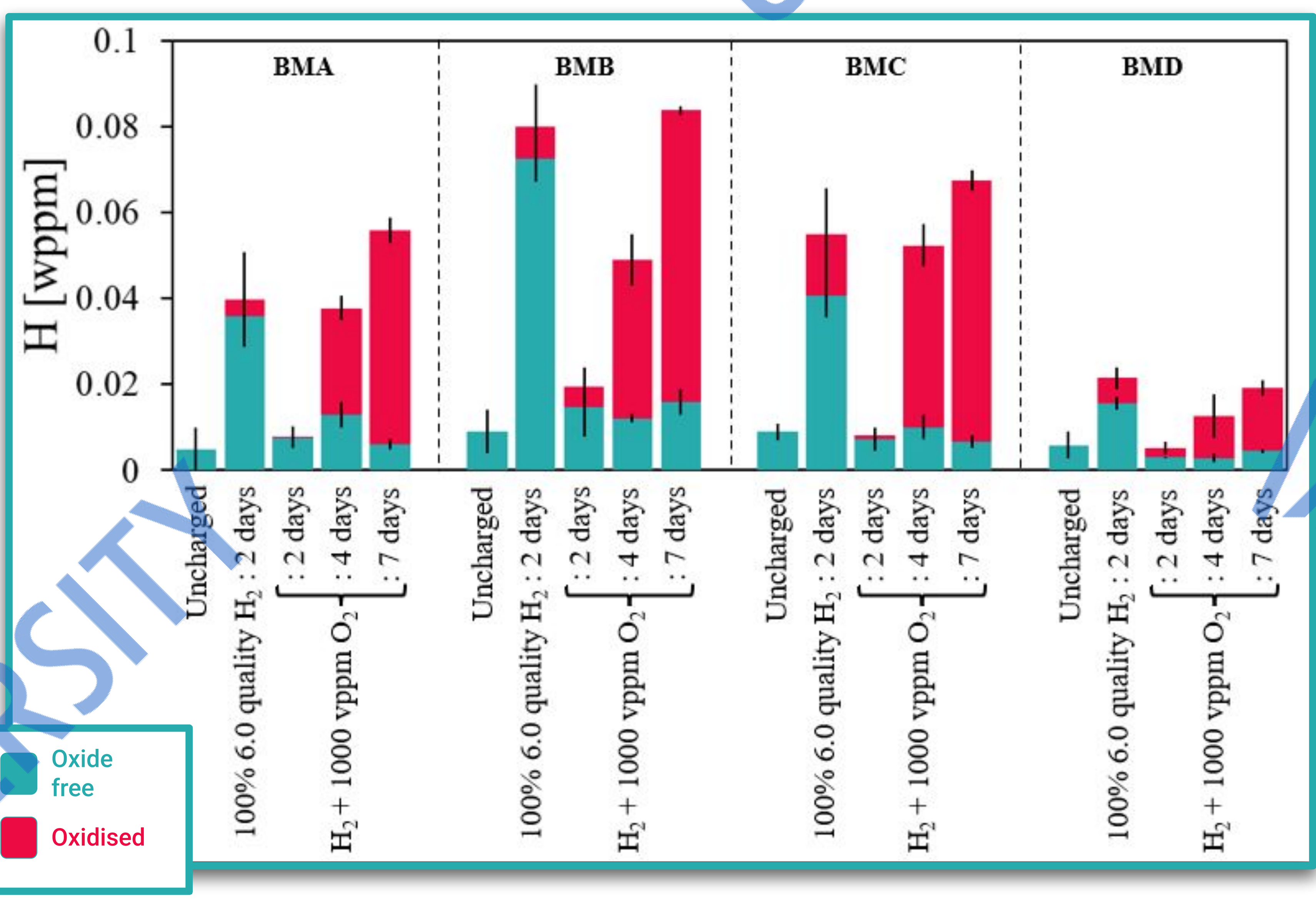
Effect of external load



Role of oxide layer

During extended gaseous charging periods, hydrogen adsorption is slowed by oxygen but not completely prevented, ultimately reaching equilibrium, [2].

With 1000 vppm O_2, does sustained hydrogen uptake occur in the steel or the surface oxide layer?

