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Energy Pipeline Innovation Conference

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Screening hydrogen sensitivity of pipeline steels

8th – 10th September 2025 – Jubica

Screening method for assessing hydrogen degradation sensitivity of pipeline steels

Jubica*, Lisa Claeys, Laura De Pue, Julien Schweicher, Wim De Waele, Kim Verbeken, Tom Depover

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Which material parameter(s) guides initial screening?

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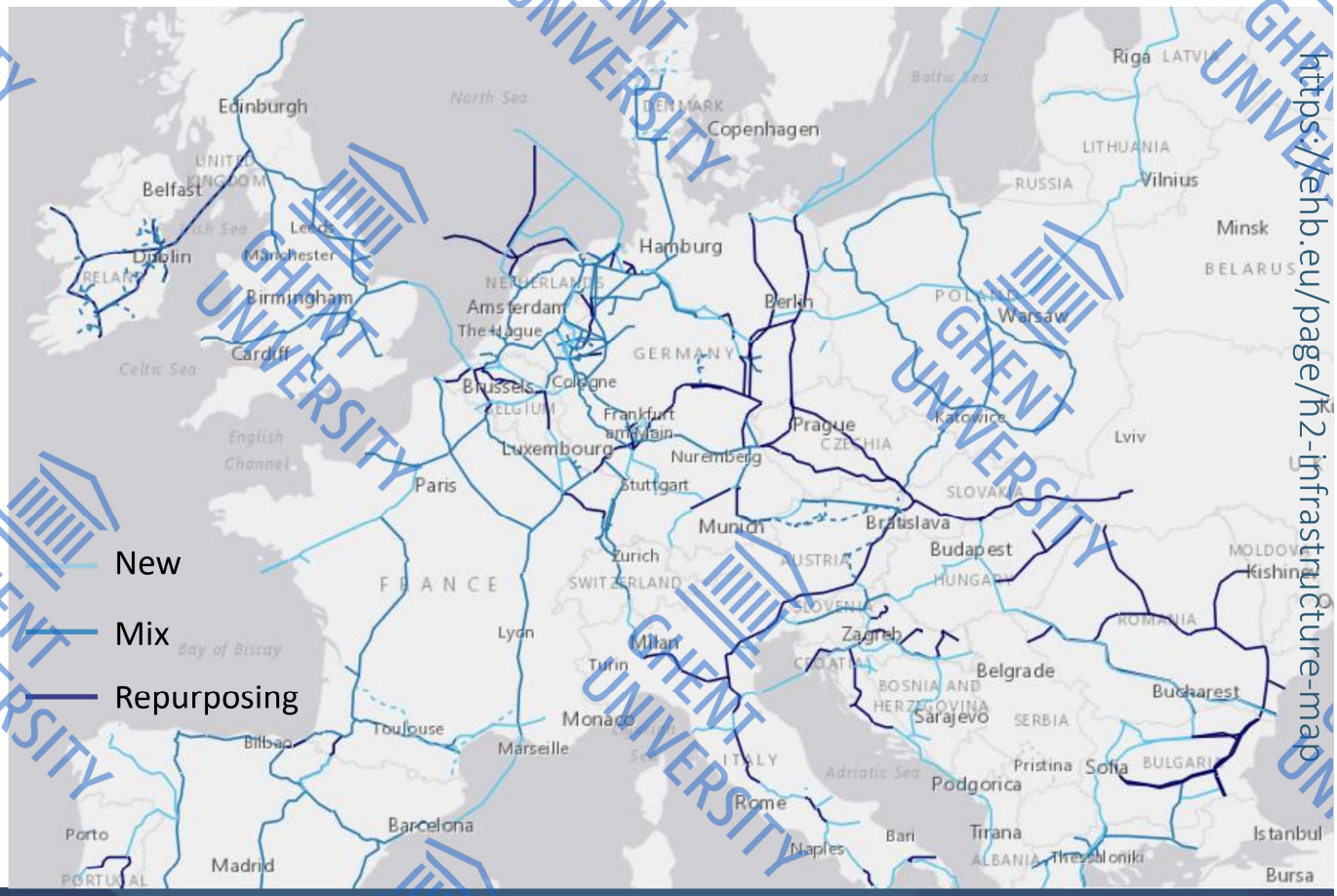
- Preliminary assessment of pipeline steels
- Identifying microstructural parameters
- Facilitating rapid screening



Material bank

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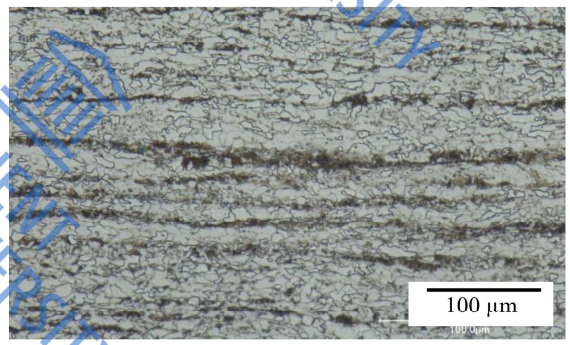
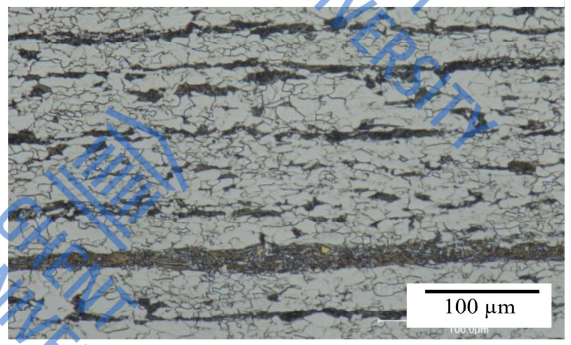
BM1 (L485-2009)

Stock

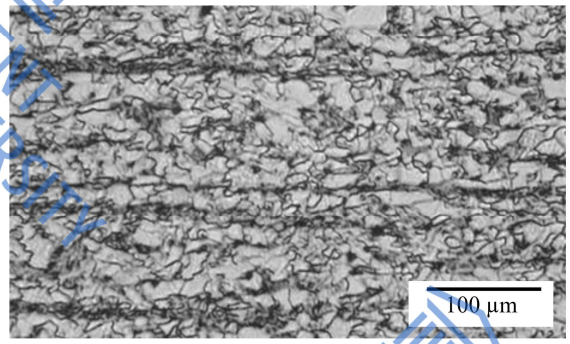


BM2 (L485-2009)

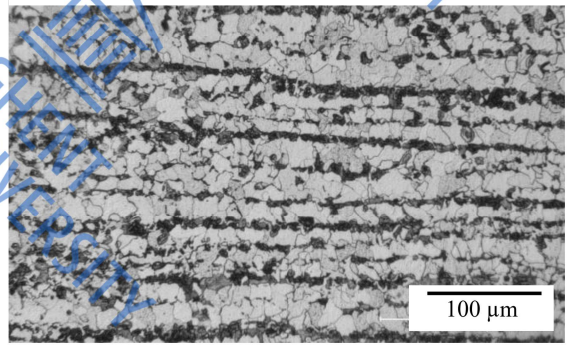


BM3 (X70-1980)

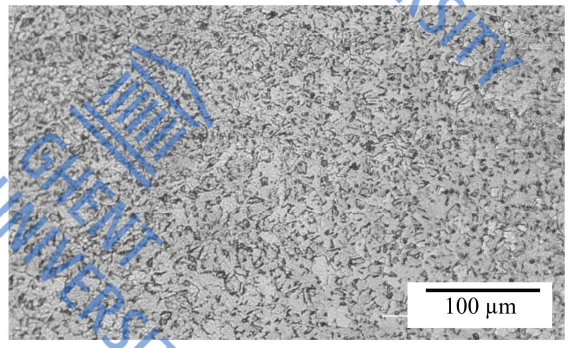
Excavated



BM4 (St. 60.7 – 1972)



BM5 (L415 – 2013)

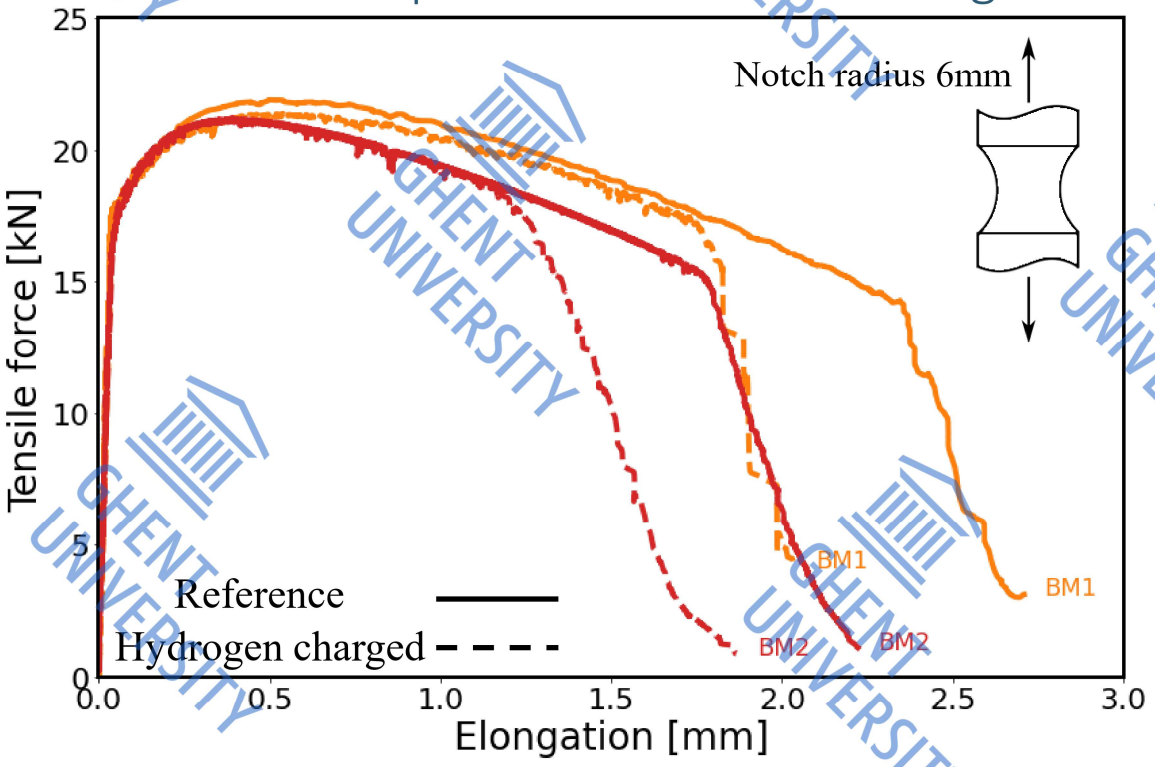


ND
TD

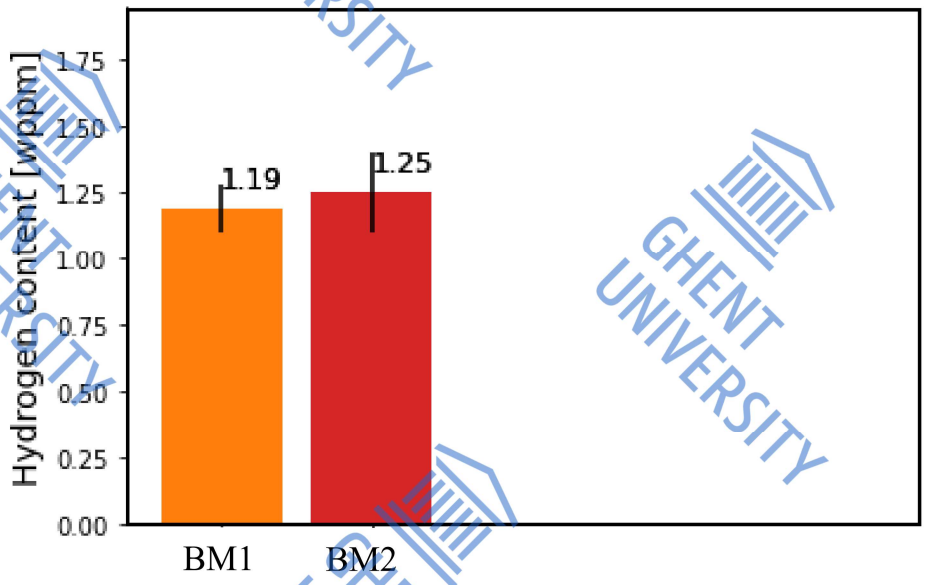
*Middle region of the wall thickness

Absolute comparison of pipeline base materials

Ex-situ quasi-static tensile testing



Electrochemical charging



Charging until saturation

Absolute comparison of pipeline base materials

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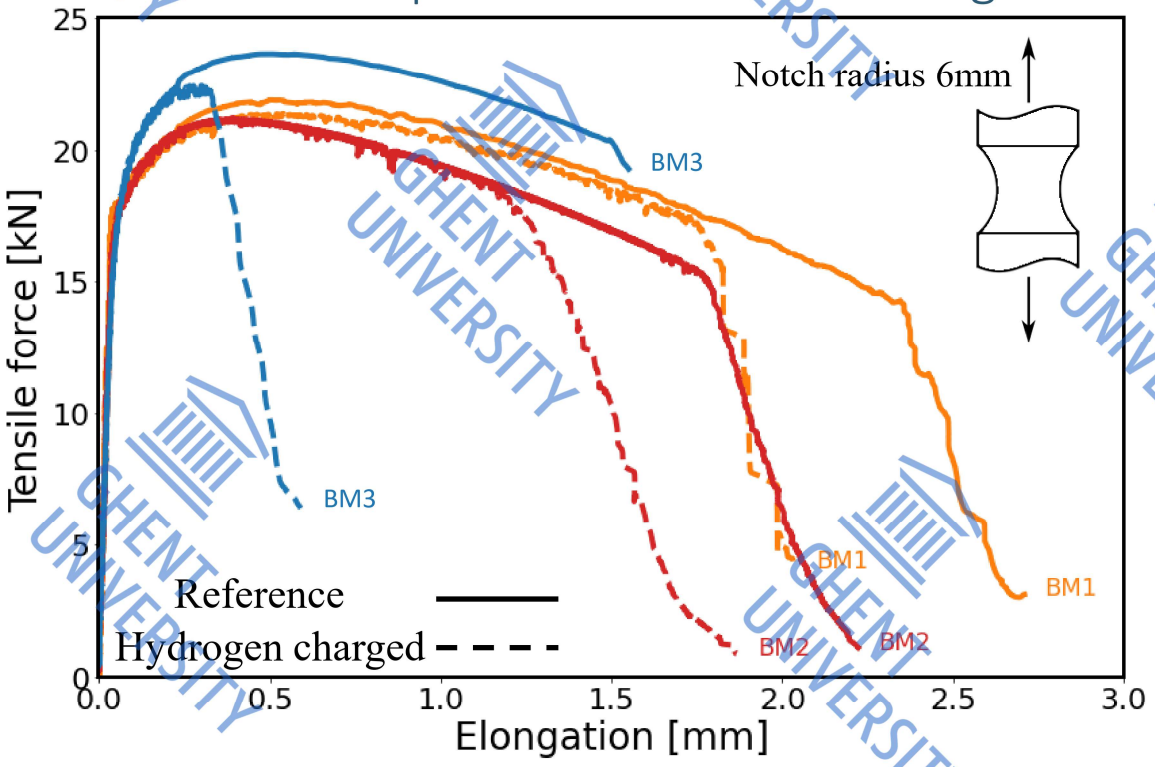
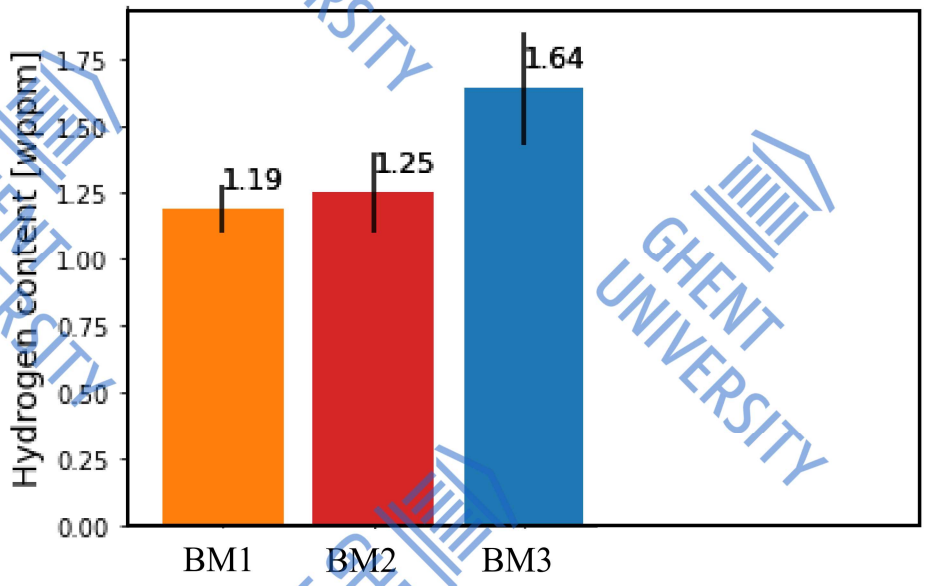
Ex-situ quasi-static tensile testing



