Crystallographic texture

- Introduction
- Representation of Texture
- Experimental Methods for Texture Determination
- Deformation Texture
- Annealing Texture

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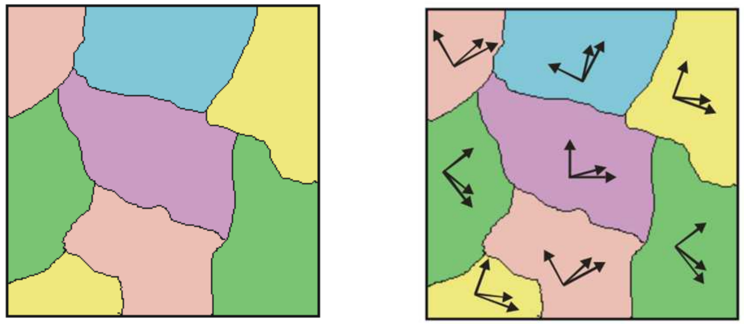
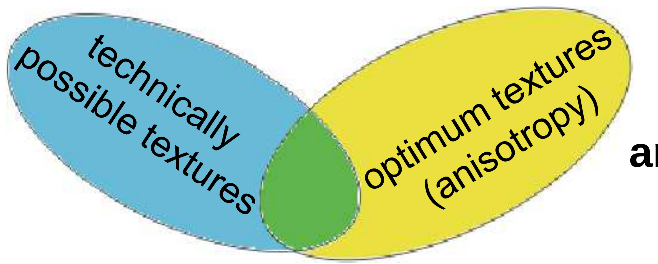
Texture and anisotropy of polycrystals

grain structure **texture**



texture forming processes



anisotropic properties

directional solidification
deformation
recrystallization
etc.

elasticity
plasticity
magnetism
etc.

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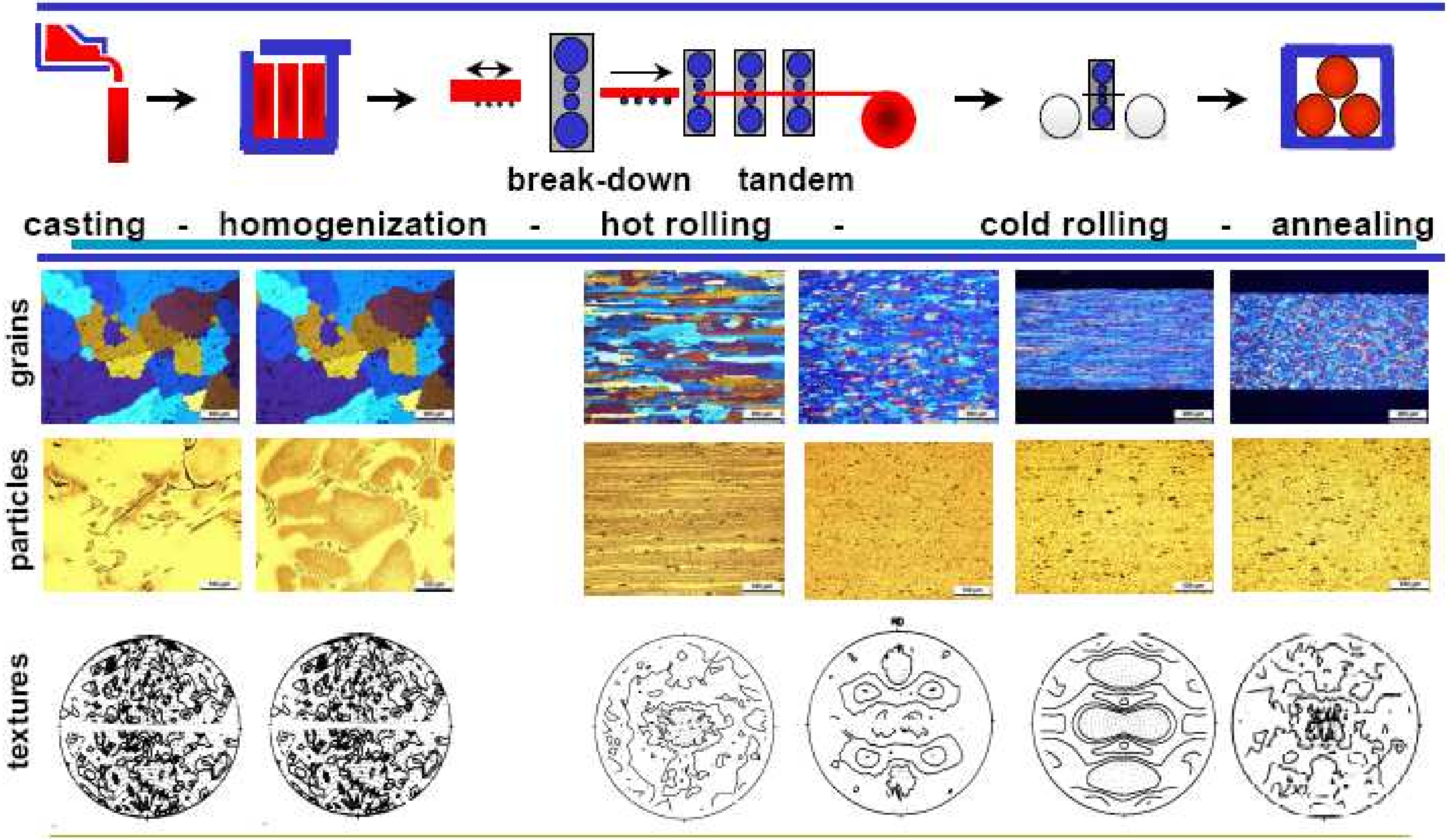
Evolution of typical microstructures in industrial aluminium sheet production



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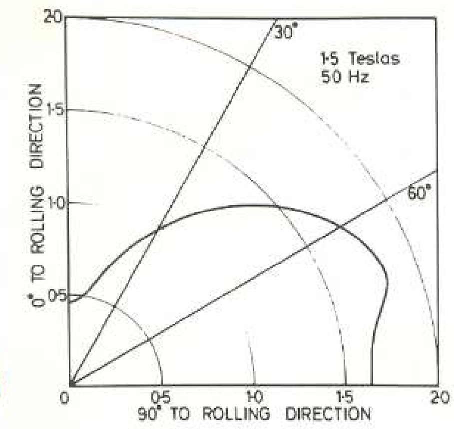
HYDRO

Texture and anisotropy of polycrystals

- **Texture in polycrystalline materials is ubiquitous**
- Goss oriented Silicon steel



- Earing of aluminum cans
- Substrate for semiconductor tapes
- Fatigue properties of aluminum and titanium all
- Quality of epitaxial films: **$YBa_2Cu_3O_{7-\delta}$ Pmmm space group c$_\perp$ epitaxy**
- Recoverable strain in SMA