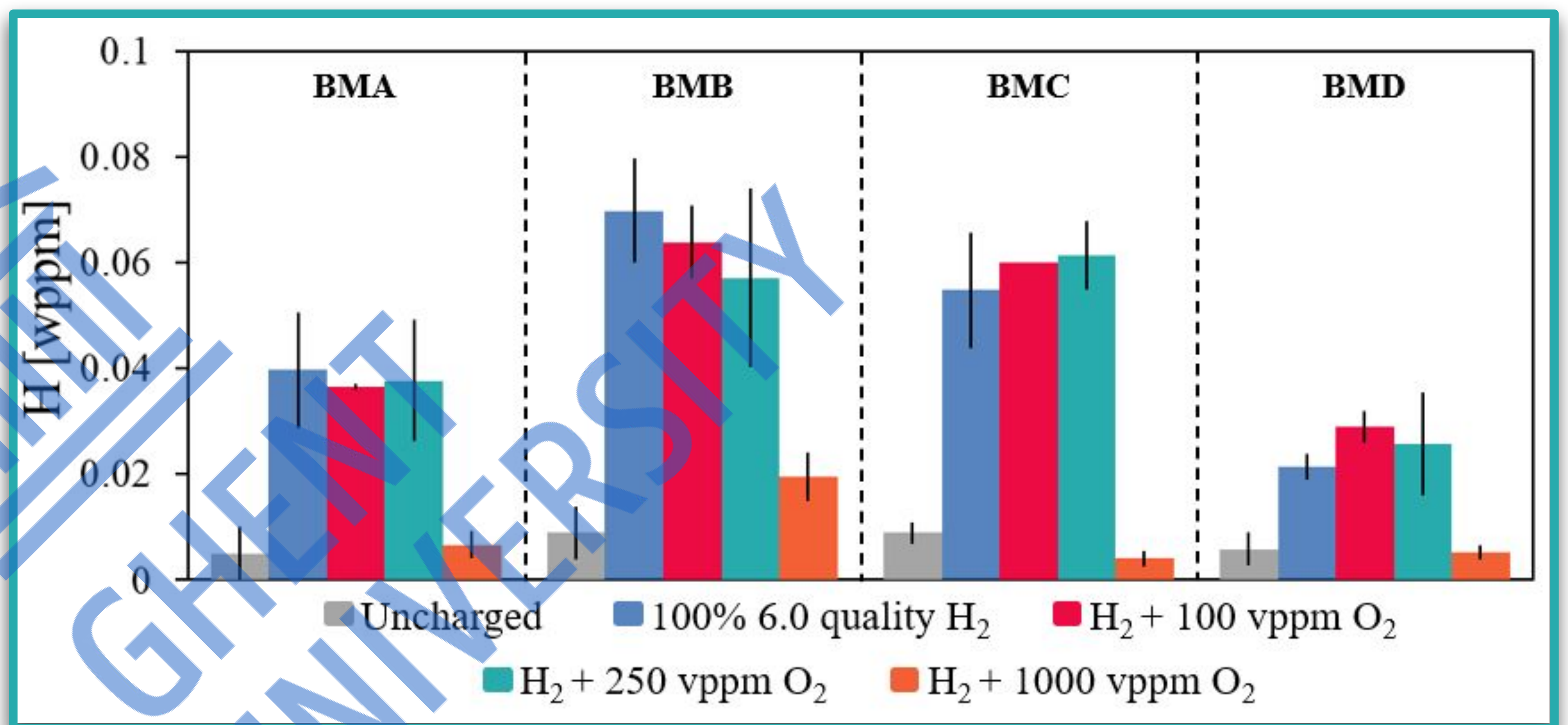


If undisturbed, the surface oxide layer traps hydrogen in the above conditions.

Role of inhibitor

Based on the above parametric tests, gaseous charging was set at 100 bar, 80°C, for 2 days. These conditions were applied across all base materials with varying gas environments.

Introducing trace amounts of oxygen in pure hydrogen gas, reduces hydrogen absorption by slowing down the adsorption kinetics, which helps mitigate HE, [2].



Hydrogen uptake is similar to 6.0 H_2 environment at low oxygen levels.

At 1000 vppm O_2, all materials show hydrogen levels similar to their uncharged state.

Conclusions

High-temperature exposure in pure H_2 alters the hydrogen distribution.

1000 vppm O_2 completely inhibits hydrogen absorption under 100 bar, 80°C for a duration of 2 days.

Longer exposure at 100 bar, 80°C increases hydrogen uptake, trapped by the intact oxide layer.

References

[1] Drexler, A., Konert, F., Sobol, O., Rhode, M., Domitner, J., Sommitsch, C., & Böllinghaus, T. (2022). Enhanced gaseous hydrogen solubility in ferritic and martensitic steels at low temperatures. *International Journal of Hydrogen Energy*, *47*(93), 39639-39653.
[2] Jubica, L. Claeys, Laureys, A., De Waele, W., Schweicher, J., Depover, T., & Verbeken, K. (2025). Gaseous inhibitors: A comprehensive overview on mitigating hydrogen embrittlement in pipeline steels. *International Journal of Hydrogen Energy, 136*, 630–642.

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