

Discovery of Multiple Element Alloys (MEAs) for Enhancing the Resistance to Hydrogen Embrittlement

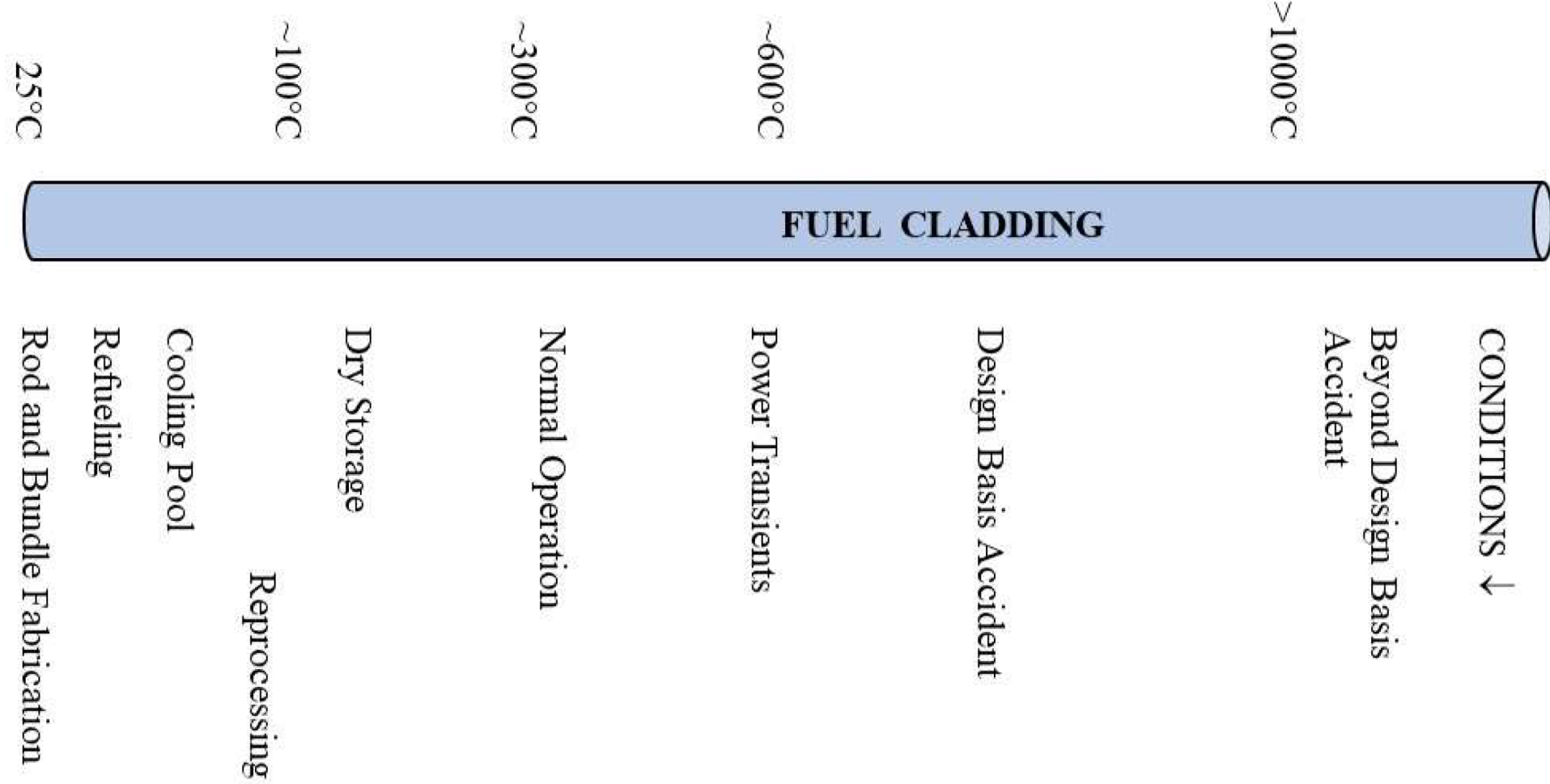
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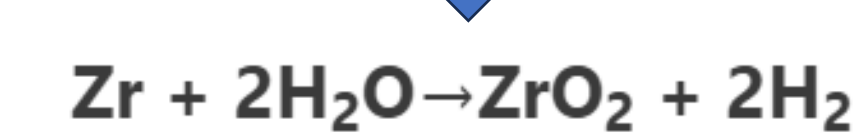
Introduction

