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Science & Technology Facilities Council
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Revealing deformation mechanisms of FCC alloys at low temperature range: *in situ* neutron diffraction

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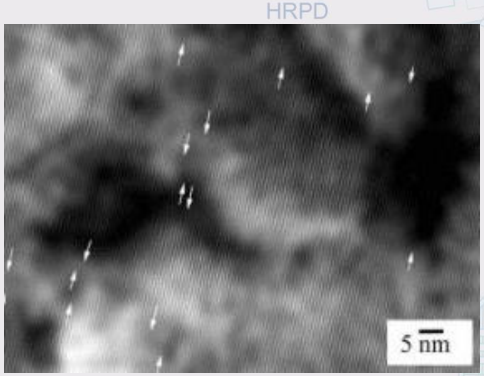
Background Introduction: Main Strengthen Mechanisms

- Dislocation motion
- TWIP (Twinning induced plasticity)
- TRIP (Transformation induced plasticity)

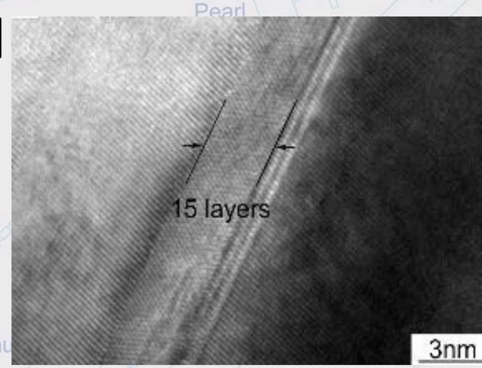
Background Introduction: Role of stacking fault energy

SFE ≥45mJm^{-2}	45mJm^{-2} ≥SFE ≥ 18 mJm^{-2}	18 mJm^{-2}≥ SFE
Dislocation Motions (*Dislocation Interaction*)	**Twinning** (*Twinning induced plasticity*)	**Phase Transformation** (*Transformation induced plasticity*) (*f.c.c.—h.c.p./b.c.c./b.c.t.*)



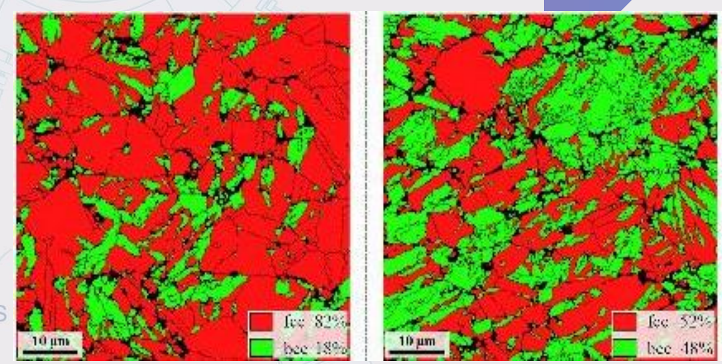
[1]

Highly deformed Al alloy, SFE=180mJm^{-2}



[2]

$FeCoNiCrAl_{0.1}$, SFE=30mJm^{-2}



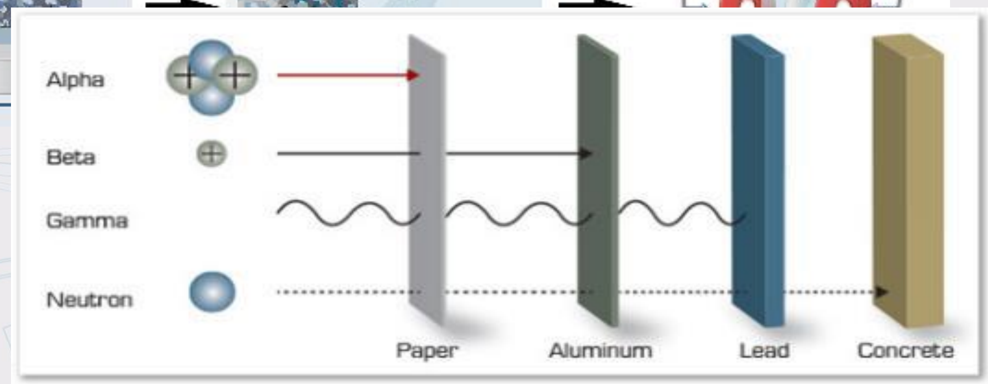
[3]

$Fe_{60}Co_{30}Ni_{30}Cr_{10}$ at 77 K, SFE=~10mJm^{-2}

[1] Y.H. Zhao, X.Z. Liao, Z. Jin, R.Z. Valiev, Y.T. Zhu, Acta Mater. 52 (2004) 4589–4599.
[2] J. Liu, C. Chen, Y. Xu, S. Wu, G. Wang, H. Wang, Scr. Mater. 137 (2017) 9–12.
[3] H.Y. Um, J.B. Seol, H.S. Kim, J.W. Bae, J. Moon, B.-J. Lee, S.S. Sohn, M.J. Jang, Acta Mater. 161 (2018) 388–399.

Background Introduction: why neutrons?

[4,5]