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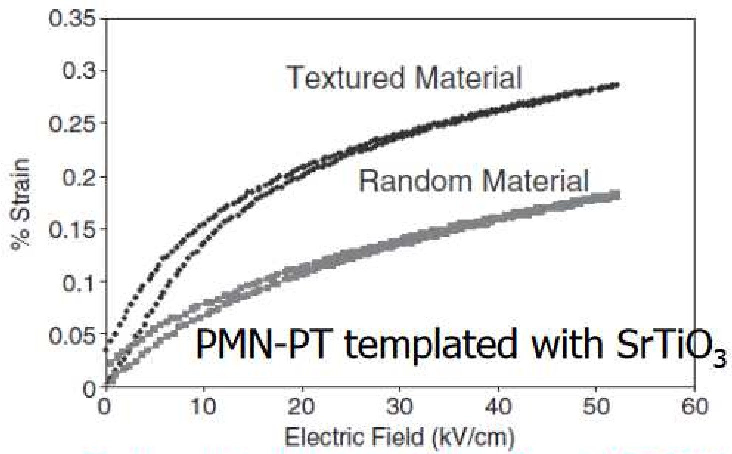
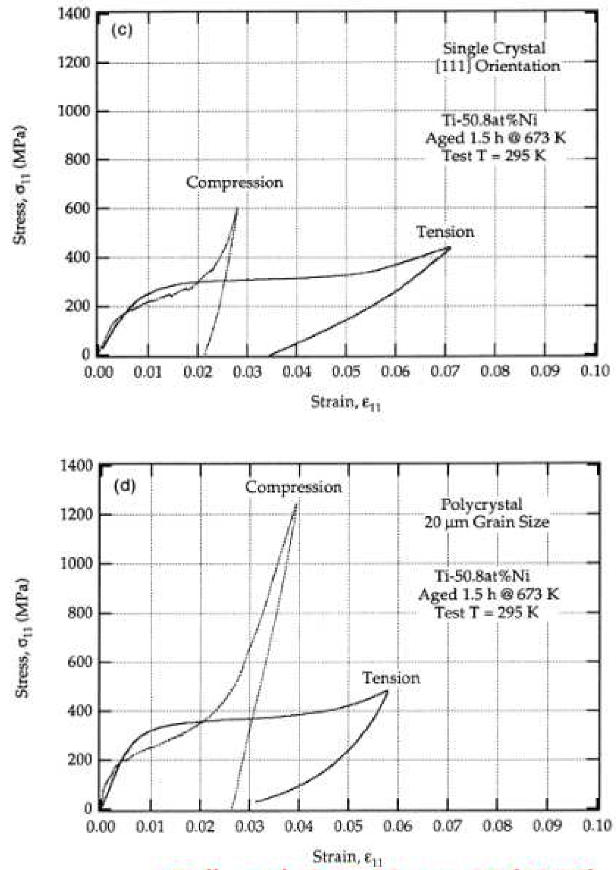
Texture and anisotropy of polycrystals

www.alumatter.org.uk



Seabaugh et al. J. Intel. Mater. Struct. 15 (2004)



Gall et al. Acta Mater. 47 (1999)

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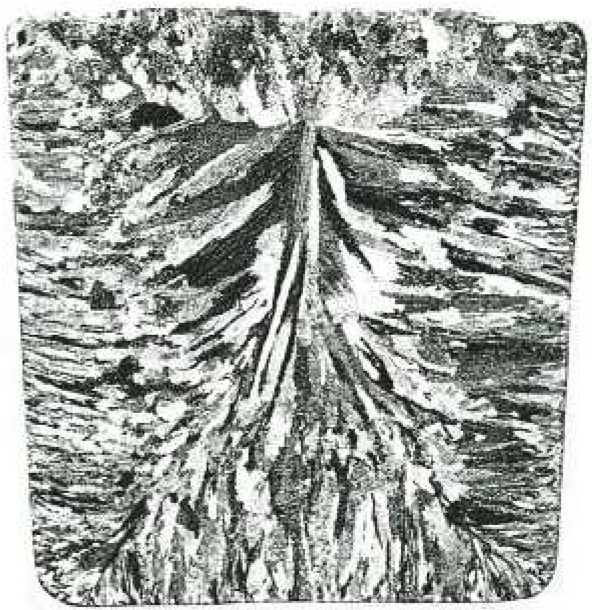
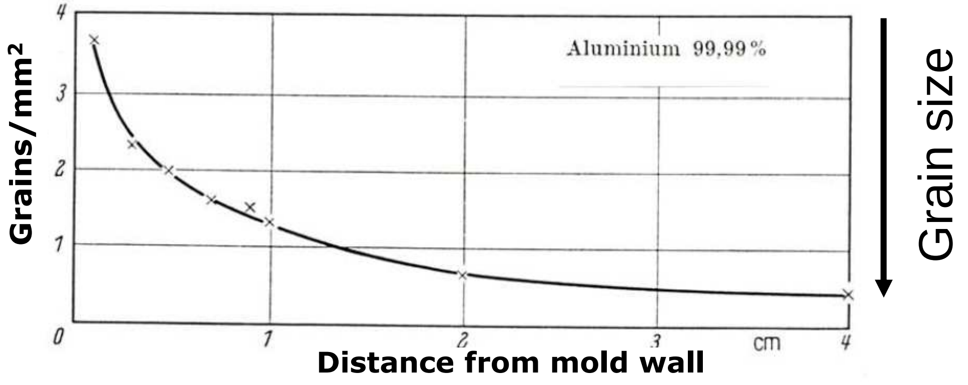
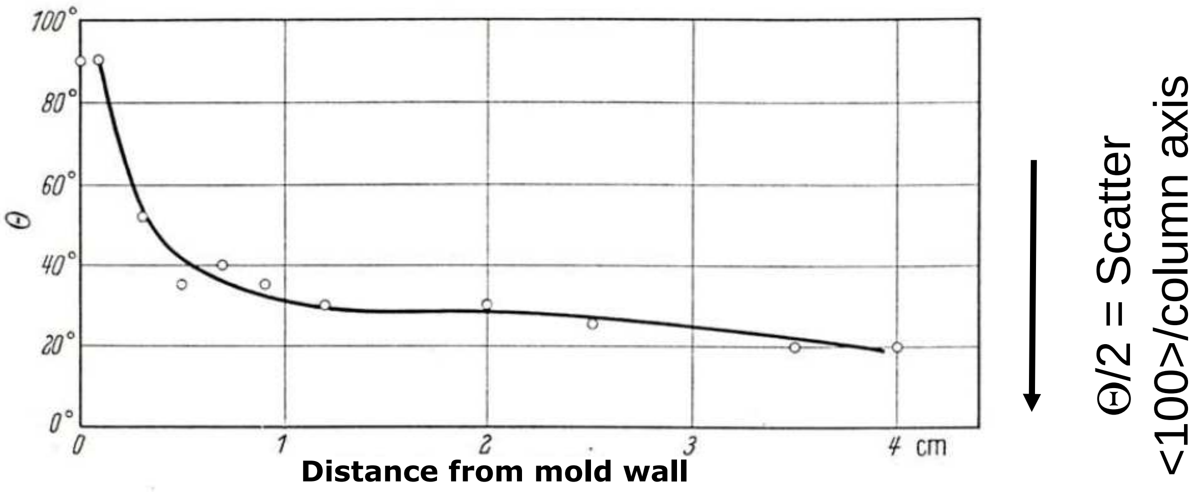
Cast grain stucture and cast texture







