Hydrogen Embrittlement of Ultra-High Strength Aluminized Press Hardening Steel

Jun. 30th, 2021

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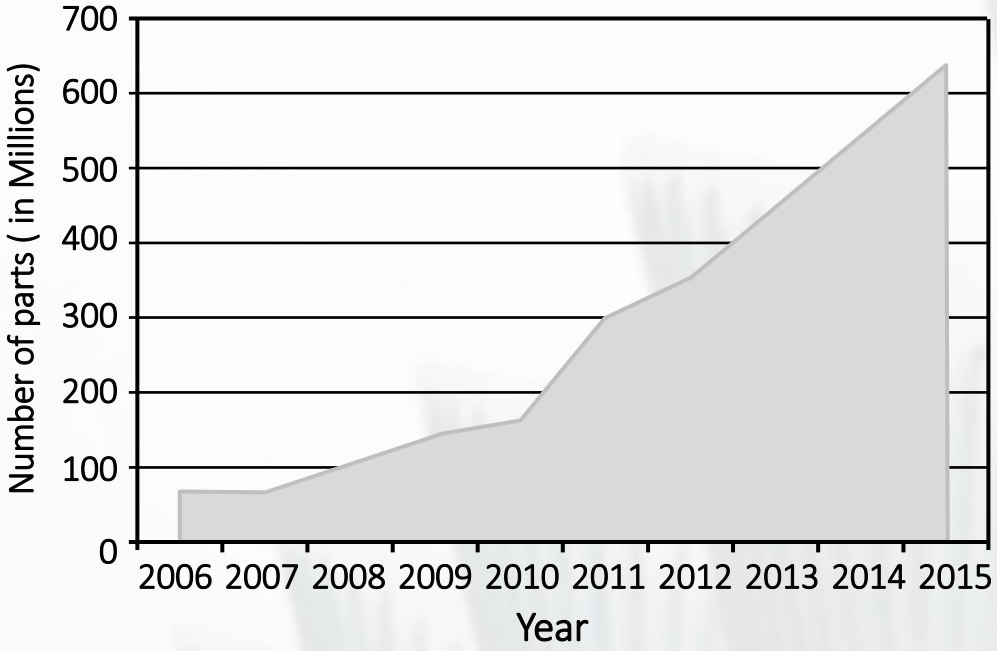
Seminar Online Teknik Metalurgi UNTIRTA 2021

1. Introduction

1.1 Ultra-high Strength Press Hardening Steel



http://articles.sae.org/13849/

Paul J. Belanger et al., International Symposium on New Developments in Advanced High-Strength Sheet Steels, 2013. p. 239-250.

- High strength, increase safety of passenger and no spring-back effect.
- Application of press hardening steel (PHS) : A-pillar, B-pillar, bumper, roof rail, rocker and tunnel.

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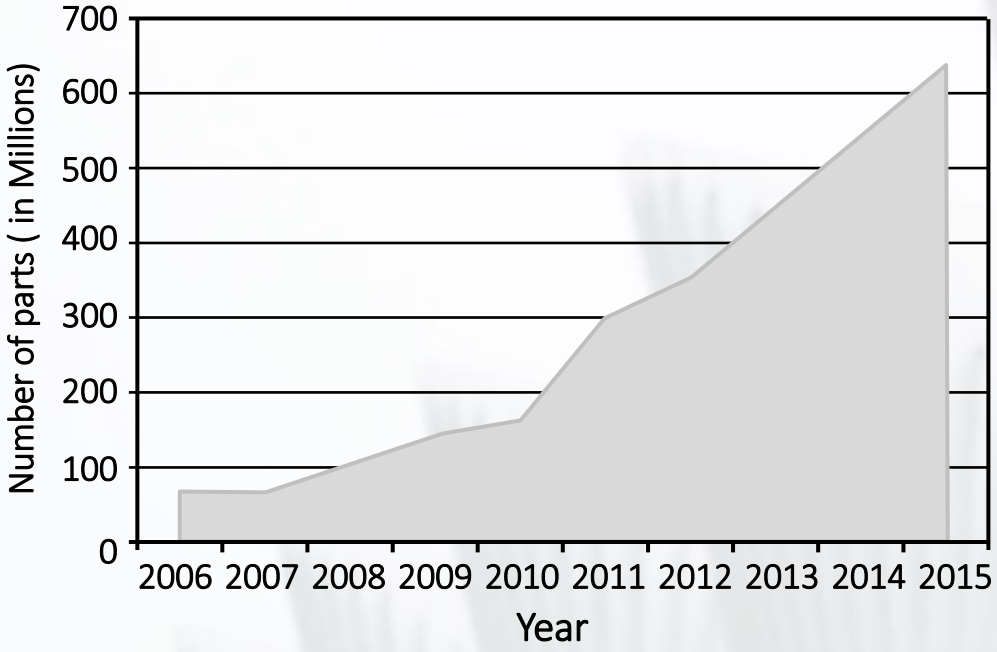

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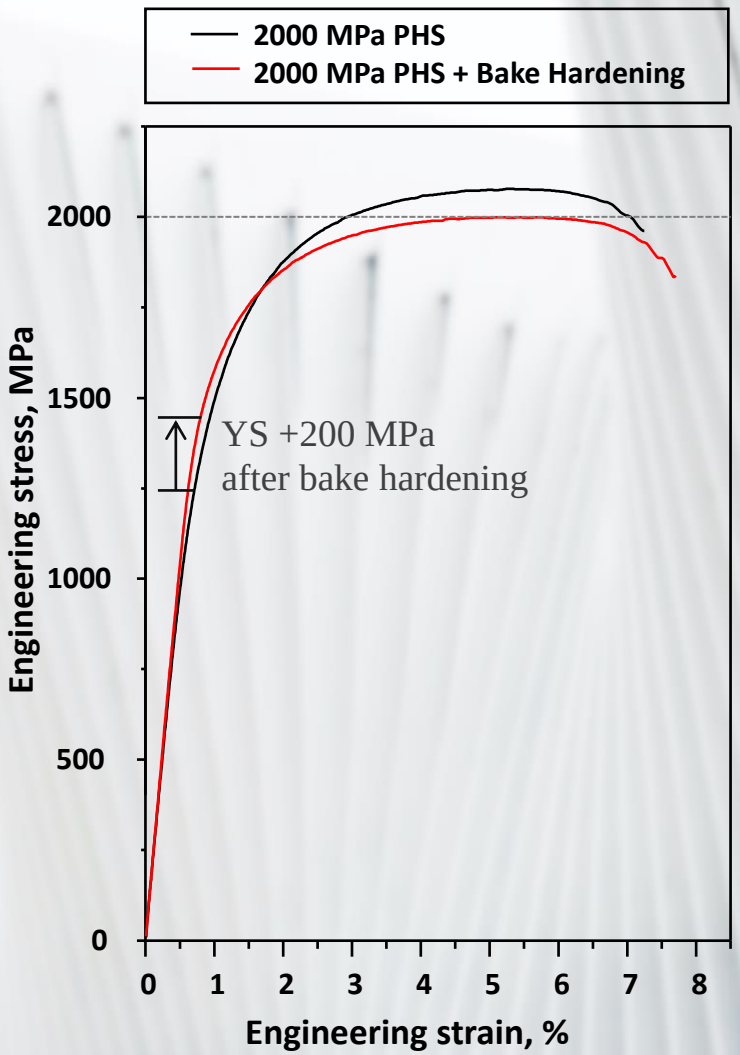

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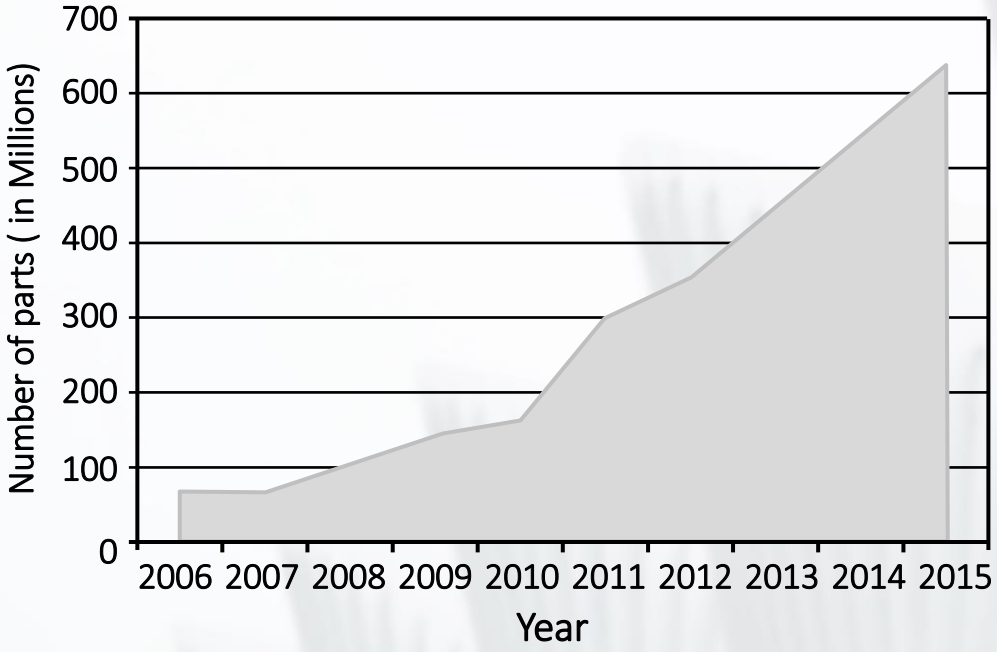

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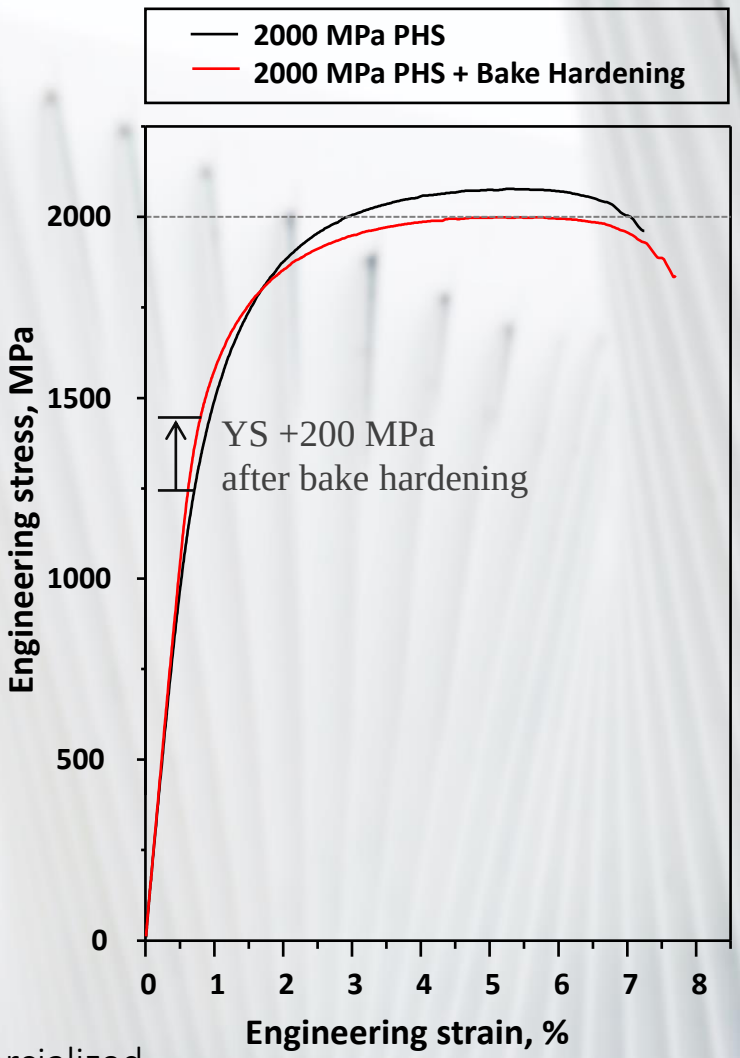

- 1500 MPa PHS + Aluminizing → commercialized

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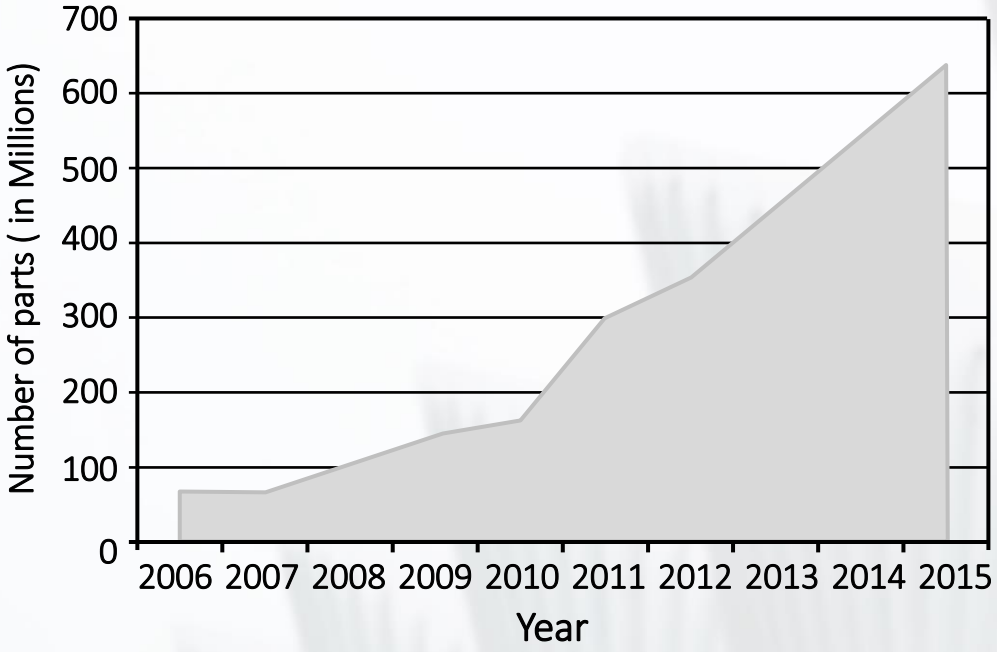