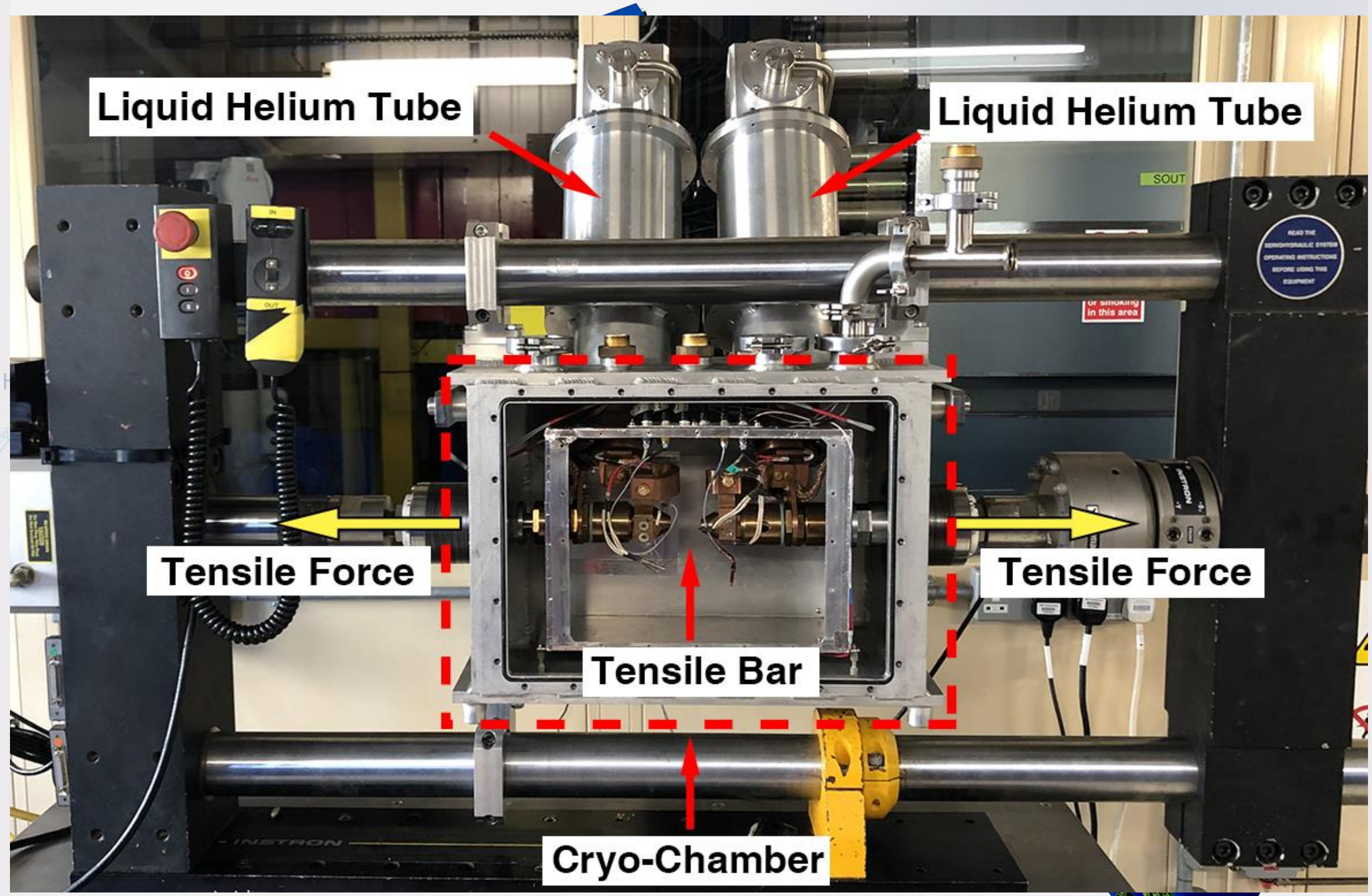


[6]

- **Non-destructive**
- **High penetration ability**
- **High Resolution**
- **Work under multiple conditions (low temperature, external loading)**
- **…**

4. *https://www.struers.com/en/Knowledge/Grinding-and-polishing*
5. *H.K. Zhang, F. Long, Z. Yao, M.R. Daymond, J. Microsc. (2013).*
6. *Nuclear Deterrence – U.S. Policy and Strategy*

Experiment design: *in situ* neutron diffraction

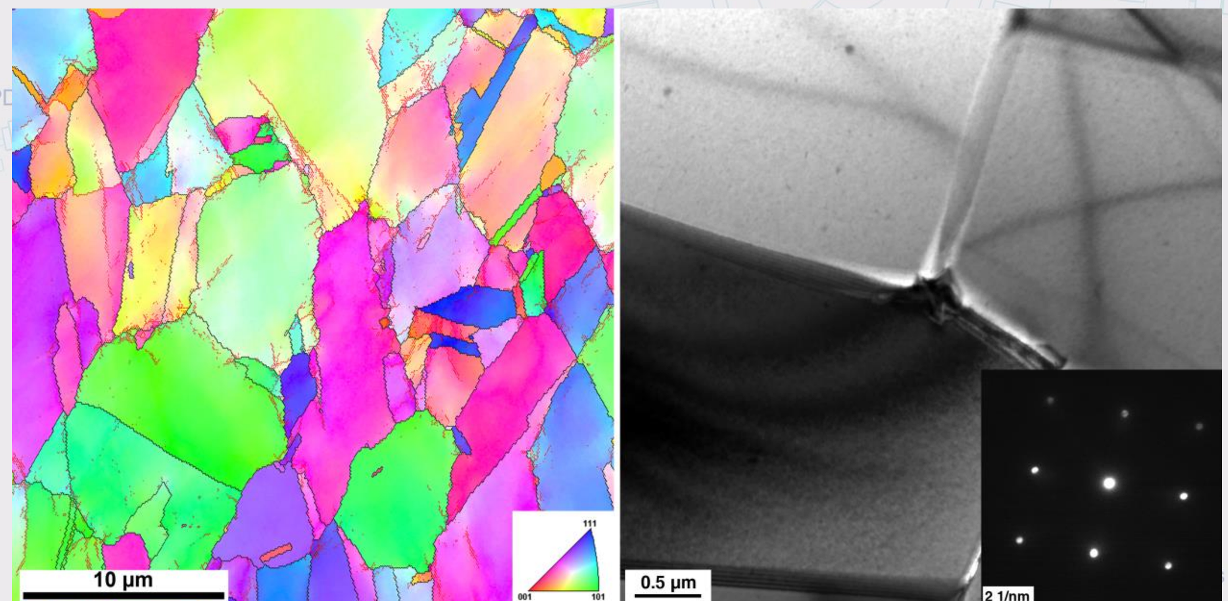


Experiment design: high Mn steel

Case 1

Case 1. High Mn steel: (Fe-24Mn)

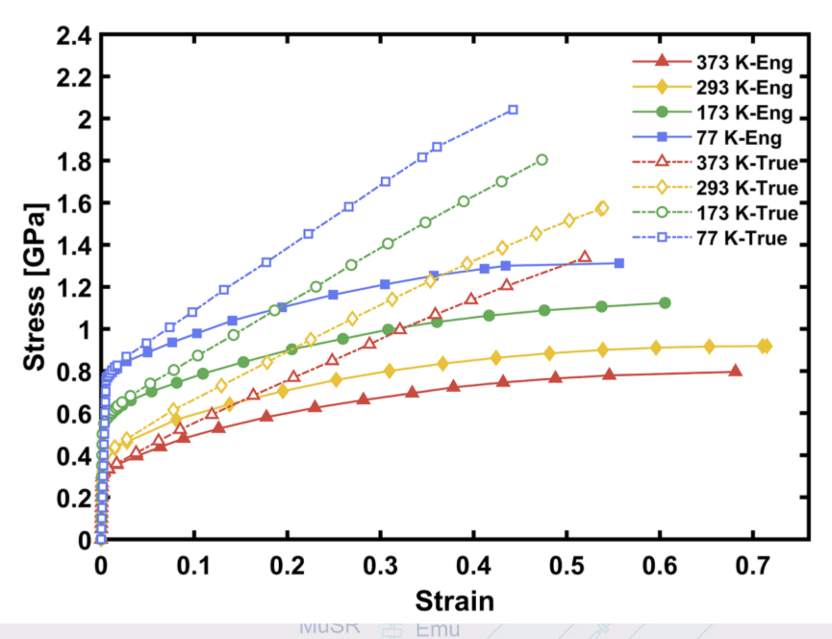
- Promising mechanical performance.
- High potential of activating multiple strengthening mechanisms.
- Wide industrial application.
- …

