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Metallic Materials with High Structural Efficiency

DYNAMIC RECRYSTALLIZATION
OF LOW STACKING FAULT ENERGY METALS

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Dynamic Recrystallization of Low Stacking Fault Energy Metals

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See also ADM001672. The original document contains color images.
Outline

- Continuous and discontinuous dynamic recrystallization (DRX)
- DRX in a high purity base austenitic stainless steel
- DRX in a 718 grade nickel base superalloy. "Continuous nucleation"
- Conclusions
Continuous vs. discontinuous dynamic recrystallization

<table>
<thead>
<tr>
<th><strong>DDRX</strong> or &quot;classical&quot; DRX</th>
<th><strong>CDRX</strong> or &quot;rotation&quot;, &quot;apparent&quot;, &quot;in situ&quot; DRX, or &quot;extended dynamic recovery&quot;</th>
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<tbody>
<tr>
<td>occurs by local (rapid) cycles of strain-hardening (\rightarrow) nucleation (\rightarrow) growth of new grains</td>
<td>occurs by progressive (slow) transformation of subgrain boundaries (LAGB) into grain boundaries (HAGB)</td>
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<tr>
<td>- dynamic recovery is weak</td>
<td>- dynamic recovery is strong (dislocation rearrangement and annihilation)</td>
</tr>
<tr>
<td>- dislocation densities are inhomogeneous (\text{(strong } \Delta \rho\text{)})</td>
<td>- dislocation densities are homogeneous (\text{(weak } \Delta \rho\text{)})</td>
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<tr>
<td>- the rate of grain boundary migration is high</td>
<td>- the rate of grain boundary migration is low</td>
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Low stacking fault energy materials: Cu, \(\gamma\)-iron and austenitic steels, Ni-base superalloys, ...

High stacking fault energy materials: Al, \(\alpha\)-iron and ferritic steels, \(\beta\)-titanium, ...
DDRX: transition from multiple peak (low Z) to single peak (high Z) DRX

\[ Z = \dot{\varepsilon} \exp \left( \frac{Q}{RT} \right) \]

[Rossard & Blain, 1959] [Blaz et al., 1983]
CDRX: "Smooth" stress-strain curves

Schematic representation of the CDRX crystallite microstructure

[1050 Al - 450 °C]

[0-10 s⁻¹]

[0.01, 0.1, 0.3, 1]

[Grain boundary (HAB)]

[Subgrain boundary (LAB)]

[D]

[ρ₁, ρ₂, ρ₃, θ₁, θ₂, θ₃]

[Gourdet & Montheillet, 2003]
DRX in a high purity base austenitic stainless steel close to the A304 grade (18 \%Cr, 12.2 \%Ni, 15 ppm C, 10 ppm S, and 10 ppm N) [Gavard, 2001]

\[ Q \approx 400 \text{ kJ/mol} \]

Multiple to single peak transition
\[ Z \approx 10^{13} - 10^{14} \text{ s}^{-1} \]
Microstructural changes – 850 °C, 10^{-3} \text{s}^{-1}

Nucleation by (initial) grain boundary bulging and (growth) twinning
Nucleation by (growth) twinning

increasing time and strain →

- Grain 1
- Grain 2

- Grain 1
- Twin
- Grain 2

- Grain 1
- Grain 3
- Grain 2
Microstructural changes (cont'd)

ε = 0.7

Necklace DRX

Mixture of "young" and "old" grains

ε = 1.5 (≈ steady state)

same area without SGB
Evolutions of the twin boundary area fractions

Single peak case
(850 °C, 10^{-3} s^{-1})

Multiple peak case
(1050 °C, 10^{-3} s^{-1})
DRX in a 718 grade nickel base superalloy (after solution treatment of $\delta$ Ni$_3$Nb phase)

$Q \approx 400$ kJ/mol

Single peak type
Grain refinement

$D_1 = 50$ µm
Fragmentation of the initial microstructure (torsion at 900 °C, $= 10^{-2}$ s$^{-1}$, $\varepsilon = 0.4$)

500 µm

nucleation by (initial) grain boundary bulging
Microstructural changes – 980 °C, 10^{-2} s^{-1}
Evolution of the twin boundary area fraction

nucleation by (growth) twinning
Strain dependence of the subgrain boundary misorientation distributions

\[ \varphi(\theta) = k \theta^{-q} \]

where \( q \) increases with strain

For the steady state (\( q = q_s \)),

\[ \varphi(\theta) \dot{\theta} = k \theta^{-q_s} \dot{\theta} = \text{constant} \]

\[ \Rightarrow \quad \dot{\theta}(\theta) = C \theta^{q_s} \]

(For Al alloys, \( q_s = 0 \))
"Continuous nucleation" (A)
Conclusions

• Discontinuous DRX in low stacking fault energy metals occurs with variable kinetics, e.g. much more slowly in 718 alloy than in 304 steel

• Nucleation of new grains takes place by three distinct mechanisms:
  - (initial) grain boundary bulging,
  - repeated (growth) twinning,
  - and, in alloy 718, "continuous nucleation", similar to CDRX

• Slower grain boundary migration rates in alloy 718 may be attributed to
  - smaller driving forces due to more efficient dynamic recovery,
  - grain boundary mobility reduced by niobium solutes

• Respective contributions of CDRX and DDRX in nickel base superalloys could be controlled by adjusting volume fractions of Nb or other addition elements