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Walton & Chalmers, 1959

Crystallization

Stationary melt

Requirement for growth texture:
a) temperature gradient
b) anisotropic crystal growth ⇒ growth selection

Cast texture is correlated with dendrite alignment
⇒ related to dendrite formation
Requirement for dendrite formation:
thermally or constitutionally supercooled melt
ahead of growth front, negative T-gradien
Moving melt (laminar flow, e.g. magma flow)

Dendrite growth and cast texture

Tabelle 53. *Zusammenhang zwischen dem dendritischen Wachstum und der Gußtextur* (nach Walton und Chalmers)

Metall bzw. Legierung	Struktur	Dendriten-Richtung beobachtet	Dendriten-Richtung erwartet	Gußtextur
Fe–Si	kubisch raumzentriert		⟨100⟩	⟨100⟩
β-Messing	kubisch raumzentriert		⟨100⟩	⟨100⟩
Na	kubisch raumzentriert	⟨100⟩	⟨100⟩	
Al	kubisch flächenzentriert	⟨100⟩	⟨100⟩	⟨100⟩
Cu	kubisch flächenzentriert		⟨100⟩	⟨100⟩
Ag	kubisch flächenzentriert		⟨100⟩	⟨100⟩
Au	kubisch flächenzentriert		⟨100⟩	⟨100⟩
Pb	kubisch flächenzentriert	⟨100⟩	⟨100⟩	⟨100⟩
Cd	hexagonal dicht. Kugelp.		$\langle 10\bar{1}0\rangle$	$\langle 10\bar{1}0\rangle$
Zn	hexagonal dicht. Kugelp.	$\langle 10\bar{1}0\rangle$	$\langle 10\bar{1}0\rangle$	$\langle 10\bar{1}0\rangle$
Mg	hexagonal dicht. Kugelp.		$\langle 10\bar{1}0\rangle$	unsicher
Bi	rhomboedrisch			⟨111⟩
β-Sn	tetragonal	⟨110⟩	⟨110⟩	⟨110⟩

Wassermann & Grewen, 1962

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Plastic deformation

Orientation change through single slip of a single crystal

Models for deformation texture development of polycrystals:

1) Sachs (1928)

Stress equilibrioum: $\sigma_g = \sigma$

$\Rightarrow$ slip (in general single slip) on slip system with highest Schmid factor

$\Rightarrow$ Formation of overlaps and pores at grain boundaries

2) Taylor (1938)

Strain compatibility: $\varepsilon_g = \varepsilon$

$\Rightarrow$ Activation of 5 independent slip systems (von Mises criterion)

independent $\equiv$ shape change through slip on this system should not be achieved by combined slip on other systems.

5 independent systems, because each grain should be able of a general shape change, i.e. 5 independent components of the strain tensor (ε_{ik}) should be realized through slip on slip systems.

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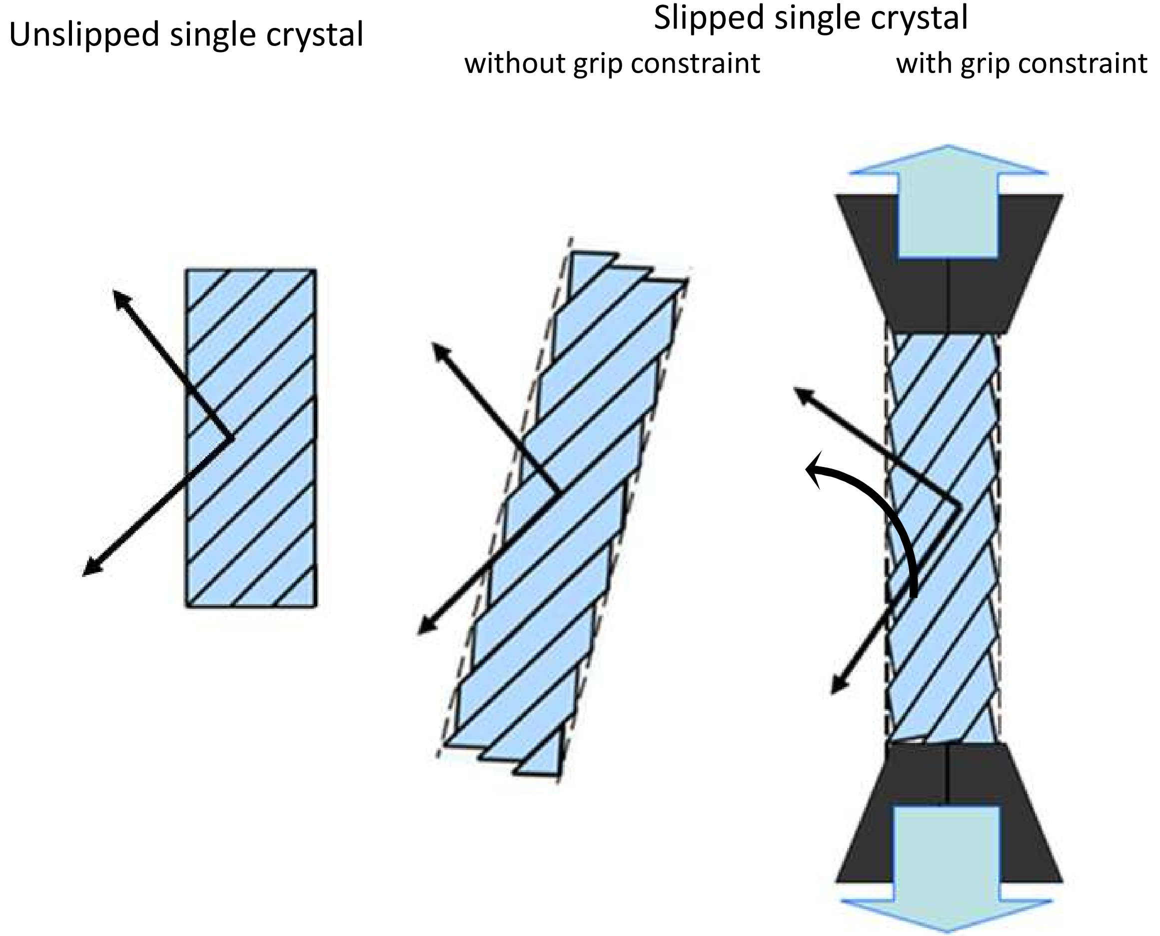
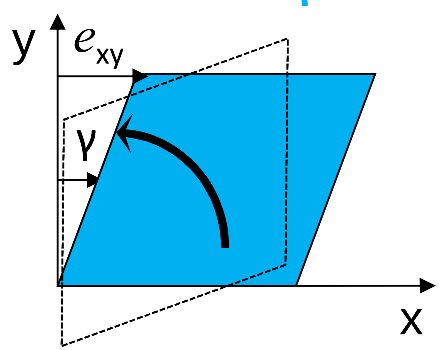
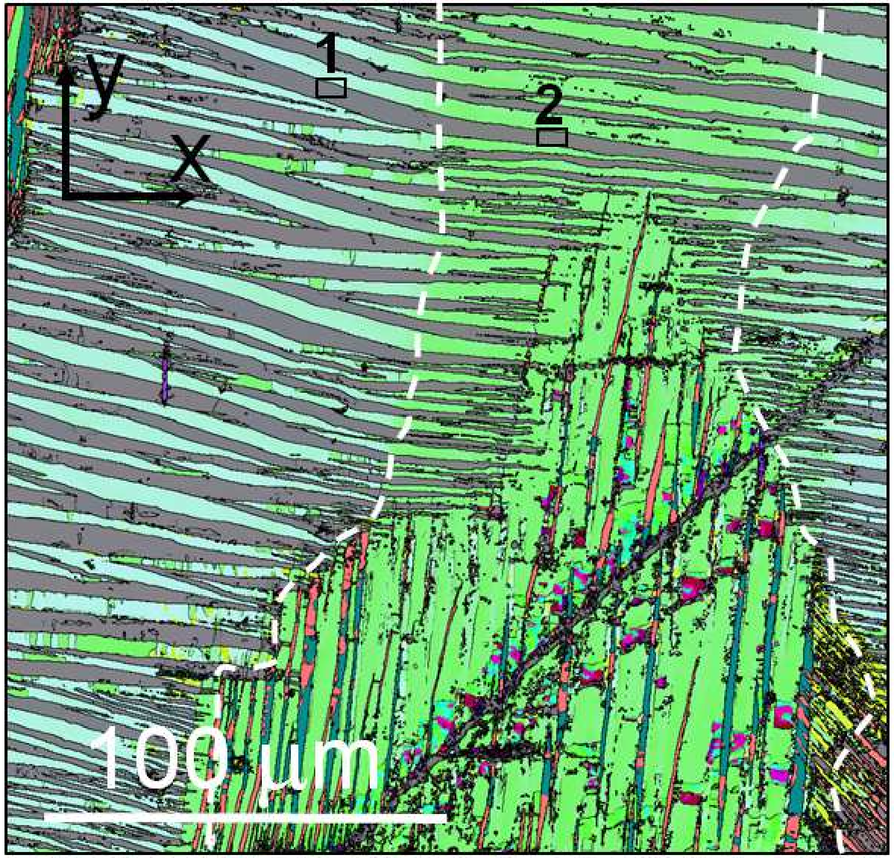
Orientation change through deformation