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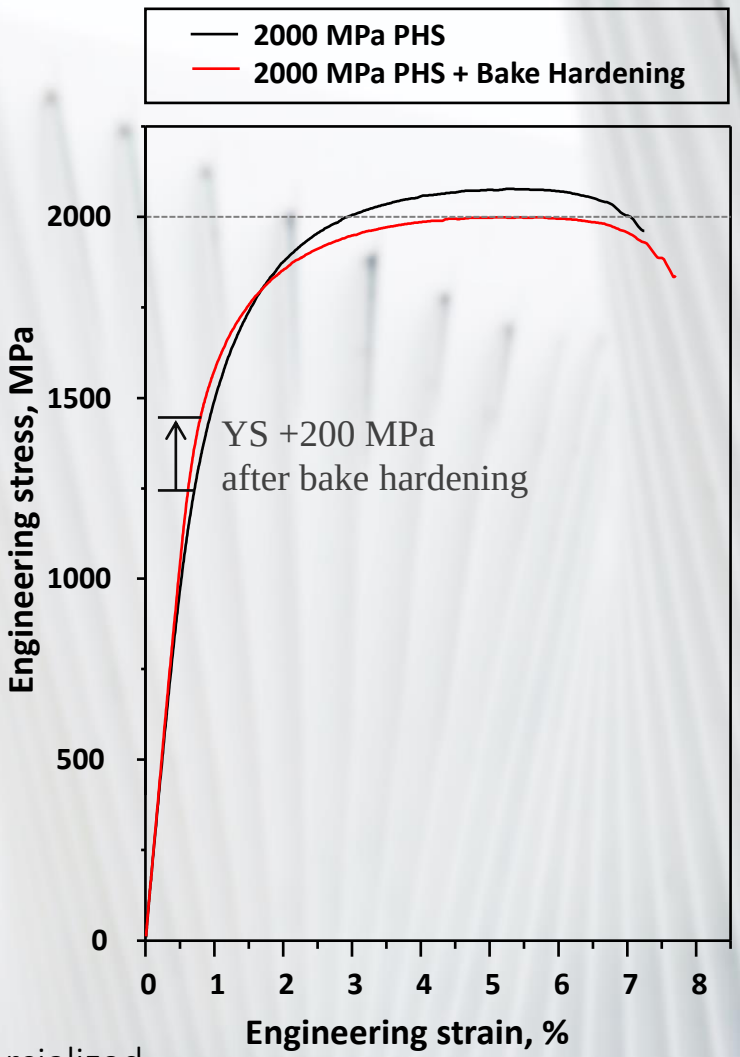
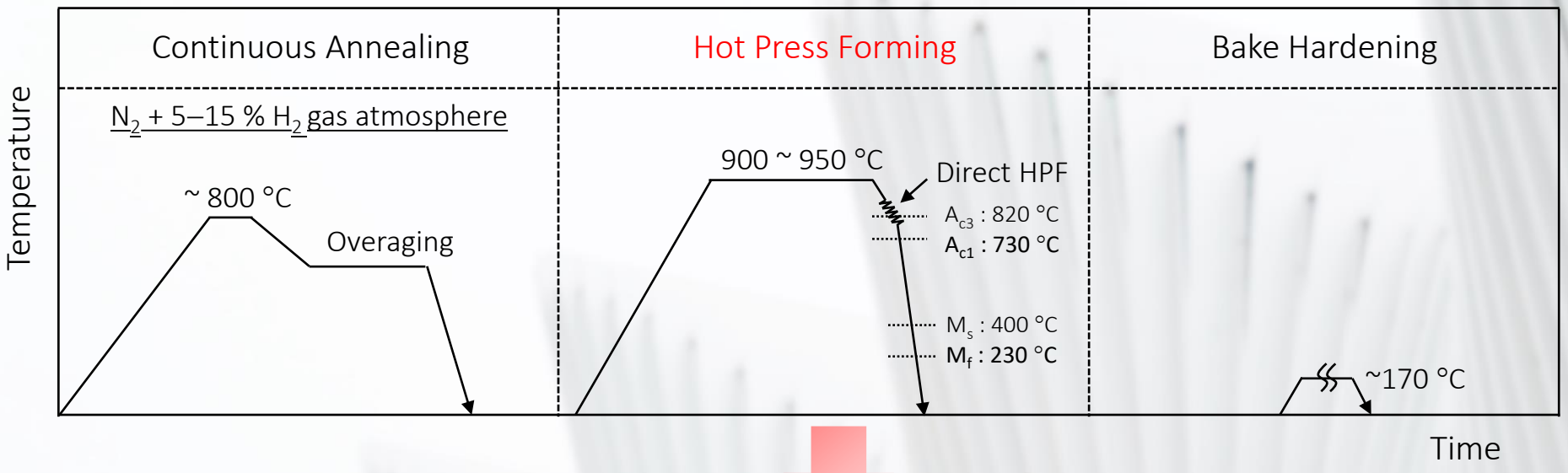


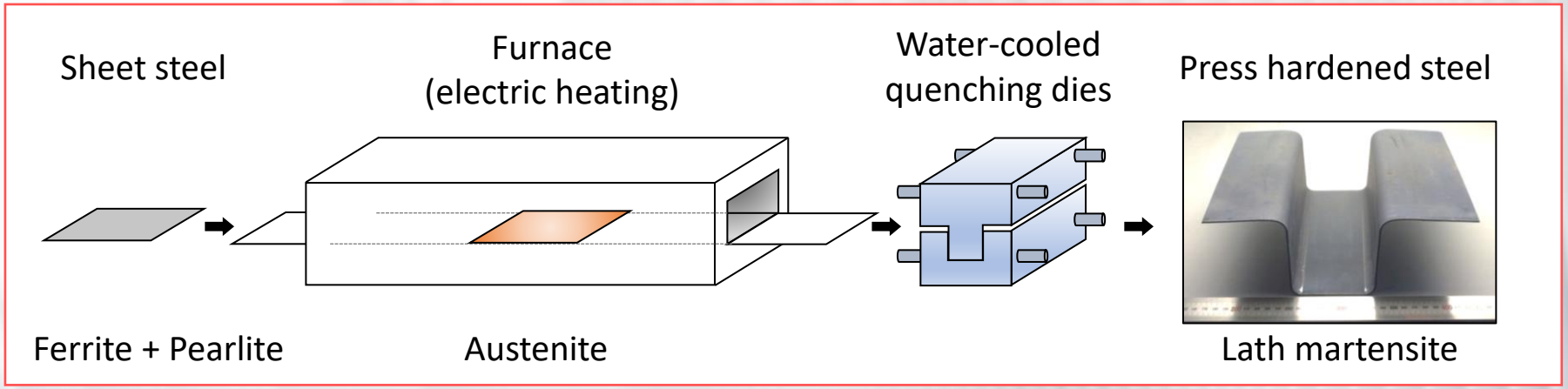
- 1500 MPa PHS + Aluminizing → commercialized

- 2000 MPa PHS + Aluminizing → hydrogen embrittlement

1. Introduction

1.2 Hot Press Forming (HPF)





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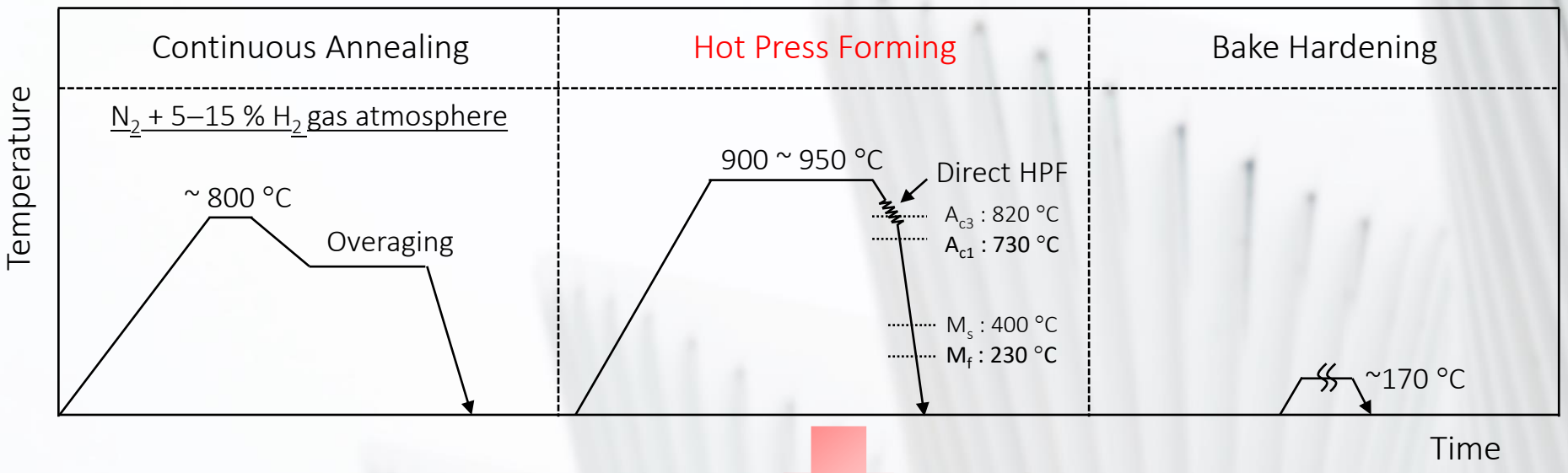