Electrochemical charging



Charging until saturation

Absolute comparison of pipeline base materials

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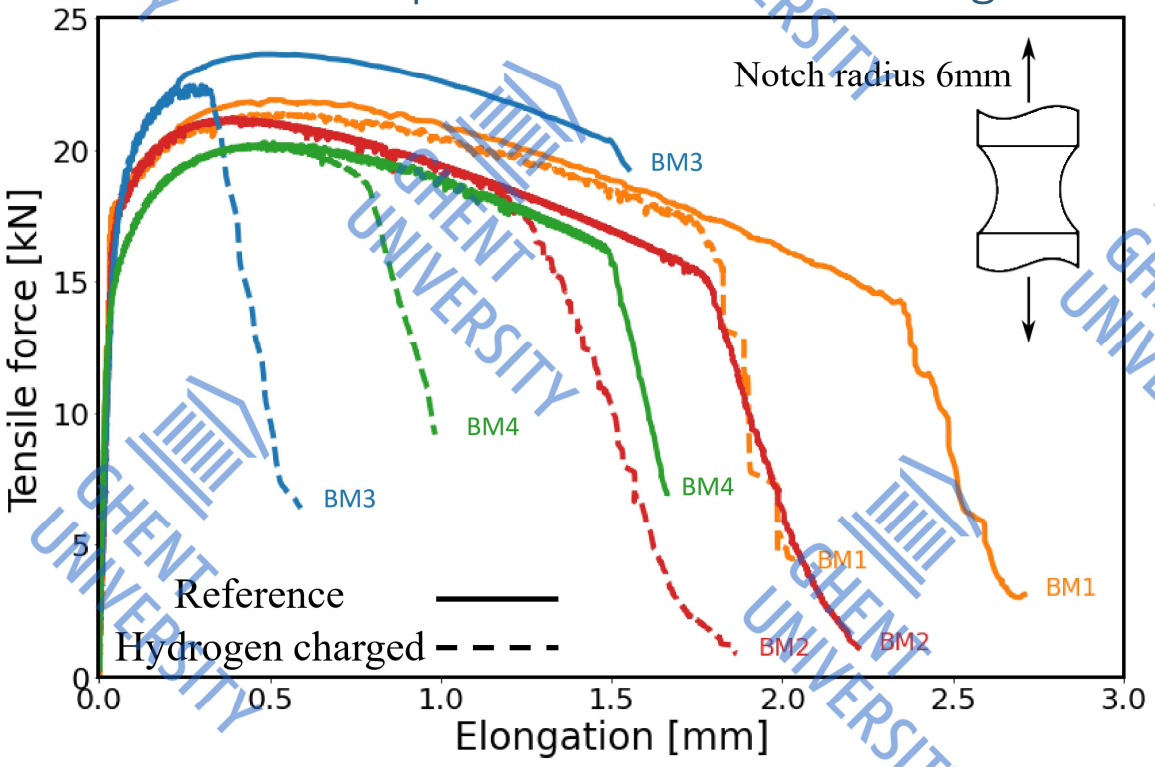
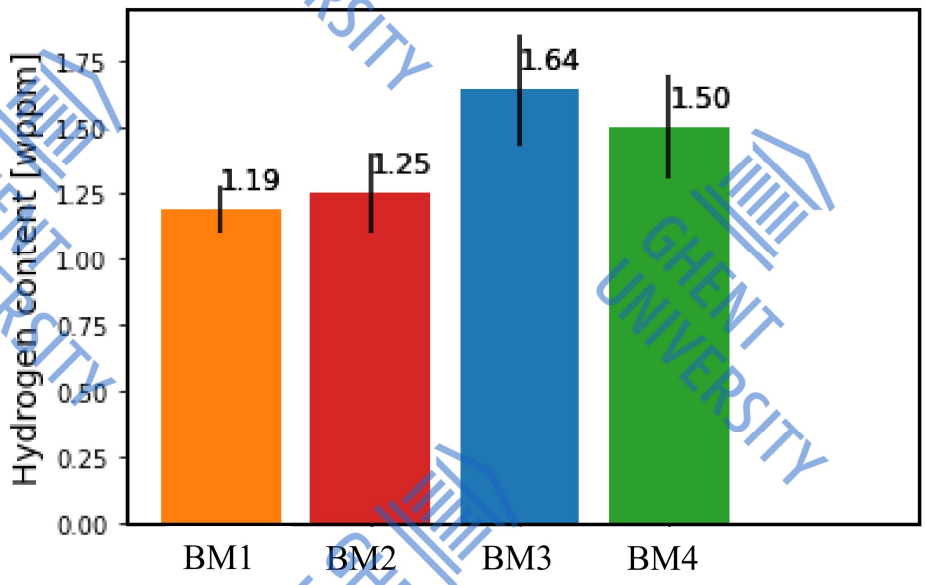
Ex-situ quasi-static tensile testing



Electrochemical charging



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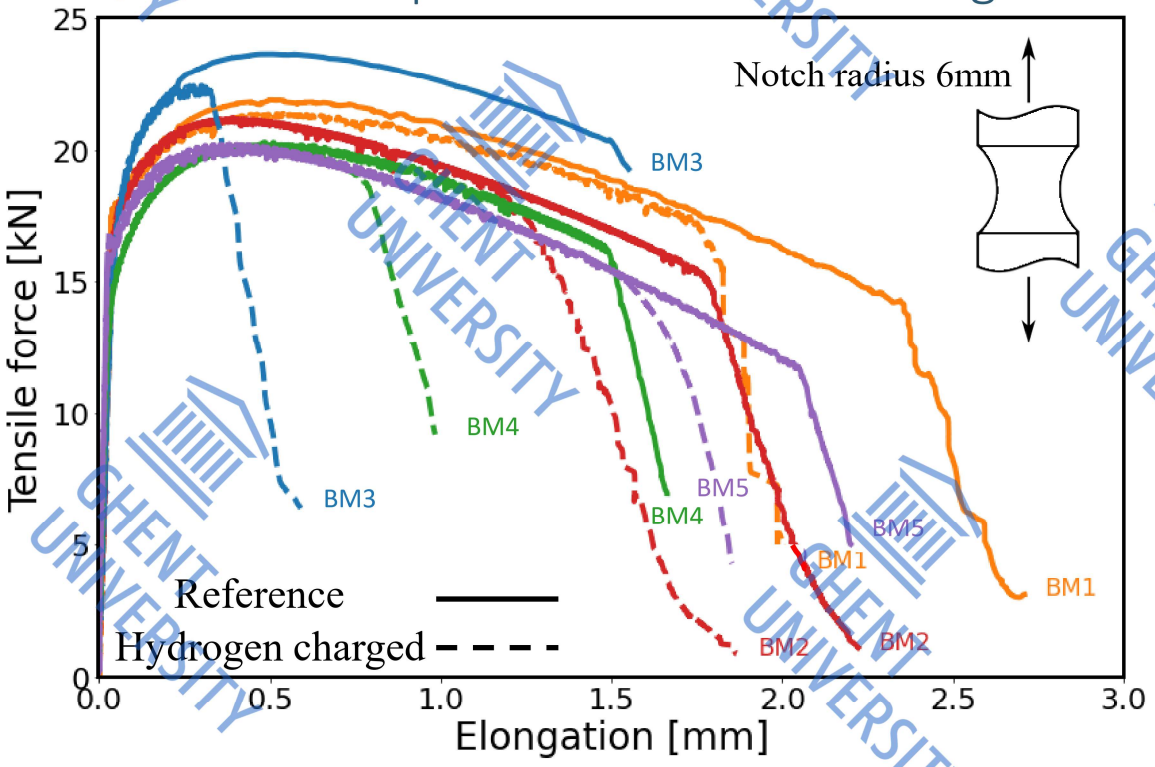
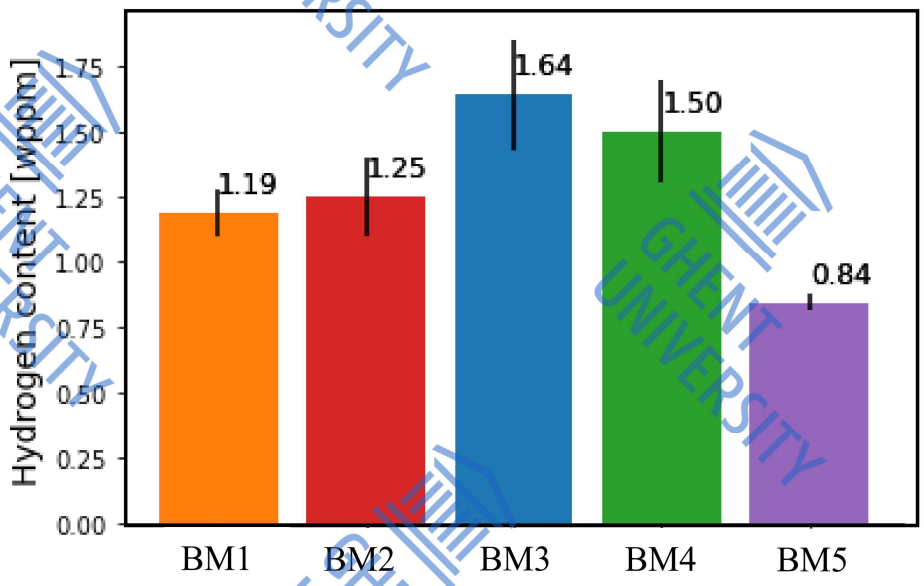


Electrochemical charging



Charging until saturation

Absolute comparison of pipeline base materials

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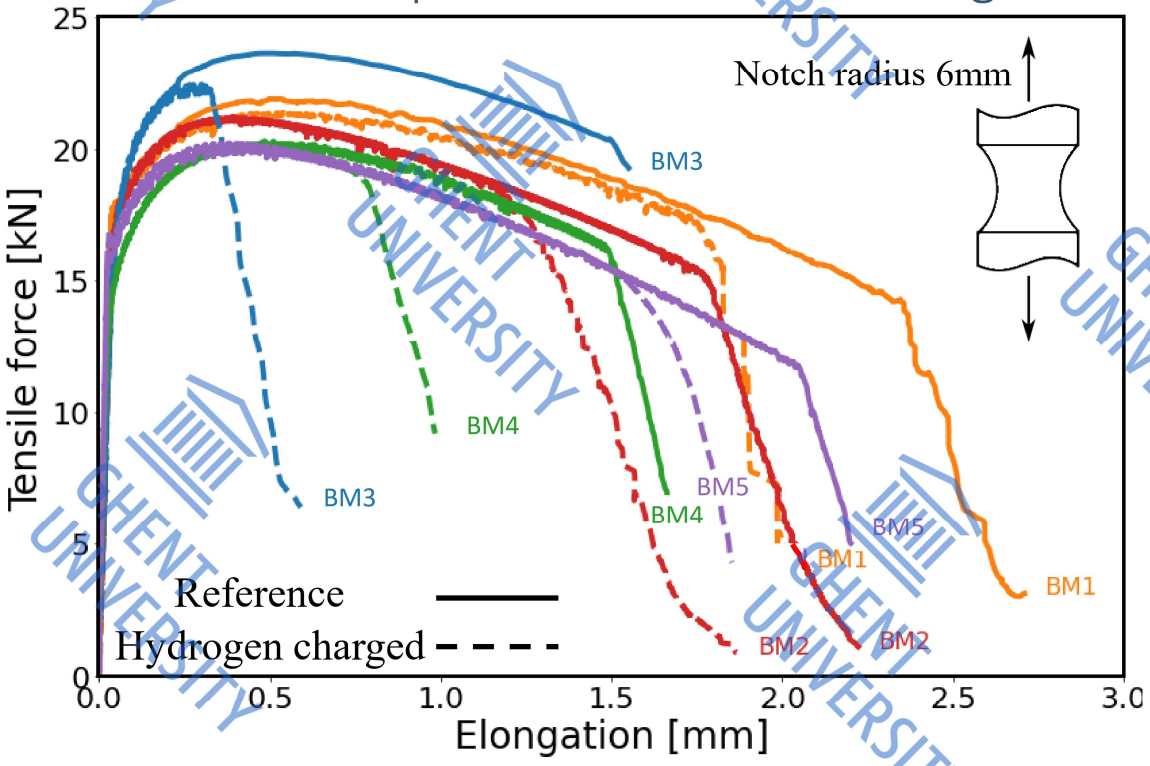
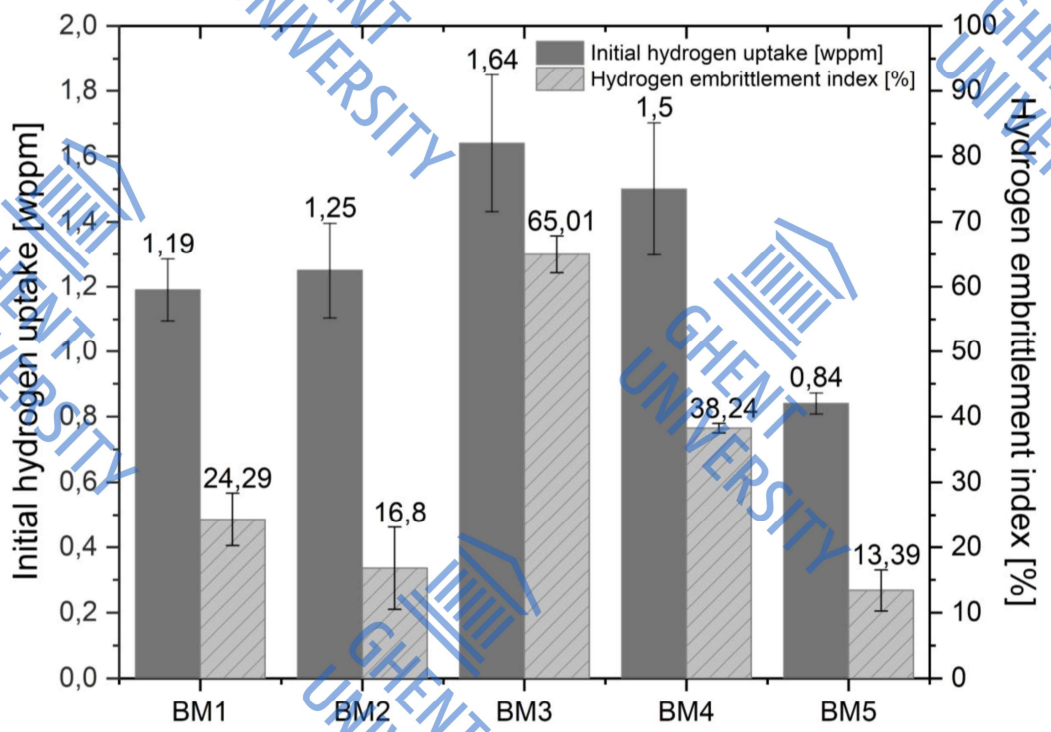
Ex-situ quasi-static tensile testing

