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Effect Of Grain Boundary Character On Chloride-induced Transgranular Stress Corrosion Cracking Propagation In An Austenitic Stainless Steel

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Objective

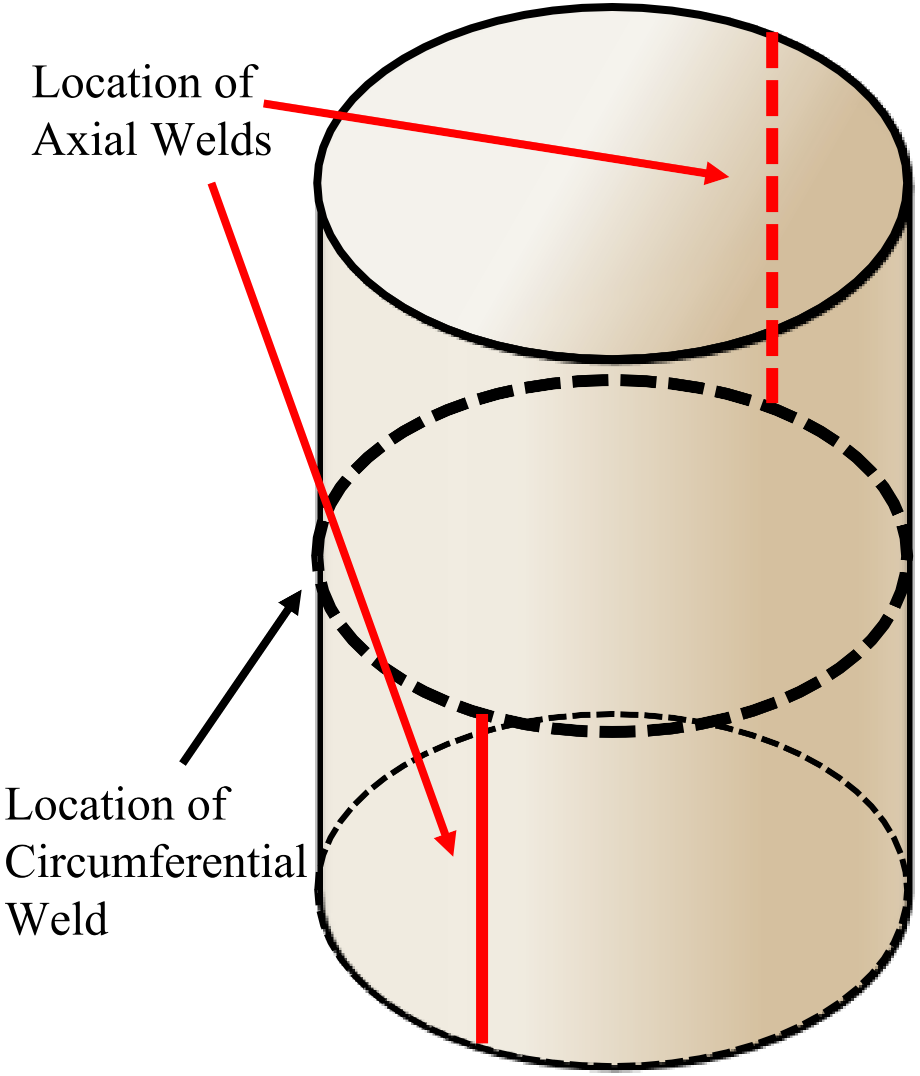
To investigate how GBs affect the propagation behavior of chloride-induced stress corrosion cracking (CISCC) growth of arc welded austenitic stainless steels (AuSS).

Outline

- Background
- Materials and Experimental
- Results and Discussion
  - Schmid factor, Taylor factor and GB type analysis of individual cracks
  - Statistical analysis of GB type effect
  - Mismatch of Schmid and Taylor factor across various grain pairs
  - Microstructural analysis of crack tip – GB interaction via TKD & STEM
- Future Works

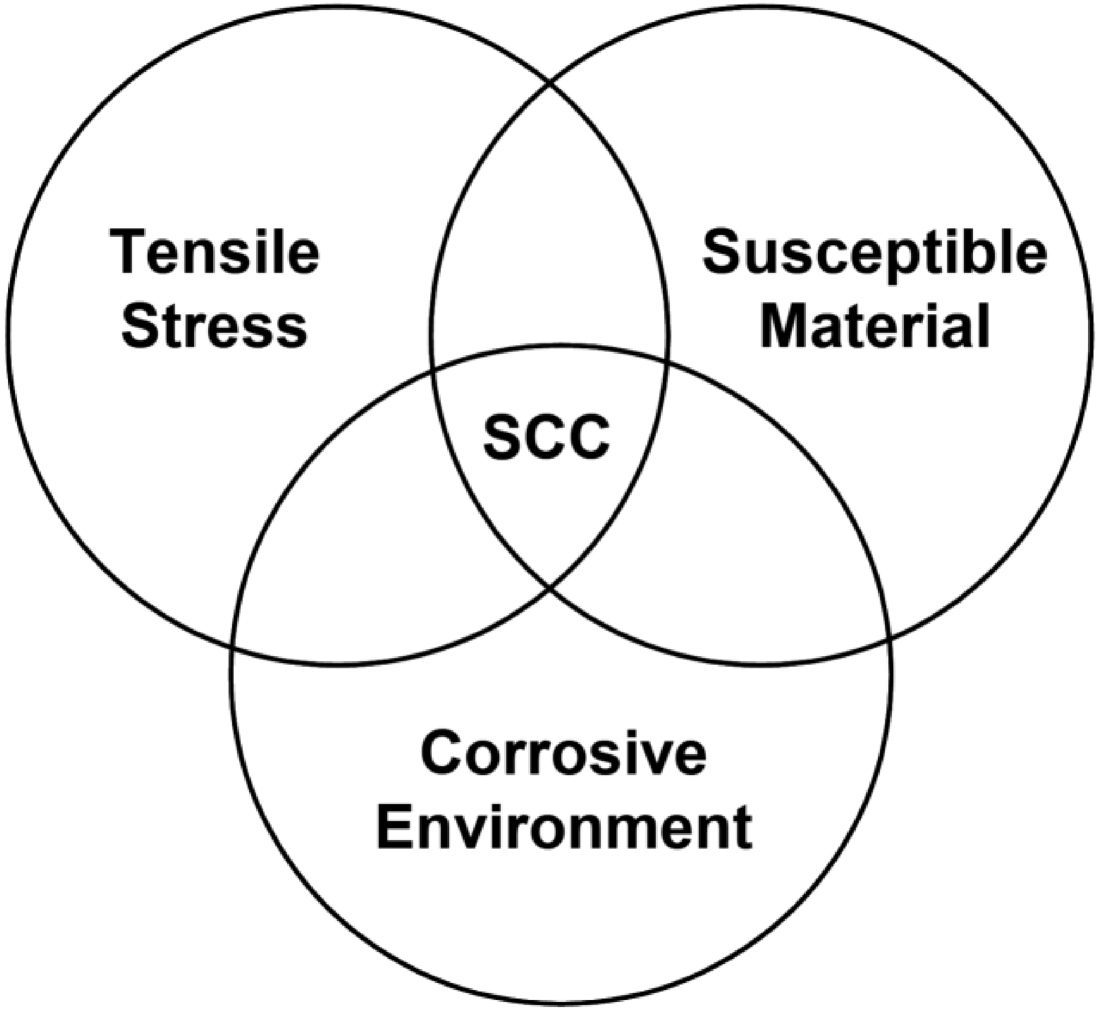
Background - SNF Canister Challenges

- Over 3,300 dry canisters are now used to store spent nuclear fuel
- Initial NRC license is 40 years, with renew possibility for another 40 years.
  - Difficult to inspect
  - Difficult to repair
- SS304L and weldment are susceptible to chloride-induced stress corrosion cracking (CISCC)