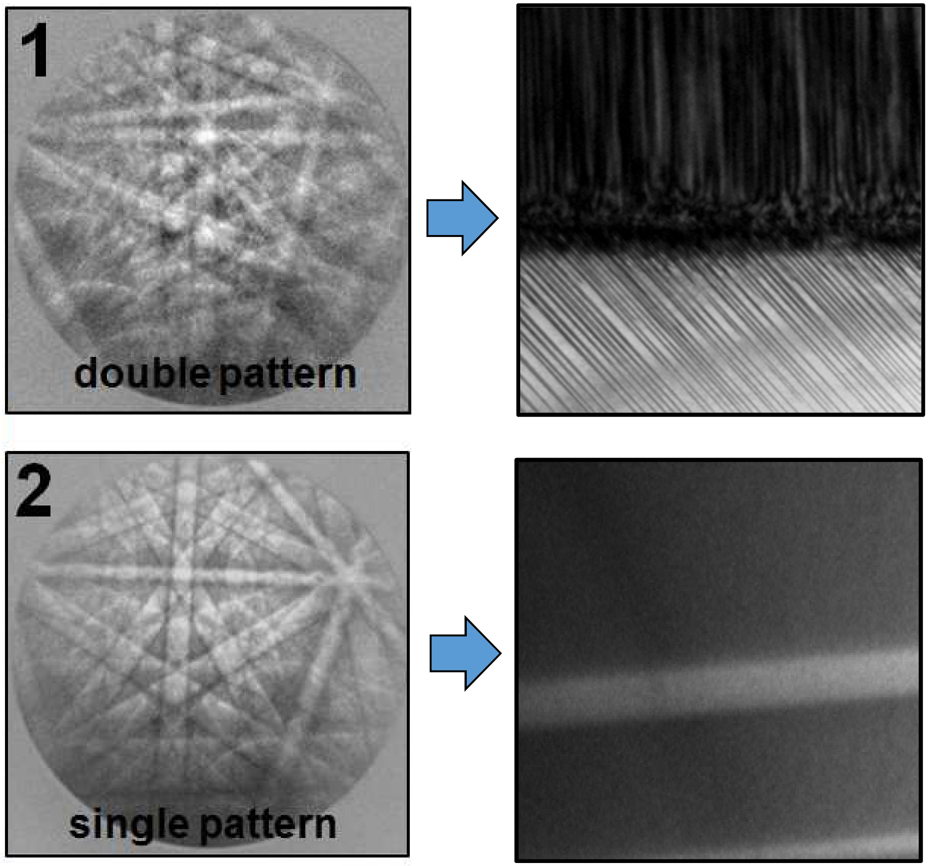


$$e_{kl} = \begin{bmatrix} e_{xx} & e_{xy} & e_{xz} \\ e_{yx} & e_{yy} & e_{yz} \\ e_{zx} & e_{zy} & e_{zz} \end{bmatrix}$$