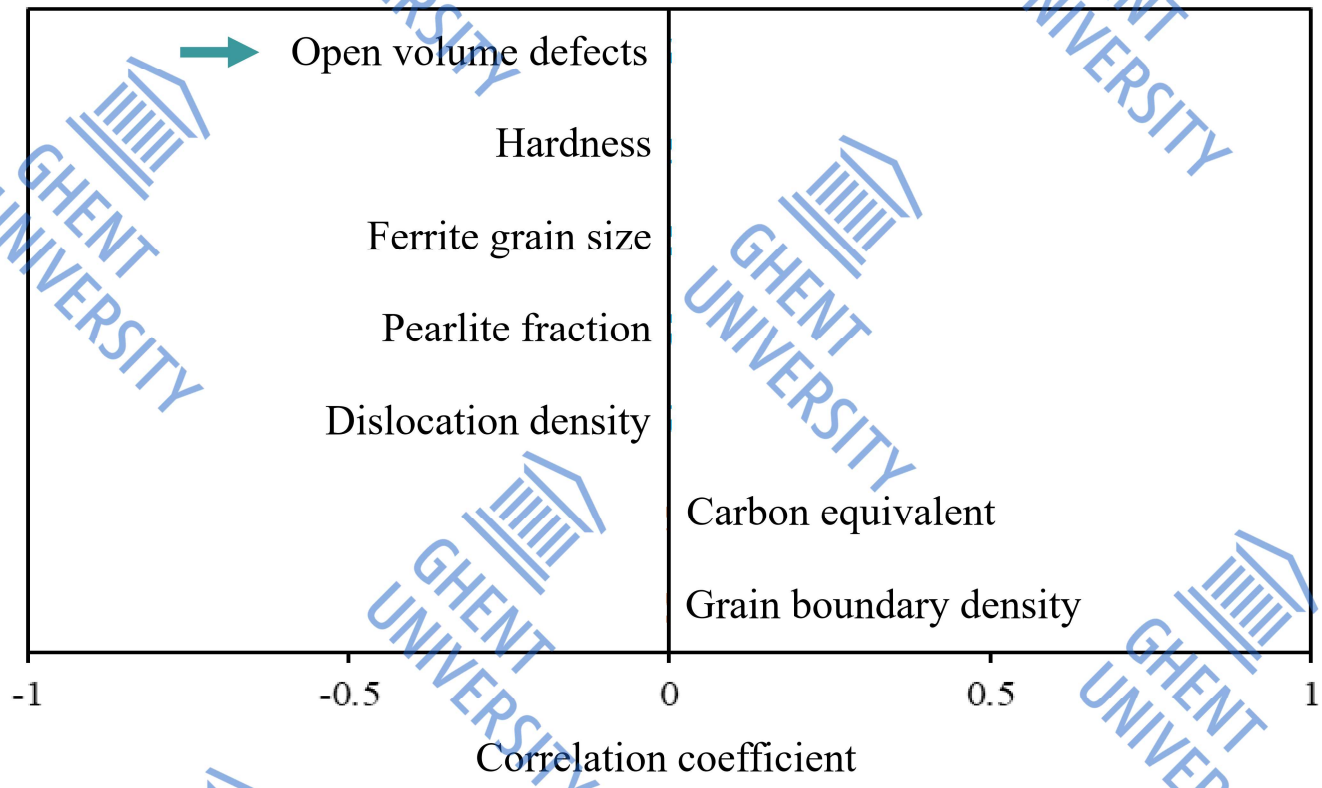




Embrittlement index = $(1 - \frac{Elongation_{hydrogen}}{Elongation_{air}}) * 100\%$

Very good correlation of hydrogen embrittlement sensitivity with initial hydrogen uptake

Microstructural parameters influencing hydrogen uptake

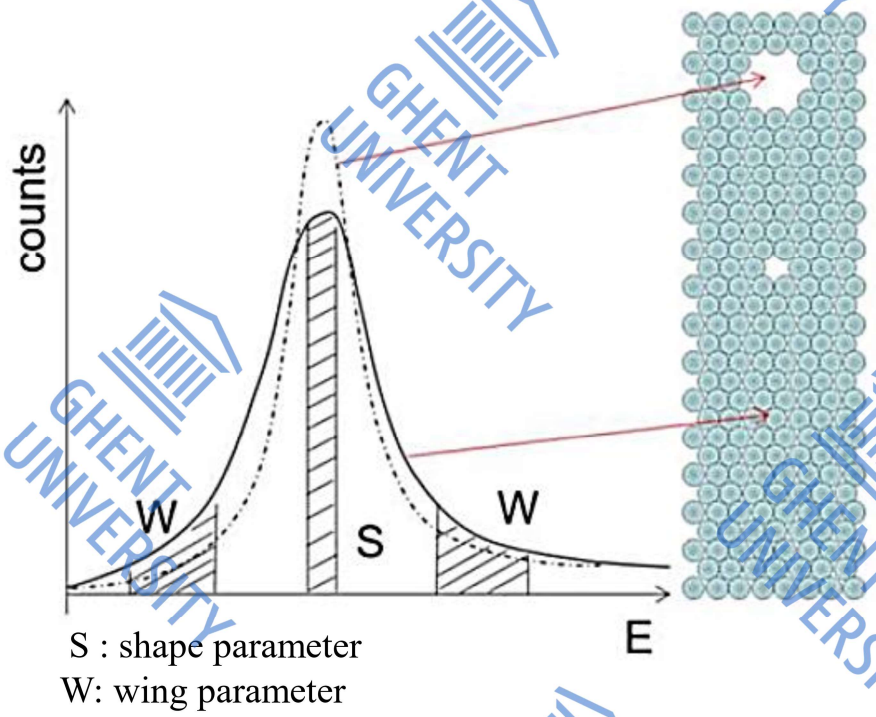


Reversible traps

- Open volume defects: Vacancies, vacancy clusters, voids and dislocations

Reversible traps

- Open volume defects: Vacancies, vacancy clusters, voids and dislocations

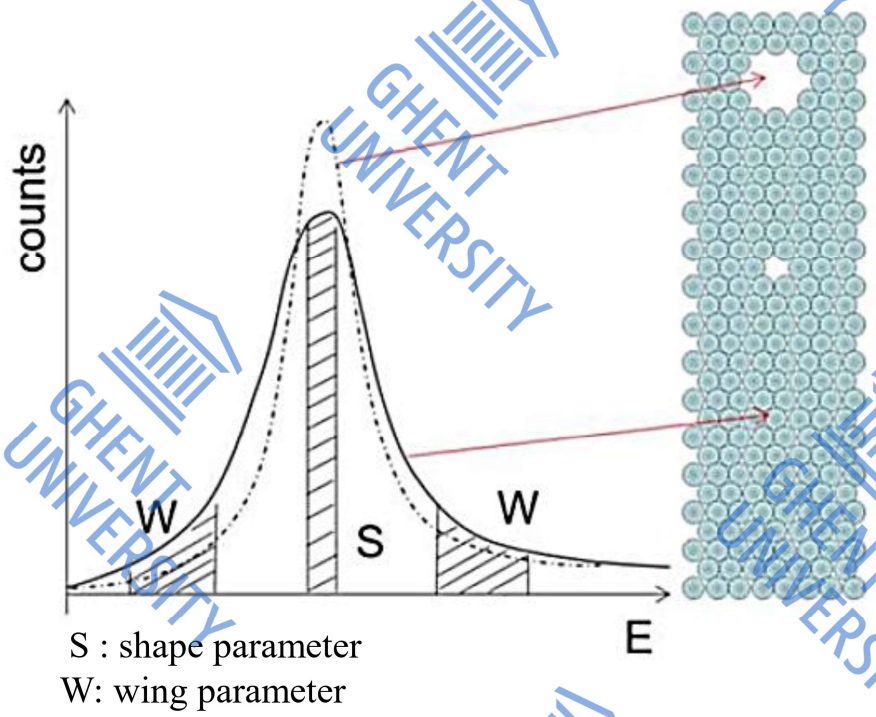


Schematic visualisation of the DB spectra analysis, PhD dissertation, Liese Vandewalle

- Positrons annihilate with electrons → emit gamma rays
- Energy spectrum of gamma rays reflects electron momentum
- Defects change electron environment → affect peak shape

Reversible traps

- Open volume defects: Vacancies, vacancy clusters, voids and dislocations



Schematic visualisation of the DB spectra analysis, PhD dissertation, Liese Vandewalle

- Positrons annihilate with electrons → emit gamma rays
- Energy spectrum of gamma rays reflects electron momentum
- Defects change electron environment → affect peak shape
- S parameter = Area in central (low-momentum) region / Total area
- W parameter = Area in wing (high-momentum) regions / Total area

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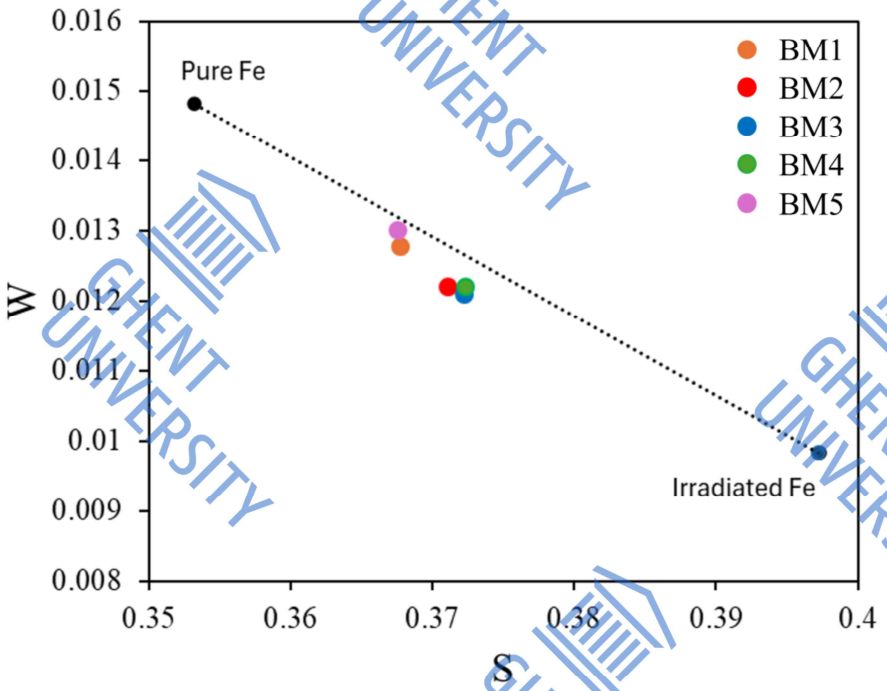
Reversible traps

- Open volume defects: Vacancies, vacancy clusters, voids and dislocations



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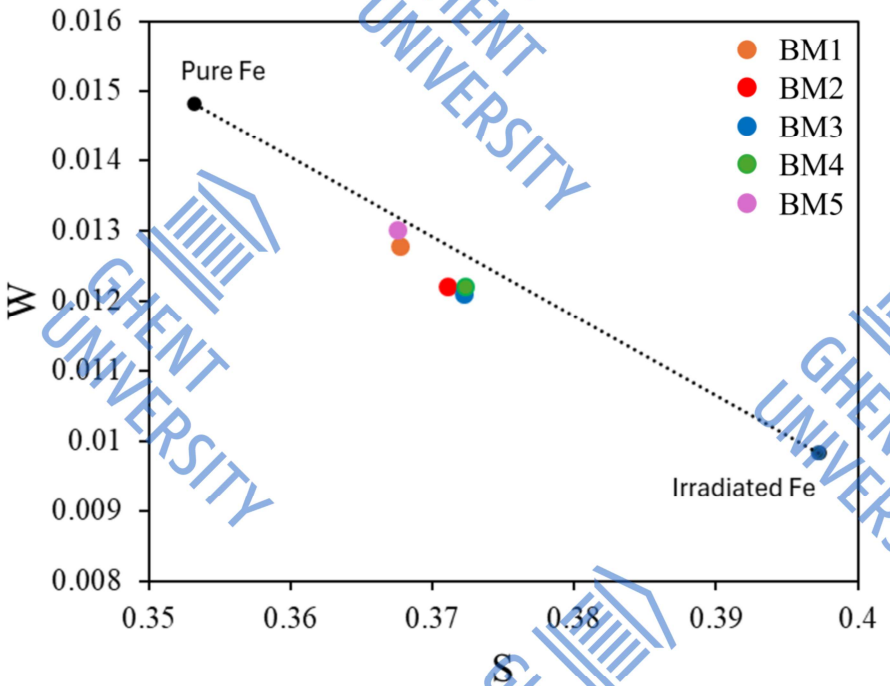
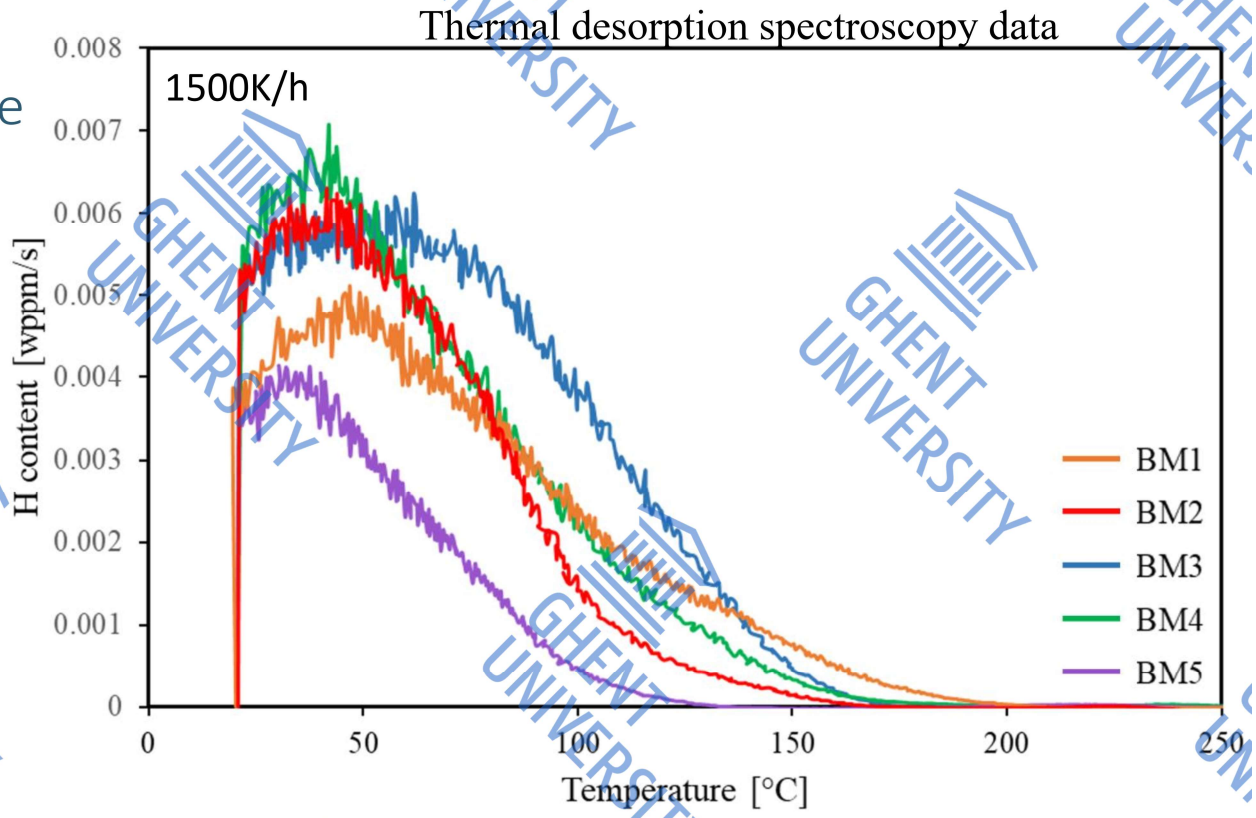
Reversible traps

- Open volume defects: Vacancies, vacancy clusters, voids and dislocations
- Grain and phase boundaries
- Ferrite-cementite interfaces in pearlite