Temperature of Nuclear Fuel Cladding:



Issues with Current Cladding Material (Zircaloy):

Above 1000°C Zr can cause exothermic reaction with water generating hydrogen



Goal:

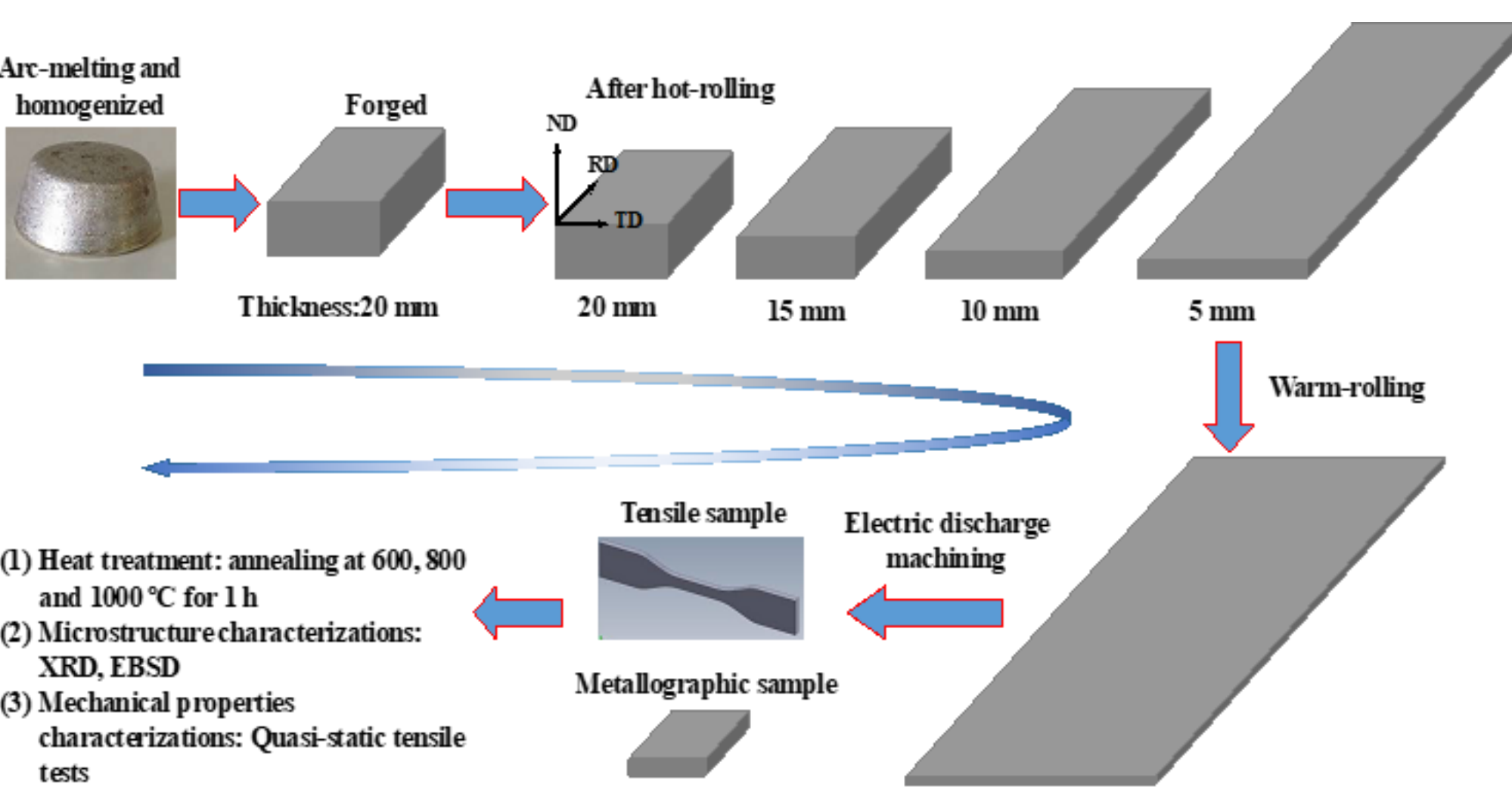
- Understanding the underlying mechanisms that facilitates the design and development of metallic alloys that enhance resistance to Hydrogen Embrittlement (HE)