Training procedure





EBSD mapping, All Euler color coding

Lüders type deformation

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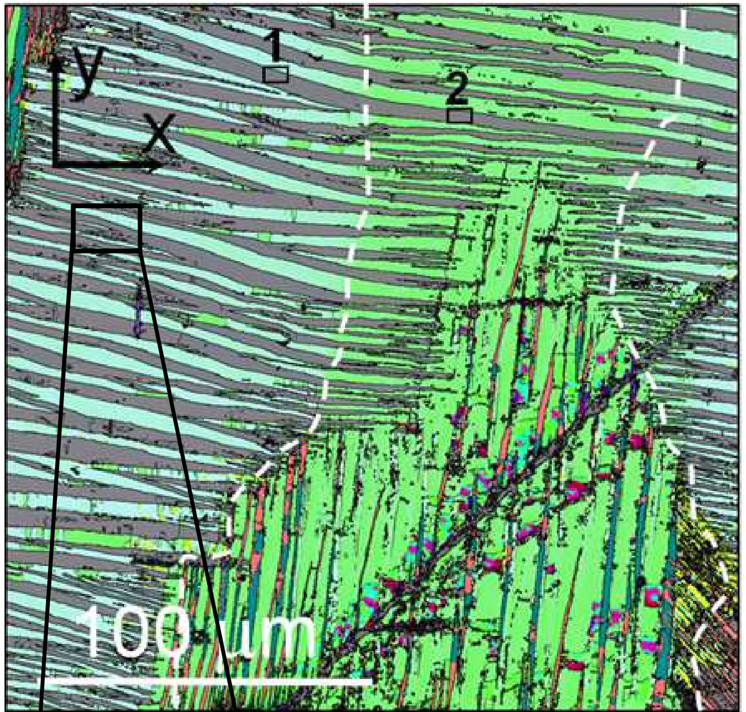
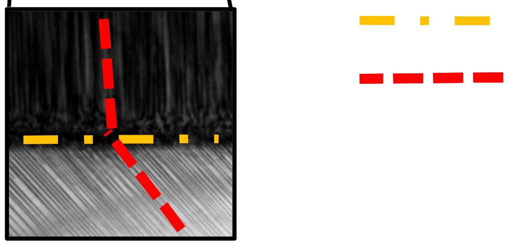
M.J. Szczerba and R. Chulist, Acta Mater. 85 (2015) 67-73

Nanotwinning

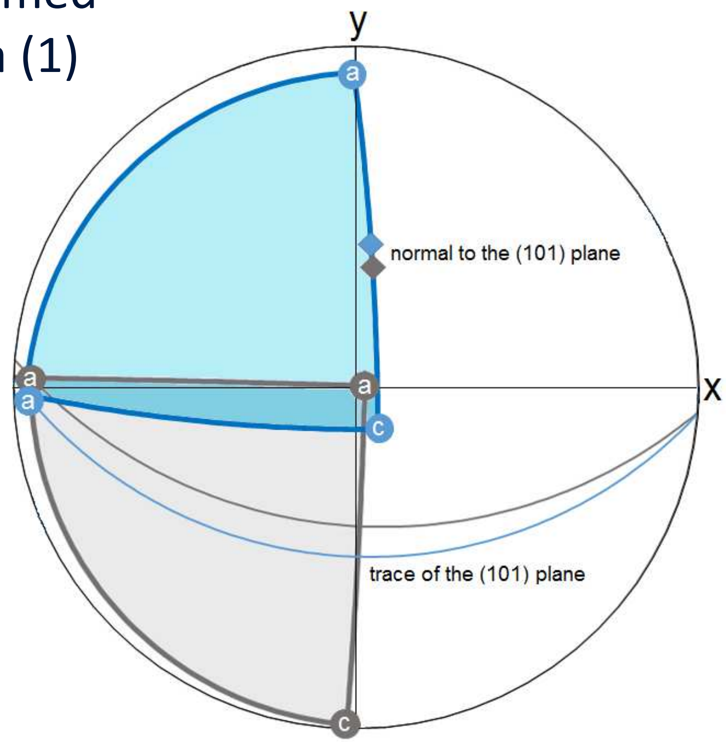


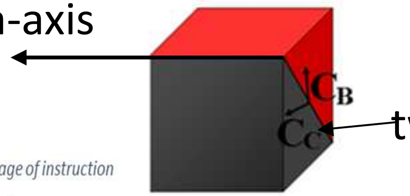
EBSD mapping, All Euler color coding



M.J. Szczerba and R. Chulist, Acta Mater. 85 (2015) 67-73

undeformed area (1)





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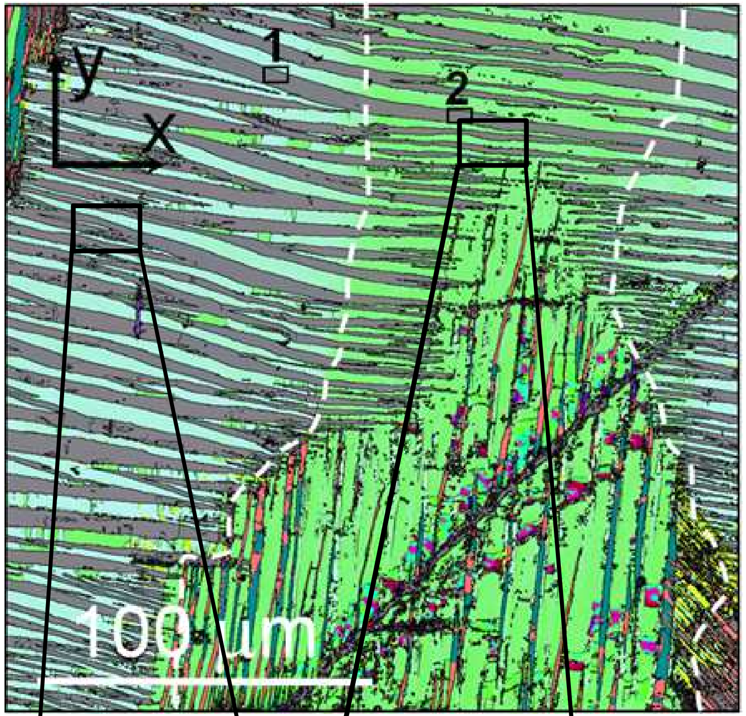
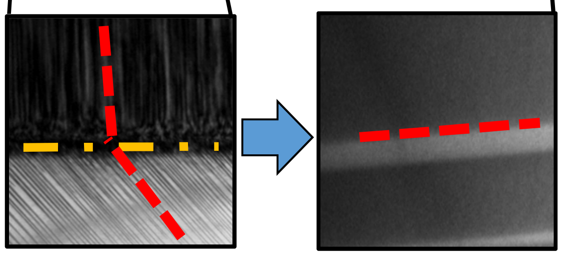
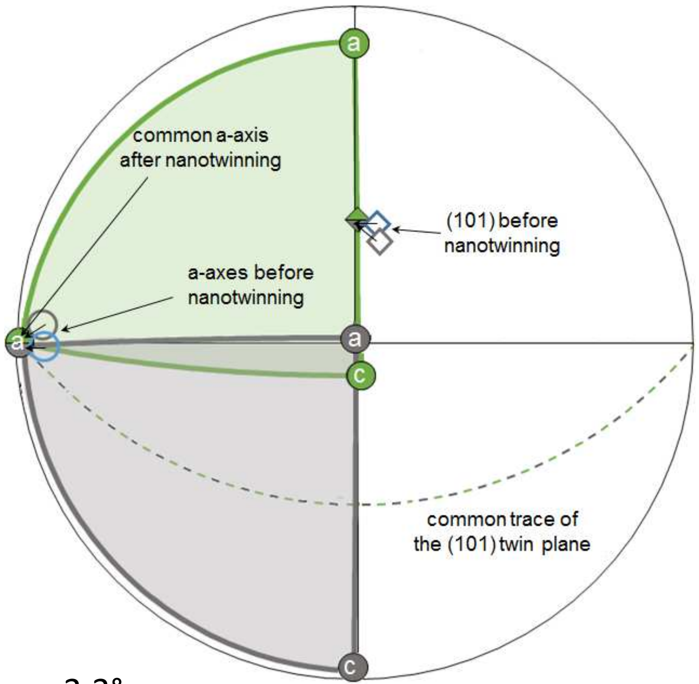
Nanotwinning