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Reversible traps

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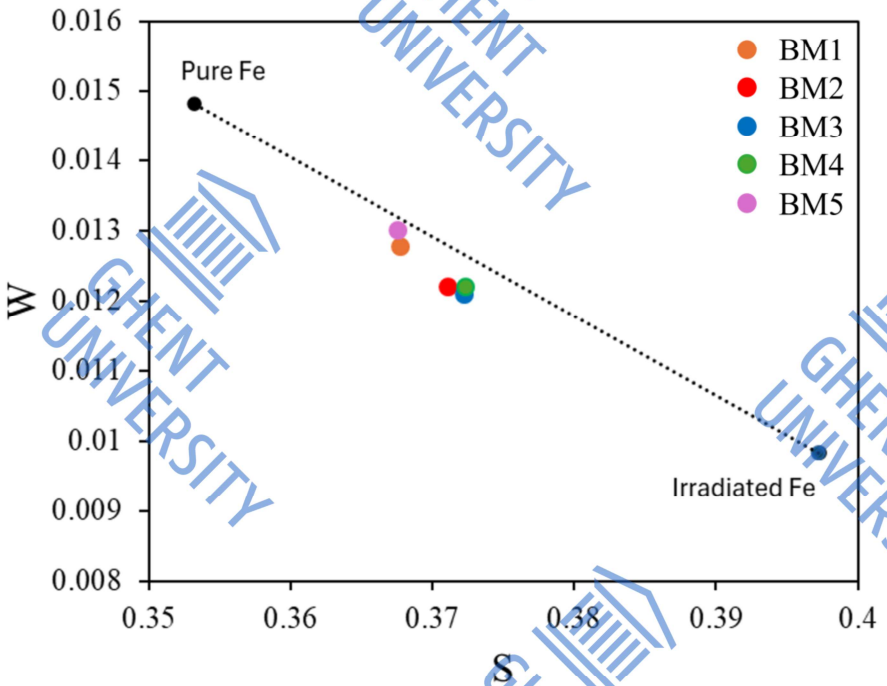
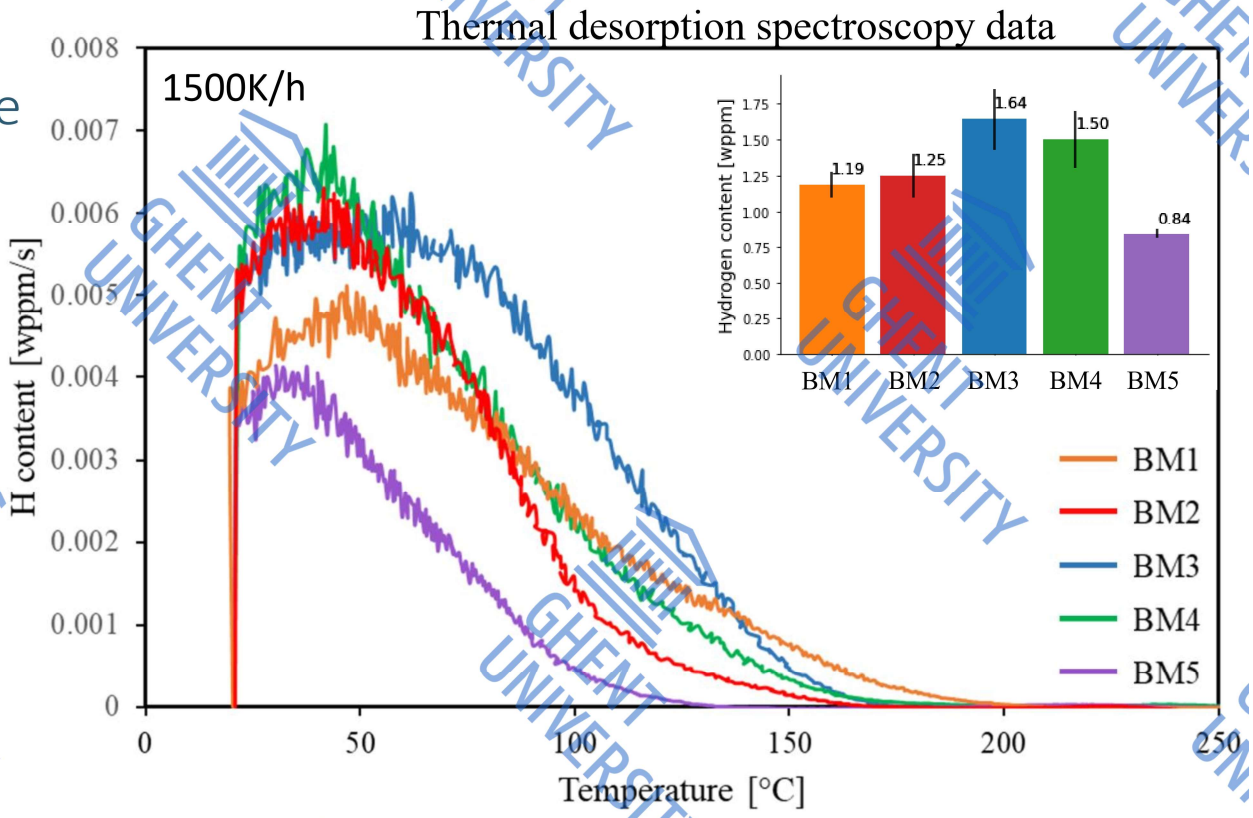
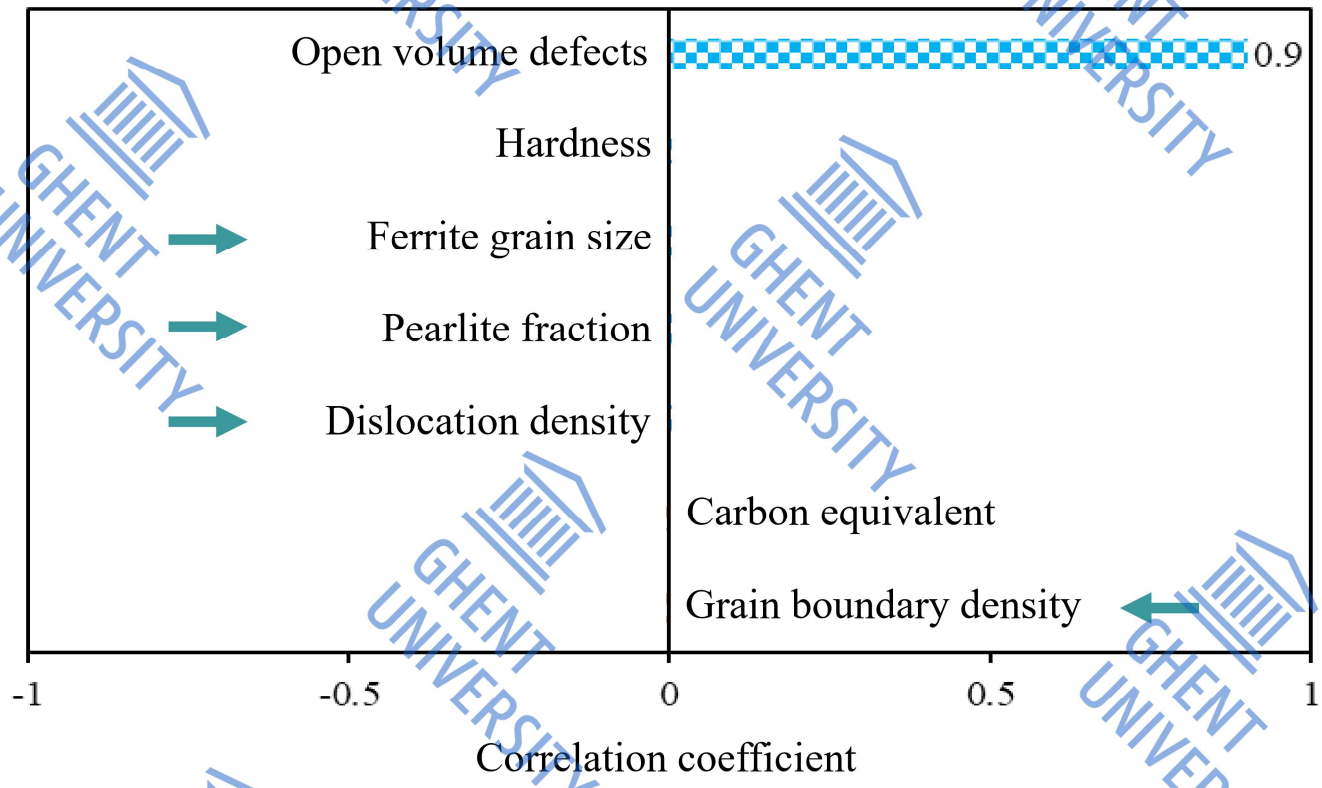
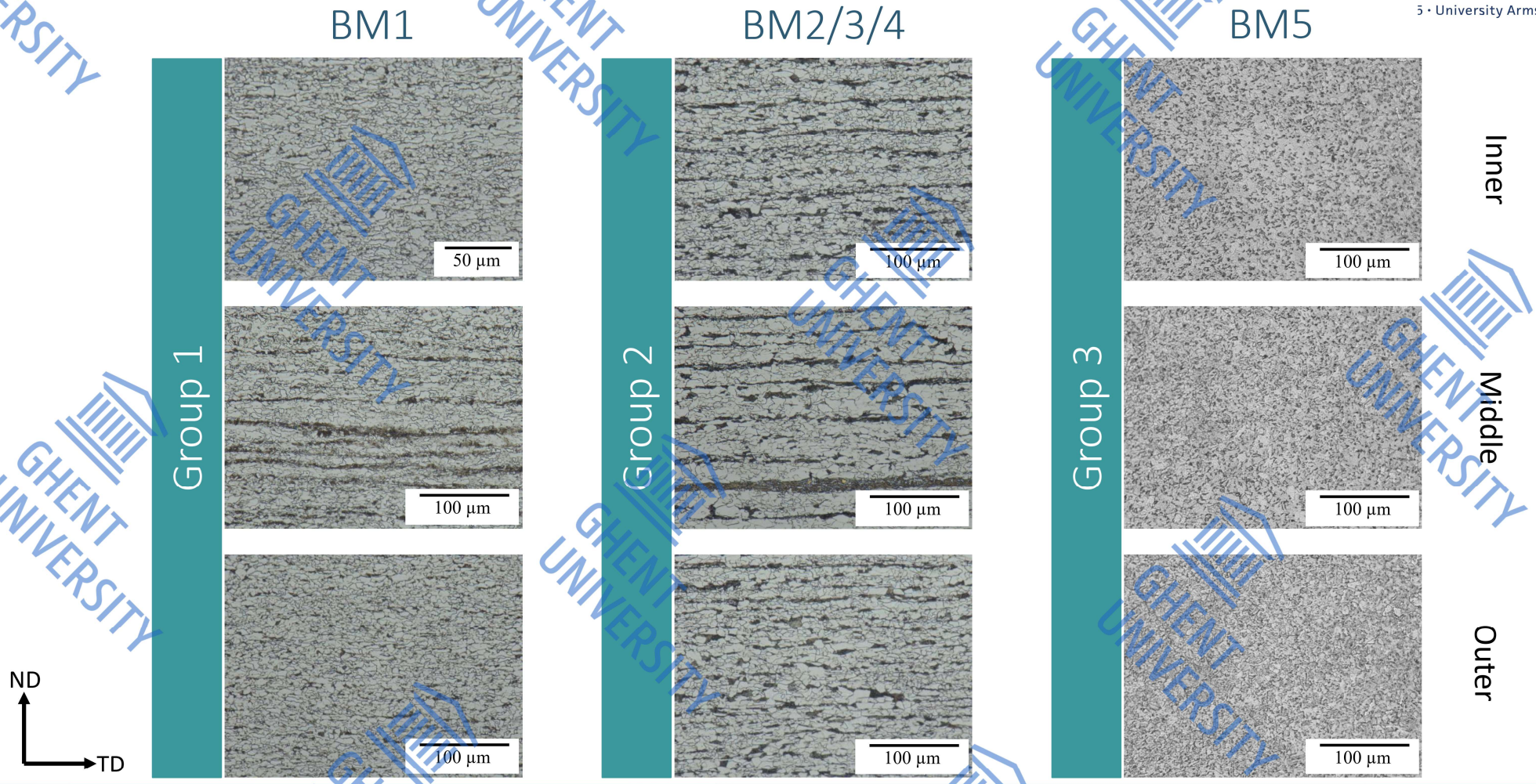




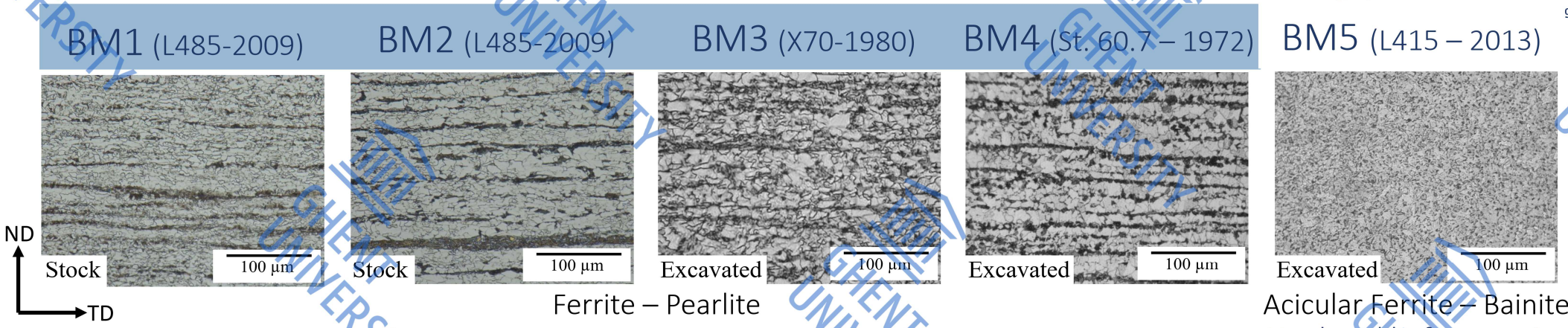
Microstructural parameters influencing hydrogen uptake



Quantifying microstructural determinants



Quantifying microstructural determinants: middle region



Ferrite – Pearlite

Acicular Ferrite – Bainite

Hot bend before service

Material	FGS	PF
BM1	●	●
BM2	●	●
BM3	●	●
BM4	●	●
BM5		

FGS: Ferrite grain size µm; PF: Pearlite fraction %

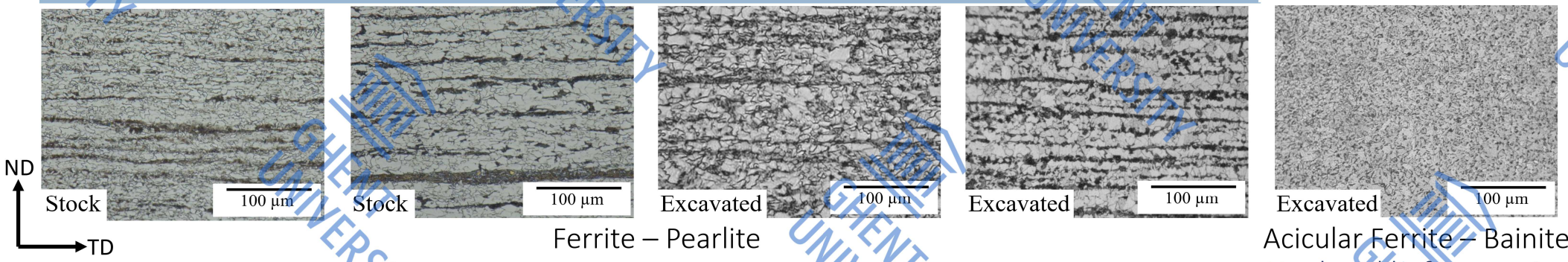
Small : ● 3.8 ± 0.2 µm ; 12.6 ± 0.9 %

Intermediate : ● 5 ± 0.5 µm ; 21.4 ± 2.2 %

High : ● 6.2 ± 0.2 µm

Quantifying microstructural determinants: middle region

BM1 (L485-2009)	BM2 (L485-2009)	BM3 (X70-1980)	BM4 (St. 60.7 – 1972)	BM5 (L415 – 2013)