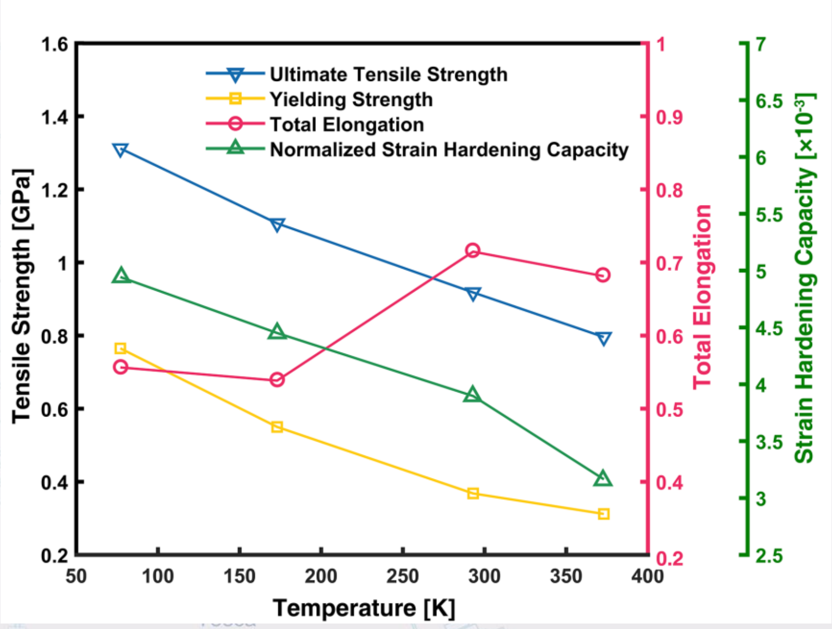


The typical IPF map shows the as-received microstructure of the TWIP steel

Results: Mechanical performance

Case 1

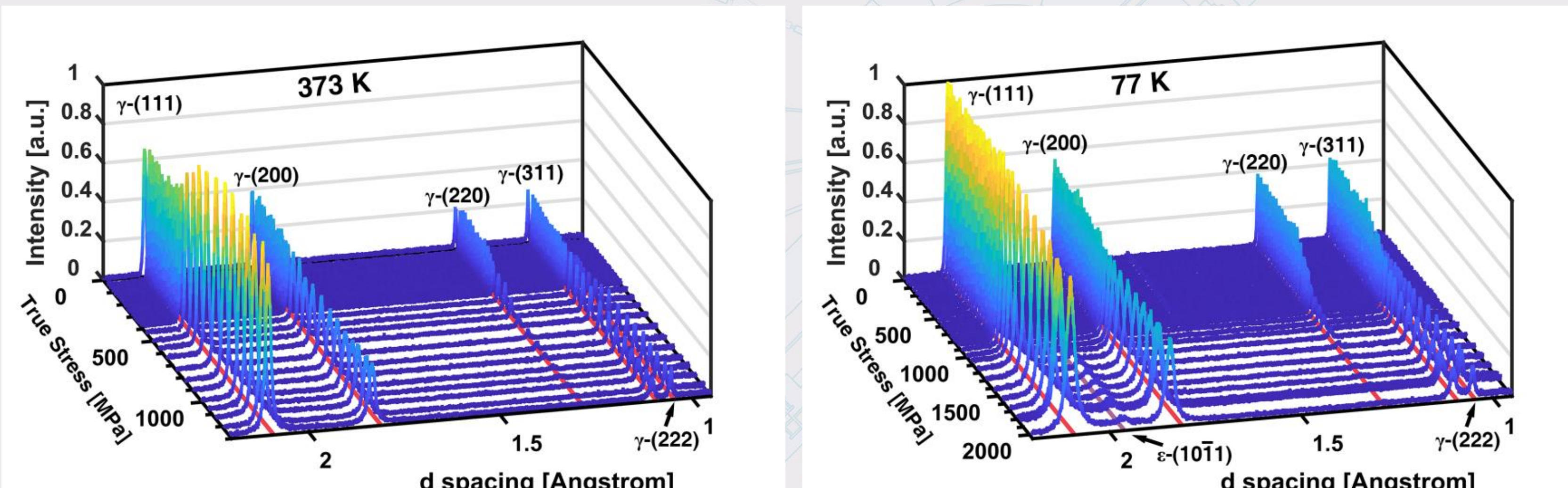




Mechanical performance of the TWIP steel at different temperatures

Results: Diffraction Patterns

Case 1



Diffraction patterns of the TWIP steel during tensile testing at (a) 373 K and (b) 77 K

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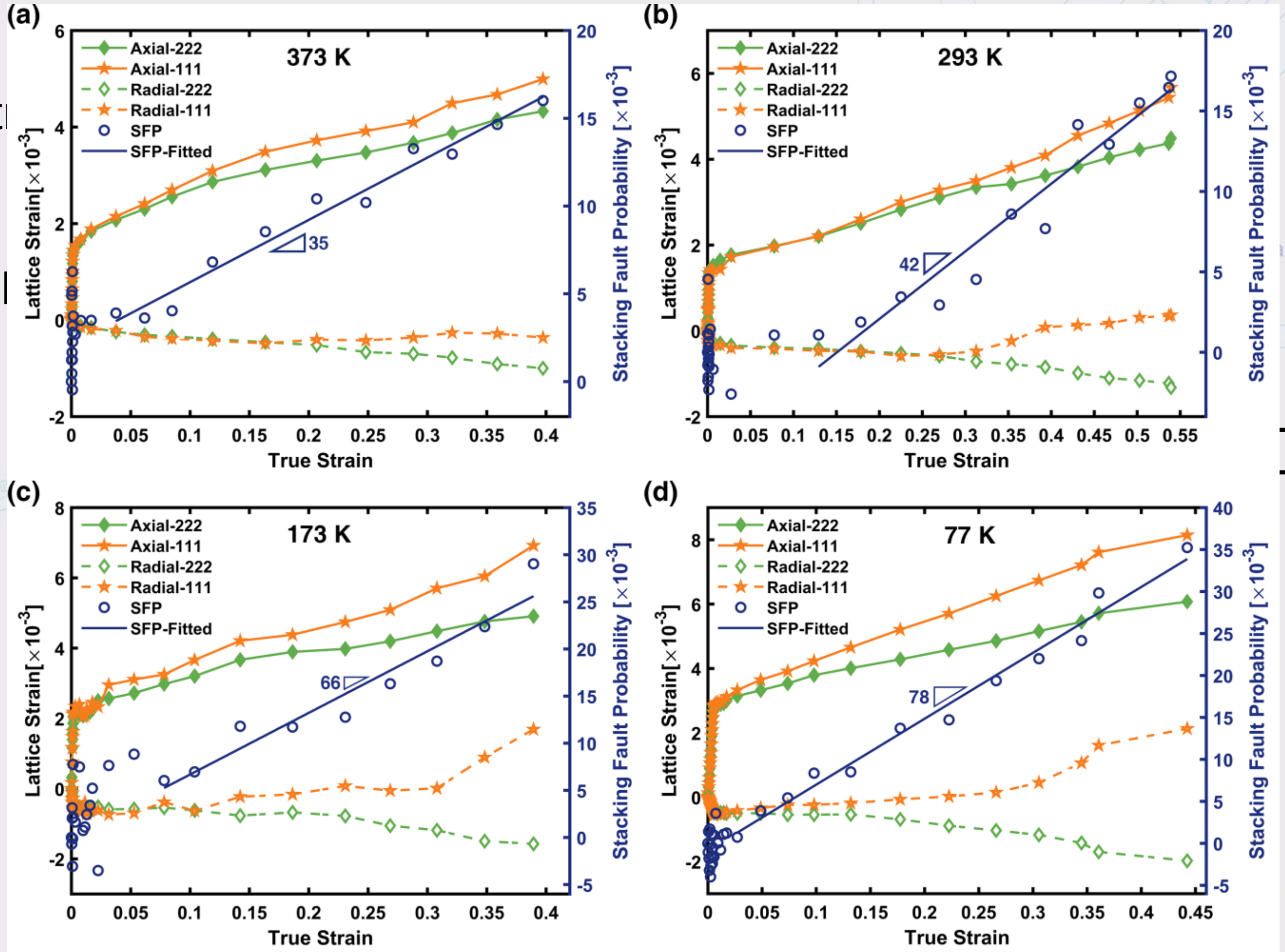
Results: Lattice Strain and Stacking Fault Probability