Background - SCC Conditions

Interdependence of various conditions for SCC



$$\sigma = \frac{\tau}{m}$$

$$m = cos\phi \cdot cos\lambda$$

Schmid Factor (m)

$$\sigma_x d\epsilon_x = \tau d\gamma$$

$$M = \frac{d\gamma}{d\epsilon_x} = \frac{\sigma_x}{\tau}$$

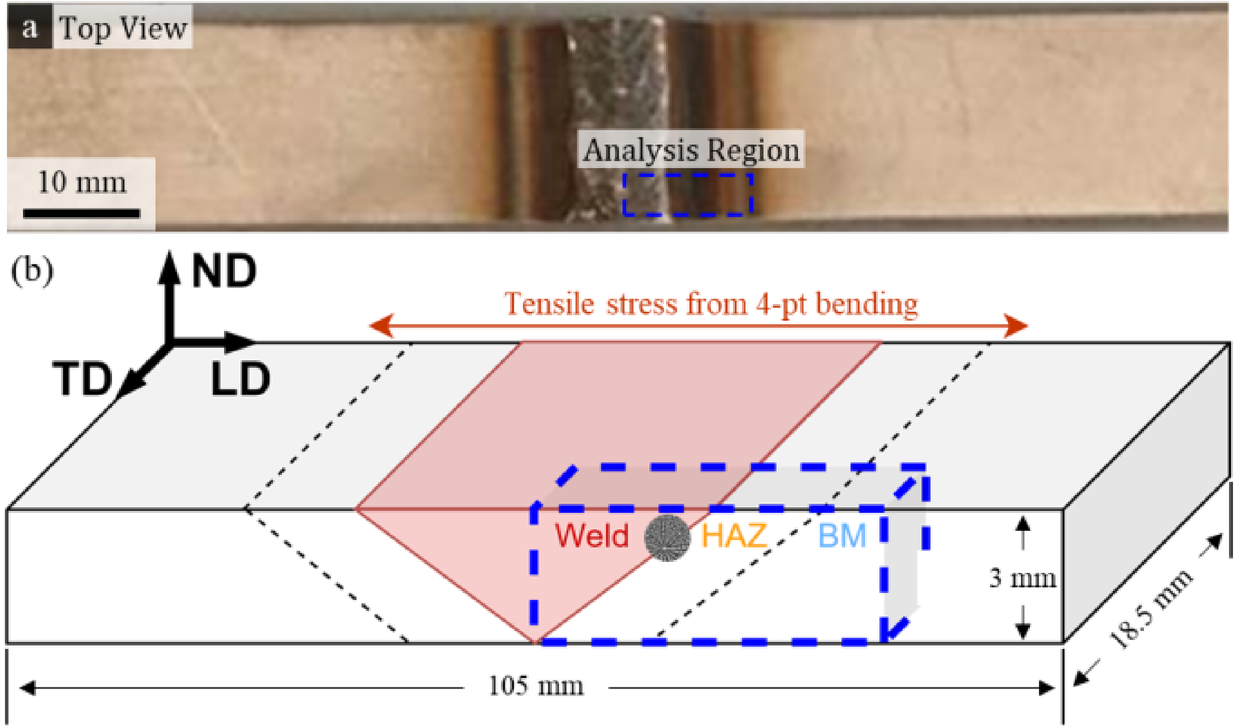
Taylor Factor (M)

R.H. Jones, "Stress-Corrosion Cracking," ASM International, 1992.

Experimental – Sample Material

Material	Alloying wt.% balance Fe										Yield Strength (MPa)	Tensile Strength (MPa)	Elongation %
	C	Si	Cr	P	S	N	Mn	Ni	Mo	Cu			
S30403	0.027	0.35	18.11	0.023	0.004	0.056	1.31	8.02	–	–	273	699	64
S30880	0.014	0.47	19.88	0.021	0.002	–	1.83	9.66	0.01	0.10	–	580	29

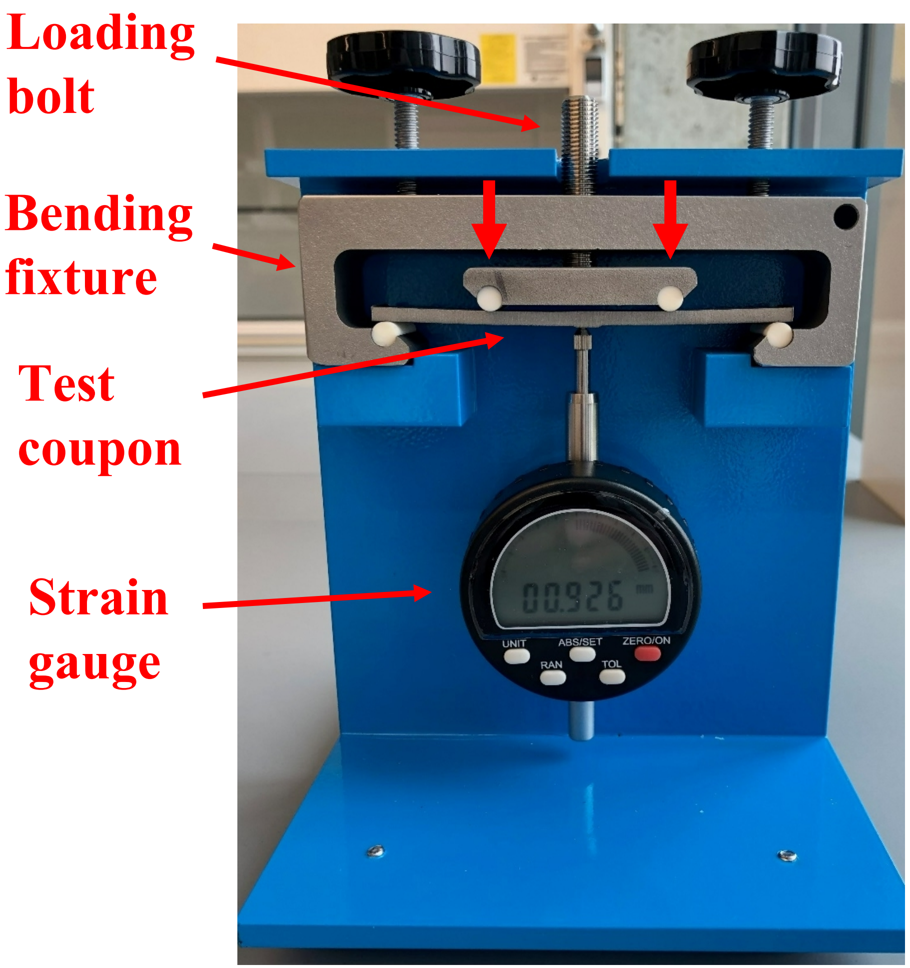
- Stainless steel 304L base with 30 -degree bevel
- Tungsten inert gas (TIG) welding with stainless steel 308L filler



Experimental – Corrosion Test and Analysis

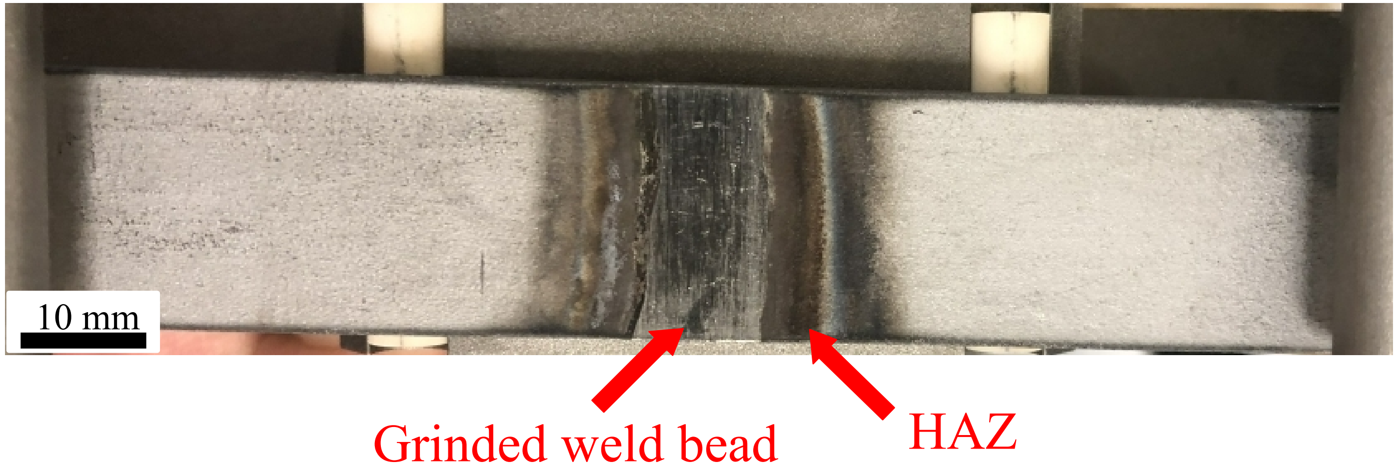
4-point bending test was applied to induce tensile stress