Ferrite – Pearlite

Acicular Ferrite – Bainite

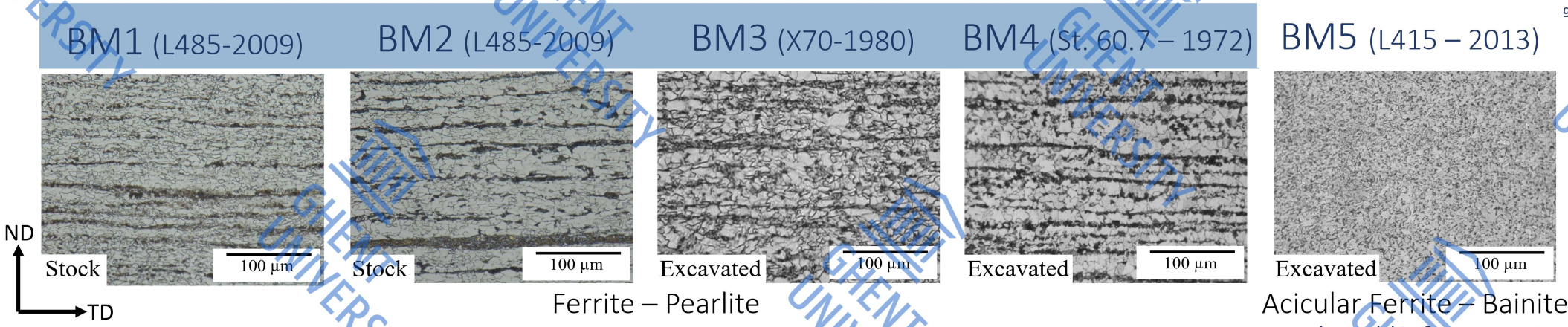
Hot bend before service

Material	FGS	PF	GBD
BM1	●	●	1st
BM2	●	●	4th
BM3	●	●	2nd
BM4	●	●	5th
BM5			3rd

FGS: Ferrite grain size µm; PF: Pearlite fraction %; GBD: Grain boundary density m^{-1};

Small : ● Intermediate : ● High : ●

Individual microstructural parameters difficult to group



Ferrite – Pearlite

Acicular Ferrite – Bainite

Hot bend before service

Material	FGS	PF	GBD	DD
BM1	●	●	1st	3rd
BM2	●	●	4th	2nd
BM3	●	●	2nd	1st
BM4	●	●	5th	4th
BM5			3rd	2nd

FGS: Ferrite grain size µm; PF: Pearlite fraction %; GBD: Grain boundary density m^{-1}; DD: Dislocation density m^{-2}

Small : ● Intermediate : ● High : ●

Open volume defects govern hydrogen uptake and HE%

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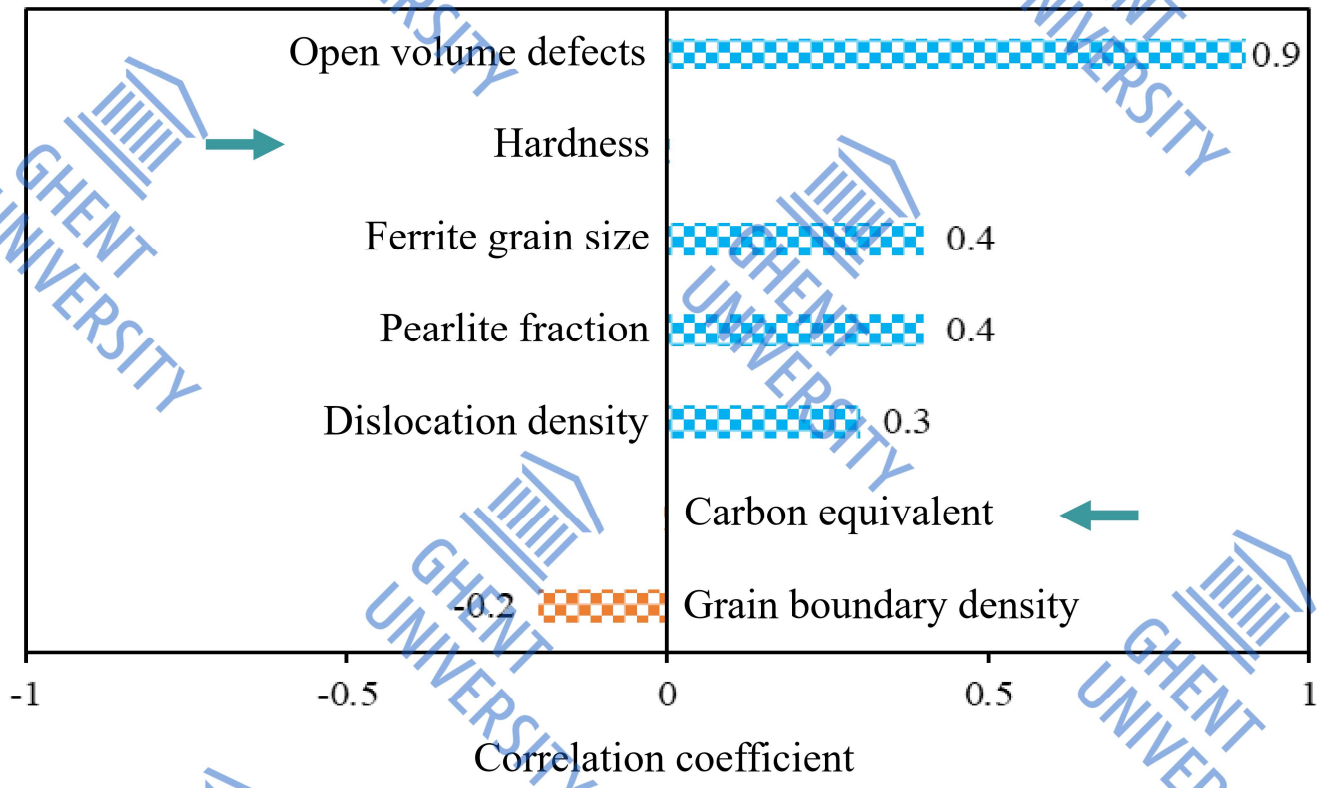


Pressing question

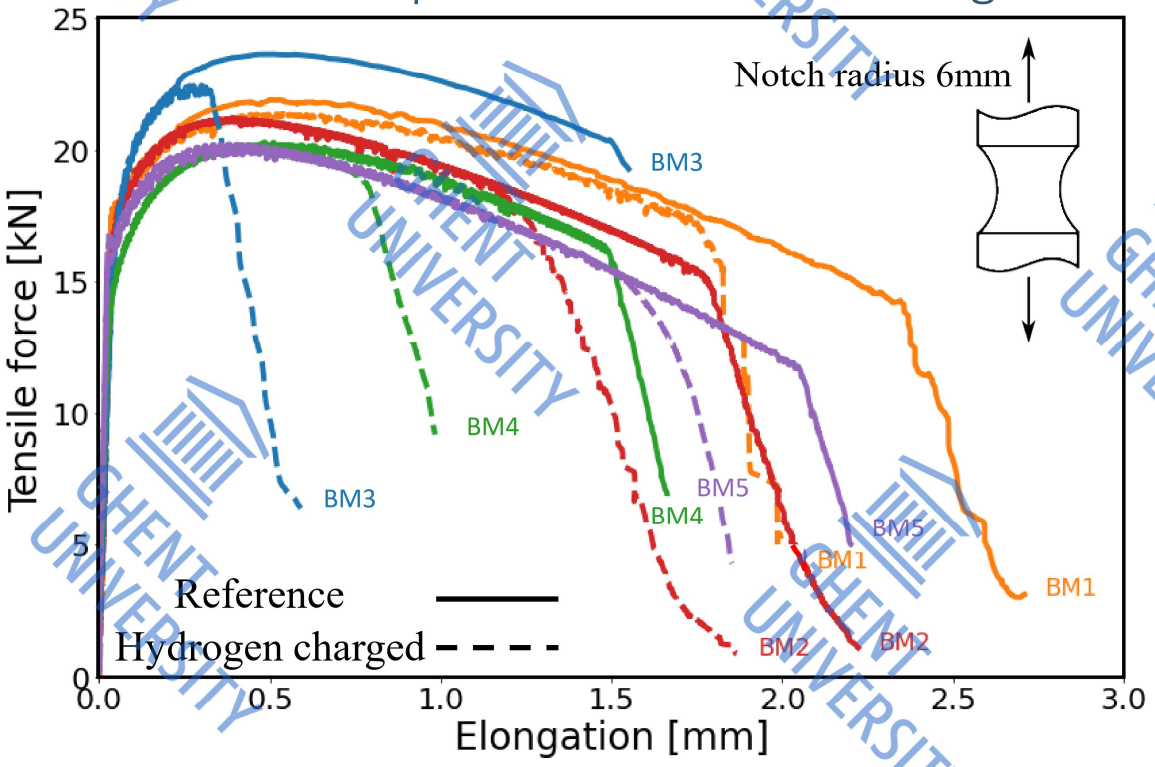
Hardness or Hydrogen uptake?

"For carbon steel in hydrogen service, ASME B31.12 mandates a maximum hardness of 235 HV10 as the acceptance criterion."

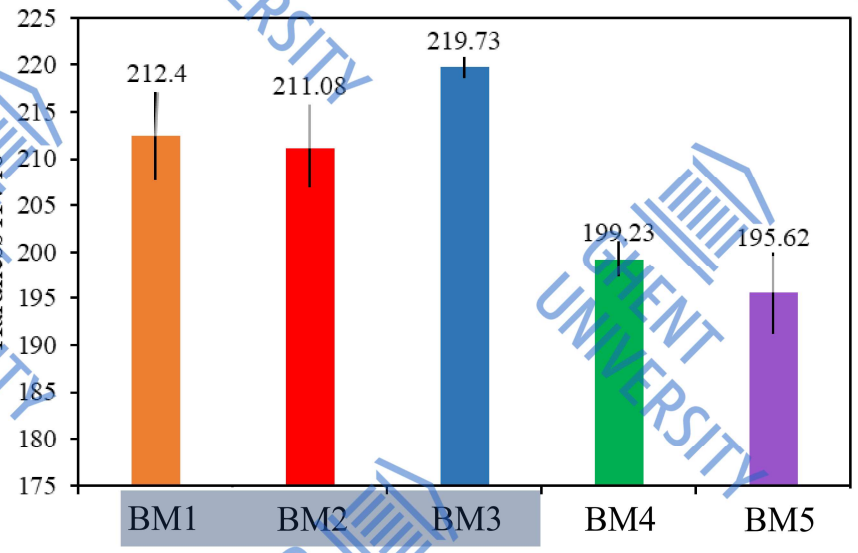
– ASME B31.12 2023 – Hydrogen Piping and Pipelines

Absolute comparison of pipeline base materials : Hardness

Ex-situ quasi-static tensile testing



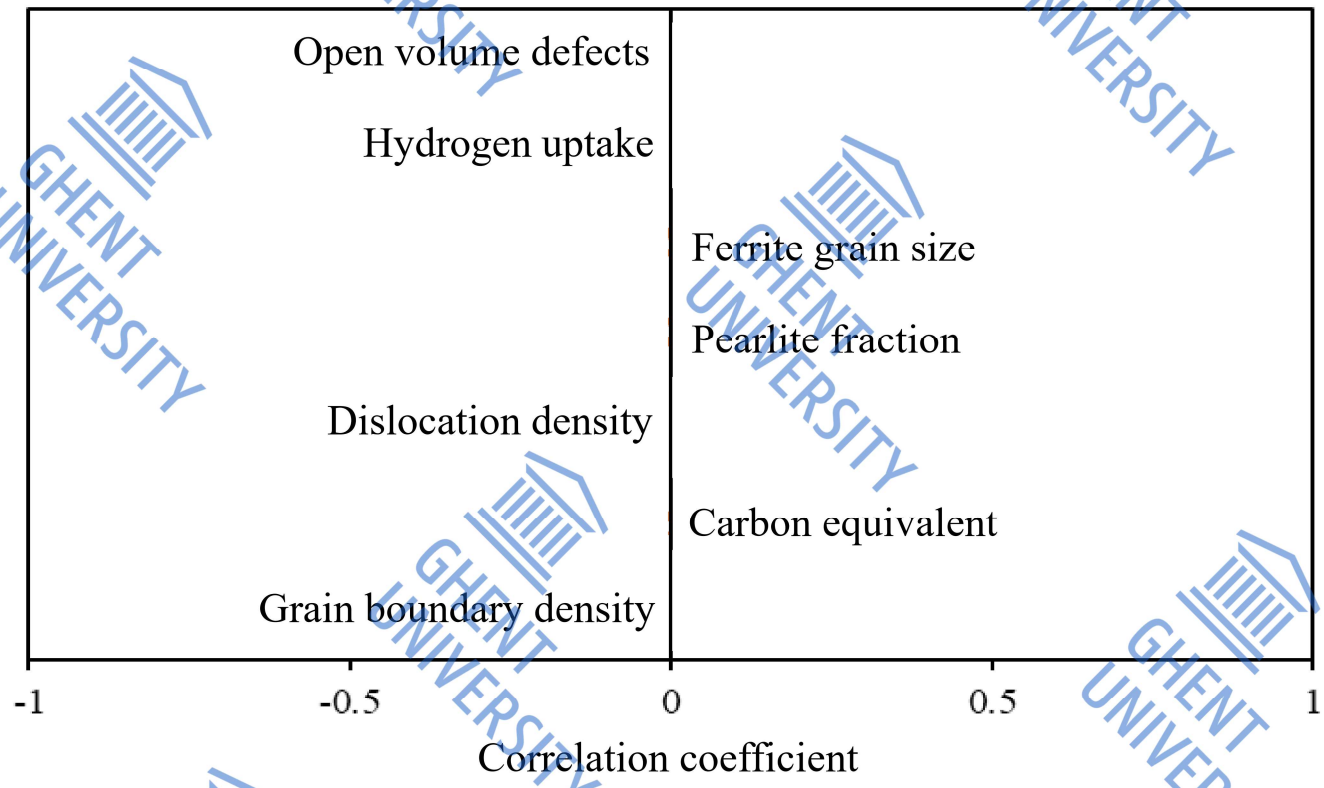
Hardness HV10



Middle region

Still a good correlation of hydrogen embrittlement sensitivity with hardness !?