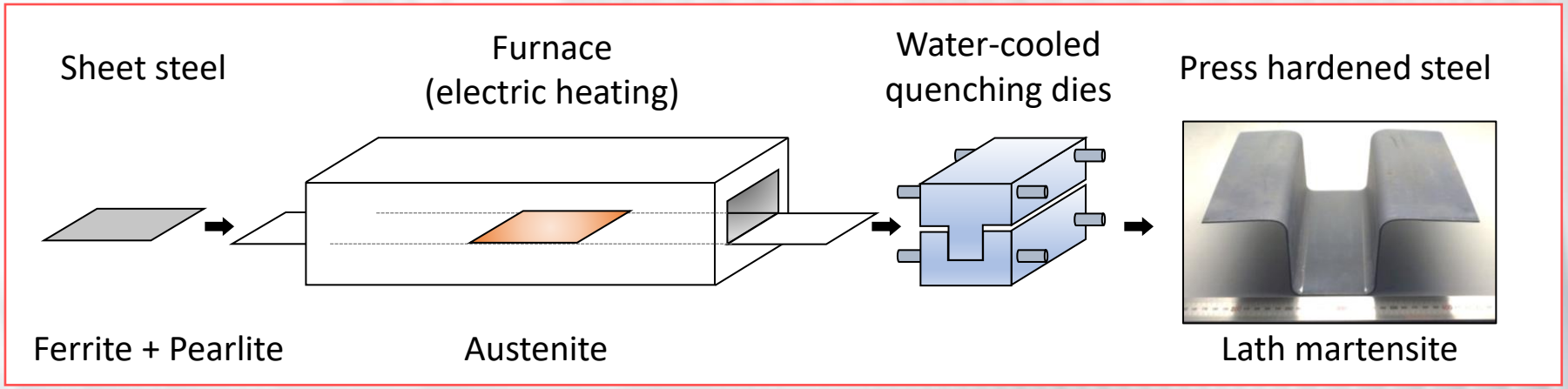

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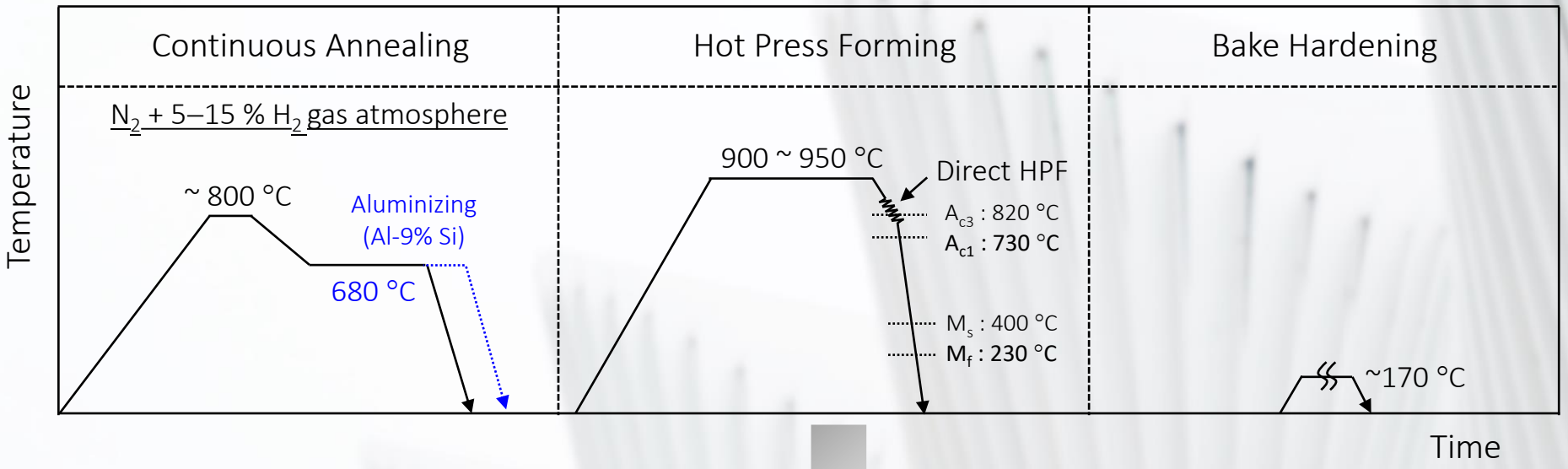
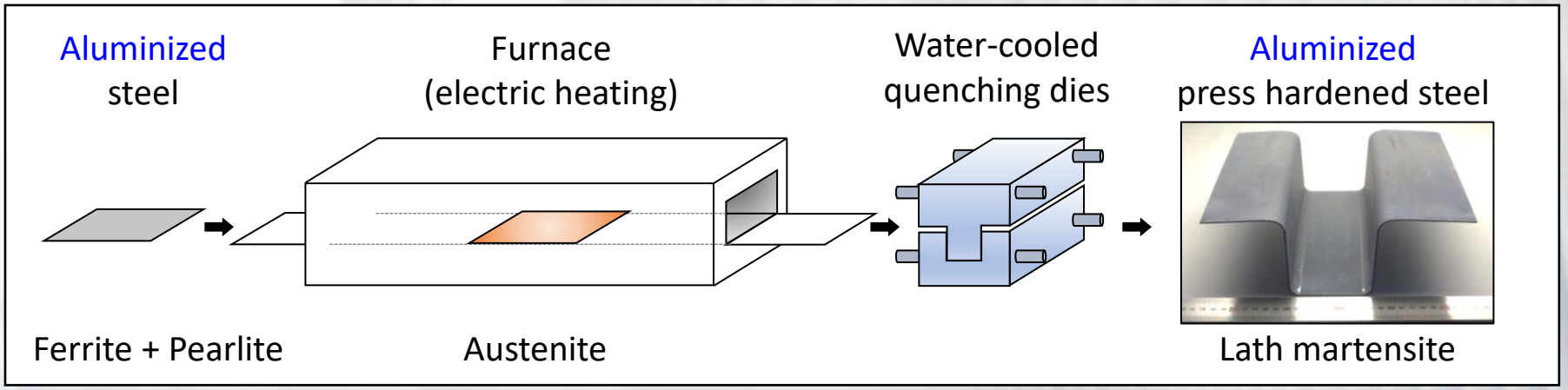
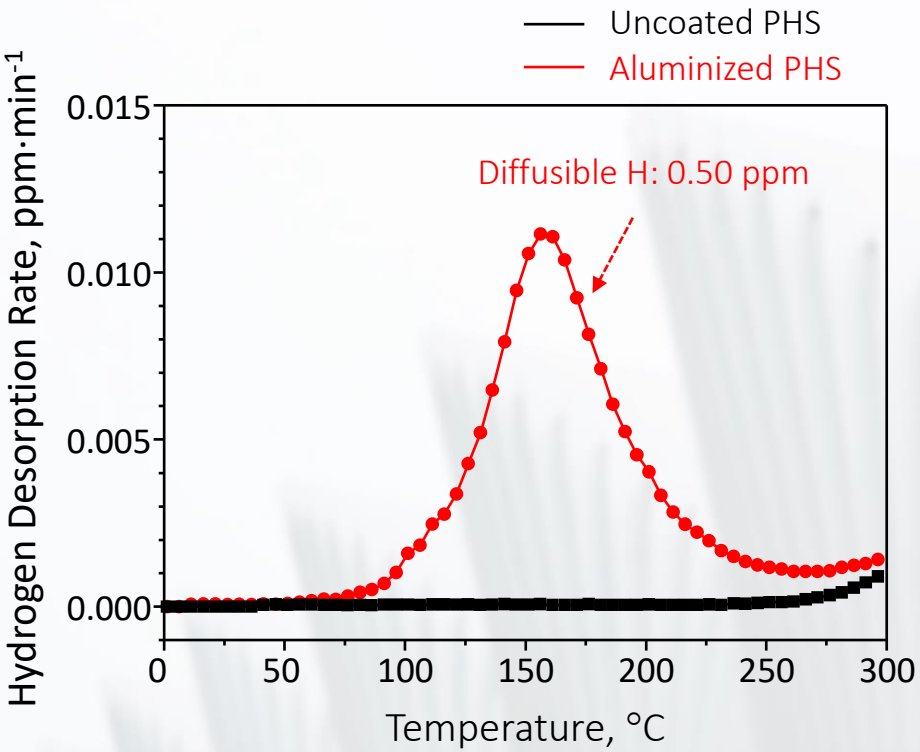


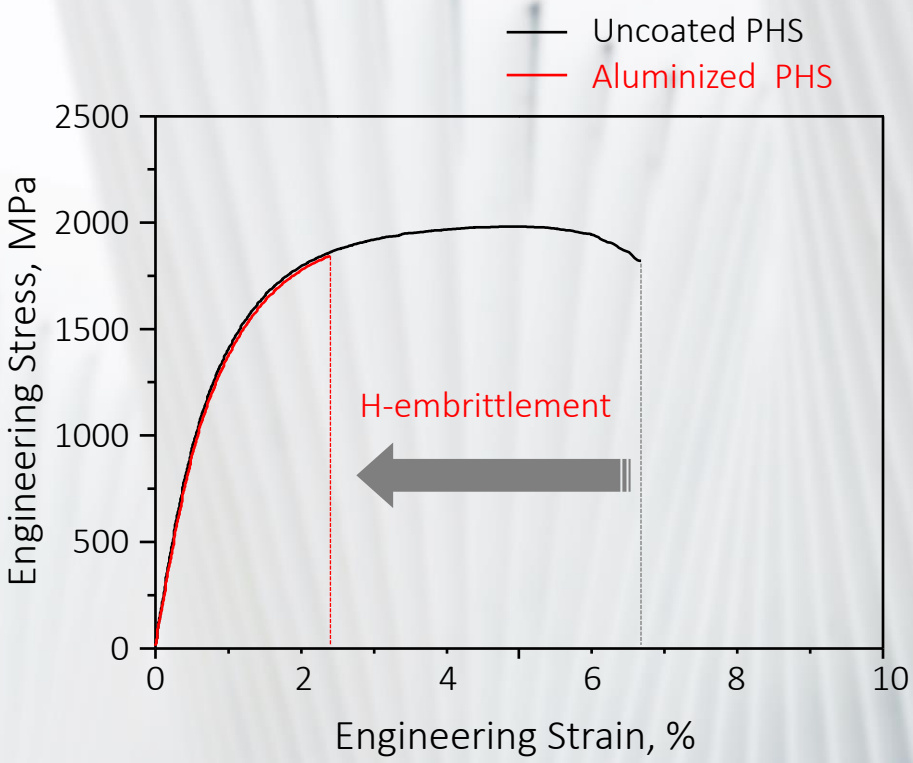


1. Introduction

1.3 Hydrogen Embrittlement of Aluminized Press Hardened Steel

- Hydrogen was detected in the aluminized PHS, but not in uncoated PHS
- The aluminized PHS specimens ruptured in the early stages of tensile straining.





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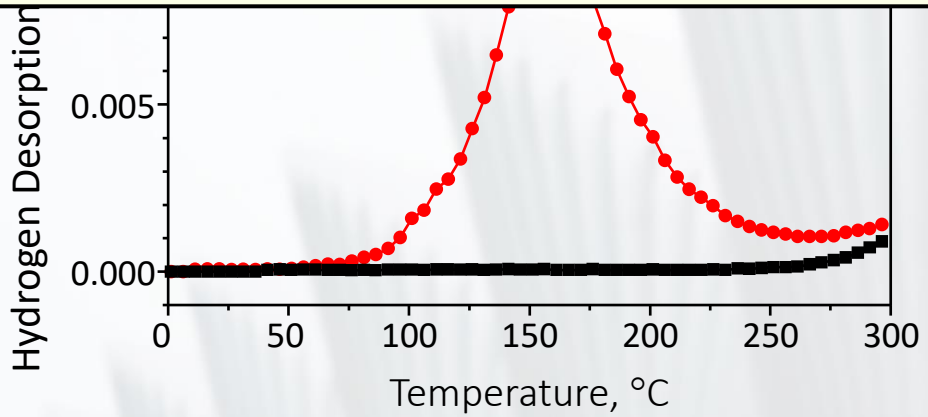
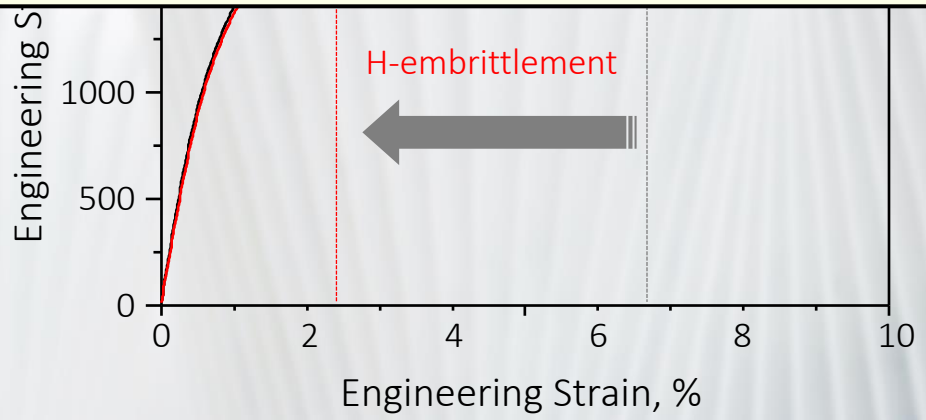
1.3 Hydrogen Embrittlement of Aluminized Press Hardened Steel

- Hydrogen was detected in the aluminized PHS, but not in uncoated PHS
- The aluminized PHS specimens ruptured in the early stages of tensile straining.

- ✓ Aluminized PHS→ sensitive to hydrogen embrittlement
- ✓ Identification of the process responsible for the hydrogen-uptake
- ✓ Hydrogen absorption mechanism
- ✓ Effect of bake hardening on the hydrogen embrittlement



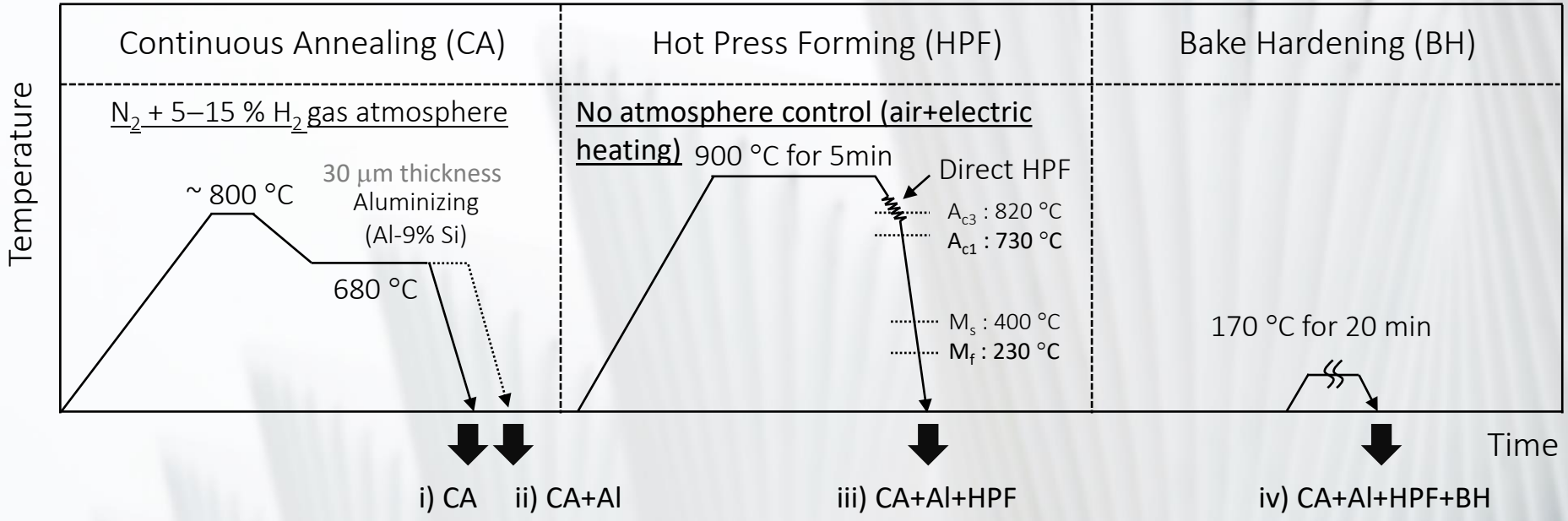


2. Experimental

2.1 Steel Composition

Steel Grades	C	Mn	Si	Ti, Mo, and B
Press hardening steel	0.4 wt.%	1.5 wt.%	1.0 wt.%	…

2.2 Thermal Cycles



- Measurement of the diffusible hydrogen content
- Evaluation of the mechanical properties
- Fracture surface analysis