Lattice St

Stacking

$$\varepsilon_{hkl}^{exp} = \quad \cdots \quad \frac{\cdots l)}{\cdots + l^2)} SFP$$

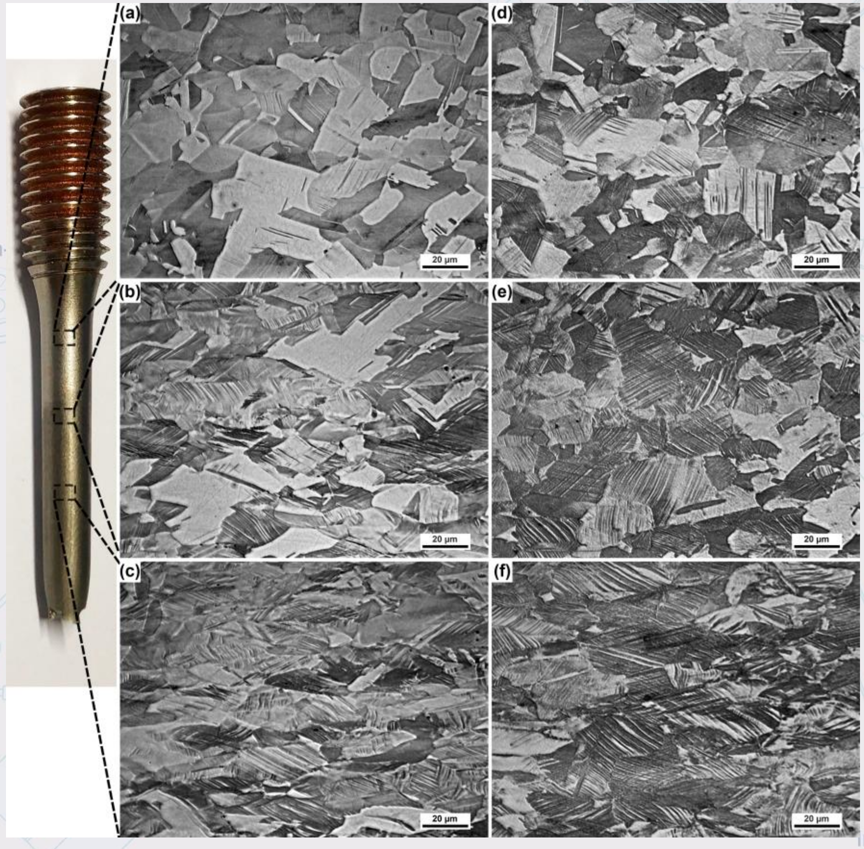


Lattice strain evolution of grain plane (111) and (222) from axial and radial direction and stacking fault probability evolution of the high entropy alloy during tensile testing at different temperatures: (a) 77 K (b) 15 K: (a) 373 K (b) 293 K (c) 173 K (d) 77 K.

Results: Twinning Formation

Case 1

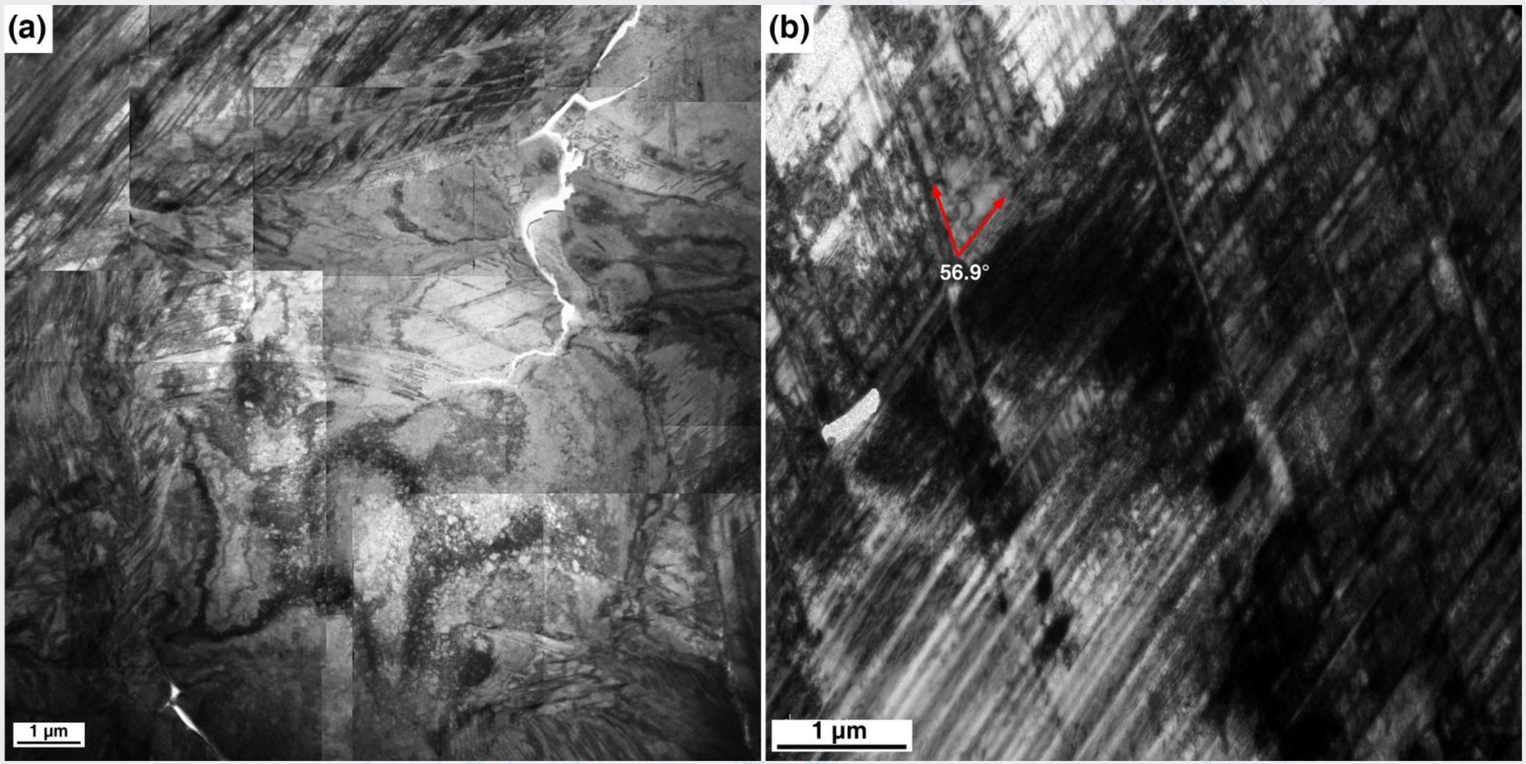
At same strain level, the twinning density increases with the decreasing of deforming temperature.