- ASTM G-39: 4-point Bending Test
  - 380 MPa maximum tensile stress
- ASTM G-36: Boiling $MgCl_2$ Corrosion Test at Sandia National Laboratories
  - 54.3 wt% $MgCl_2$ solution at 155.0 ± 1.0 °C
- Post-mortem Analysis
  - EBSD: FEI Quanta 650 SEM + EDAX OIM
  - TKD: Tescan MIRA3 GMH SEM + Oxford
  - (S)TEM: Thermo Talos F200X FEG-STEM

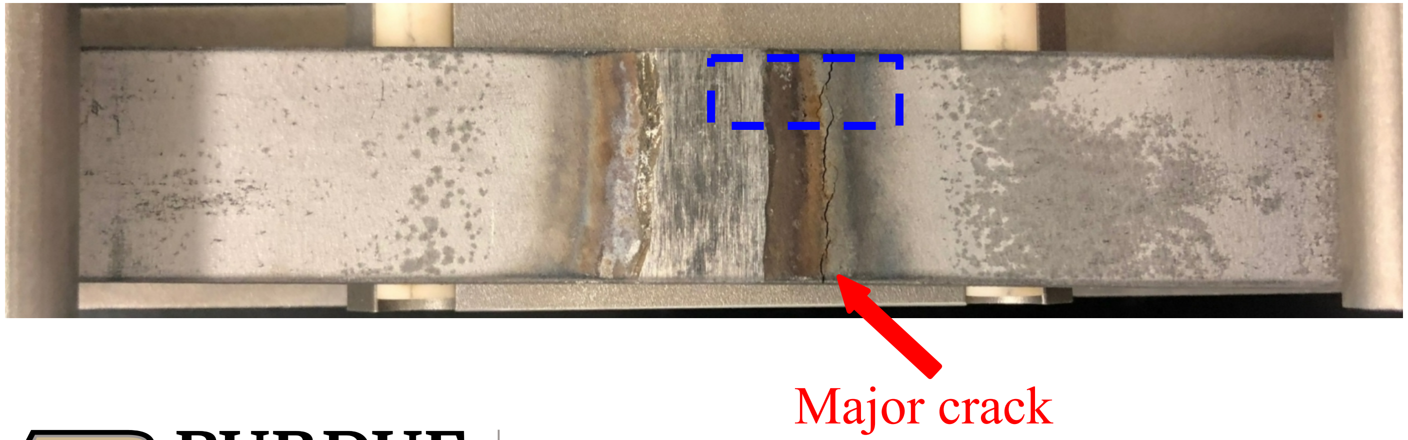


Results – Post-corrosion Sample

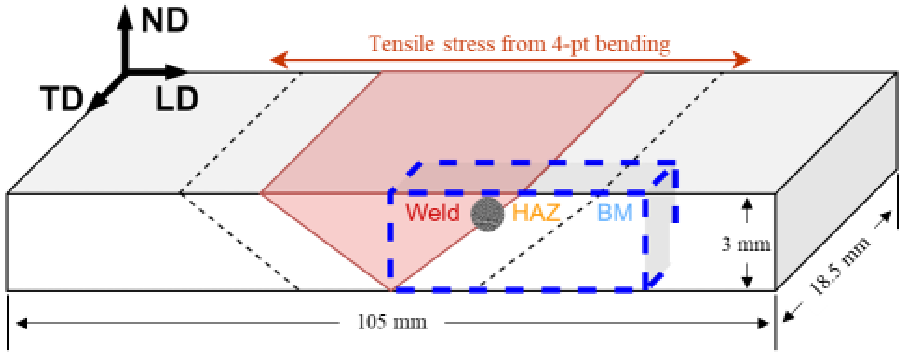
As-bent sample before corrosion



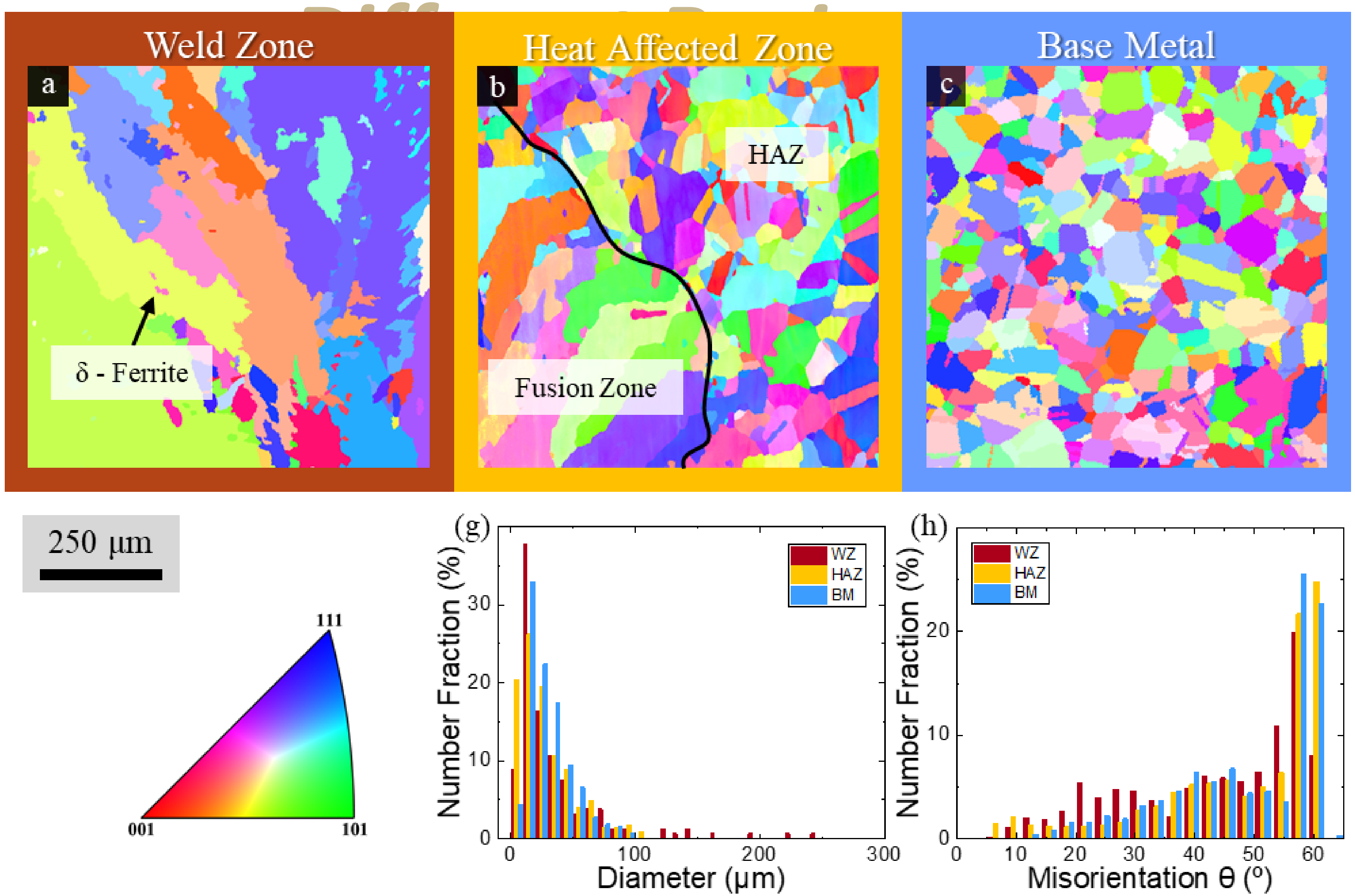
Result after 17 hours of corrosion



- Major crack appears in HAZ after 17 hours boiling
- Cross section including the major crack is further analyzed



Results – EBSD Mappings of



- HAZ is more susceptible to SCC.
- Most cracks are transgranular.
- 338 grains on crack paths are analyzed in detail.