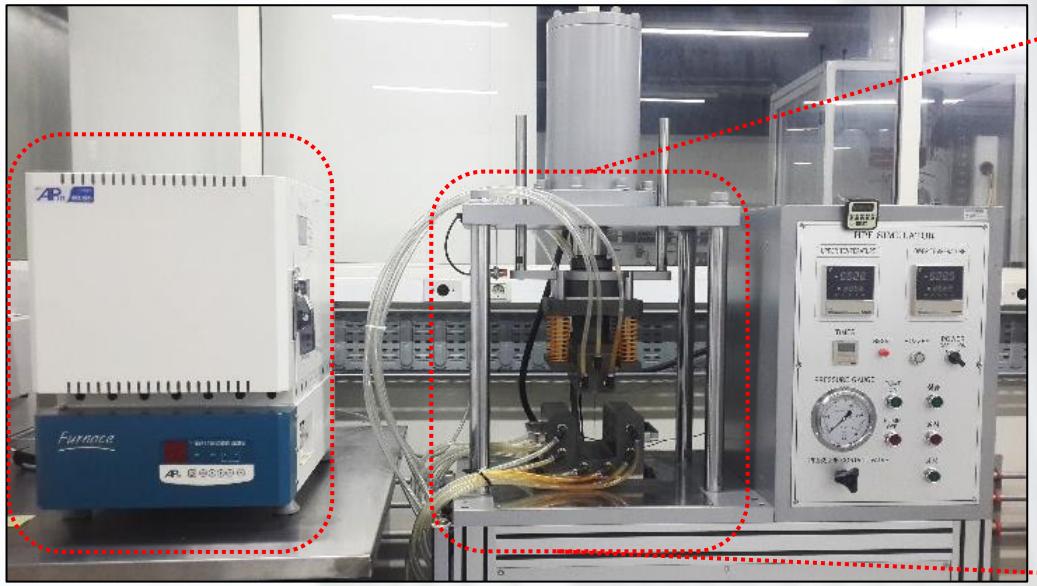
2. Experimental

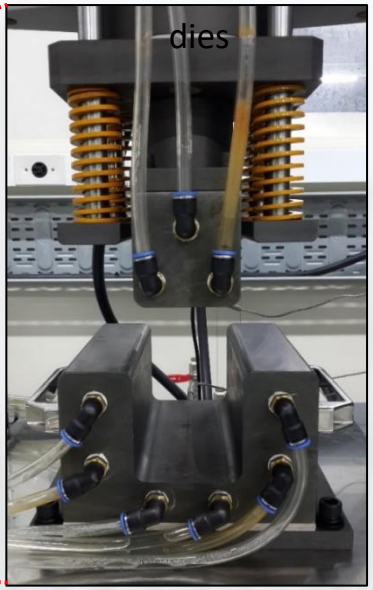
2.3 Hot Press Forming Simulator

Electric furnace

Hot press forming simulator

Hydraulic press with water-cooled dies

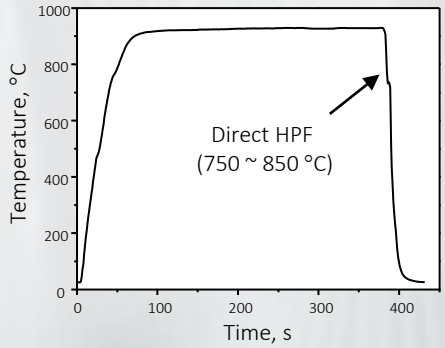




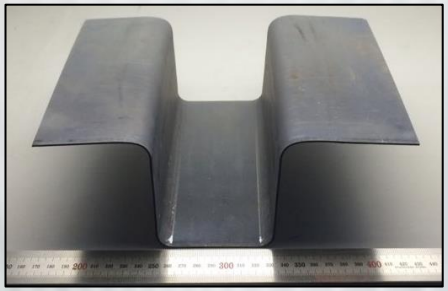
Water-cooled bottom die (fixed part)

Aluminized steel panel

Thermal cycle



U-shape press hardened steel



2. Experimental

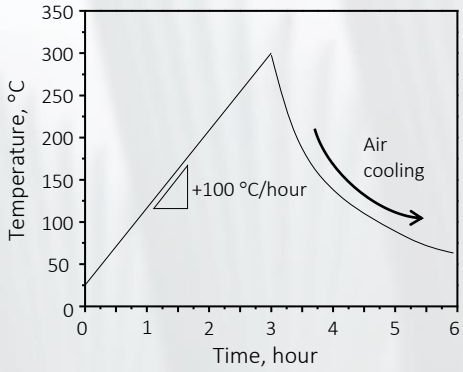
2.4 Hydrogen Thermal Desorption Analysis (TDA)

* Agilent 7890A Gas Chromatography

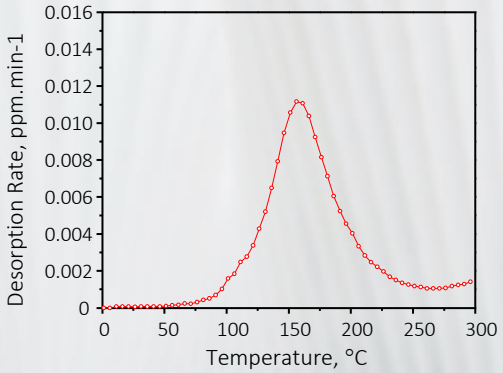
Electric furnace

Gas detector

Thermal cycle for TDA



TDA result



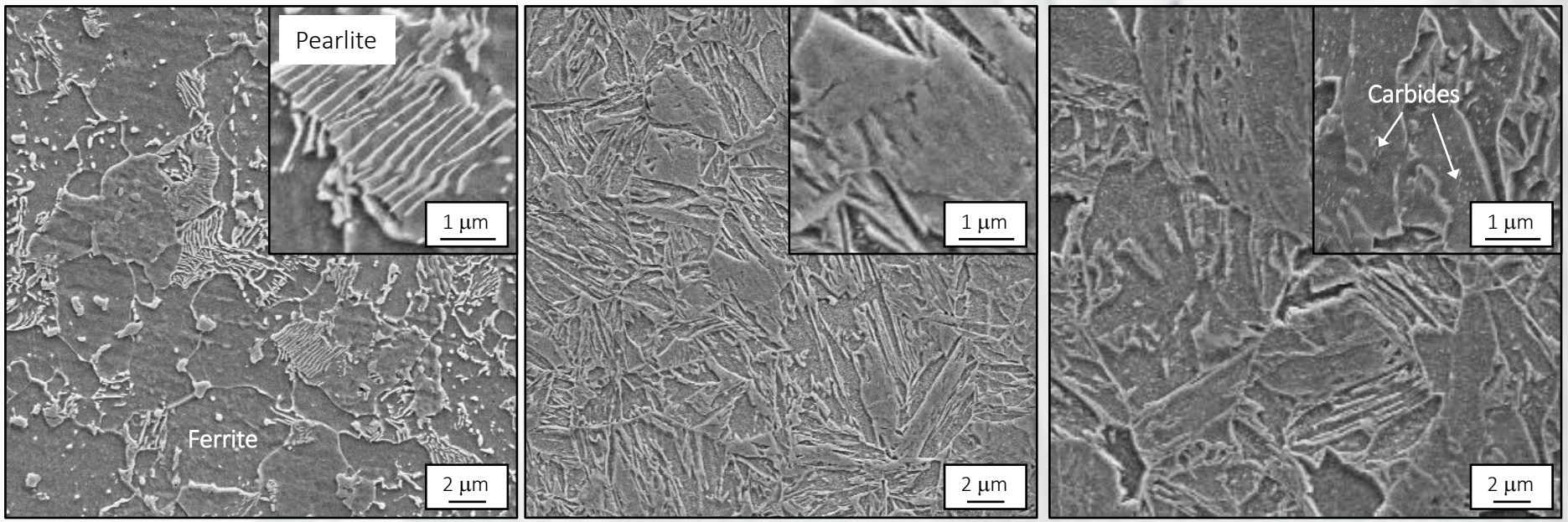
3. Results and Discussion

3.1 Lath Martensite Microstructure of the Press Hardening Steel

After CA:
Ferrite + Pearlite

After CA+HPF:
Lath martensite

After CA+HPF+BH:
Tempered martensite

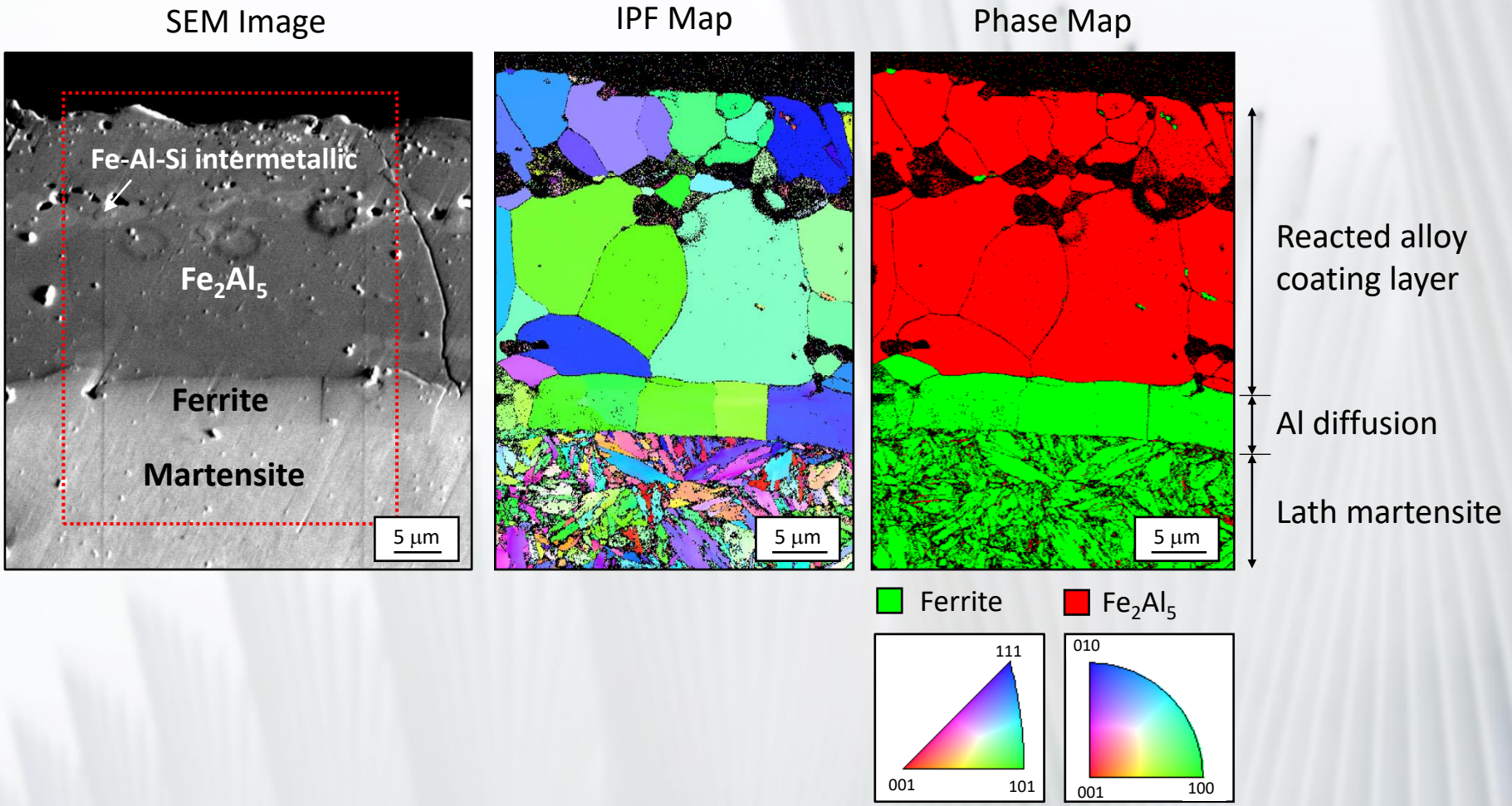


- CA: Continuous Annealing
- HPF: Hot Press Forming
- BH: Bake Hardening

3. Results and Discussion

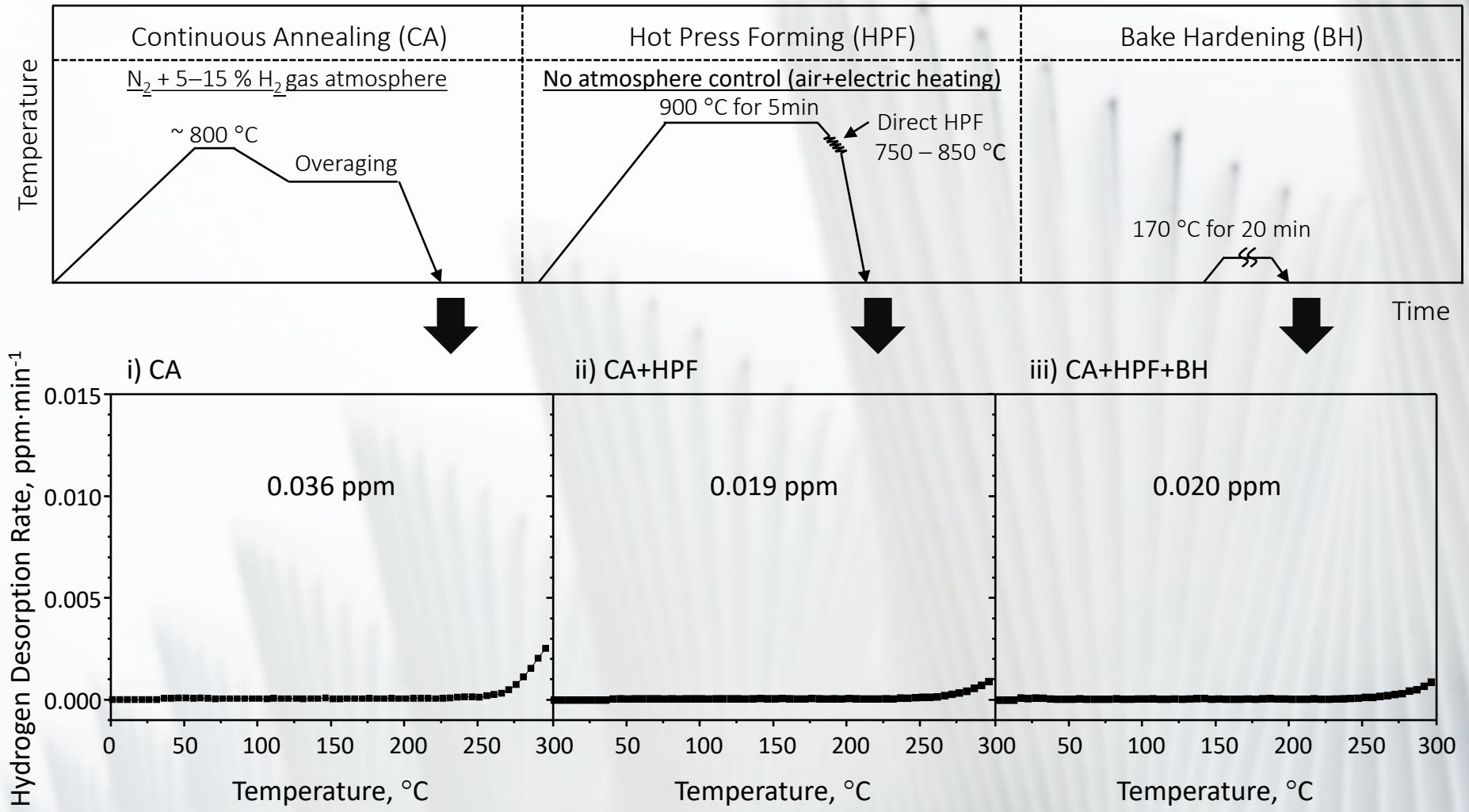
3.2 Coating Microstructure of the Aluminized Press Hardening Steel