Materials & Methods

C35M Alloy Composition

Alloy designation	Nominal composition, wt. %
C35M	Fe-13Cr-5Al-2Mo-0.2Si-0.05Y

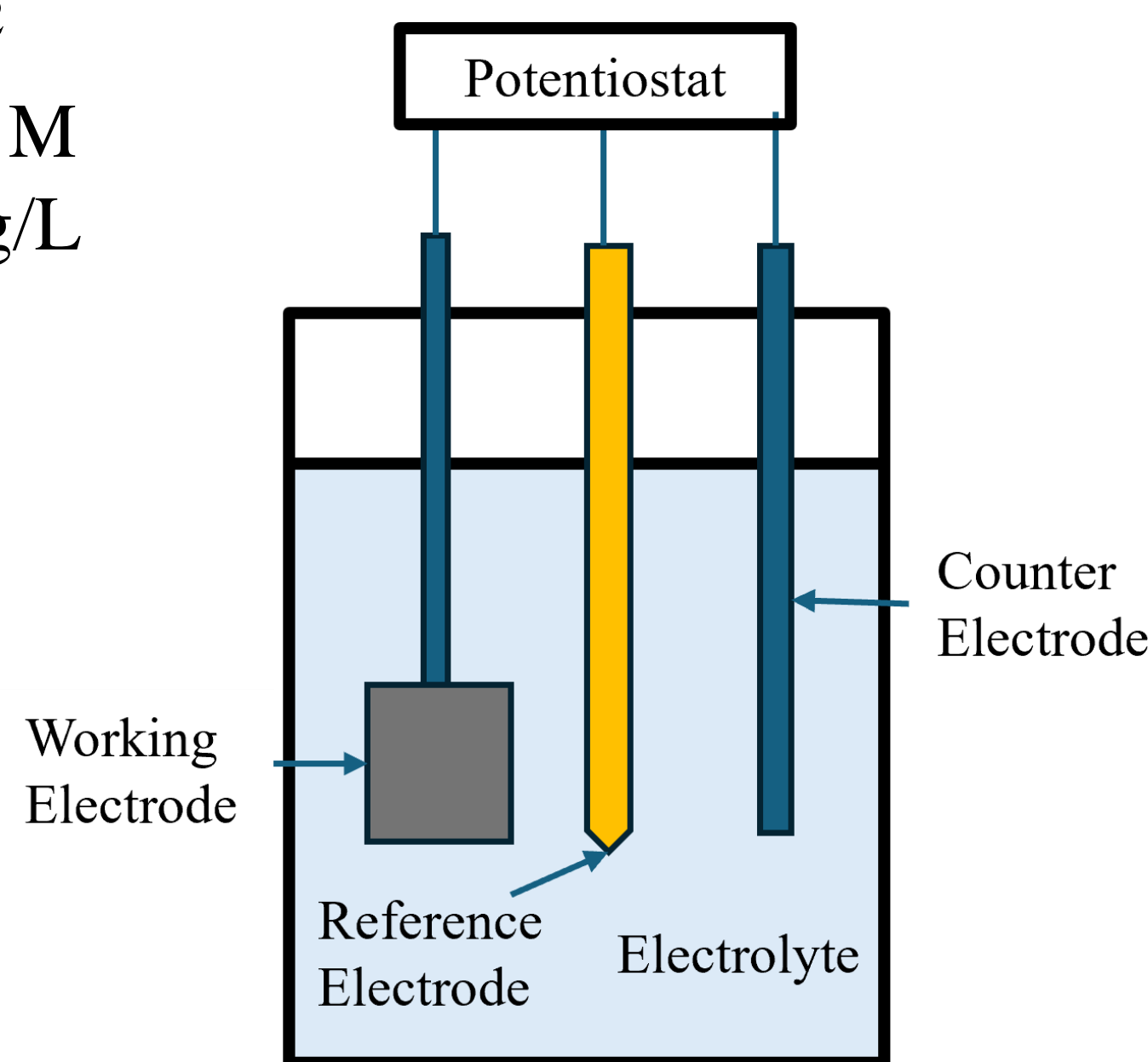
C35M Alloy Preparation



Materials & Method

Cathodic Hydrogen Charging condition

- Concentration measurement Sample were charged for 2 hours at 50 mA/cm²
- Mechanical Tests samples were charged for 4 hours at 10 mA/cm²
- Solution: 0.5 M H₂SO₄+0.25g/L As₂O₃