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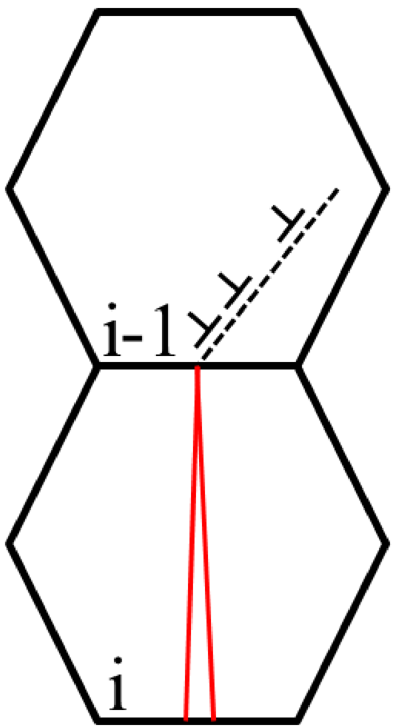
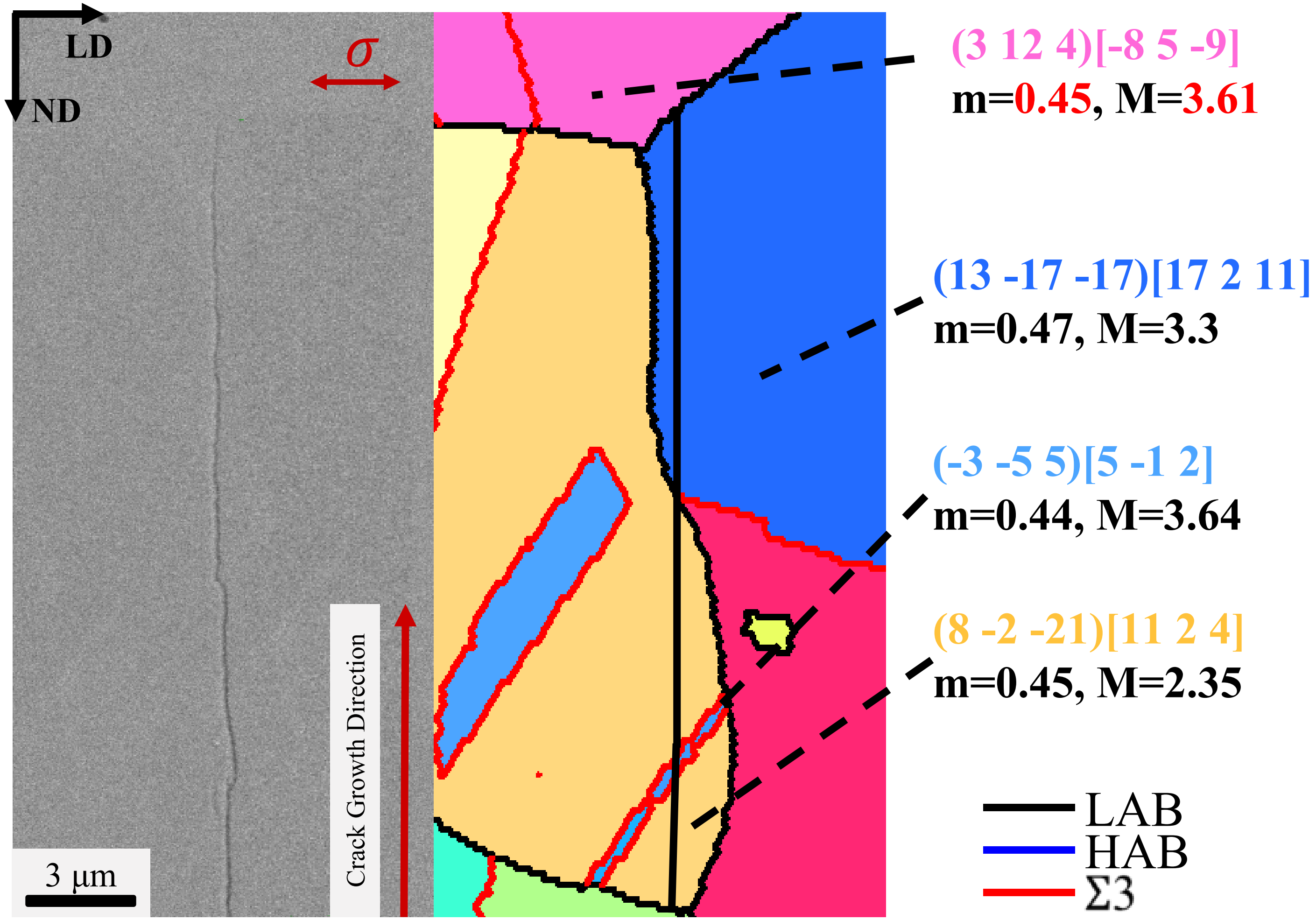
Results – Different Cracking Behaviors

Crack Termination: Hard Grain

Termination at GB





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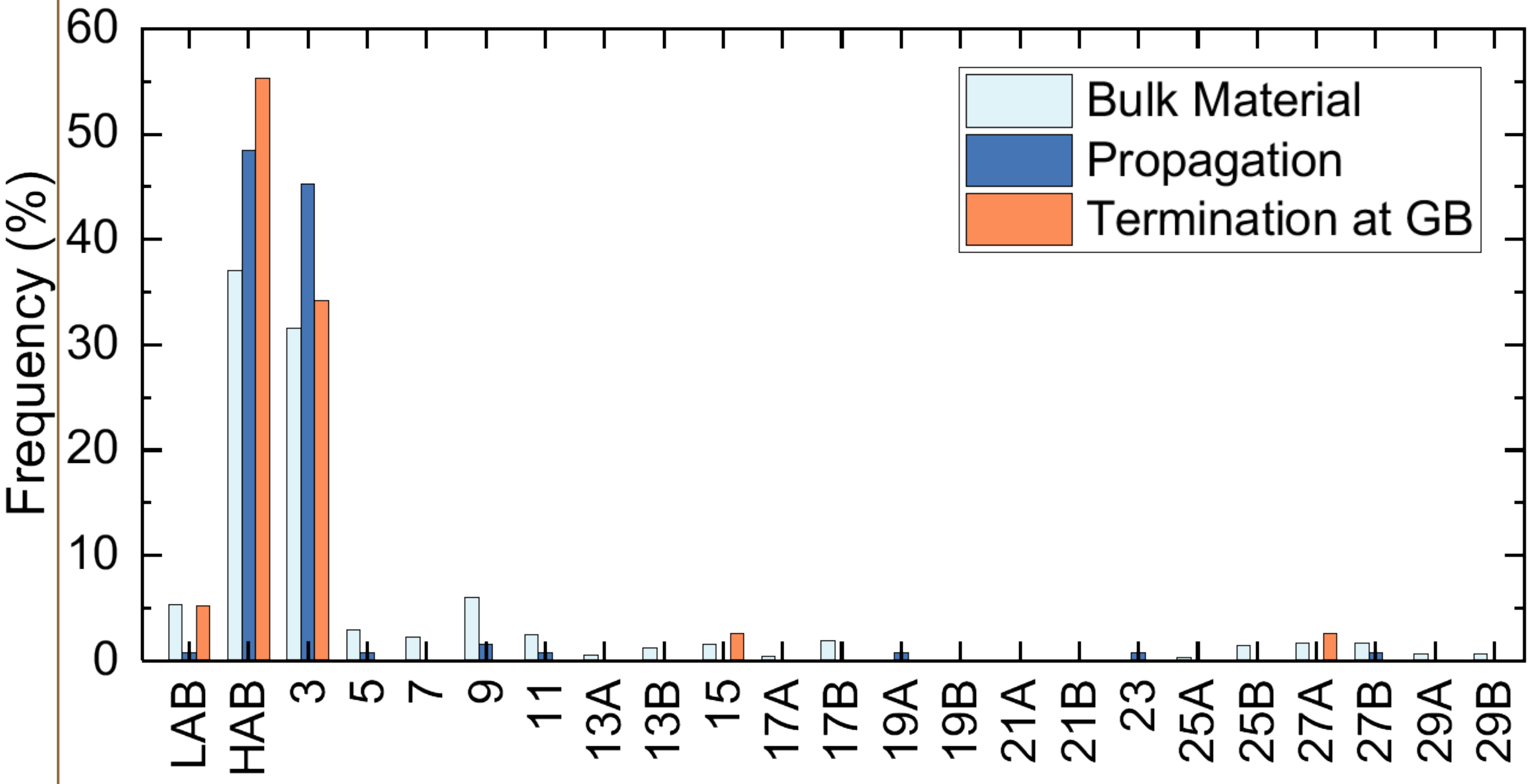
Results – GB Type Effect



- HAB and Σ3 are the most frequent GB types for bulk material.
- Both Propagation and termination at GB concentrate at HAB and Σ3.
- From statistical point of view, GB type doesn't influence cracking behavior.