* After hot press forming (HPF) of the aluminized press hardening steel



3. Results and Discussion

3.3 Hydrogen Thermal Desorption Analysis (Uncoated PHS)



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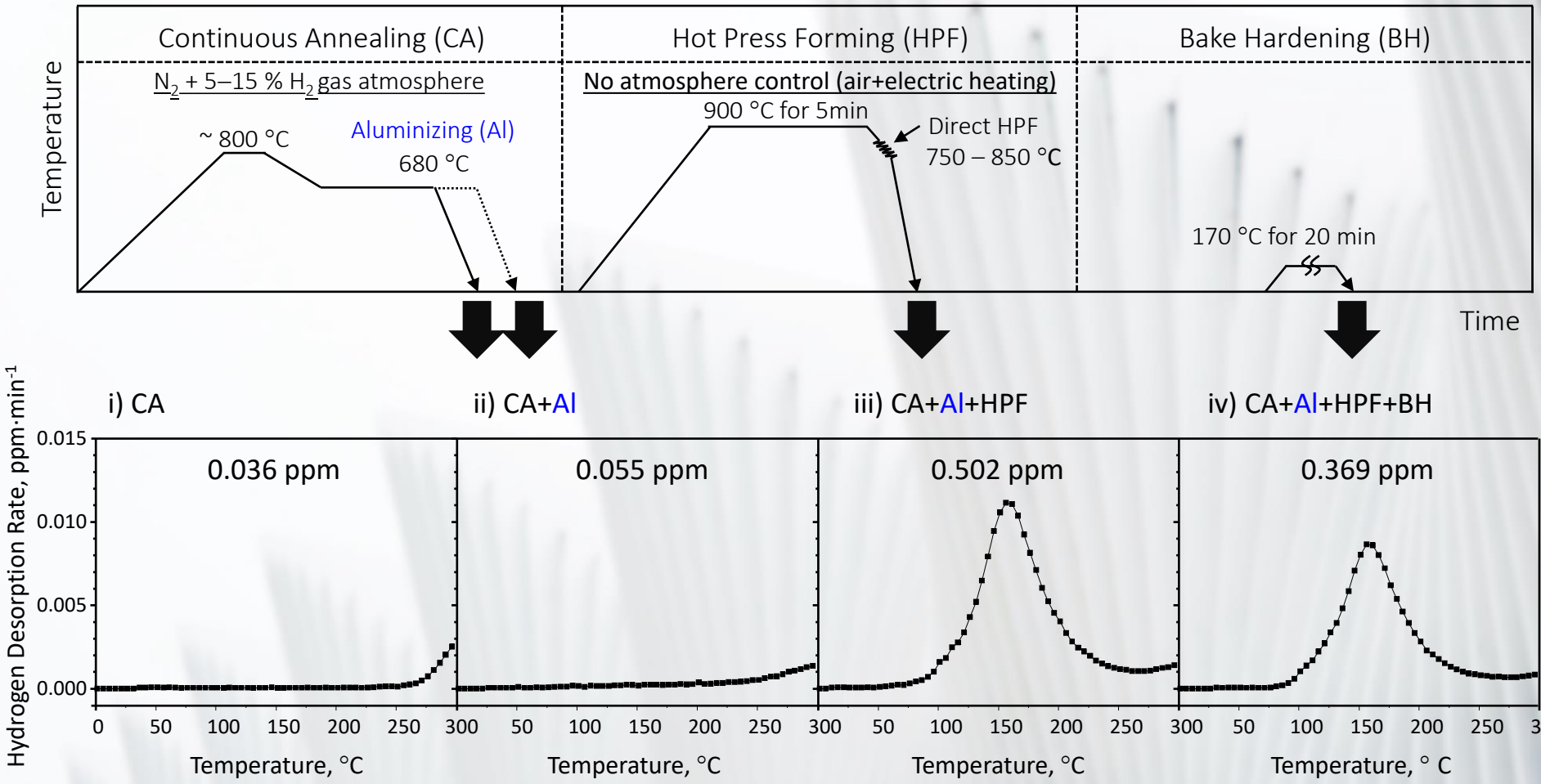

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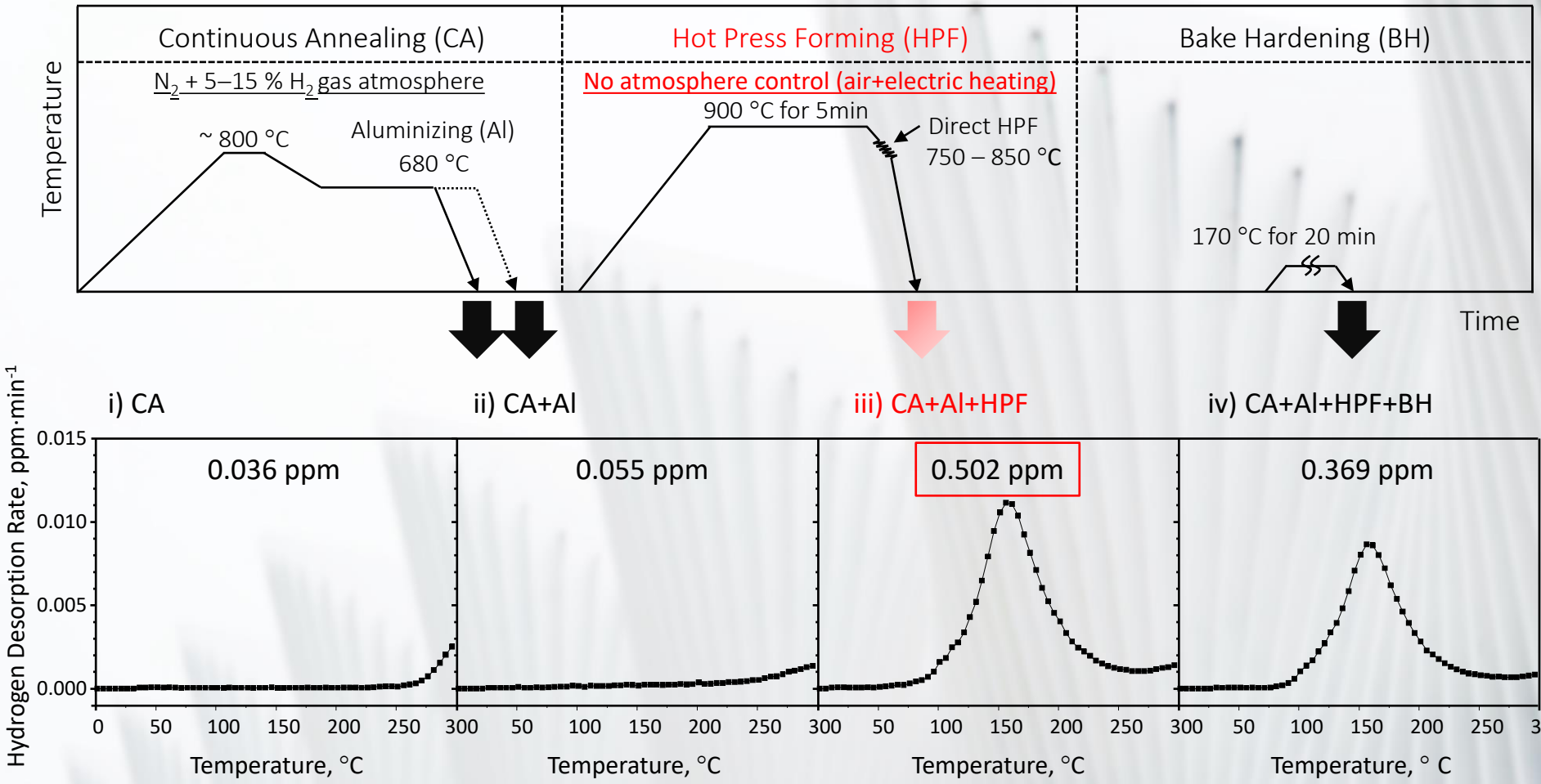

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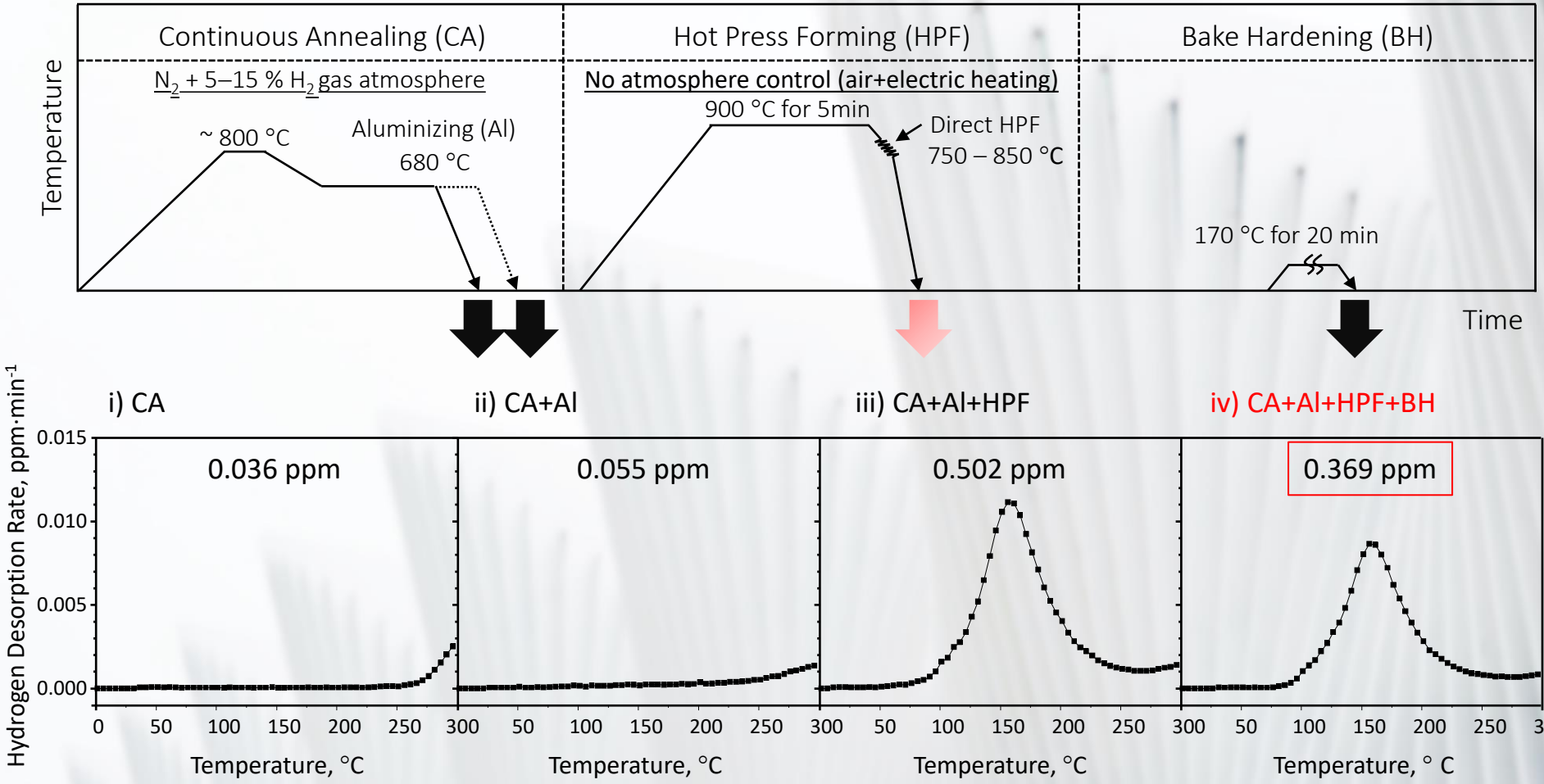
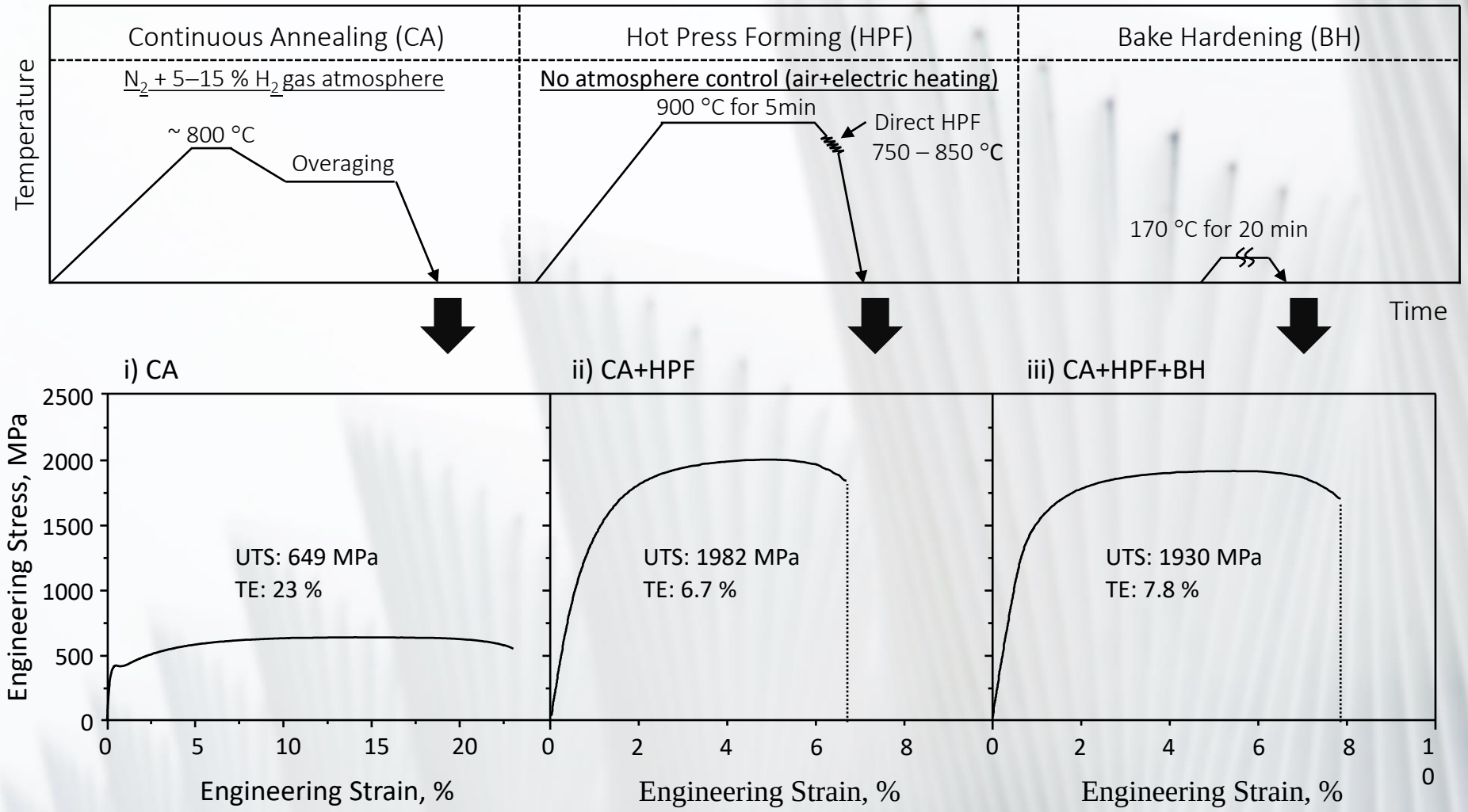