Concentration measurement

In 0.2M NaOH and a constant potential of -0.45 V_{SCE} was applied on the charged samples for 10 000 s [1].

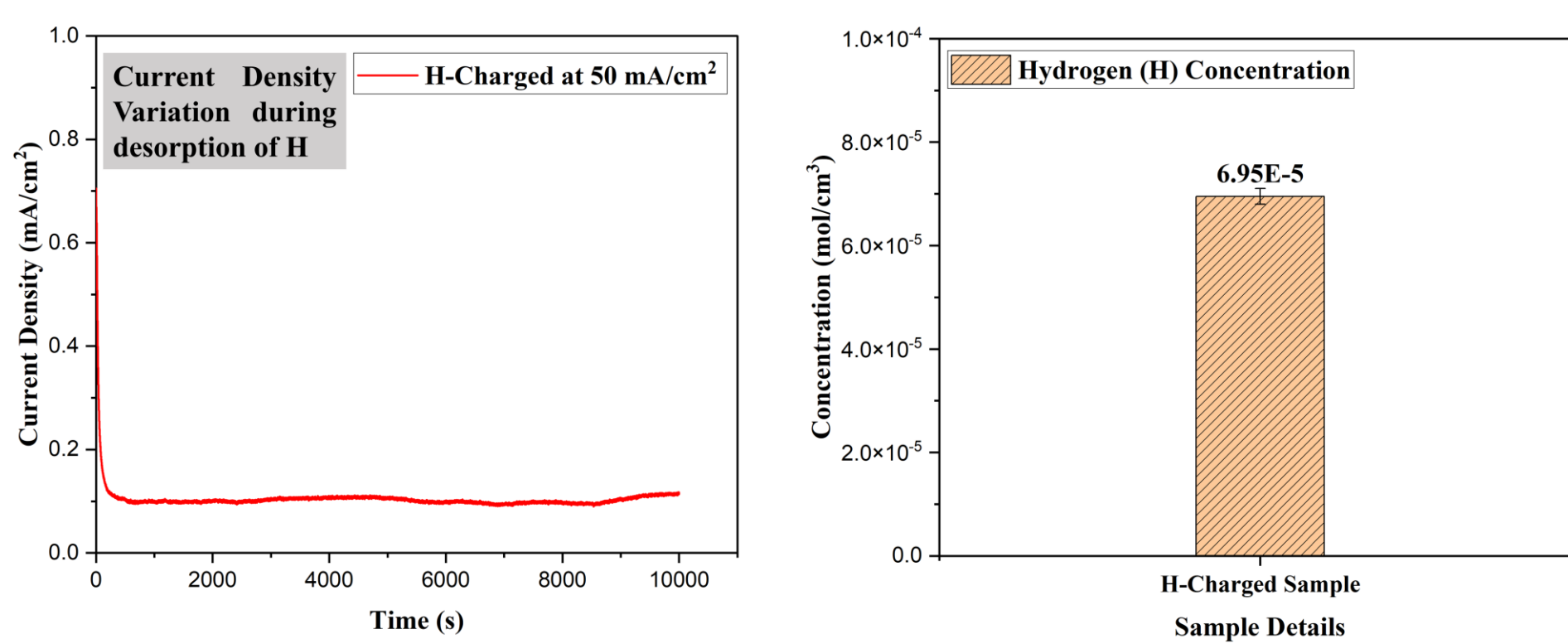
Concentration Measurement Formula:

$$C_H = \frac{Q}{zFw} = \frac{\int_0^\infty i_a dt}{zFw}$$

Q = Total Charge
 F = Faraday's Constant
 z = transferred electron per atom
 w = Thickness of the Sample
 i_a = Current Density