Typical optical images of the TWIP steel deformed with different strain and different temperature:
(a) 0.01, 293 K; (b) 0.1, 293 K; (c) 0.3, 293 K; (d) 0.01, 77 K; (e) 0.1, 77 K; (f) 0.3, 77 K

Results: Twinning and phase transformation

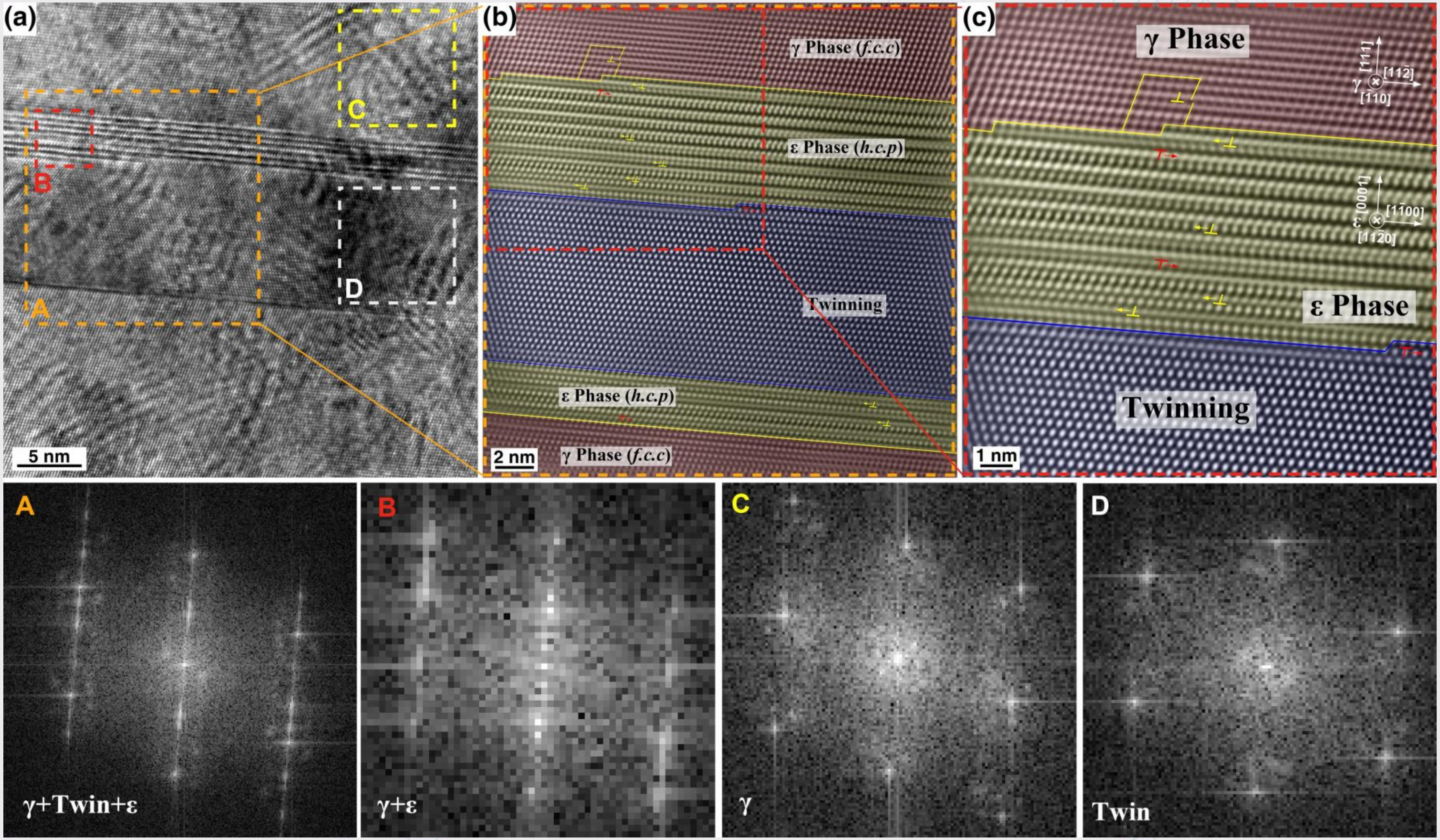
Case 1



Typical bright field TEM image of the TWIP steel deformed at (a) 373 K and (b) 77 K with strain of ~0.3.

Results: Twinning and phase transformation

Case 1



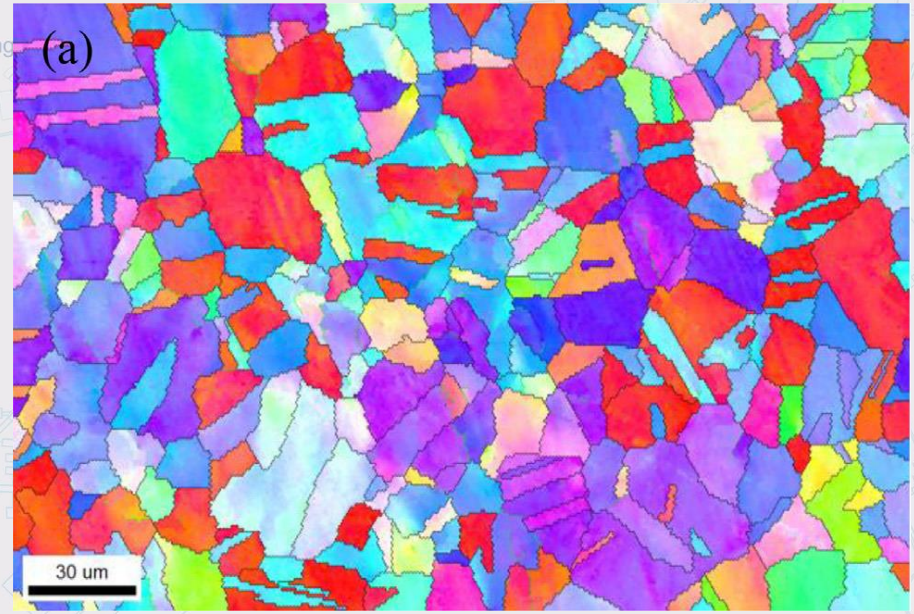
Twinning formation and phase transformation process (γ→ε) of the TWIP steel deformed at 77 K (strain of ~0.3) revealed by HRTEM images.