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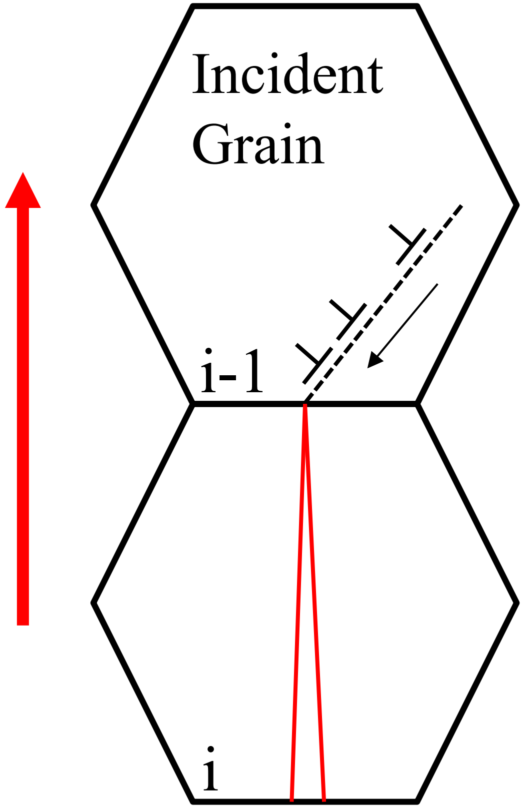
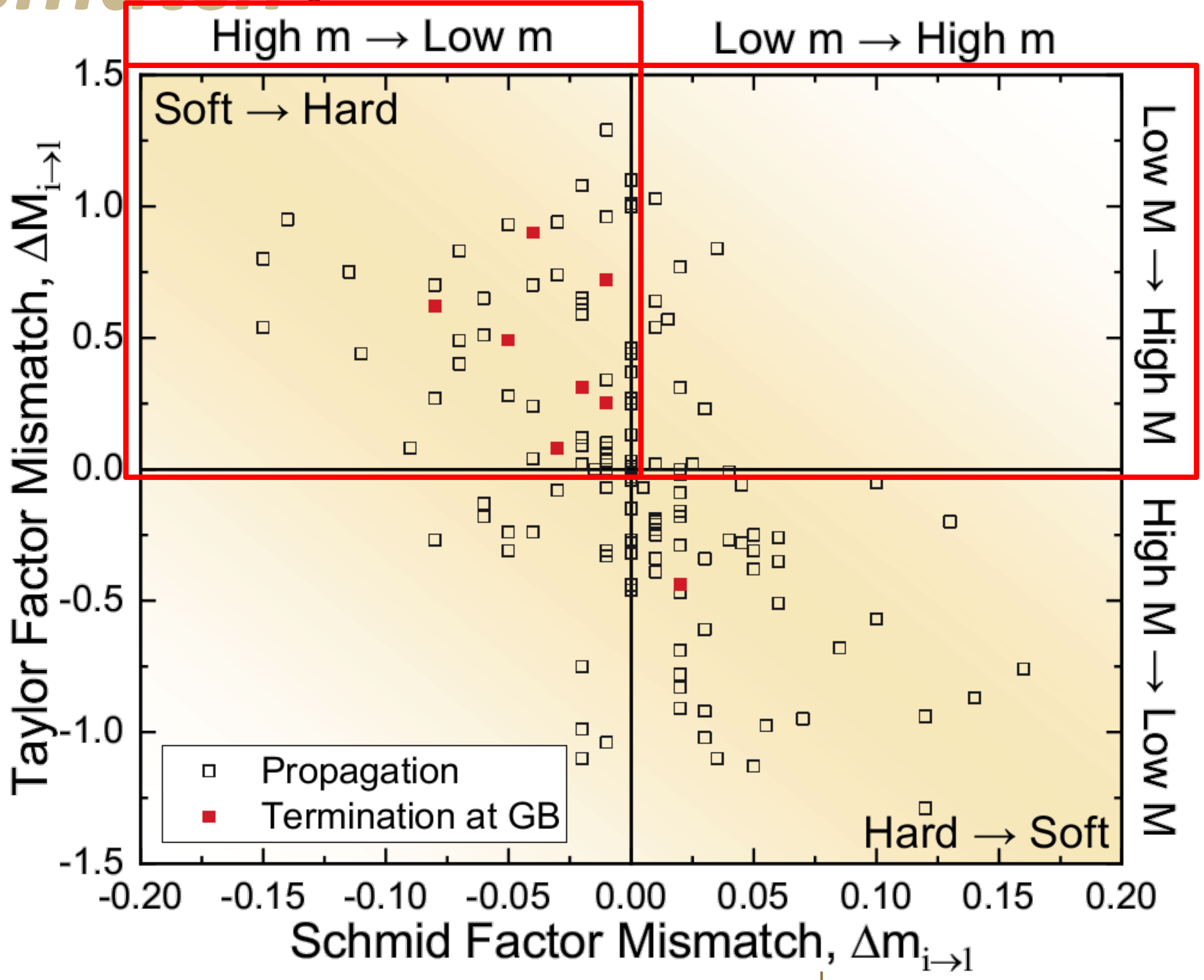
Results – Schmid & Taylor Factor Mismatch

m and M Mismatch Between Adjacent Grains on Crack Path





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Results – Schmid & Taylor Factor Mismatch

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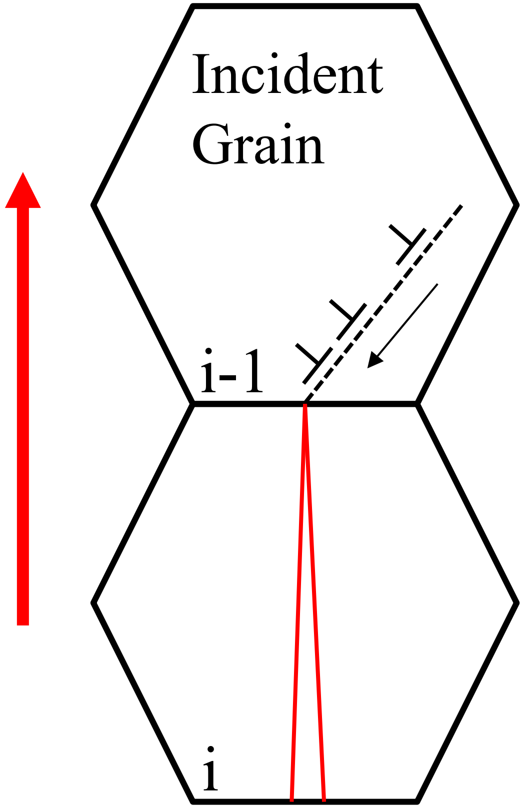