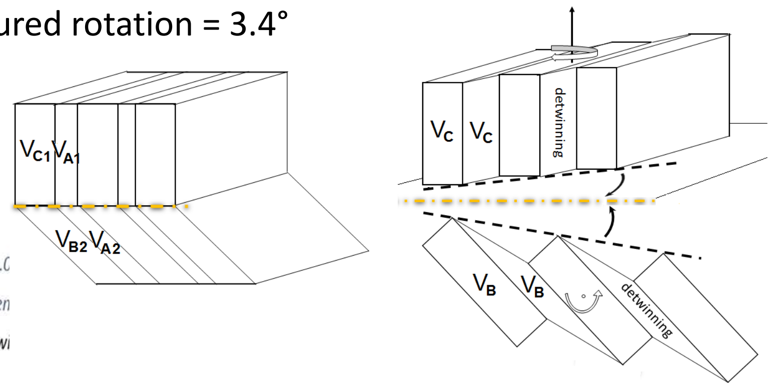
EBSD mapping, All Euler color coding



deformed
area (2)



calculated rotation = 3.3°
measured rotation = 3.4°



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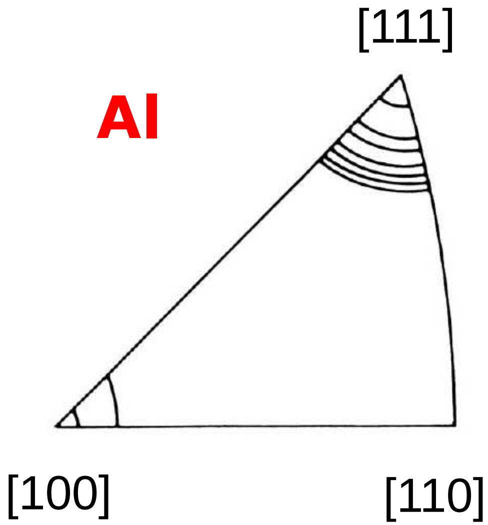
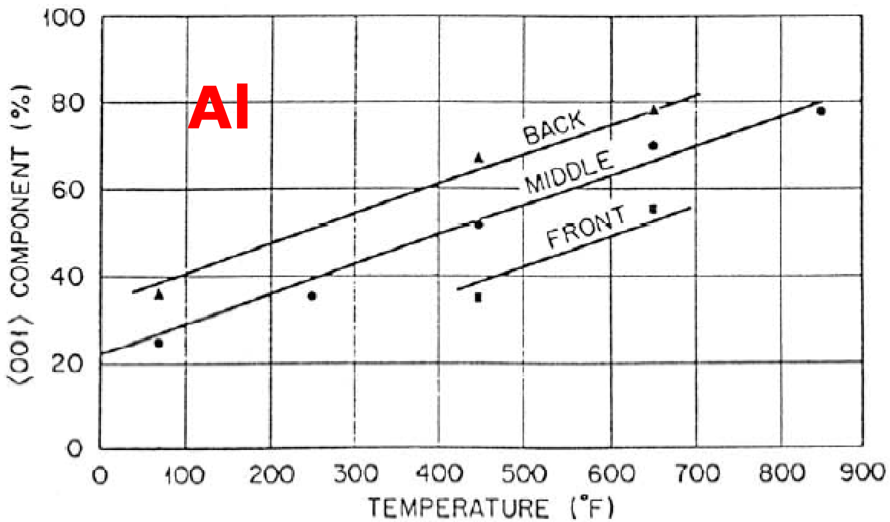
Crystallography of slip and twinning in cubic metals

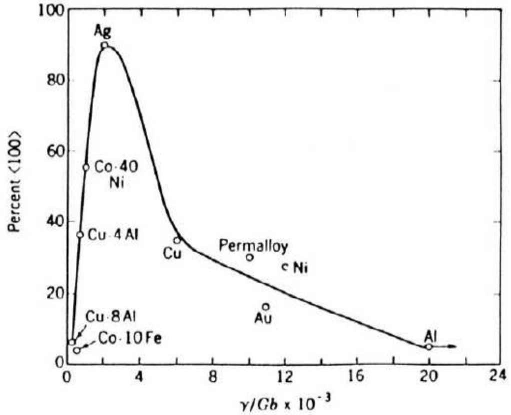
Structure	Slip System	
	Plane	Direction
fcc	{111}	<110>
bcc	{110}	<111>
	{112}	<111>
	{123}	<111>

Structure	Twinning shear	Twinning Plane	Twinning Direction
fcc	0.707	{111}	<112>
bcc	0.707	{112}	<111>