3. Results and Discussion

3.4 Tensile Properties of Uncoated Press Hardening Steel



3. Results and Discussion

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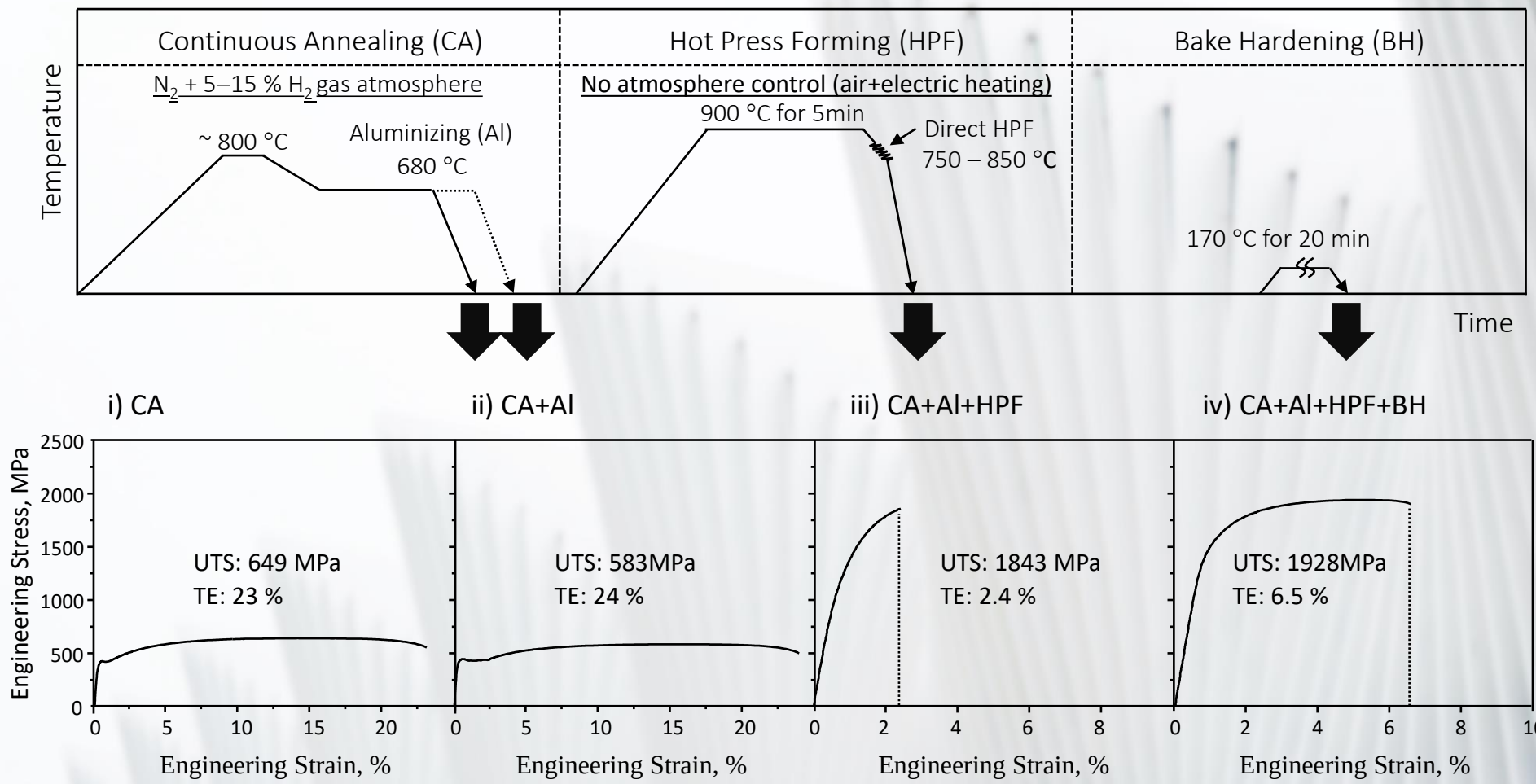

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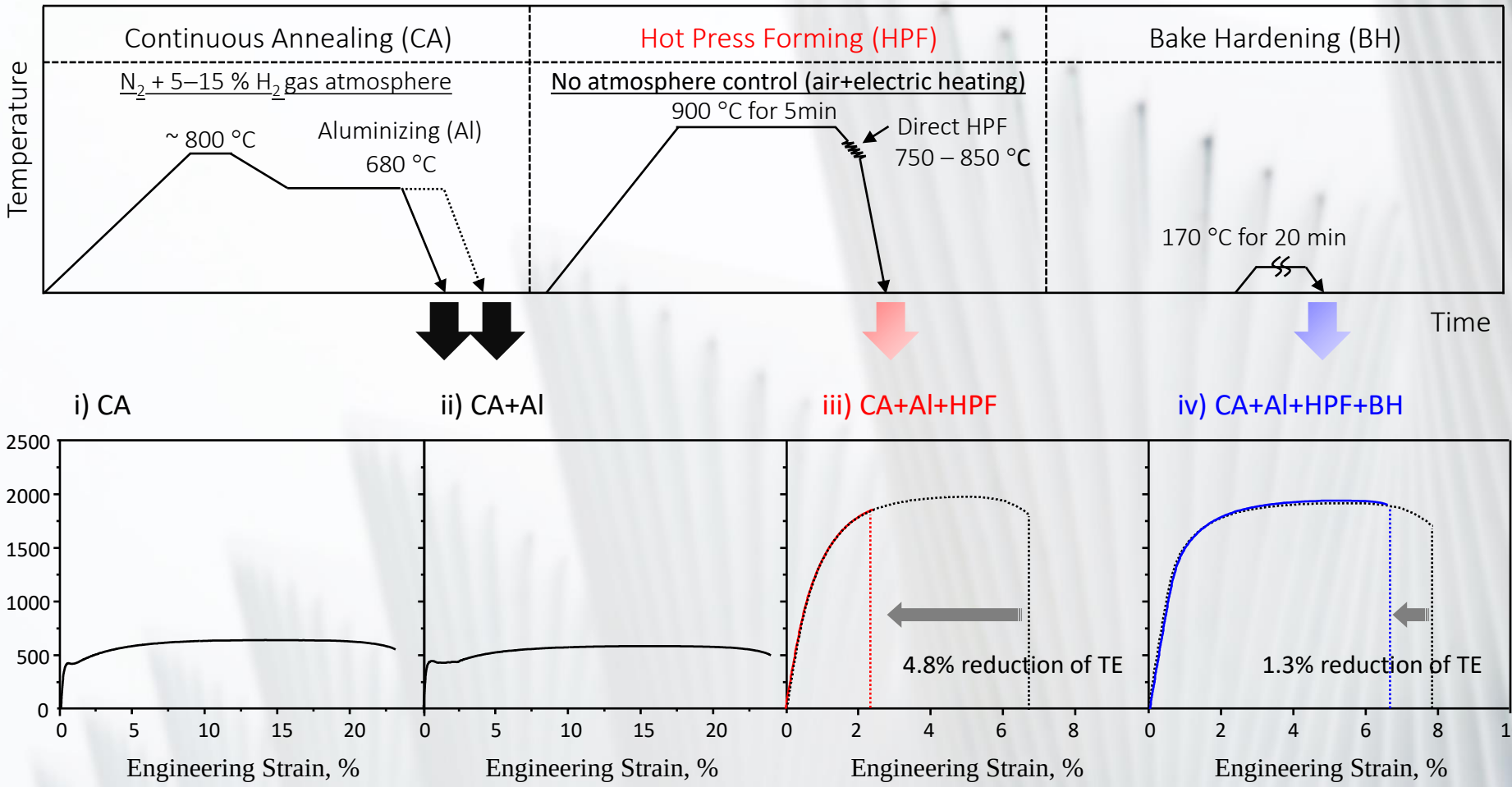

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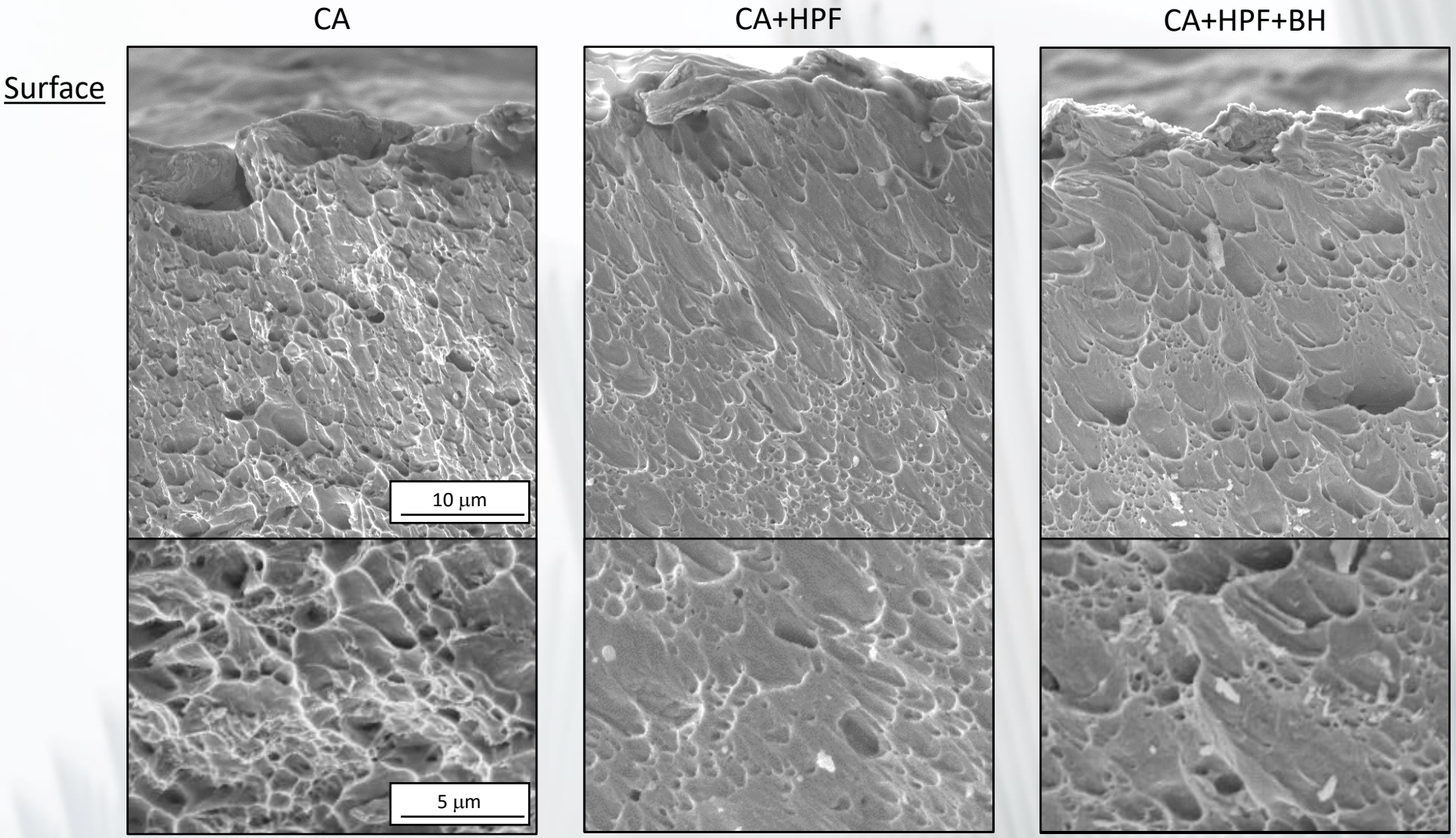
- HPF: Hot Press Forming
- BH: Bake Hardening