Correlating hardness with microstructural parameters



Correlating hardness with microstructural parameters

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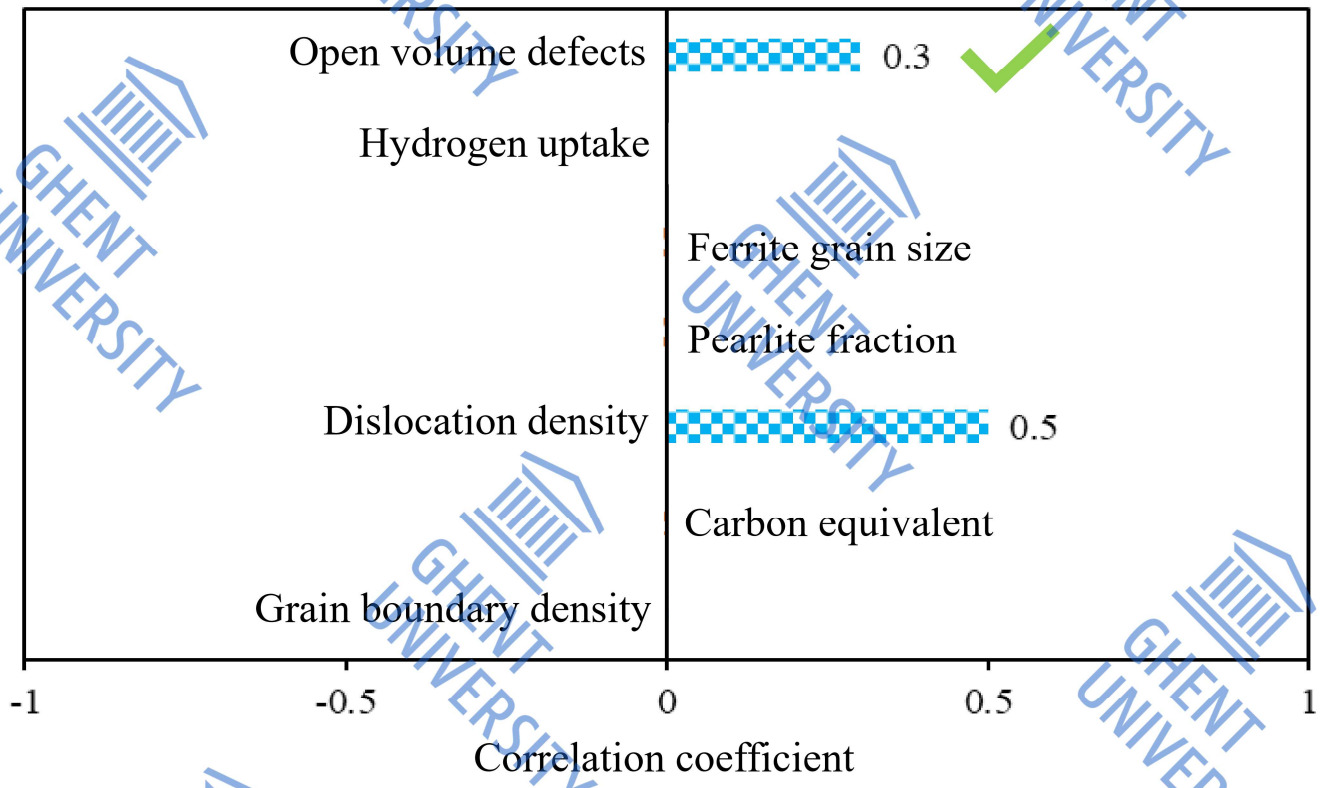
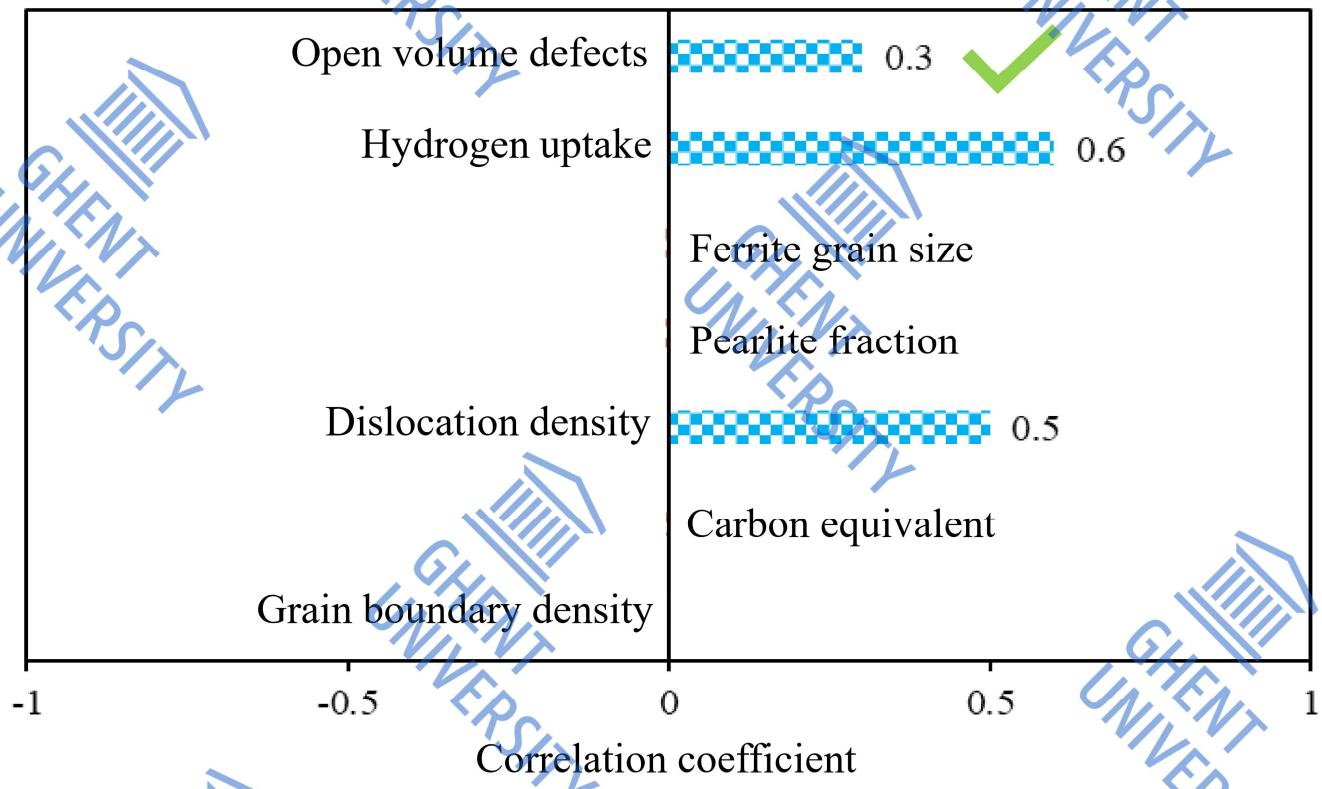
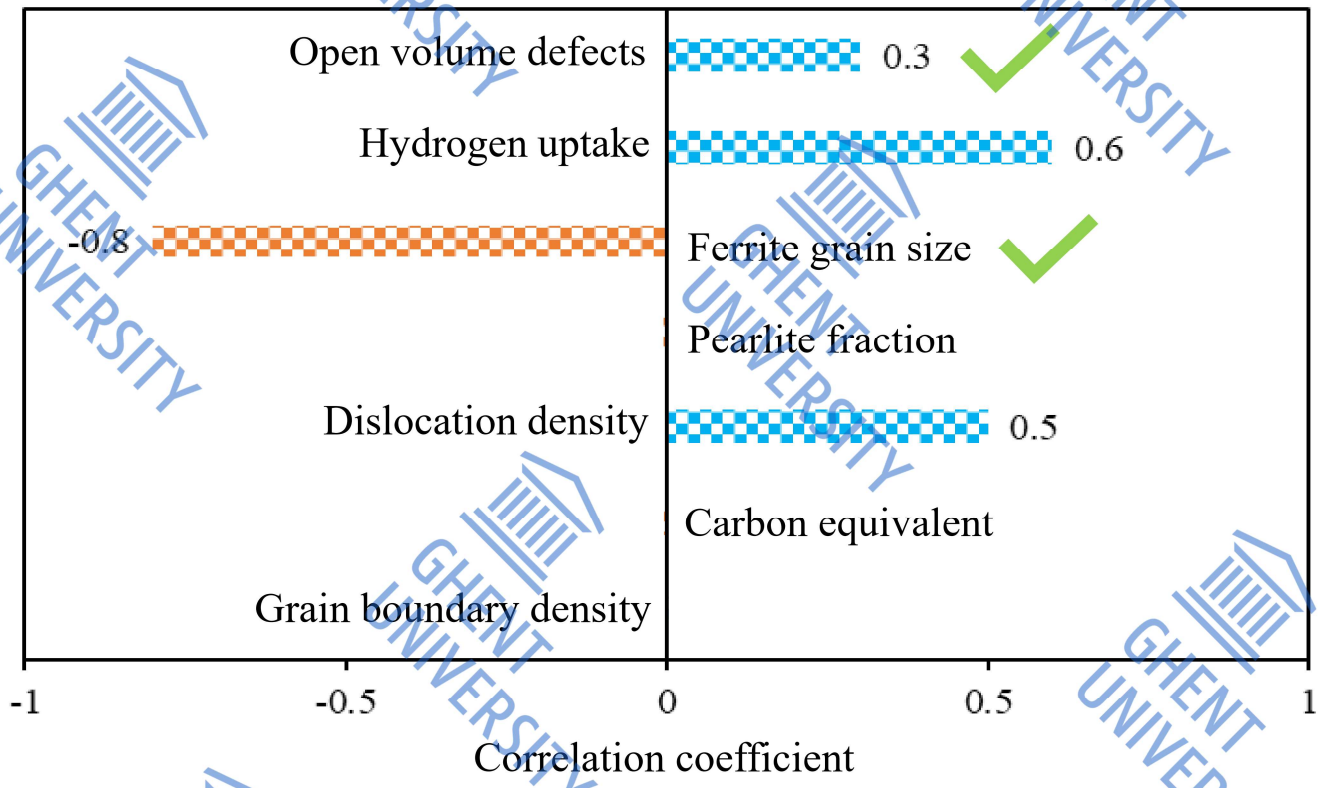


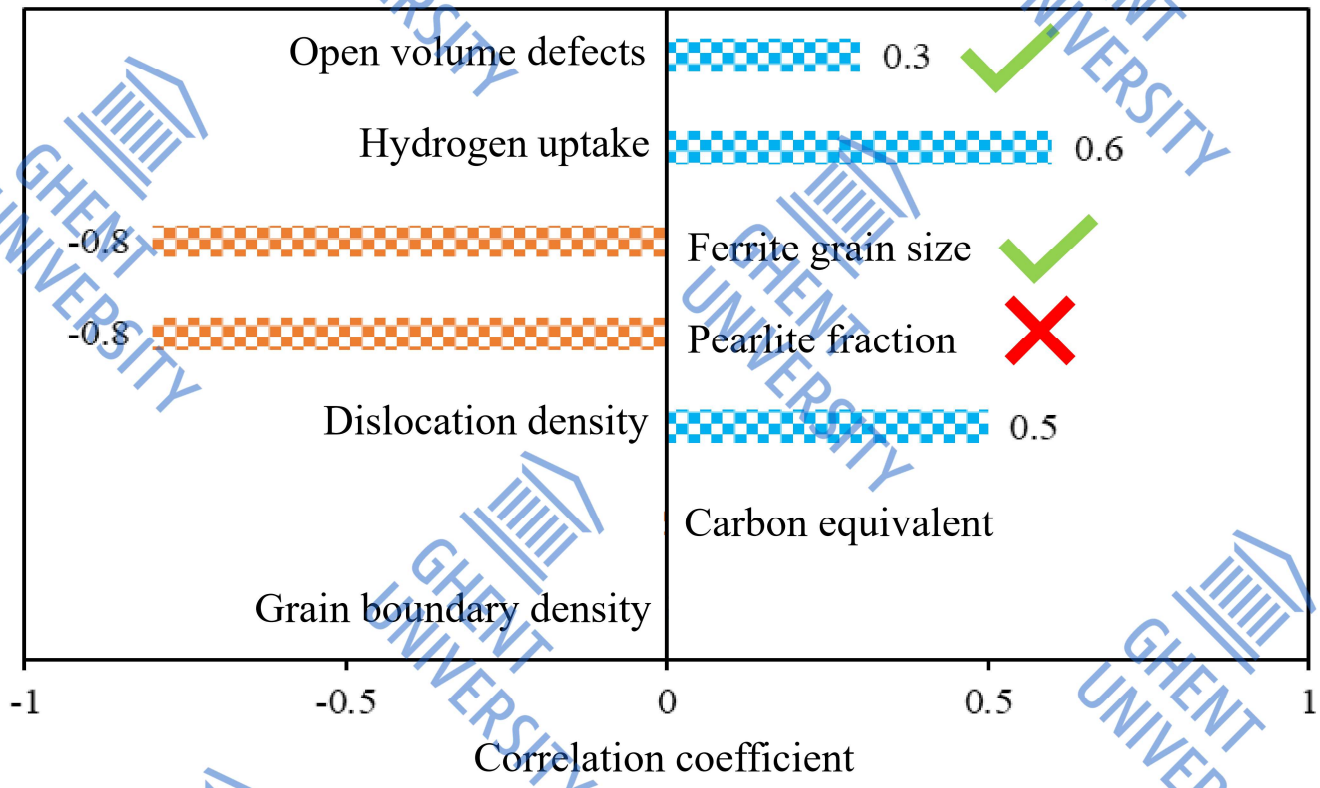
Correlating hardness with microstructural parameters



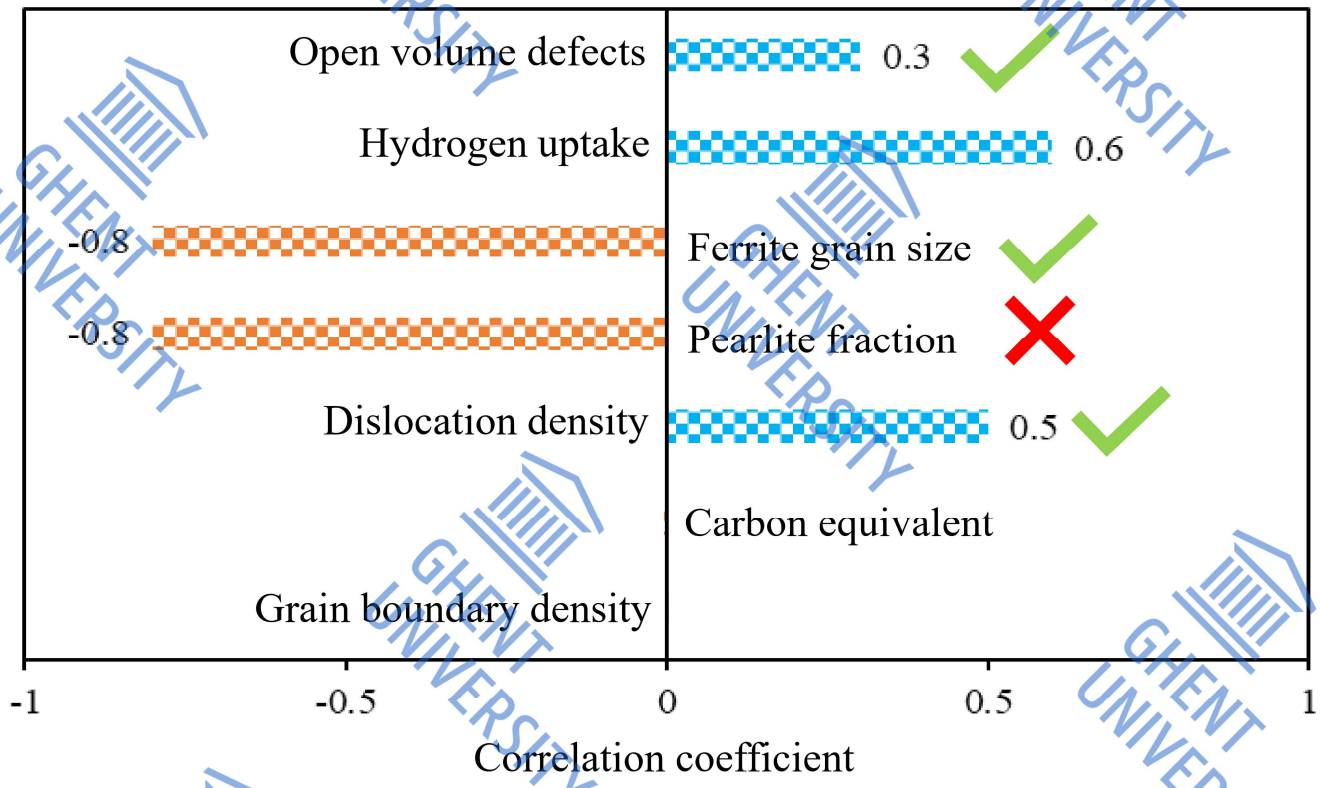
Correlating hardness with microstructural parameters