Tension textures of fcc metals

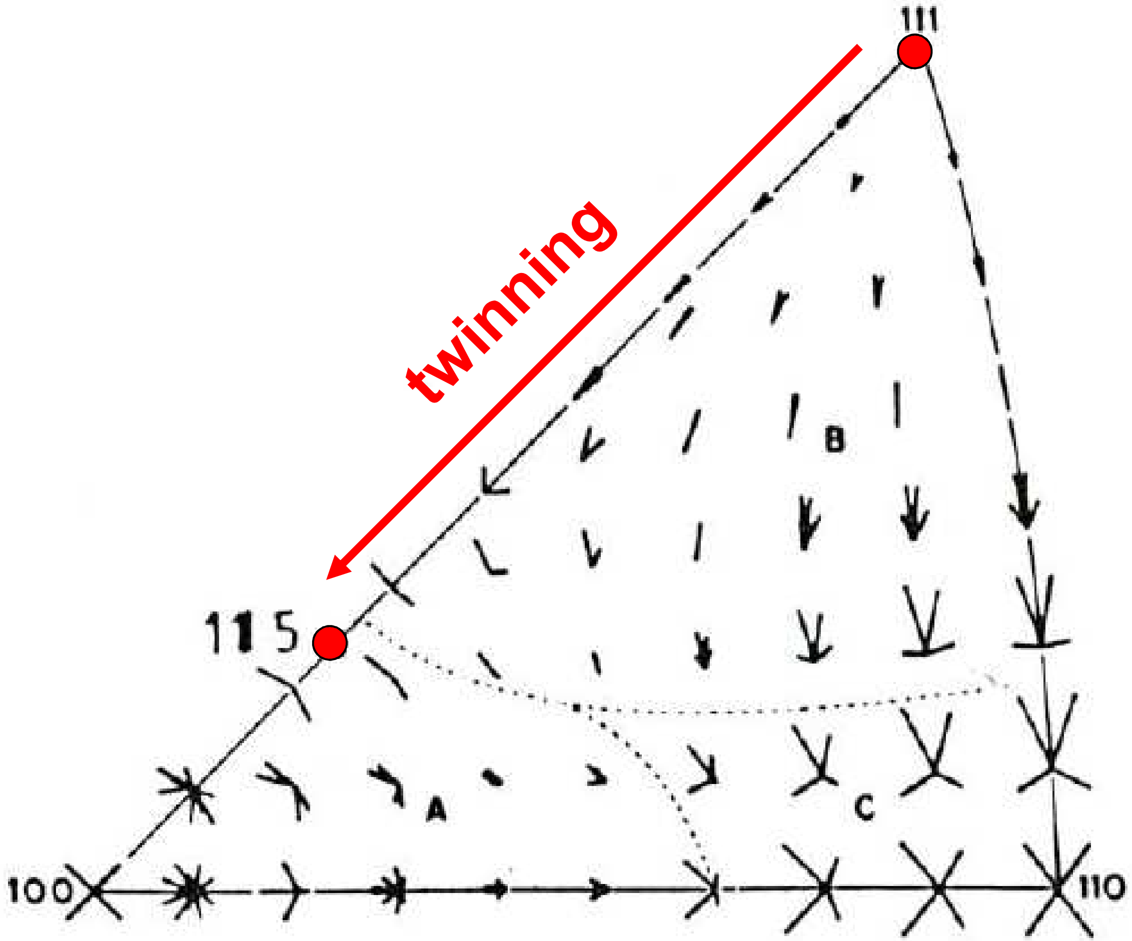






English & Chin, 1965

Orientation changes in tension (FC Taylor)



Chin et al., 1967

Young's Modulus

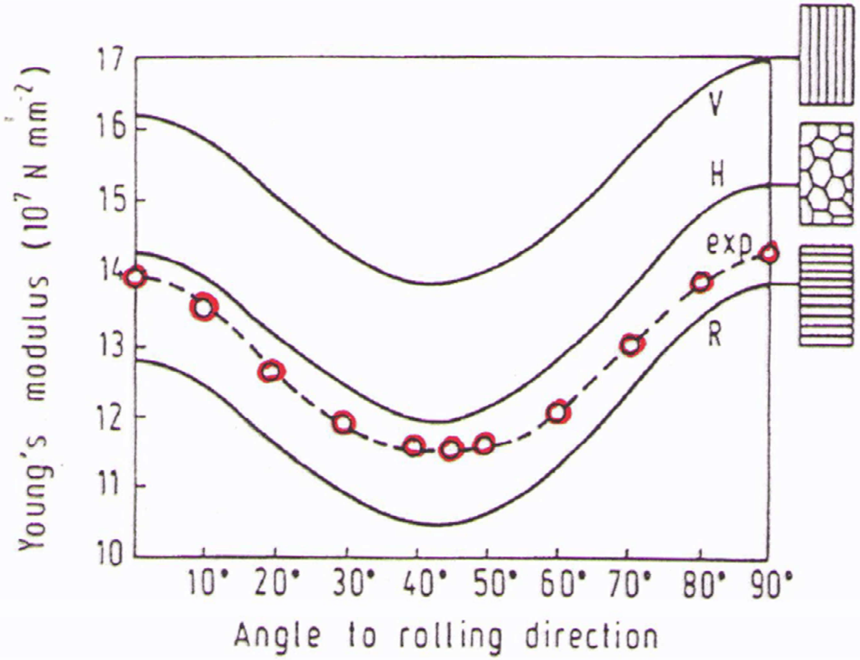


Fig. 5 Young's modulus as a function of the direction in the sheet plane for a textured copper sheet compared with the Voigt–Reuss–Hill approximations calculated from the ODF.

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Compression textures of fcc metals

	n>>4	n≈4	n≈3
Al-2%Mg	T=25°C, $\dot{\varepsilon}=10^{-2}s^{-1}$ T=282°C, $\dot{\varepsilon}=10^{-1}s^{-1}$	T=282°C, $\dot{\varepsilon}=10^{-5}s^{-1}$ T=380°C, $\dot{\varepsilon}=10^{-3}s^{-1}$	T=360°C, $\dot{\varepsilon}=5\cdot10^{-5}s^{-1}$ T=440°C, $\dot{\varepsilon}=10^{-4}s^{-1}$
Al-5%Mg	T=25°C, $\dot{\varepsilon}=10^{-2}s^{-1}$ T=300°C, $\dot{\varepsilon}=5\cdot10^{-2}s^{-1}$	T=473°C, $\dot{\varepsilon}=1s^{-1}$ T=380°C, $\dot{\varepsilon}=10^{-3}s^{-1}$	T=473°C, $\dot{\varepsilon}=10^{-2}s^{-1}$ T=473°C, $\dot{\varepsilon}=10^{-4}s^{-1}$ **(Tension <u>or</u> Compression)**

