Revealing deformation mechanisms of FCC alloys at low temperature range: \textit{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

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.)

Highly deformed Al alloy,  
SFE=180mJm⁻²

FeCoNiCrAl₀.₁,  
SFE=30mJm⁻²

Fe₆₀Co₃₀Ni₃₀Cr₁₀ at 77 K,  
SFE=10mJm⁻²

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Background Introduction: why neutrons?

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

Experiment design: *in situ* neutron diffraction
Experiment design: high Mn steel

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

Mechanical performance of the TWIP steel at different temperatures
Results: Diffraction Patterns

Diffraction patterns of the TWIP steel during tensile testing at (a) 373 K and (b) 77 K
Results: Lattice Strain and Stacking Fault Probability

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**

At the 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

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

Twinning formation and phase transformation process ($\gamma \rightarrow \varepsilon$) of the TWIP steel deformed at 77 K (strain of $\sim 0.3$) revealed by HRTEM images.
Experiment design: high entropy alloy

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]

Results: Mechanical performance

Results: Diffraction Patterns

The diffraction pattern change indicates the phase transformation process (from $\gamma$ to $\alpha'$) 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]

Results: Lattice strain and SFP evolution

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.

Results: Phase Transformation

Phase transformation process of the high entropy alloy during tensile testing at 15 K\cite{8}.

Results: Stacking Fault energy v.s. temperature

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

Conclusion:

1. Significant improvement of mechanical properties.
2. Strengthening mechanism changing.
3. Relationship between SFE and temperature.
Thanks for listening!

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