3.5 Fracture Surface of Uncoated Press Hardening Steel



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- Al: Aluminizing
- HPF: Hot Press Forming
- BH: Bake Hardening

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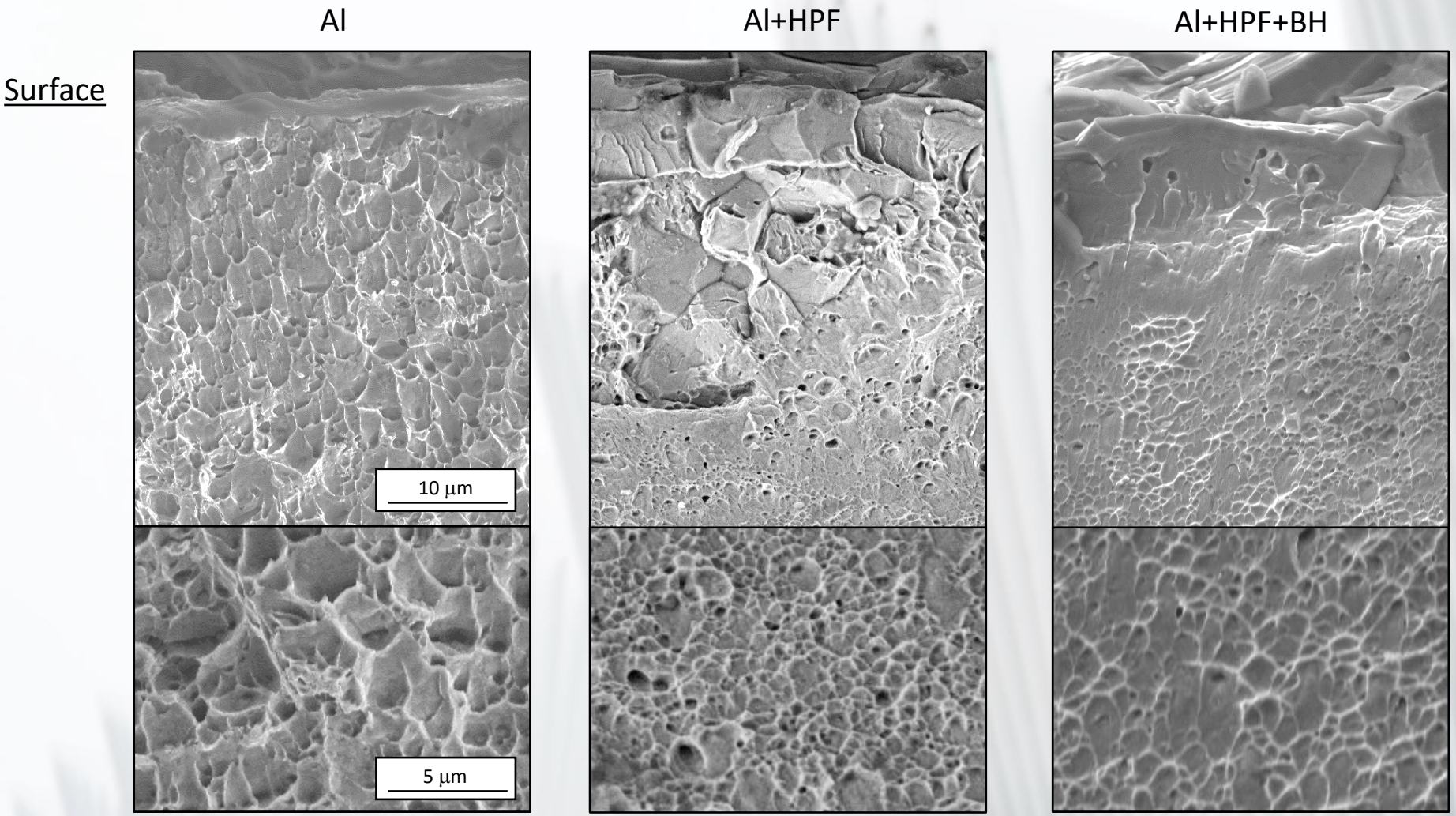

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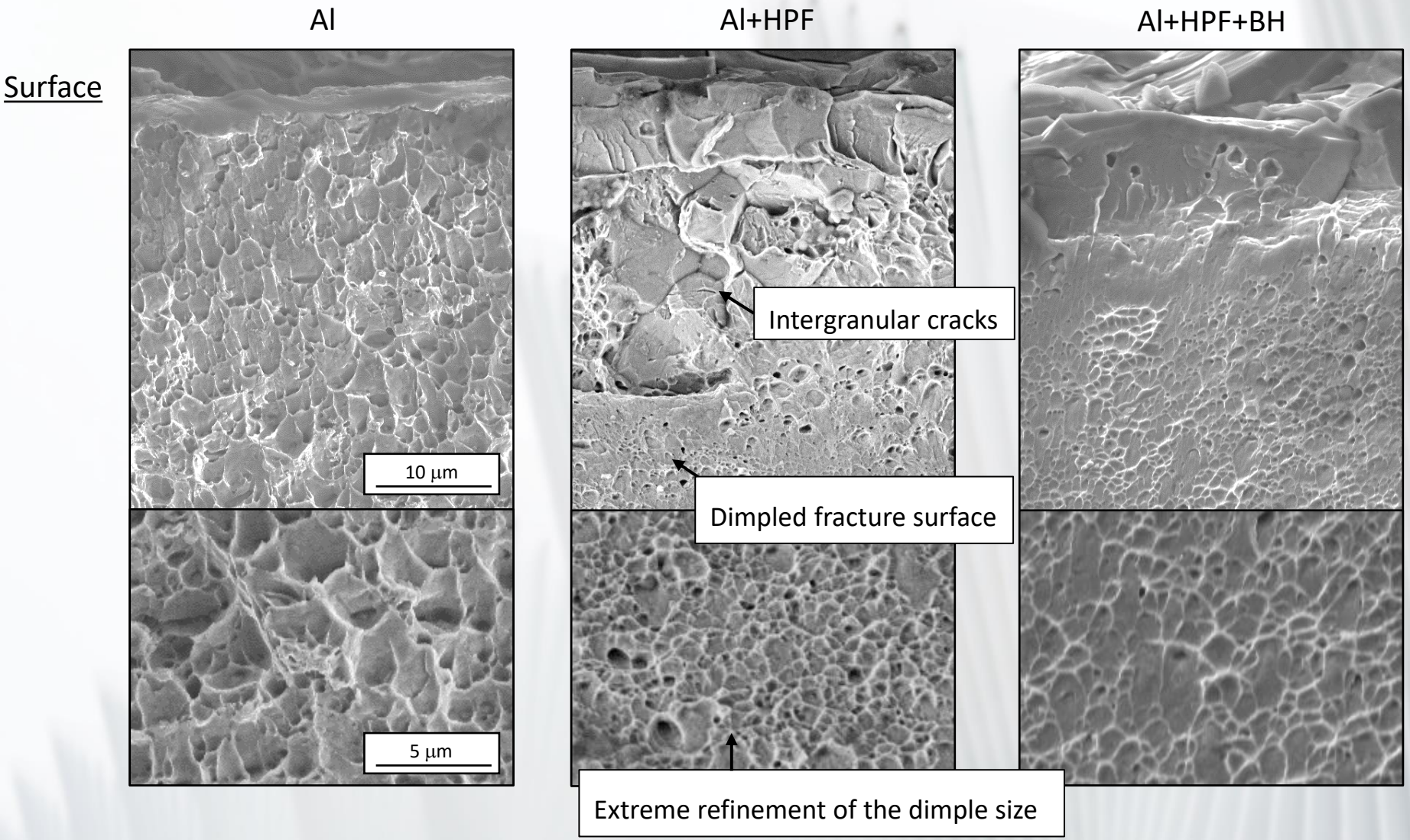
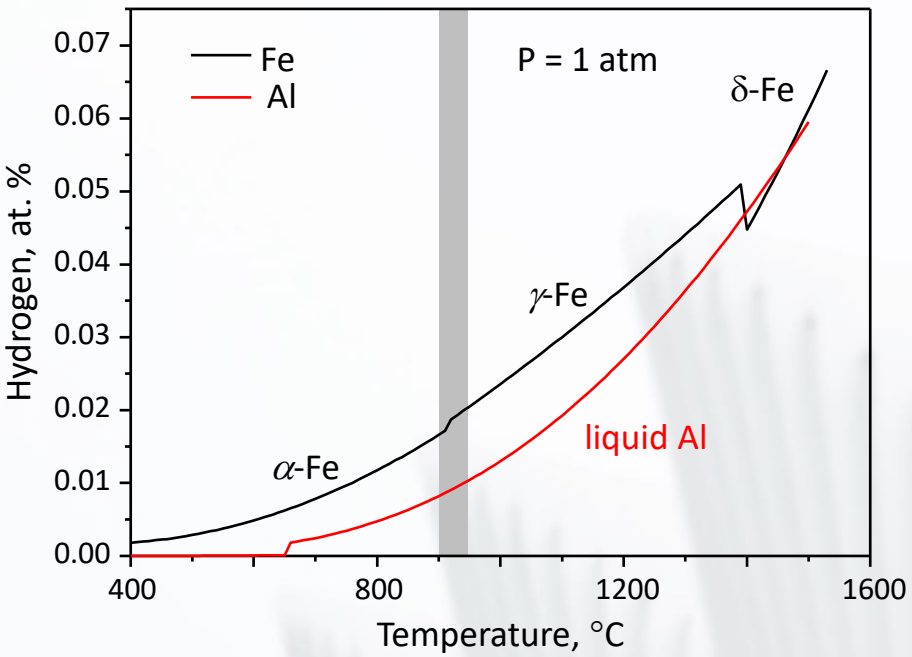


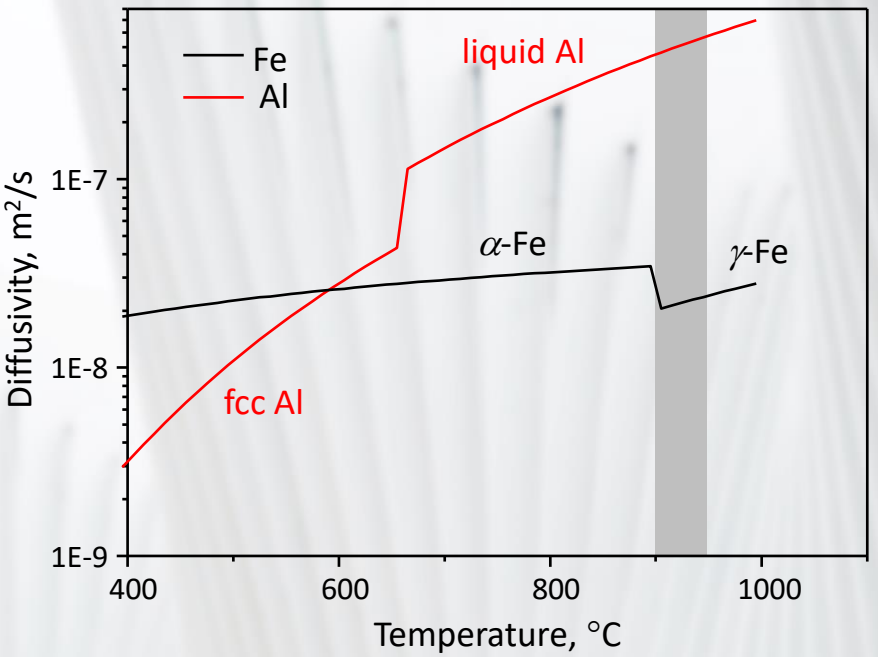
3. Results and Discussion

3.6 Hydrogen Absorption Mechanism

* Solubility of hydrogen in Fe and Al



* Diffusivity of hydrogen in Fe and Al



- At elevated temperature, H is significantly soluble in liquid Al
- H is more soluble in γ-Fe (austenite) as compared to liquid Al
- H diffuses very rapidly in liquid Al.
- The solubility and diffusivity of H is low in solid Al.