Results & Discussion

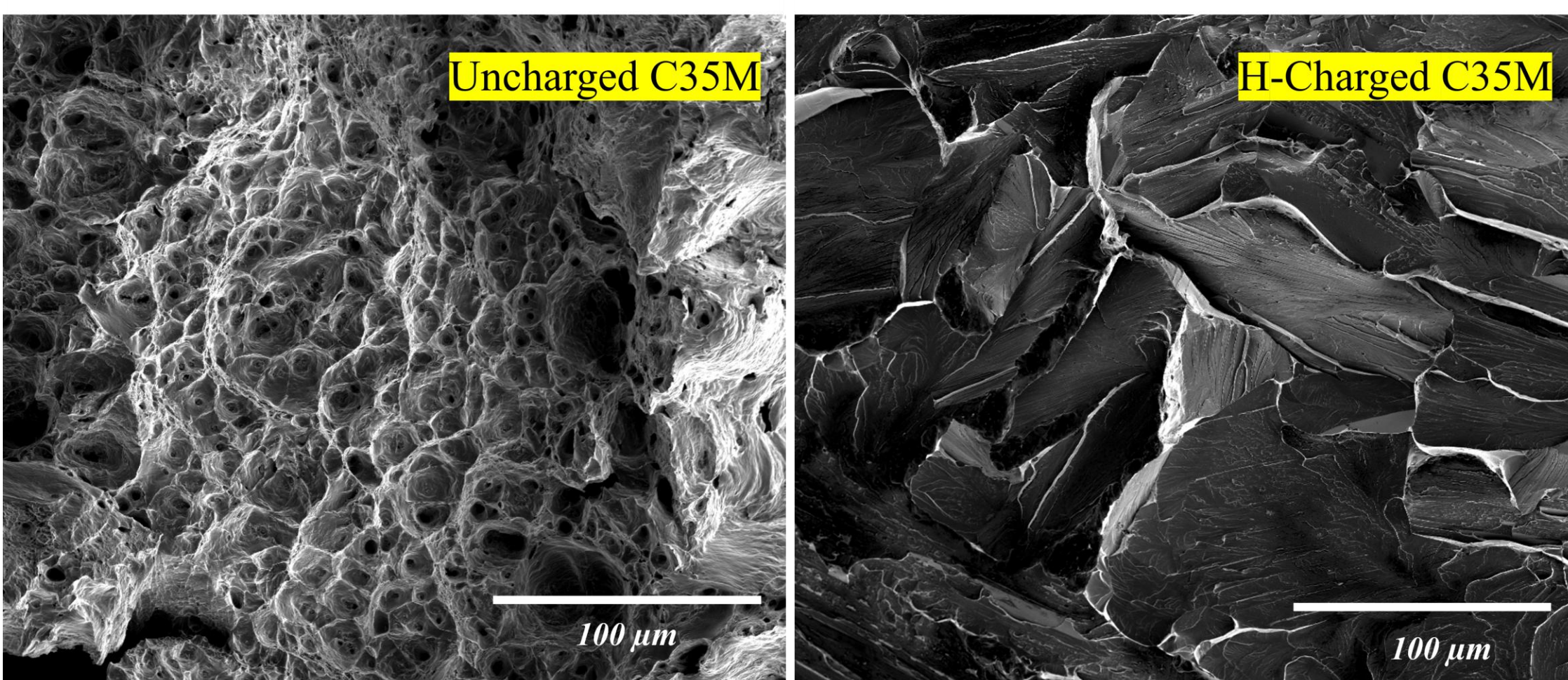