Experiment design: high entropy alloy

Case 2

2. High entropy alloy: ($FeCoCrNiMo_{0.2}$)

- Promising mechanical performance.
- New design concept.
- Many intriguing features: sluggish diffusion effect, 'Cocktail' effect…
- …

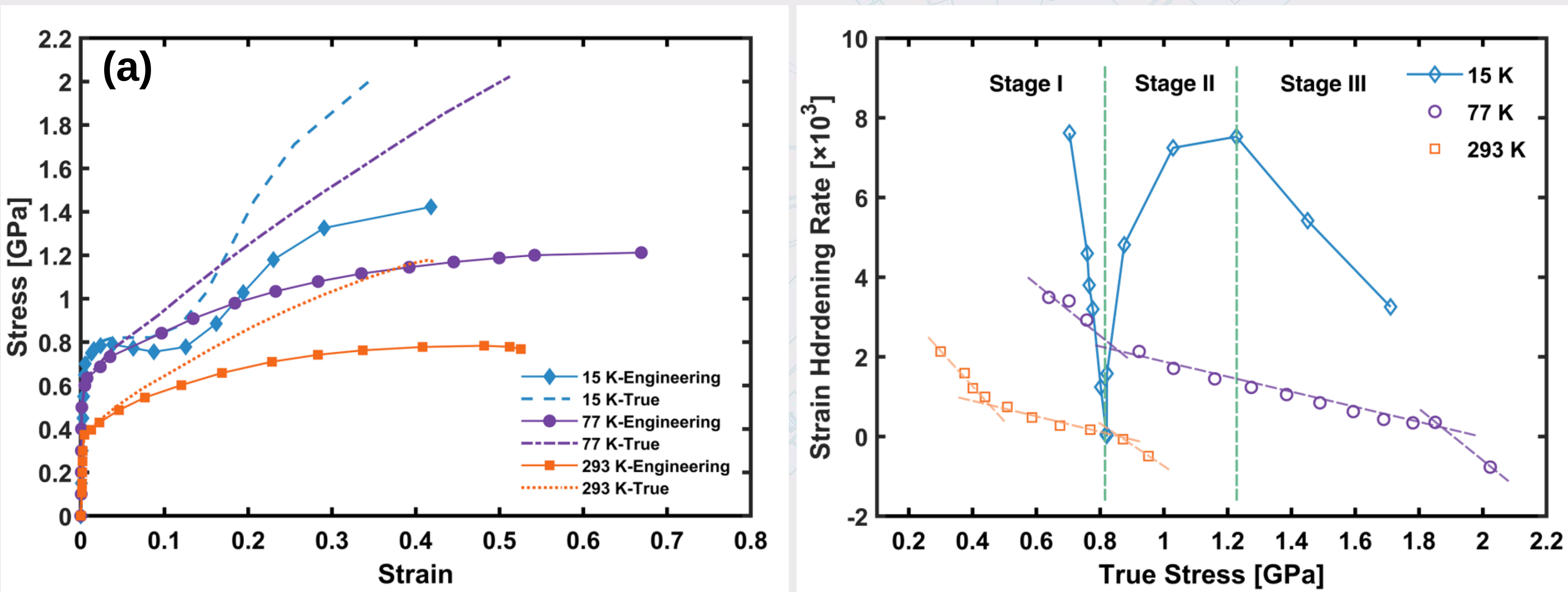


Typical IPF image shows the as-received high entropy alloy prepared by powder metallurgy [7]

[7] B. Cai, B. Liu, S. Kabra, Y. Wang, K. Yan, P.D. Lee, Y. Liu, Deformation mechanisms of Mo alloyed FeCoCrNi high entropy alloy: In situ neutron diffraction, Acta Mater. 127 (2017) 471–480. https://doi.org/10.1016/j.actamat.2017.01.034.

Results: Mechanical performance

Case 2



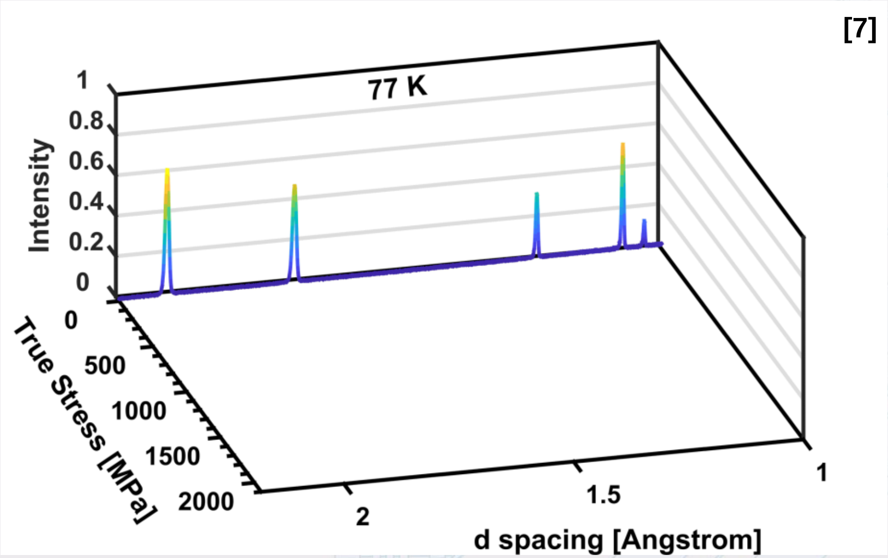
Mechanical performance of the high entropy alloy[8] at different temperatures[8]

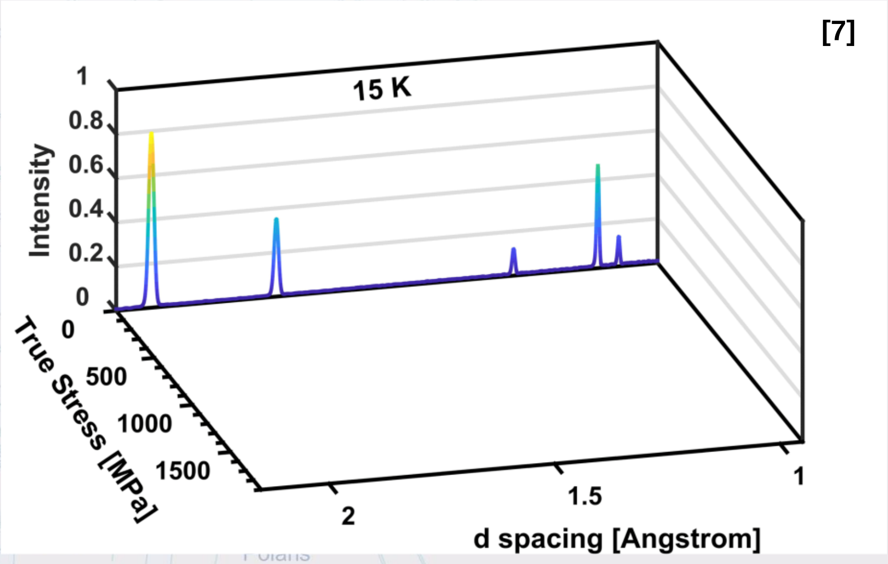
[8] L. Tang, K. Yan, B. Cai, Y. Wang, B. Liu, S. Kabra, M.M. Attallah, Y. Liu, Deformation mechanisms of FeCoCrNiMo0.2 high entropy alloy at 77 and 15 K, Scr. Mater. 178 (2020) 166–170. https://doi.org/10.1016/J.SCRIPTAMAT.2019.11.026.

Results: Diffraction Patterns

Case 2

The diffraction pattern change indicates the phase transformation process (from γ to α′) occurred during deforming at 15 K.