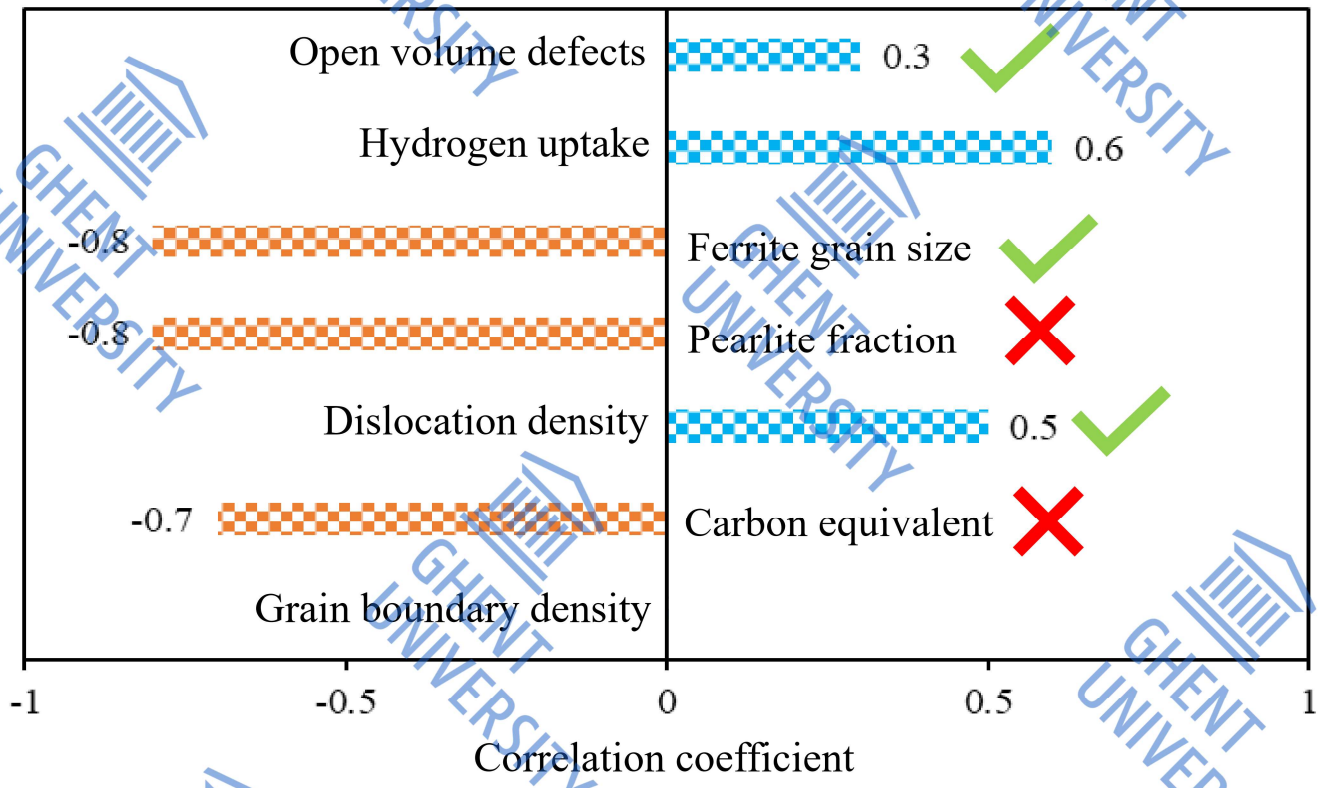
Correlating hardness with microstructural parameters



Correlating hardness with microstructural parameters



Correlating hardness with microstructural parameters



Correlating hardness with microstructural parameters

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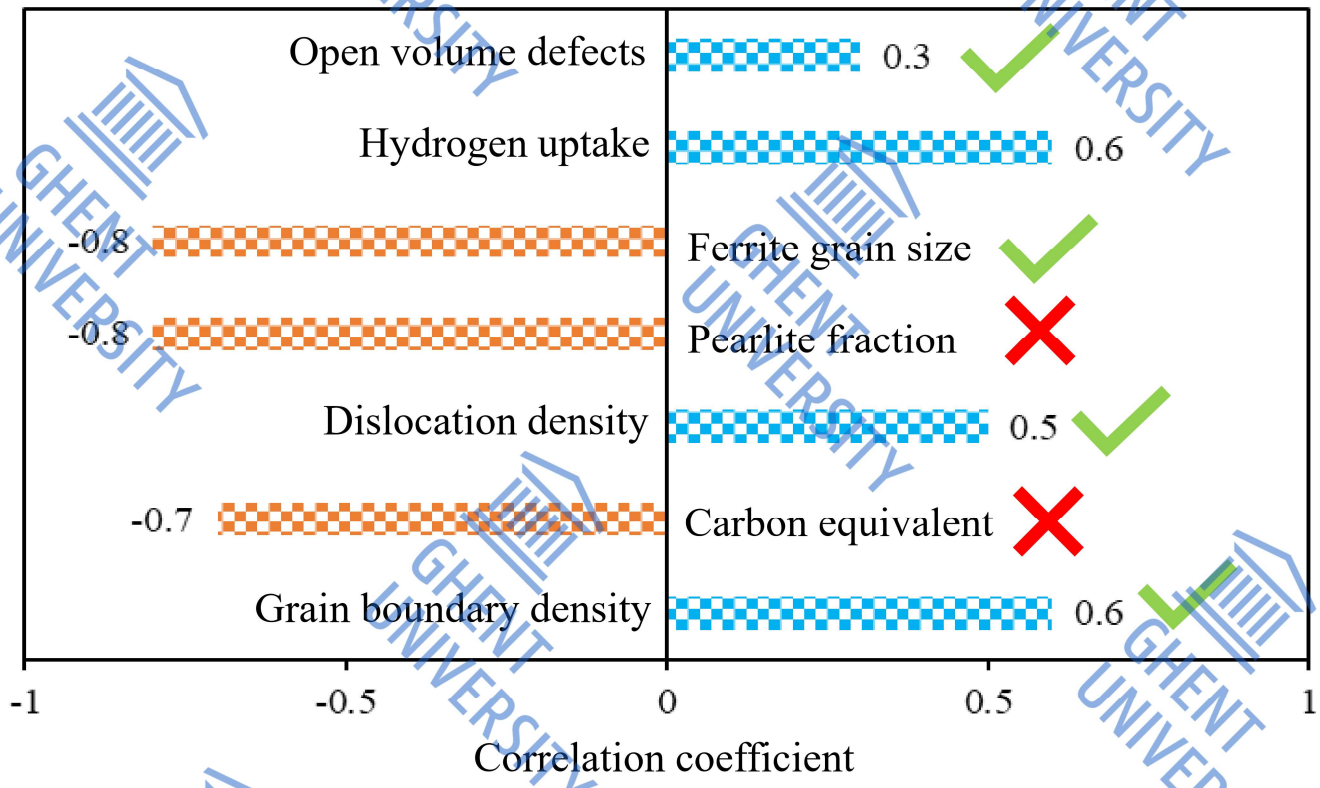
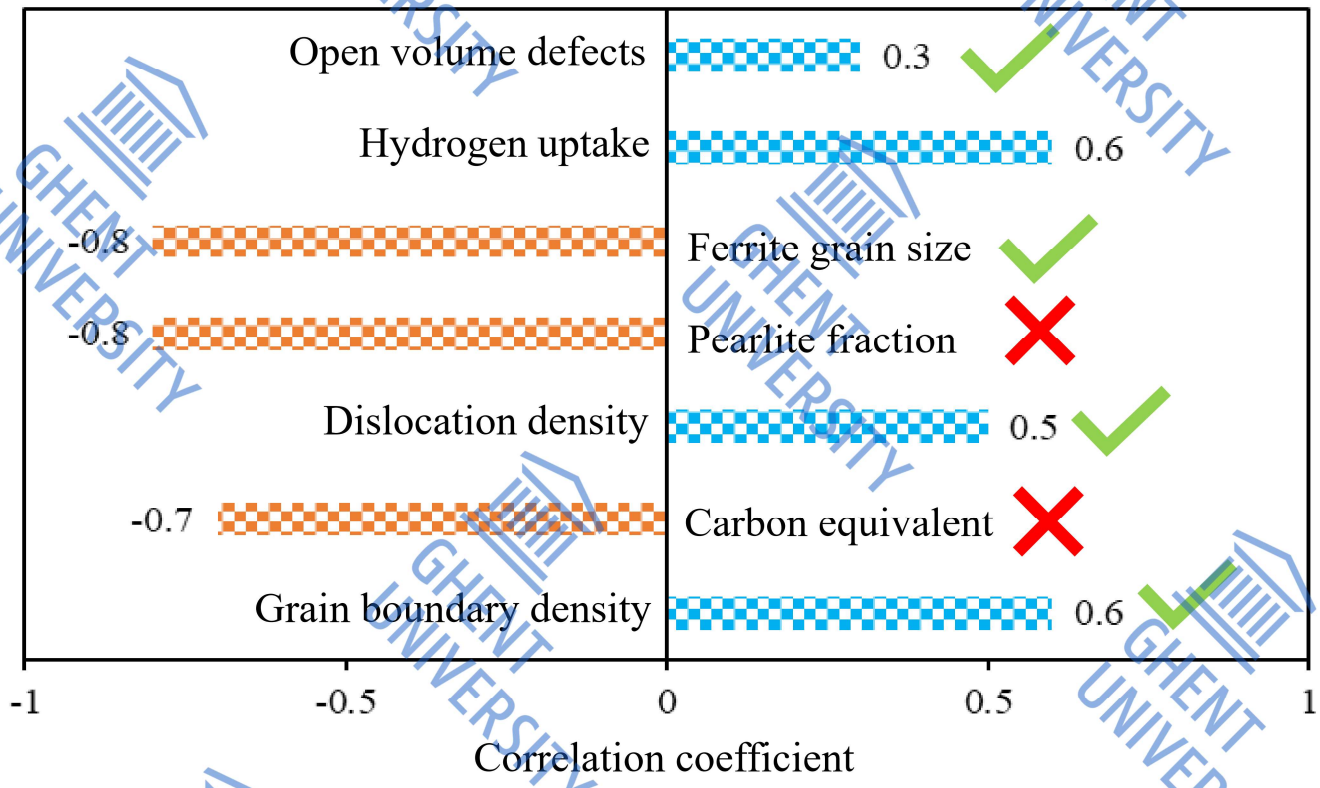
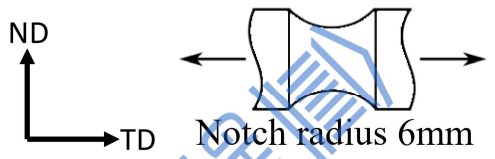


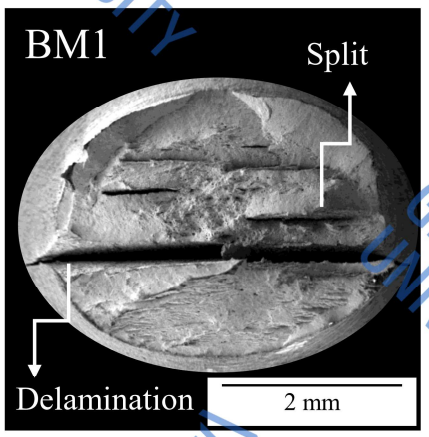
Hydrogen uptake capacity is more intuitive than hardness