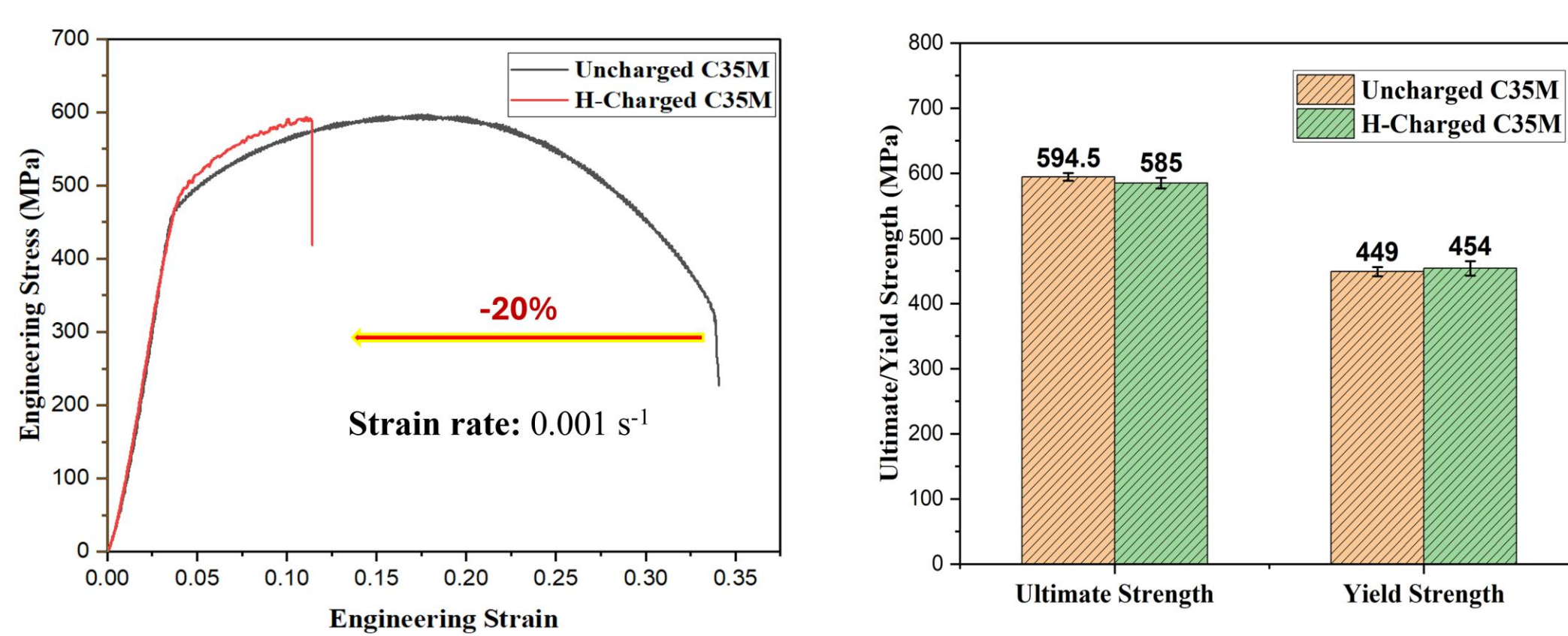
H-Concentration Measurement:



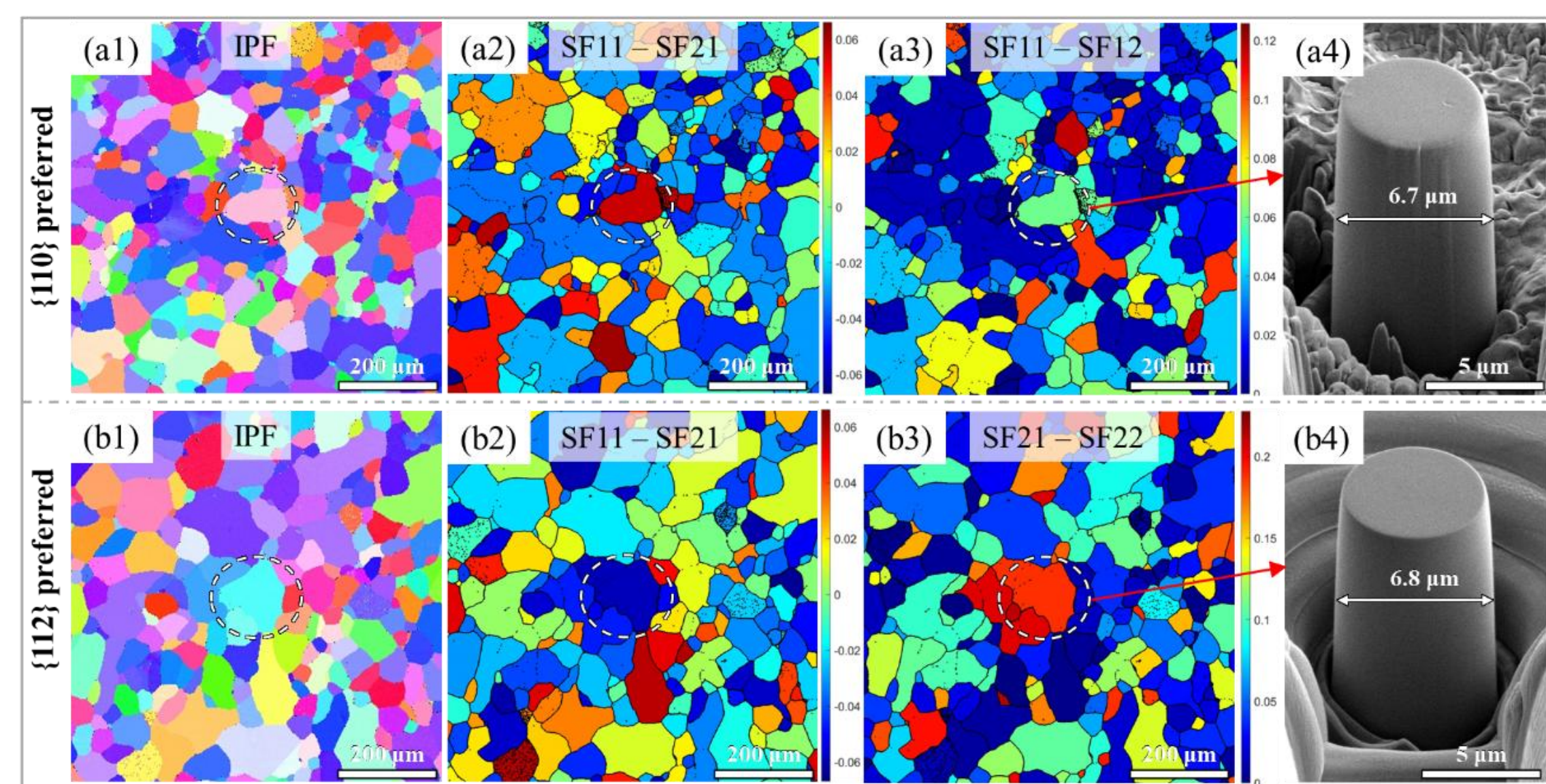
Tensile Test & Fracture Surface of Macro Samples:

- Significant reduction of Strain due to hydrogen-charging.
- H-charging changes failure mechanism from ductile fracture (dimples) to brittle fracture (intergranular fracture along GBs).

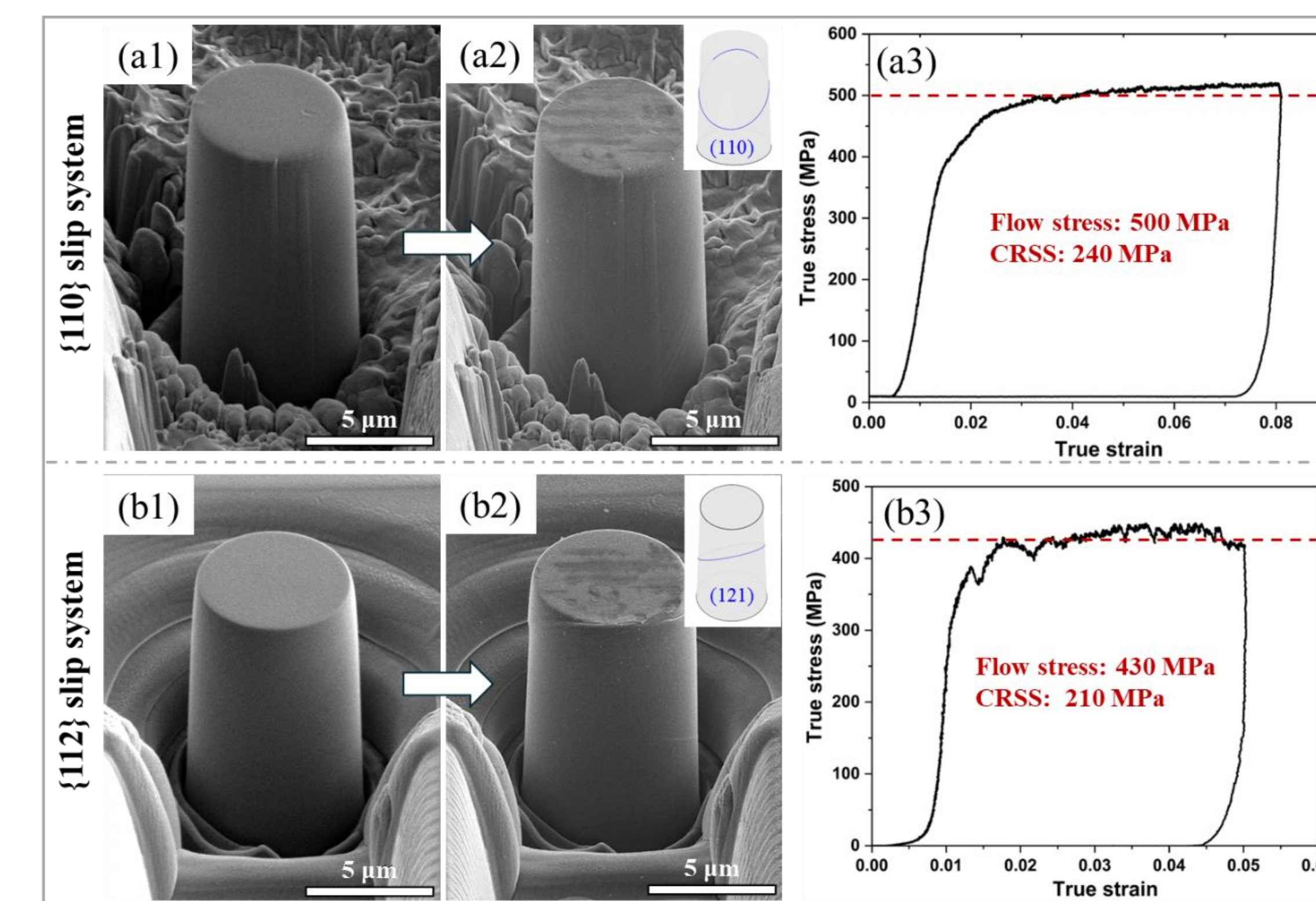
Results & Discussion



EBSD of Uncharged C35M & Micropillar Fabrication:



Micropillar compression test:



Results & Discussion

- The {110} slip system may have a dislocation core that is more prone to hydrogen segregation.

Table 1. Measured CRSS for different slip systems with and without H

CRSS	Without H	With H
{110} slip system	220 MPa	240 MPa
{112} slip system	230 MPa	210 MPa

Future Research Plan

- In our following study, Density Functional Theory (DFT) calculations will be performed to reveal the underlying mechanism

Acknowledgement

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References

- J. Yao, D.D. Macdonald, M. Macdonald, F. Cao, C. Dong, *Materials & Corrosion* **2019**, 70, 838.
- B. Wei, D. Xie, W. Wu, L. Shao, J. Wang, *JOM* **2022**, 74, 4035.