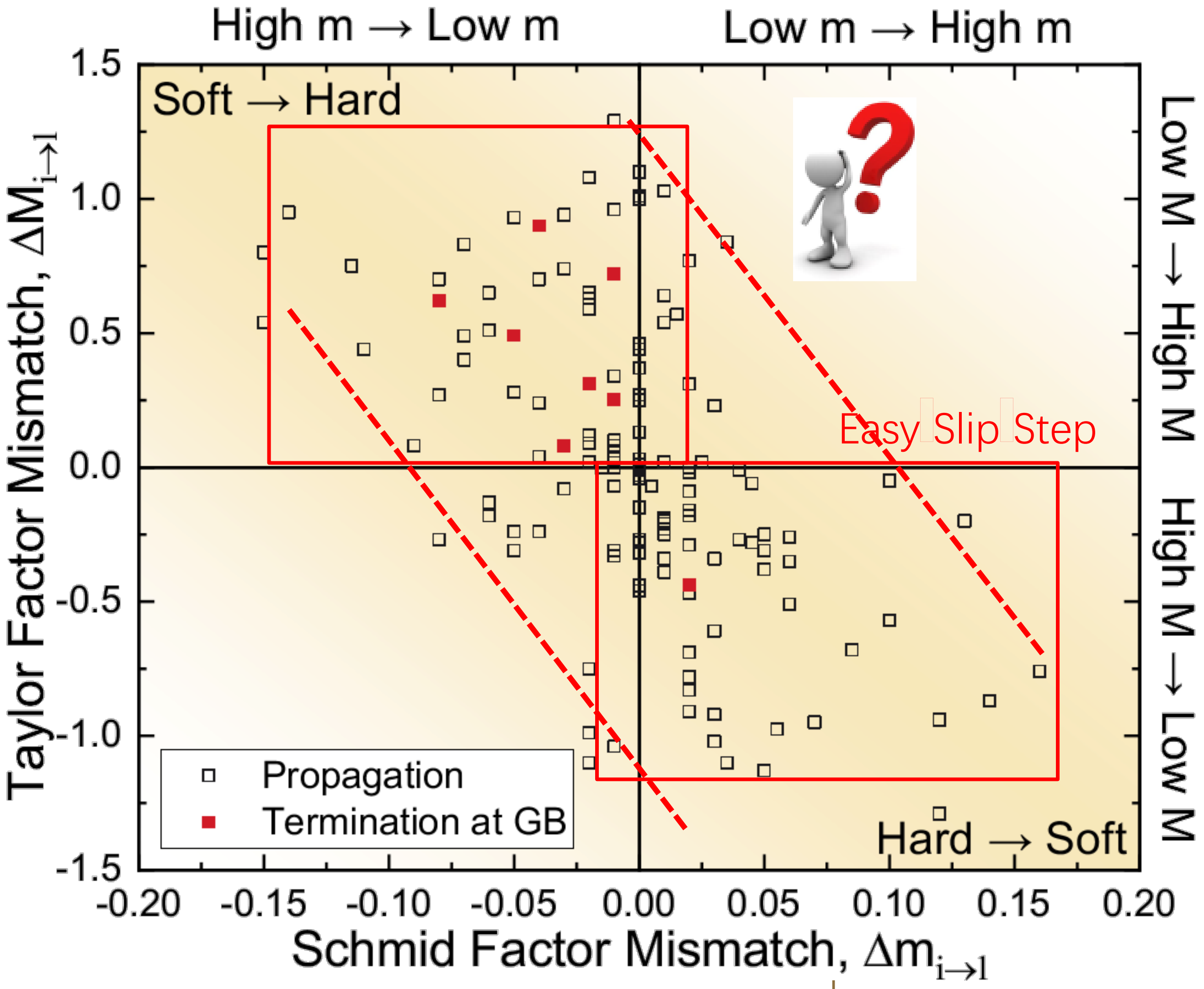

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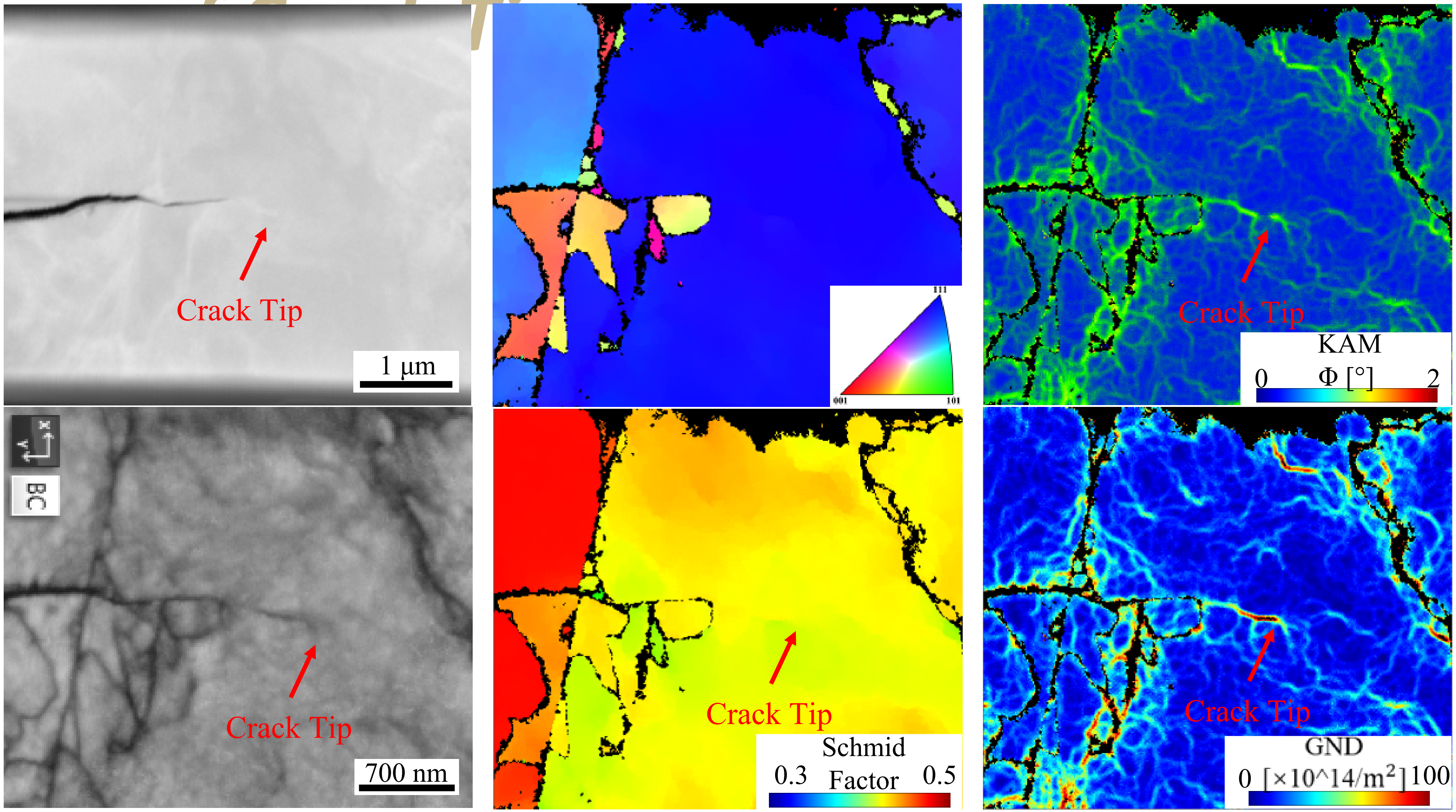
Results – TKD and STEM Analysis