3. Results and Discussion

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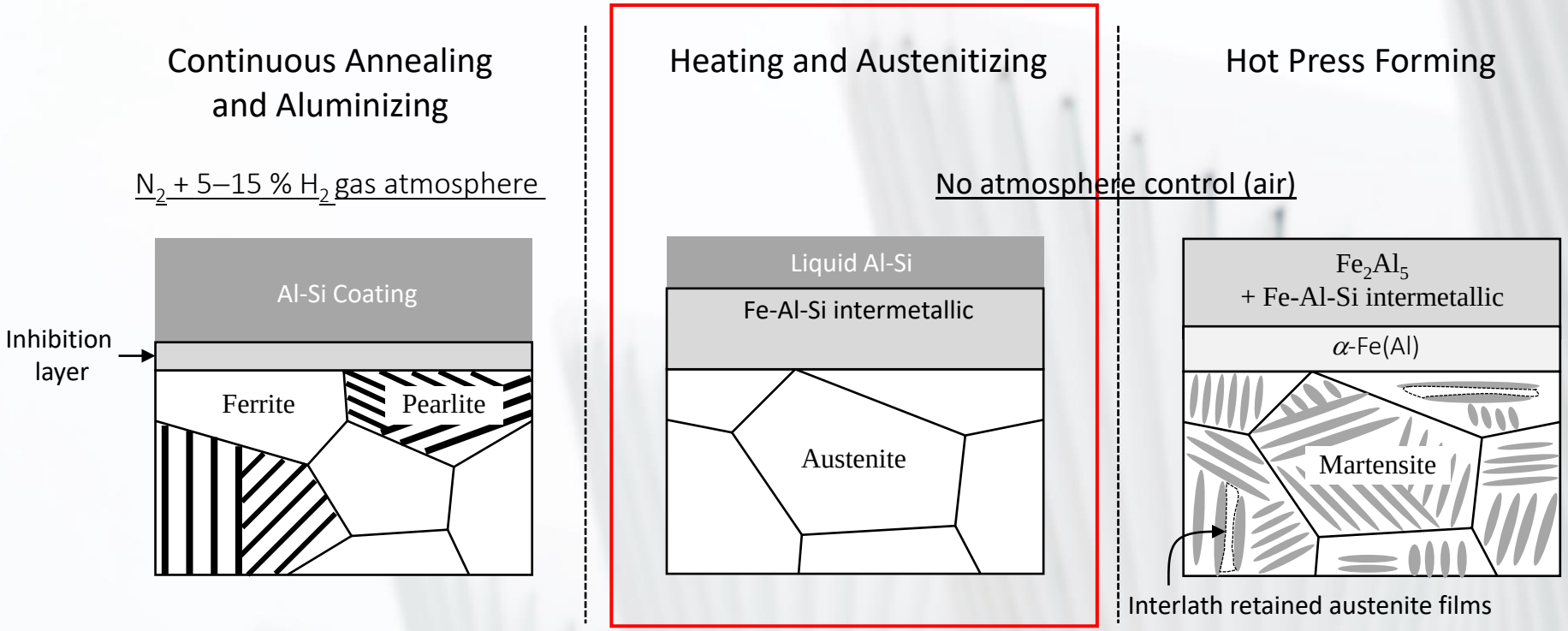

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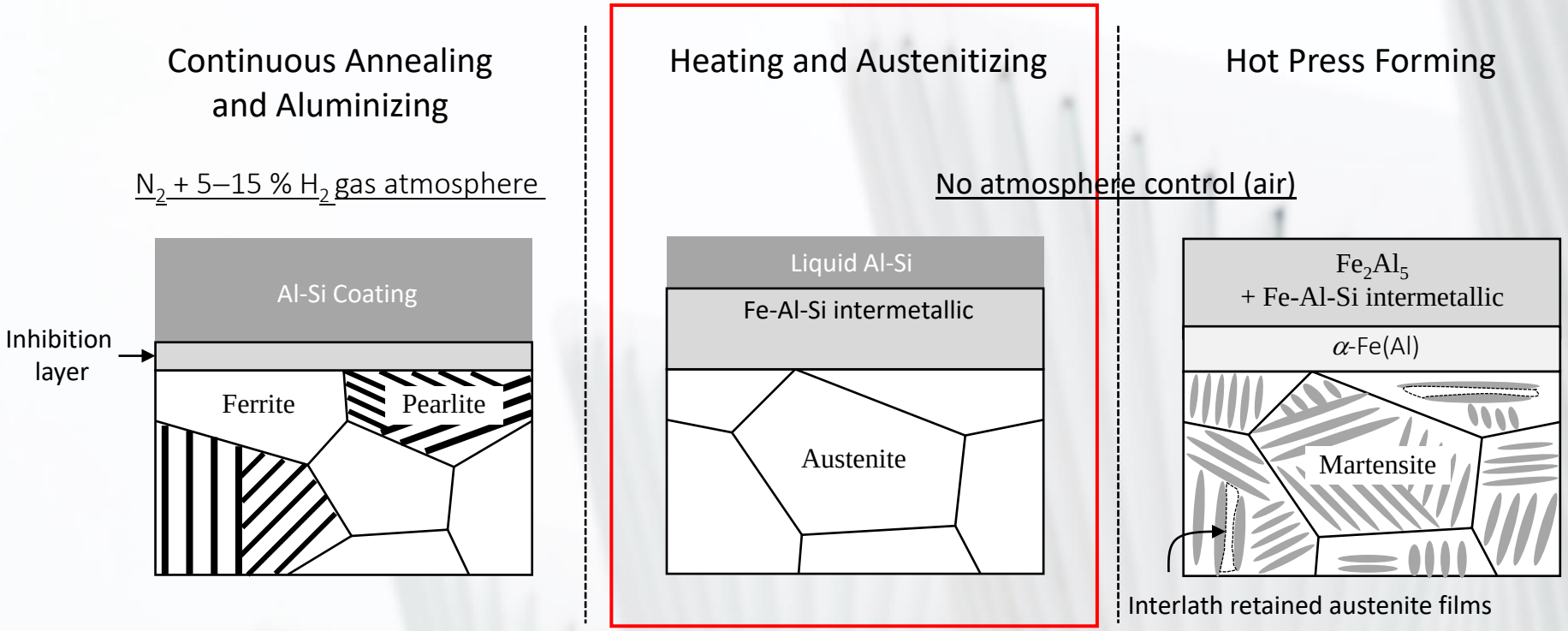


- Hydrogen is produced by the dissociation of the water vapor molecules.

- *With increasing dew point of the furnace gas atmosphere,
more diffusible hydrogen can be introduced in the aluminized steel during the austenitizing.

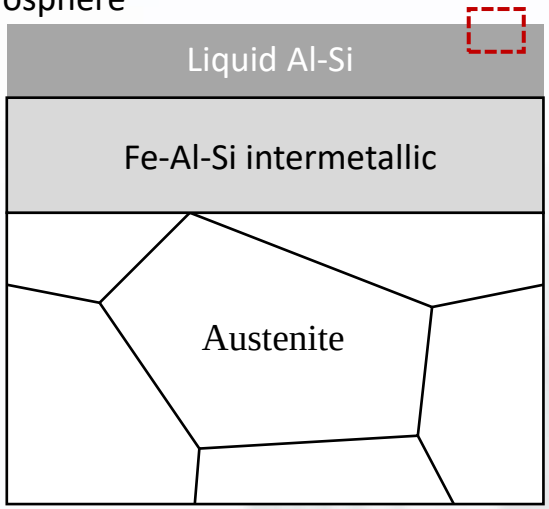
*Georges et al., ISIJ international 53 (2013) 1295-1304.

3. Results and Discussion

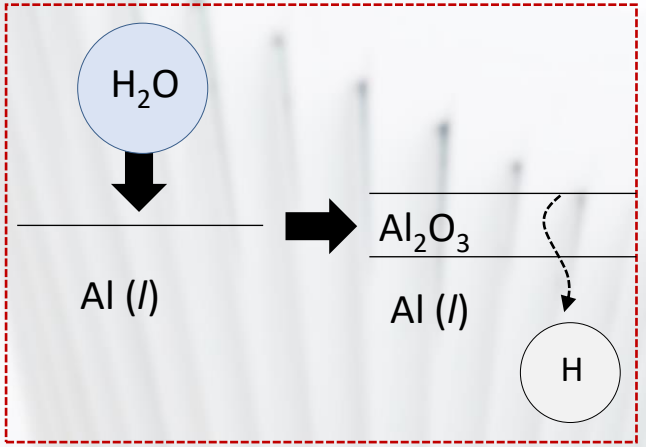
3.6 Hydrogen Absorption Mechanism

* Heating and Austenitizing

Water vapor in the furnace gas atmosphere

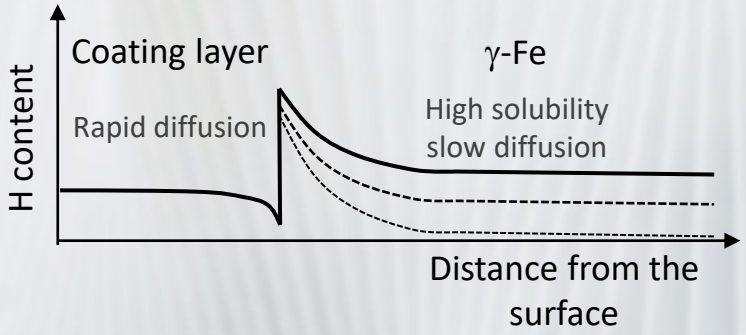


$Al + 3\,H_2O \rightarrow Al_2O_3 + 3\,H_2$



- ✓ H_2O reduction by liquid Al
- ✓ At elevated T: high solubility of H in Al_{liq}
- ✓ Transfer of H from the liquid Al-Si to the γ-Fe

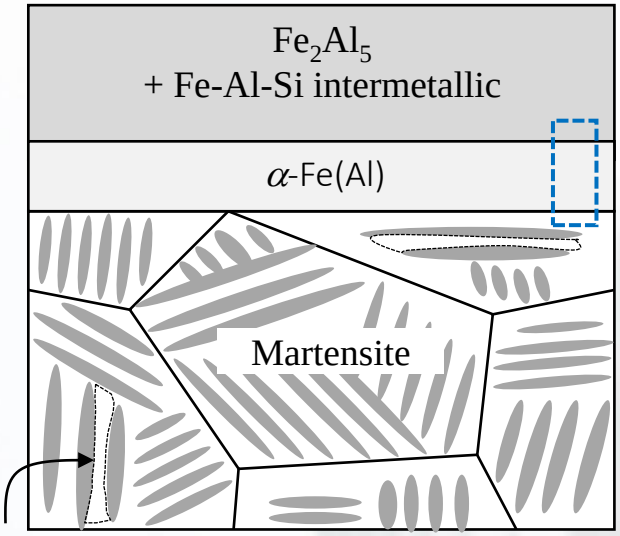
Possible H_2O reduction reactions	T (°C)	ΔG (kJ)
$2\,Al\,(l) + 3\,H_2O\,(g) \rightarrow Al_2O_3\,(s) + 3\,H_2\,(g)$	900	-755.070
$Fe\,(s) + H_2O\,(g) \rightarrow FeO\,(s) + H_2\,(g)$	900	-5.684
$2\,Fe\,(s) + 3\,H_2O\,(g) \rightarrow Fe_2O_3\,(s) + 3\,H_2\,(g)$	900	-8.068
$3\,Fe\,(s) + 4\,H_2O\,(g) \rightarrow Fe_3O_4\,(s) + 4\,H_2\,(g)$	900	-6.905



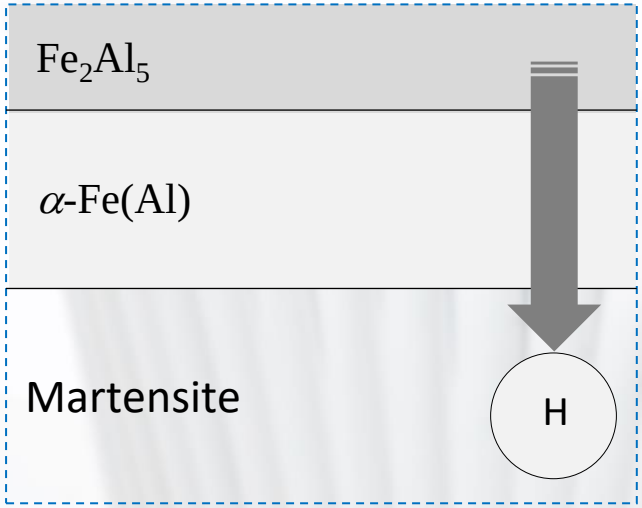
3. Results and Discussion

3.6 Hydrogen Absorption Mechanism

* Hot Press Forming



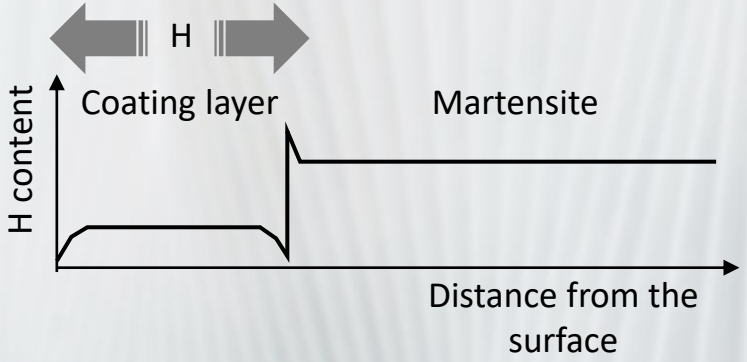
Retained Austenite



At room temperature:

✓Substantially lower H-solubility in solid Al

✓Low diffusivity of H in solid Al



4. Conclusions

1) Approximately 0.50 ppm of diffusible hydrogen is introduced in the aluminized press hardening steel during the hot press forming process, i.e. not during the aluminizing process. The hydrogen uptake is due to the Al reduction of water vapor in furnace atmosphere.

2) The diffusible hydrogen is trapped in the lath martensite and inhibited from escaping from the martensite matrix by the aluminum coating and this causes hydrogen-induced embrittlement in aluminized press hardening steel at room temperature.

3) The bake hardening process considerably reduces the negative impact of the hydrogen uptake of aluminized press hardening steel by enhancing hydrogen effusion.

Thank you