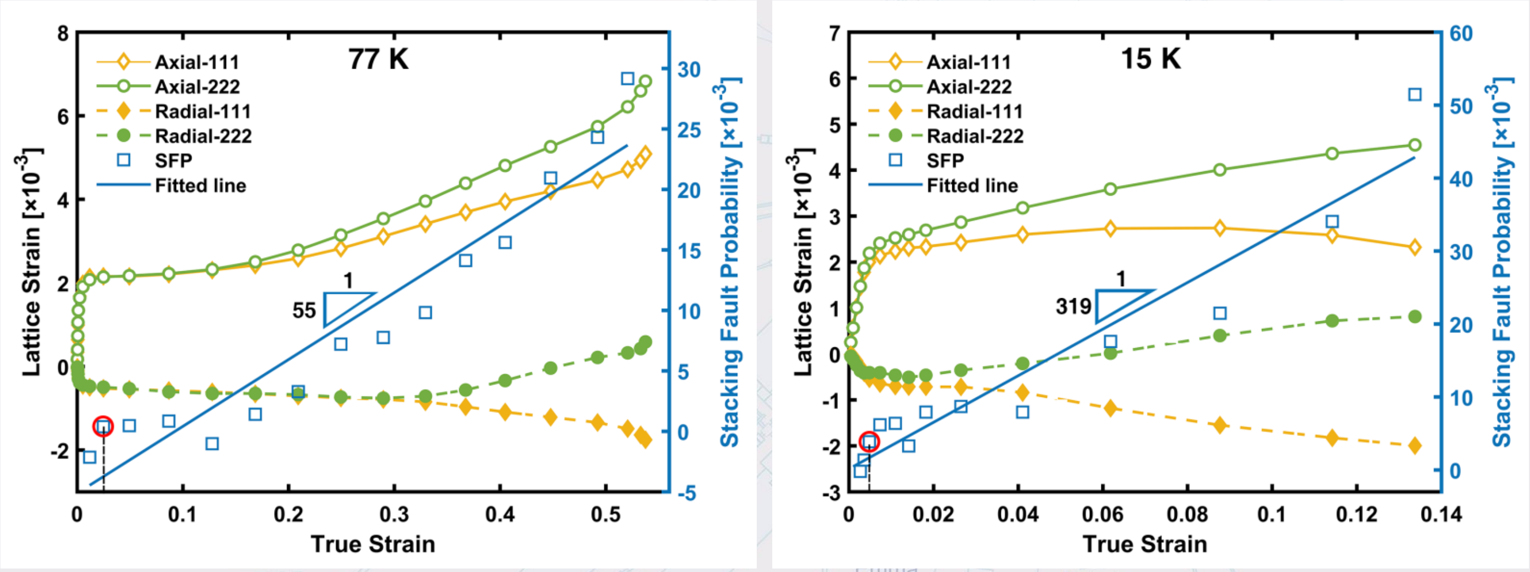


Diffraction patterns of the high entropy alloy during tensile testing at (a) 77 K and (b) 15 K [8]

[8] L. Tang, K. Yan, B. Cai, Y. Wang, B. Liu, S. Kabra, M.M. Attallah, Y. Liu, Deformation mechanisms of FeCoCrNiMo0.2 high entropy alloy at 77 and 15 K, Scr. Mater. 178 (2020) 166–170. https://doi.org/10.1016/J.SCRIPTAMAT.2019.11.026.

Results: Lattice strain and SFP evolution

Case 2

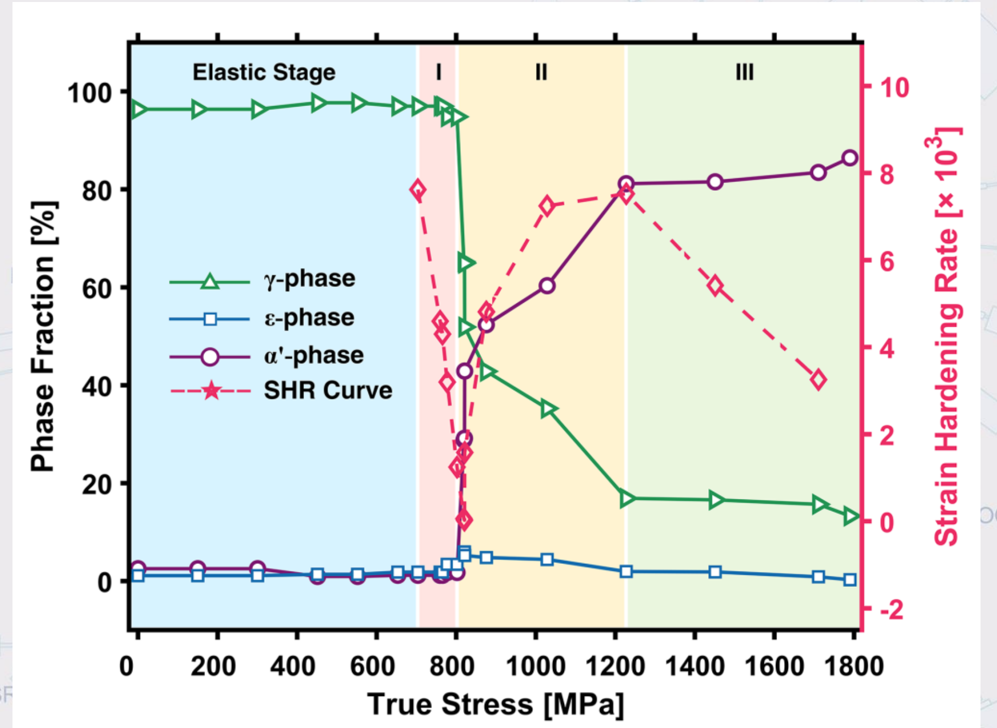


Lattice strain evolution of grain plane (111) and (222) from axial and radial direction and stacking fault probability evolution of the high entropy alloy during tensile testing at different temperatures: (a) 77 K (b) 15 K. [8]

[8] L. Tang, K. Yan, B. Cai, Y. Wang, B. Liu, S. Kabra, M.M. Attallah, Y. Liu, Deformation mechanisms of FeCoCrNiMo0.2 high entropy alloy at 77 and 15 K, Scr. Mater. 178 (2020) 166–170. https://doi.org/10.1016/J.SCRIPTAMAT.2019.11.026.