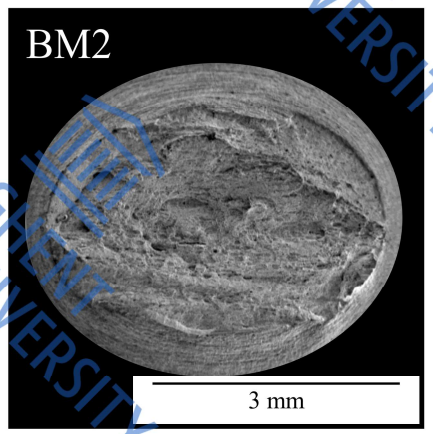


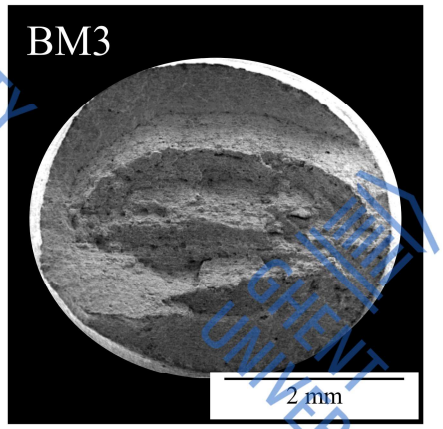
Overview

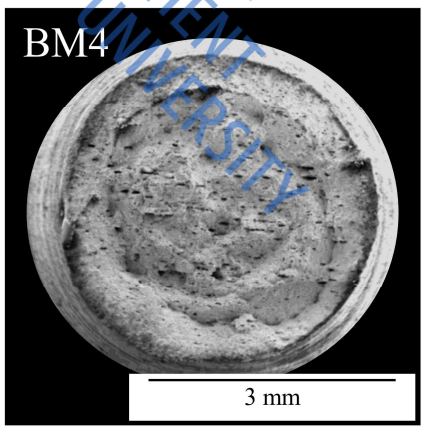
As received

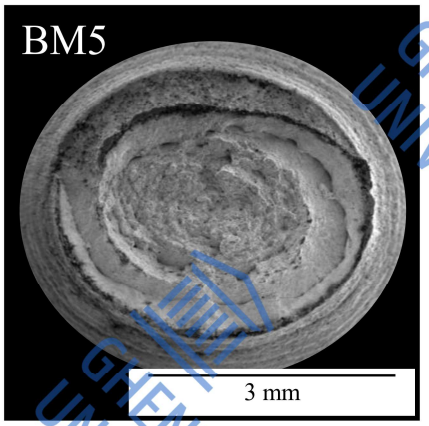


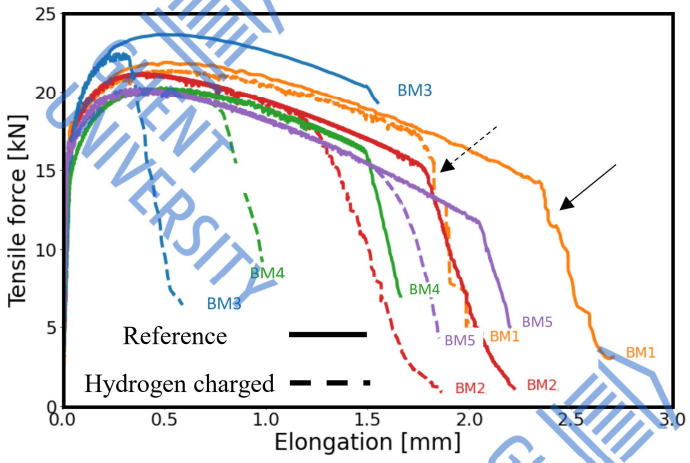


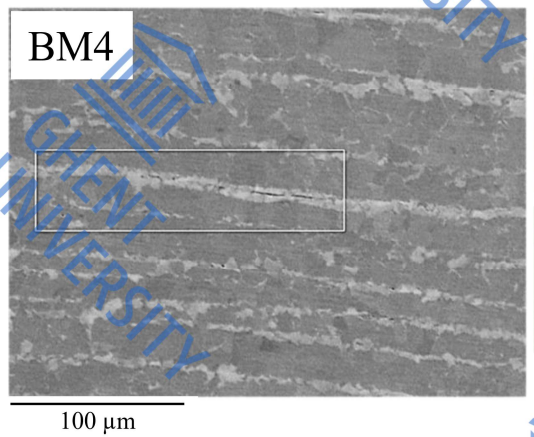


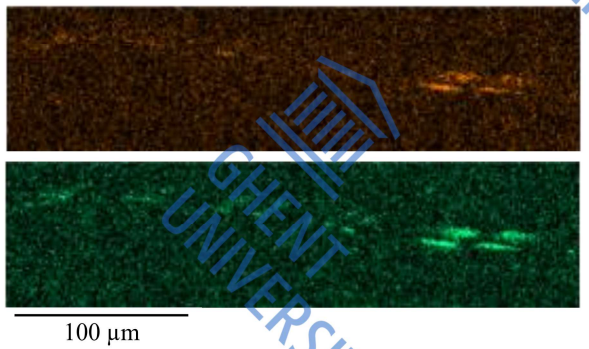






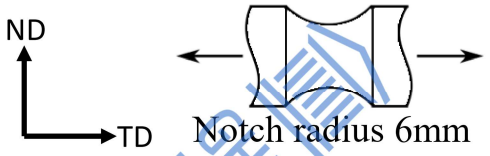


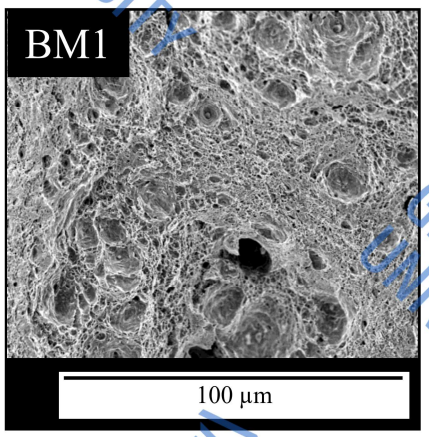


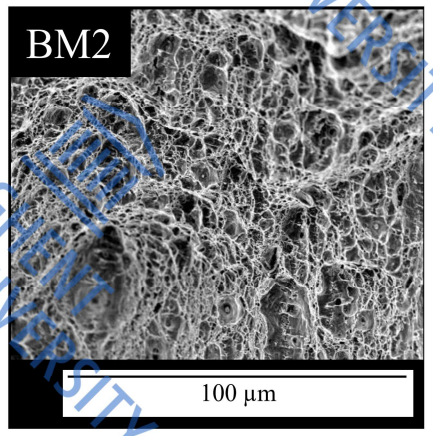


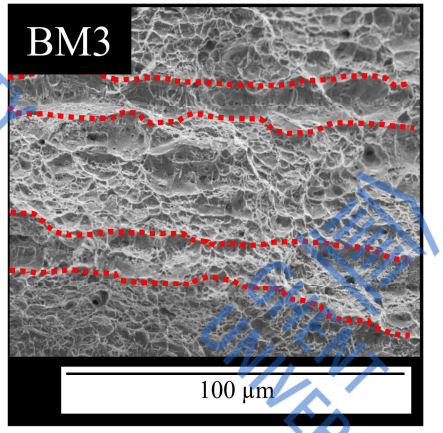
Fracture signatures: central region

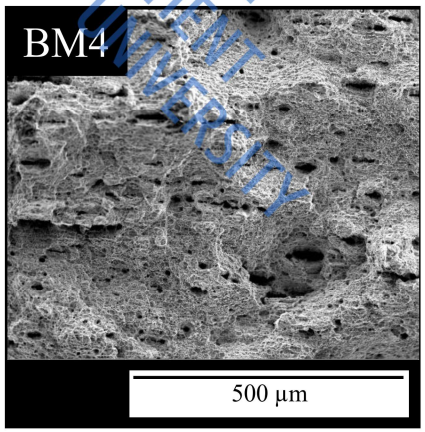
As received: Dimples

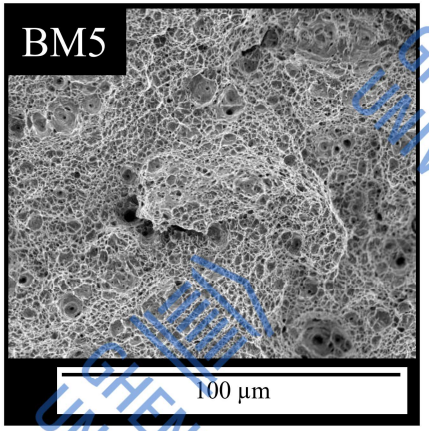






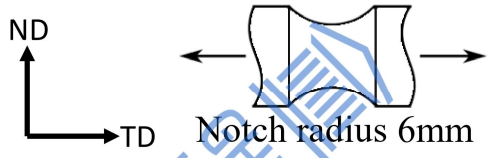


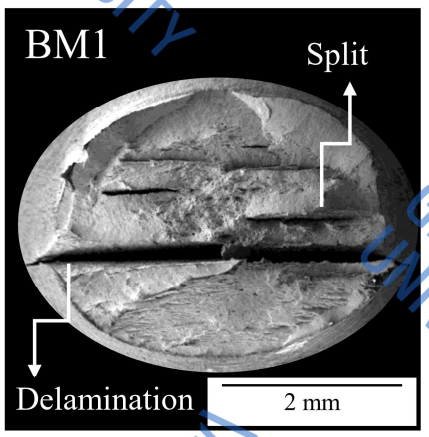


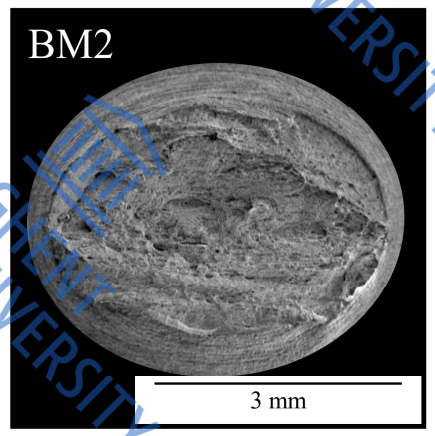


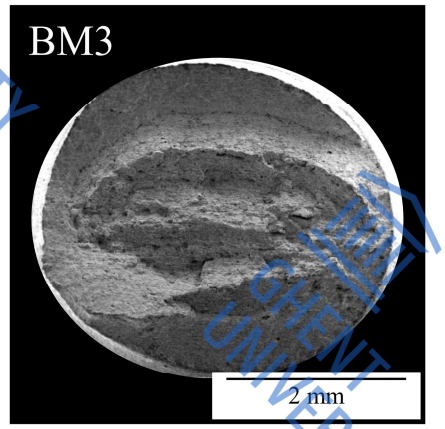
Overview

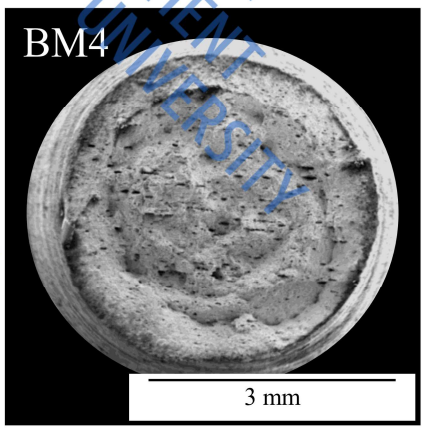
As received

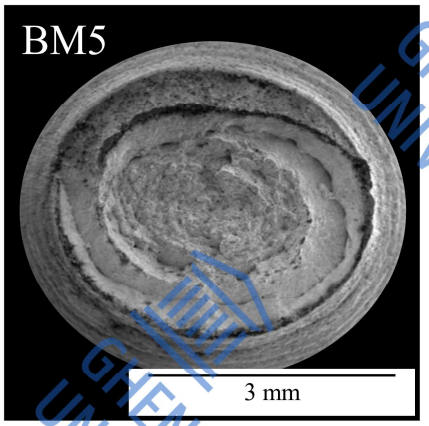




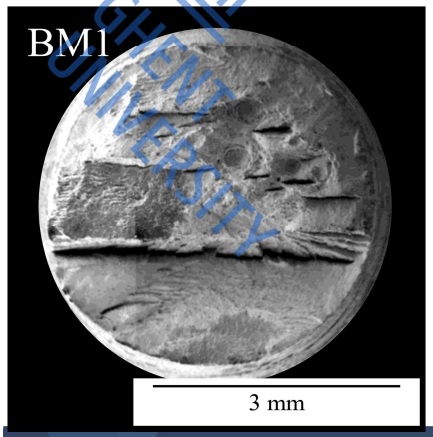


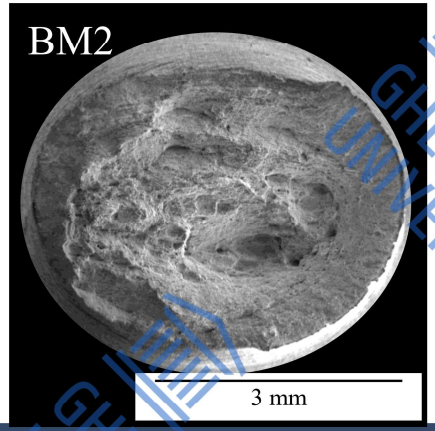


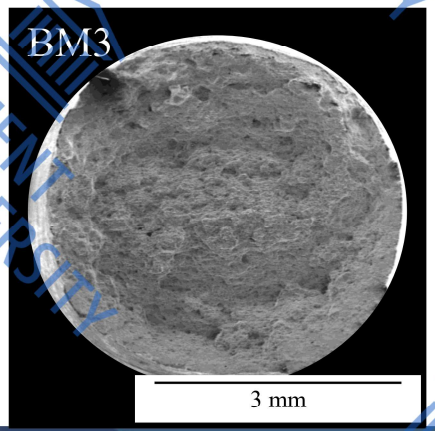


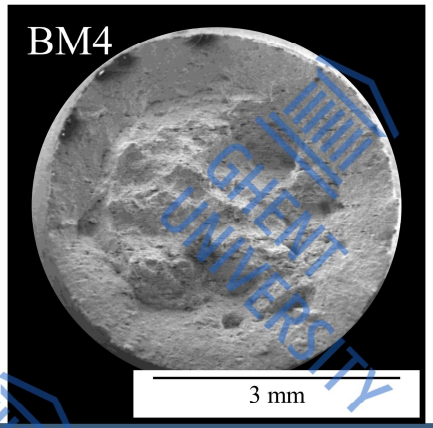


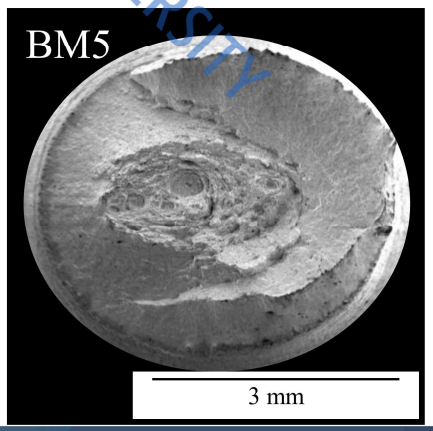
Hydrogen charged



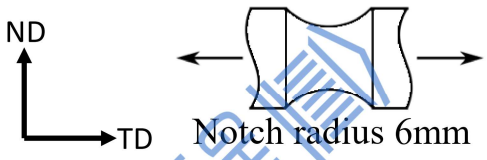




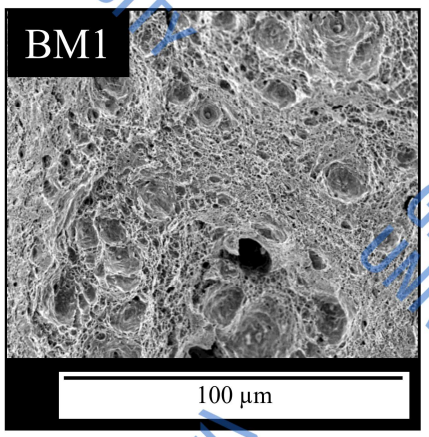


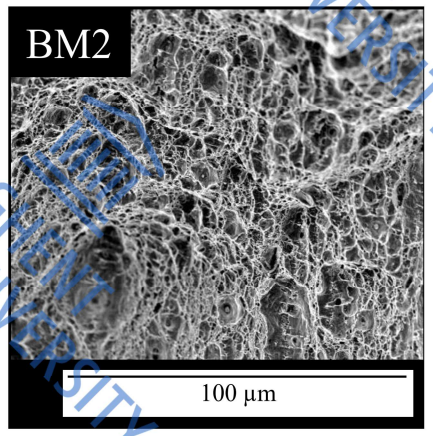


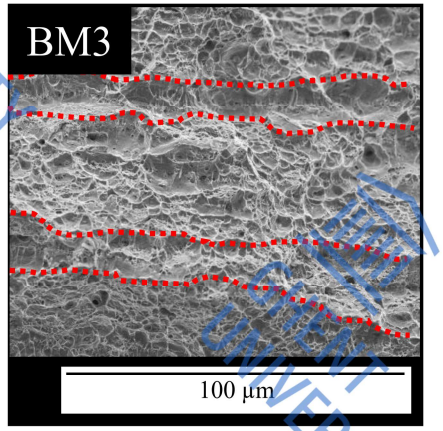
Fracture signatures: central region

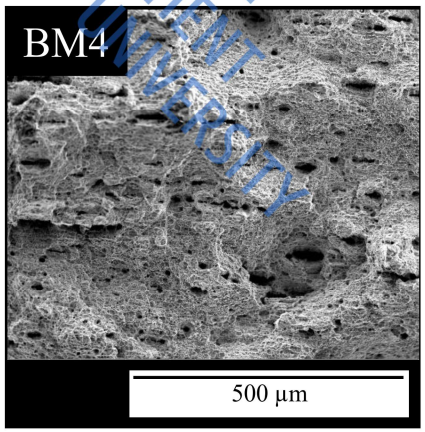


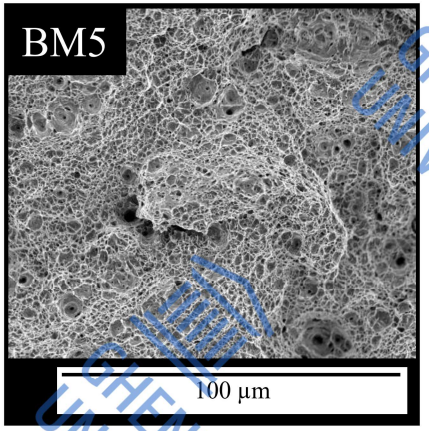
As received: Dimples



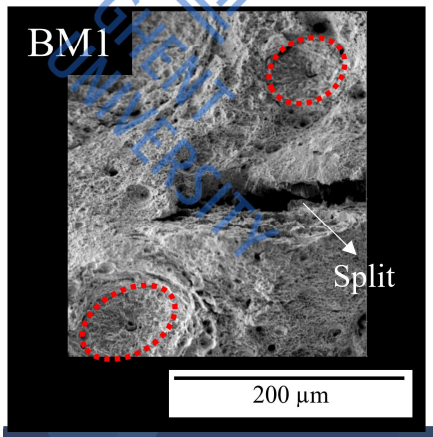


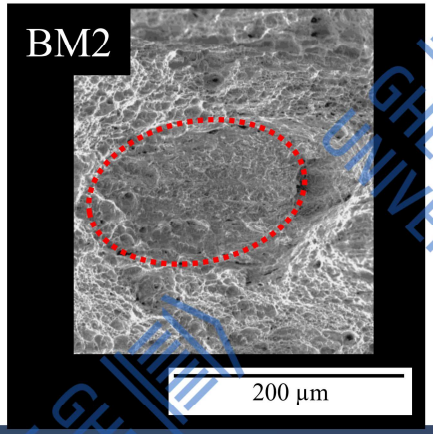


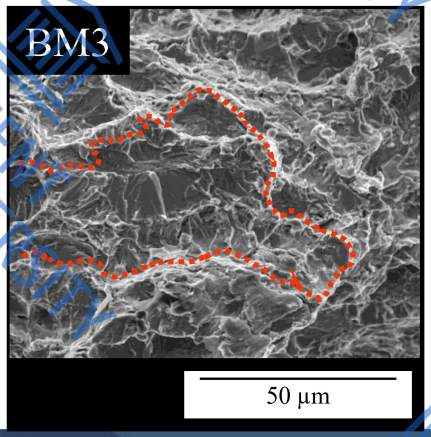


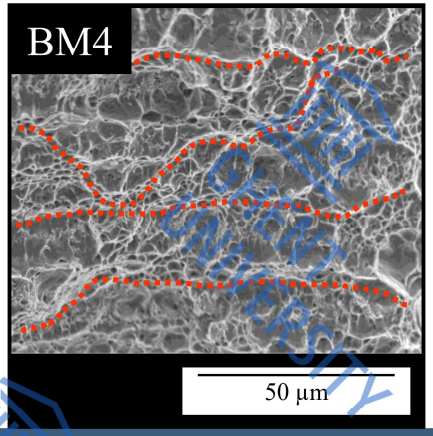


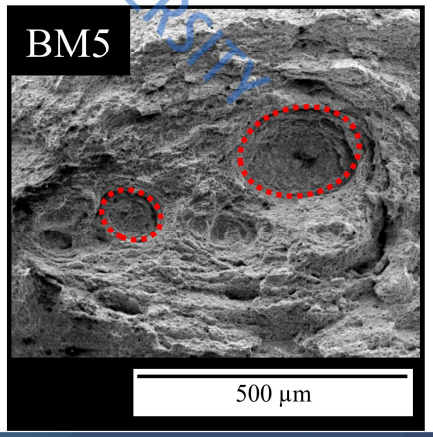
Hydrogen charged: Quasi-cleavage region











Closing remarks

- Microstructure governs hydrogen performance.
- Hydrogen embrittlement sensitivity is related to hydrogen uptake capacity rather than hardness.
- Microstructure correlates with hydrogen uptake rather than hardness.

Thank you for your attention.