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Dislocation Density Evolution in Austenite and Strain-Induced α′-Martensite during Cryogenic Straining of AISI 304 Stainless Steel: An X-ray Diffraction Line Profile Analysis

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Introduction

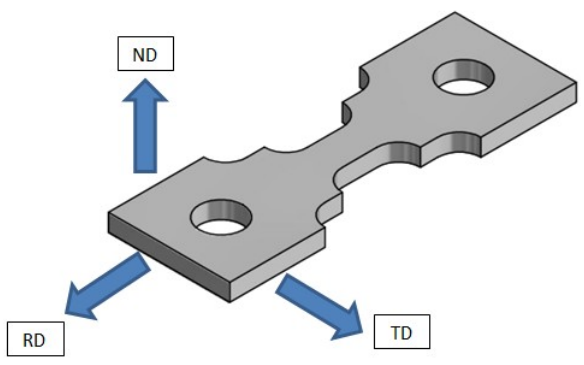
AISI 304 stainless steel combines high ductility with the strain-induced transformation of FCC austenite (γ) into BCC α'-martensite. Under cryogenic straining, reduced stacking-fault energy suppresses dynamic recovery and favors planar slip. Quantifying dislocation density and spatial arrangement in each phase is essential to explain strain hardening and microstructural stability.

Objective

Determine how engineering strain and test temperature affect the phase-averaged dislocation density (ρ) and dislocation arrangement parameter (M) in austenite and strain-induced α'-martensite using X-ray diffraction line-profile analysis.

Methodology

AISI 304 sheet specimens (2 mm) were tensile-strained at 298, 173 and 93 K at 10^{-3} s^{-1}. Tests were interrupted at engineering strains of 0.125, 0.25, 0.375 and 0.50. *In situ* synchrotron XRD used 12 keV radiation (λ = 1.0332 Å). Instrumental broadening was characterized using a Y_2O_3 standard. Pseudo-Voigt fitting provided the profile parameters required for the modified Warren–Averbach analysis.



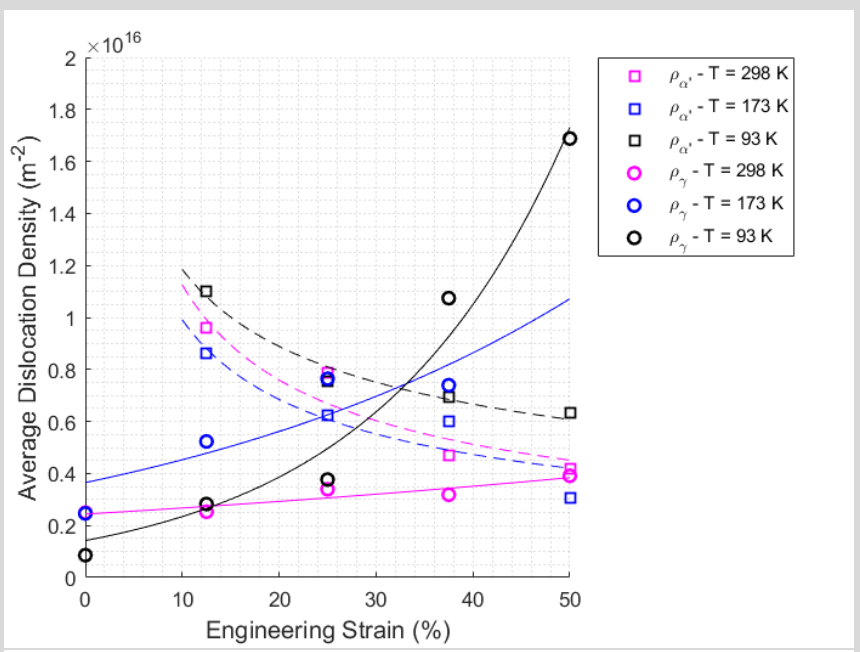
The modified Warren–Averbach approach was applied following Refs. [1–8]:

$$\ln\big(A(L)\big) \cong \ln(A^S(L)) - \frac{\rho\pi b^2 L^2}{2} f(\eta_e)\big(K^2\overline{C}\big)$$

where $A^S(L)$ is the Fourier coefficient related to the crystallite size, and $A(L)$ is the real part of the Fourier coefficient of the XRD profiles.

Results and Discussion

Austenite exhibited continuous dislocation accumulation with increasing strain, and the increase became steeper as the temperature decreased. The phase-averaged dislocation density in α'-martensite decreased with increasing strain and tended toward a plateau, revealing a distinct evolution compared with that observed in austenite. M_γ increased with strain, particularly at 93 K. In contrast, $M_{\alpha'}$ remained nearly constant at 298 and 173 K and decreased moderately at 93 K. Symbols represent the experimental estimates. Solid and dashed lines represent empirical least-squares fits used to describe the observed trends. Austenite data were fitted using an exponential function, whereas α'-martensite data were fitted using a power-law function. The fitted curves are descriptive and do not



Conclusions

- Austenite exhibits progressive dislocation storage with increasing strain, with a markedly stronger increase at lower temperatures.
- The phase-averaged dislocation density in α'-martensite decreased with increasing strain and tended toward a plateau, revealing a distinct dislocation-density evolution compared with austenite.
- Cryogenic temperatures enhance dislocation storage in austenite, consistent with the suppression of dynamic recovery at lower temperatures.
- M_γ increased with strain, particularly at 93 K, whereas $M_{\alpha'}$ remained nearly constant at 298–173 K and decreased moderately at 93 K.

References and Acknowledgments

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