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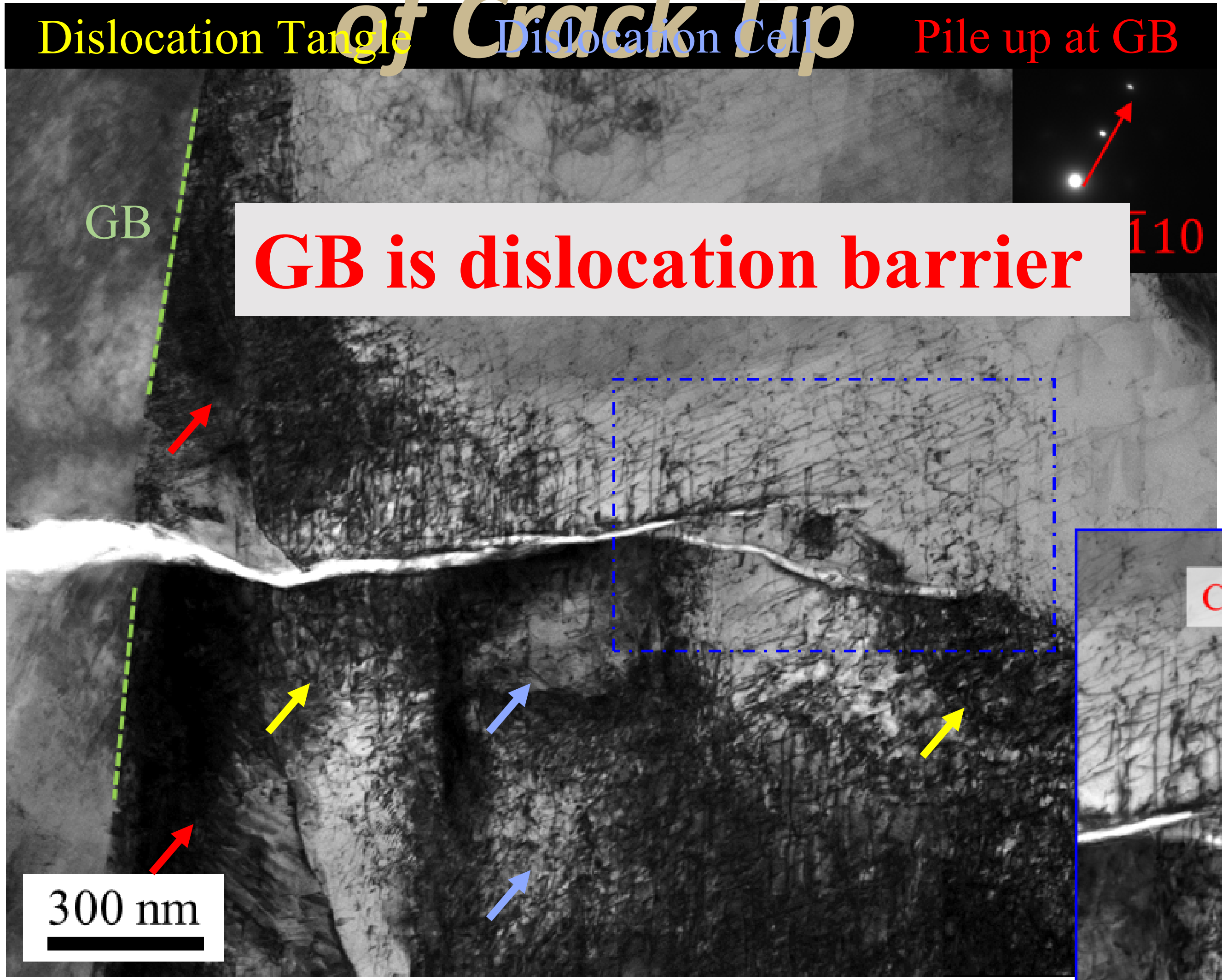
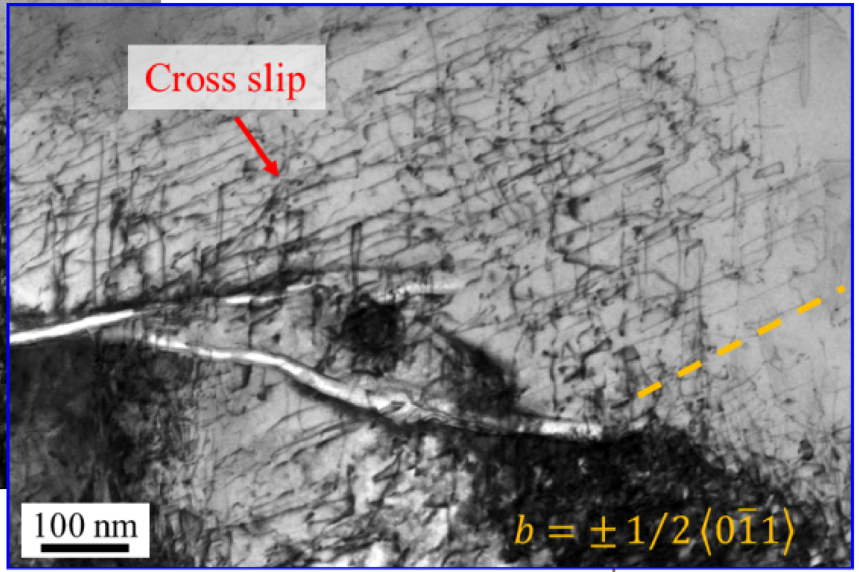
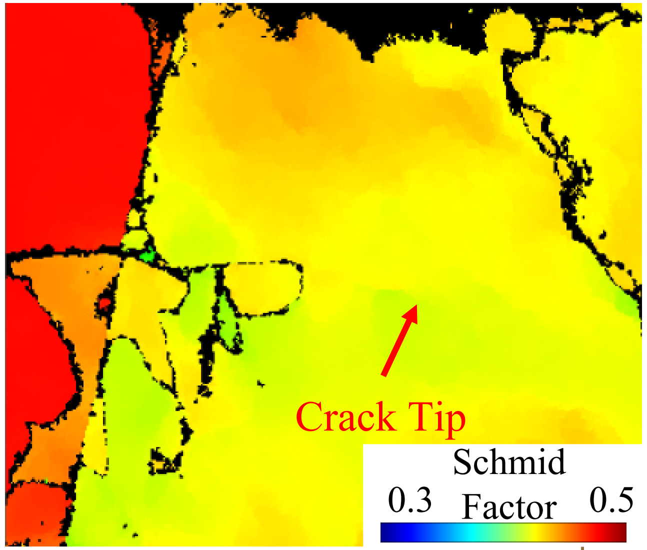
Results – TKD and STEM Analysis of Crack Tip





Soft → Hard



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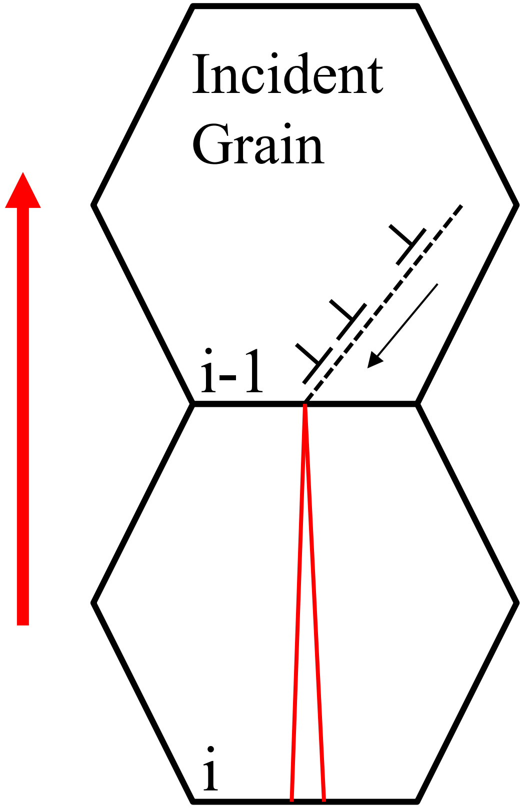
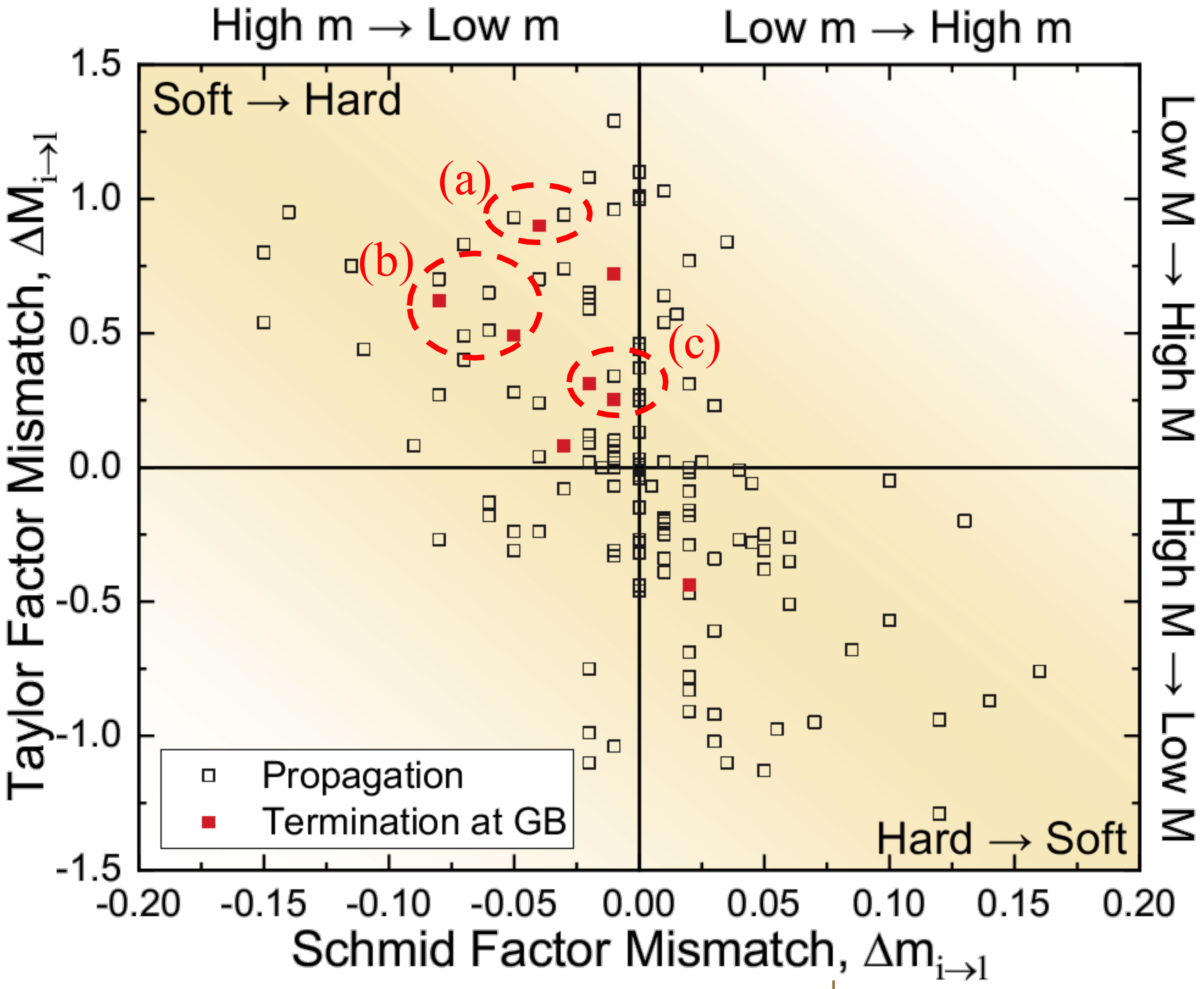
Results – Schmid & Taylor Factor Mismatch