Results: Phase Transformation

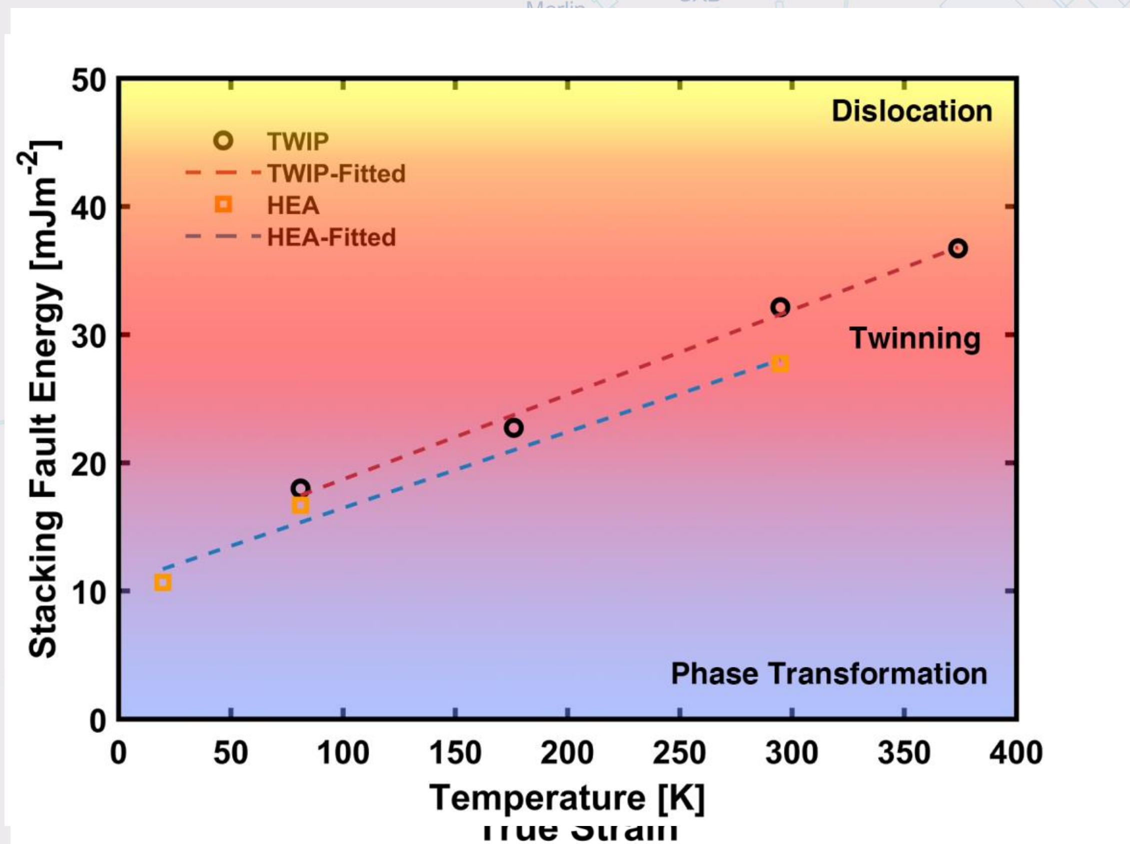
Case 2



Phase transformation process of the high entropy alloy during tensile testing at 15 K[8].

[8] L. Tang, K. Yan, B. Cai, Y. Wang, B. Liu, S. Kabra, M.M. Attallah, Y. Liu, Deformation mechanisms of FeCoCrNiMo0.2 high entropy alloy at 77 and 15 K, Scr. Mater. 178 (2020) 166–170. https://doi.org/10.1016/J.SCRIPTAMAT.2019.11.026.

Results: Stacking Fault energy *v.s.* temperature



Stacking fault energy evolution of the TWIP steel and high entropy alloy with respect to temperature.[7]

Stacking fault energy calculation process of the high entropy.

[7] L. Tang, K. Yan, B. Cai, Y. Wang, B. Liu, S. Kabra, M.M. Attallah, Y. Liu, Deformation mechanisms of FeCoCrNiMo0.2 high entropy alloy at 77 and 15 K, Scr. Mater. 178 (2020) 166–170. https://doi.org/10.1016/J.SCRIPTAMAT.2019.11.026.

Conclusion:

1. **Significant improvement of mechanical properties.**
2. **Strengthening mechanism changing.**
3. **Relationship between SFE and temperature.**

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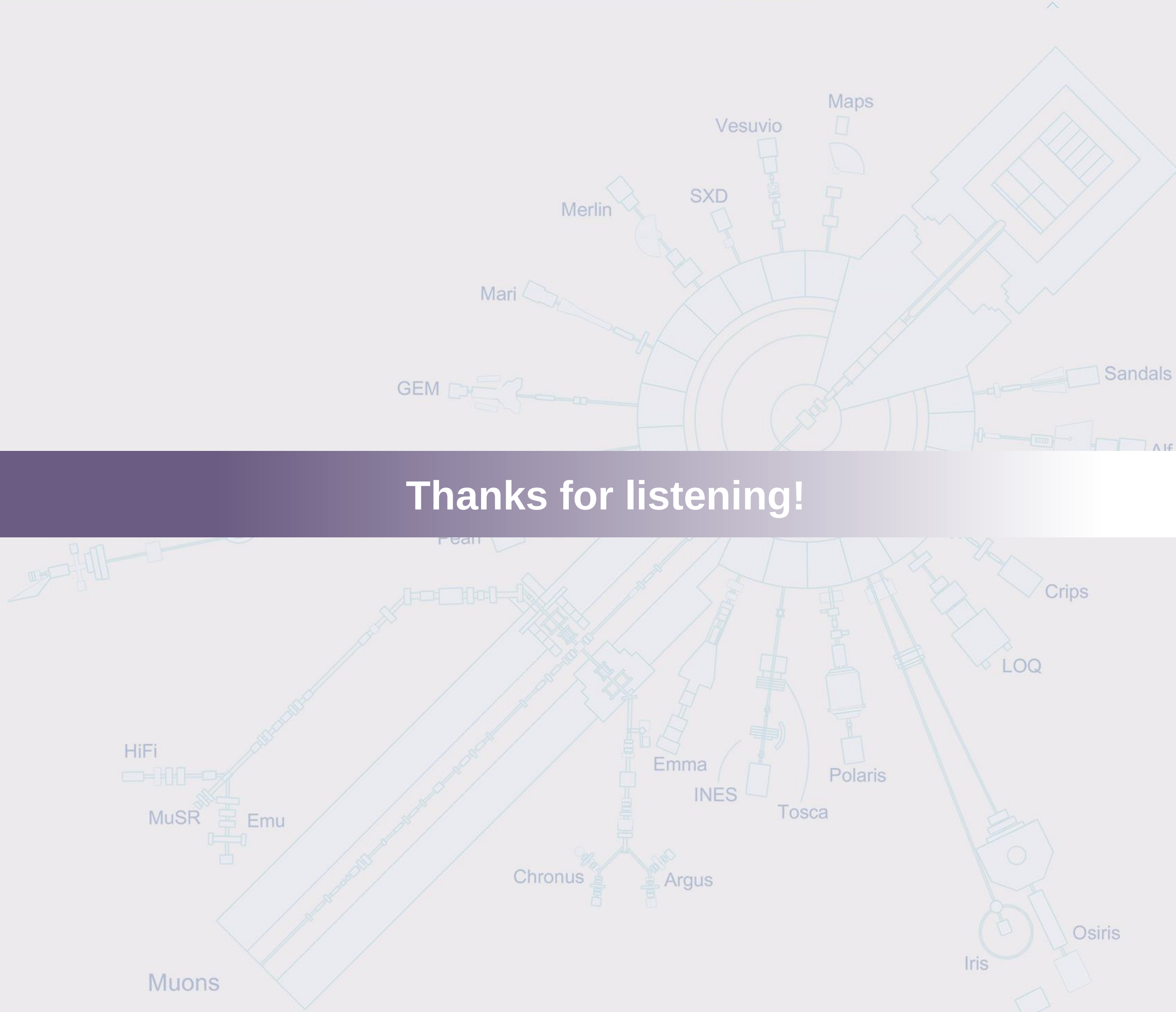

Thanks for listening!

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