m and M Mismatch Between Adjacent Grains on Crack Path





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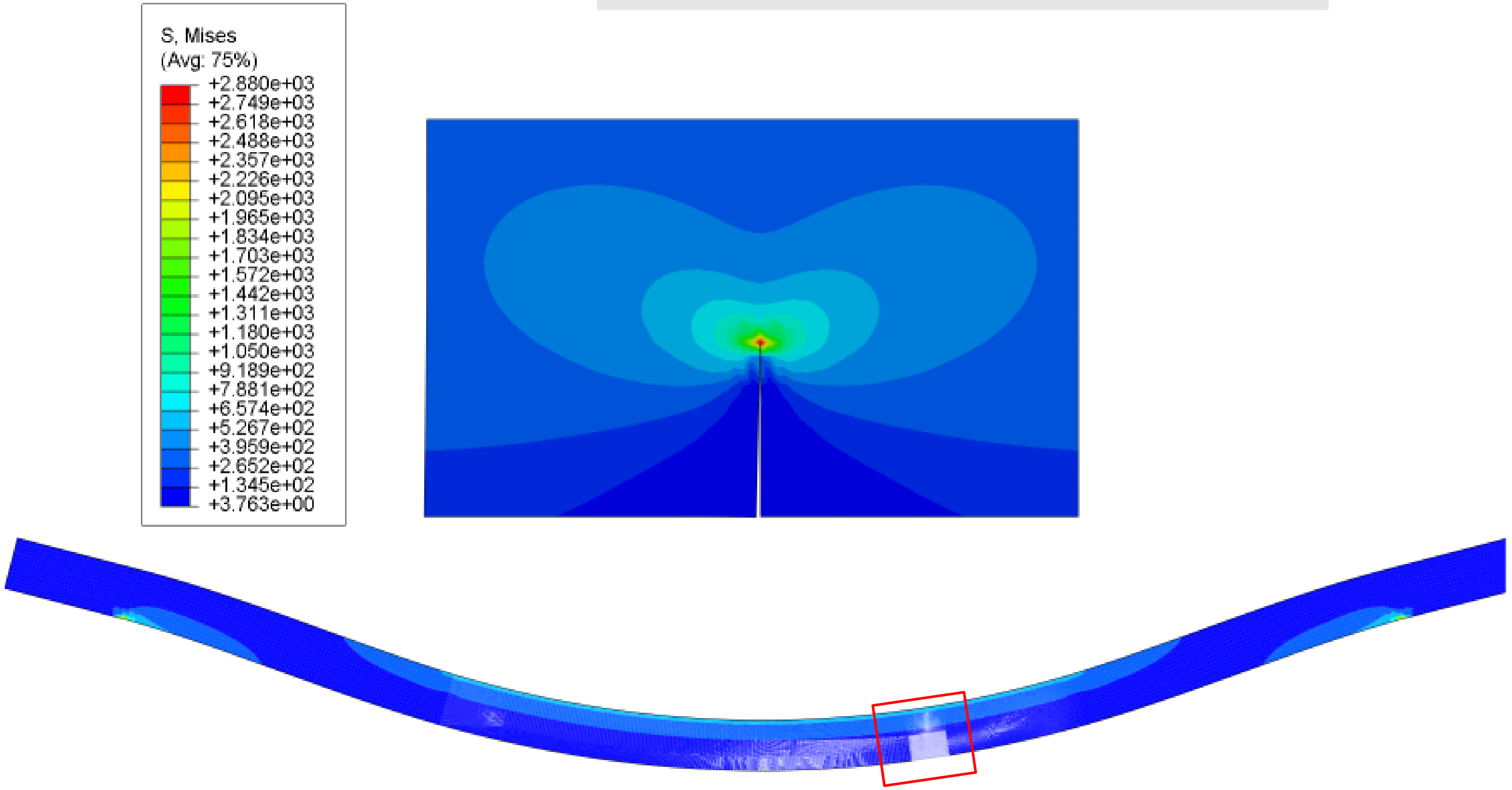
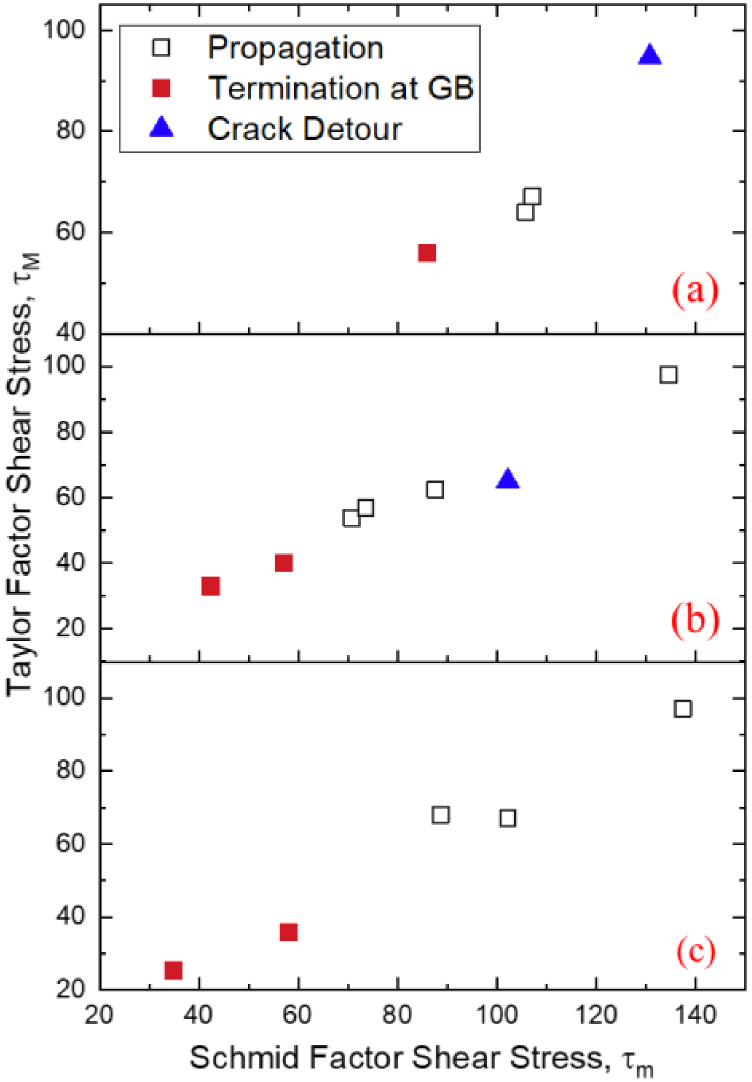
Discussion – FEA Analysis

GB is stress barrier





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Summary

- The Schmid and Taylor factor mismatch between adjacent grains determines crack propagation behavior.
- In the soft → hard scenario, GB serves as a **dislocation barrier** when the incident grain deforms under the stress field of crack tip.
- FEA results demonstrate that sufficient shear stress is required for crack tip to propagate through GB, thus, GB is also a **stress barrier**.
- Future work:
  - Direct TKD & STEM comparison of hard → soft scenario.
  - Microstructural analysis near crack tip region.

THANK YOU