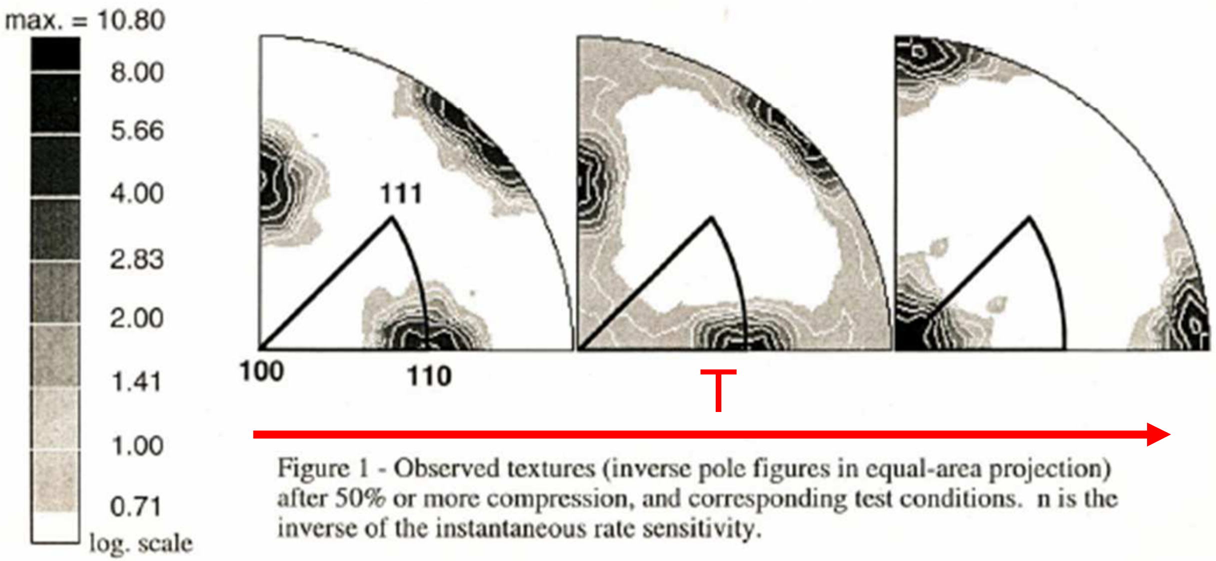
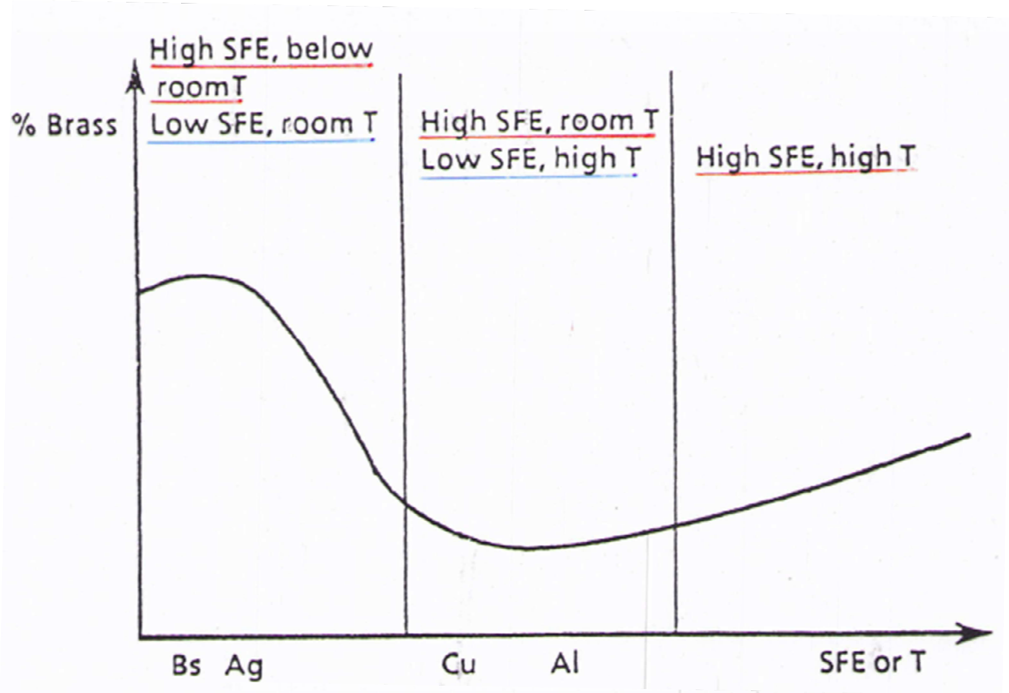


Figure 1 - Observed textures (inverse pole figures in equal-area projection) after 50% or more compression, and corresponding test conditions. n is the inverse of the instantaneous rate sensitivity.

Kocks et al., 1994

Deformation textures of fcc metals



	Brass-Type	Copper-Type
Tension	<100> fibre	<111> fibre
Rolling	α fibre	β fibre
Torsion	Mostly B	Mostly C

Bacroix, 1987

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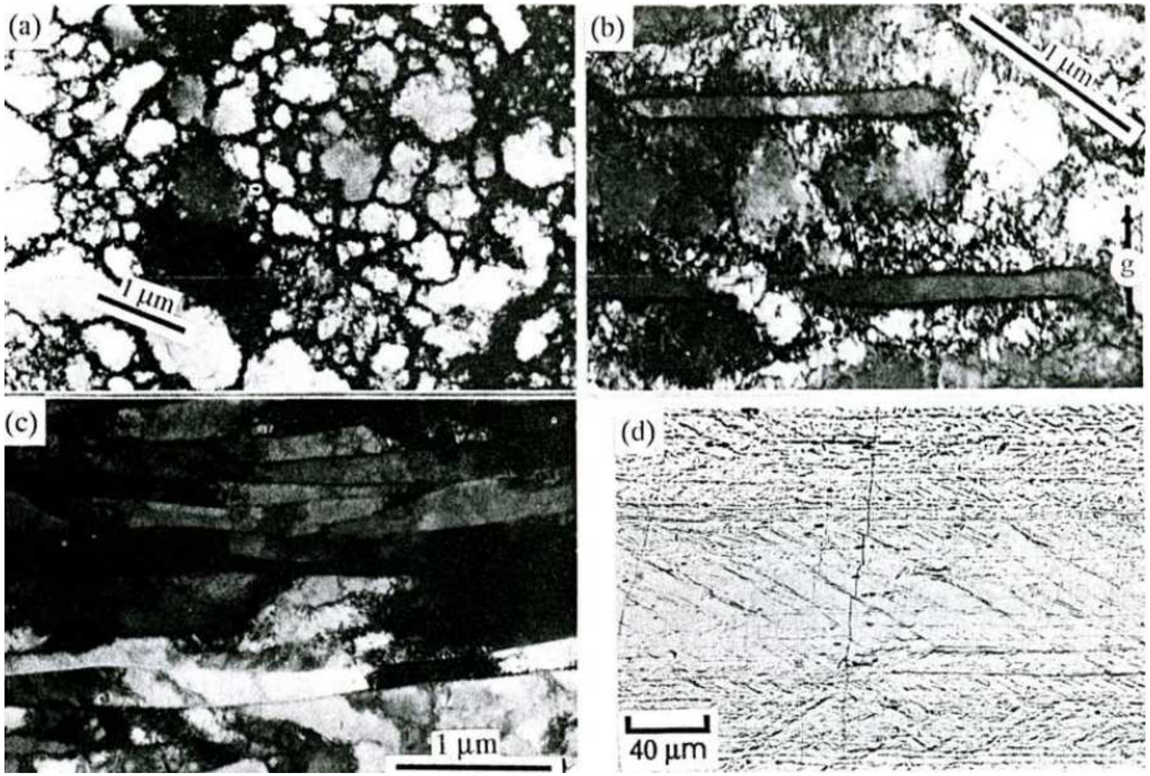
Microstructure in deformed metals (cold rolled Cu)

cell structure **mirobands**

25% **18%**



98% **83%**

mirobands **shear bands**

Humphreys & Hatherley, 1995

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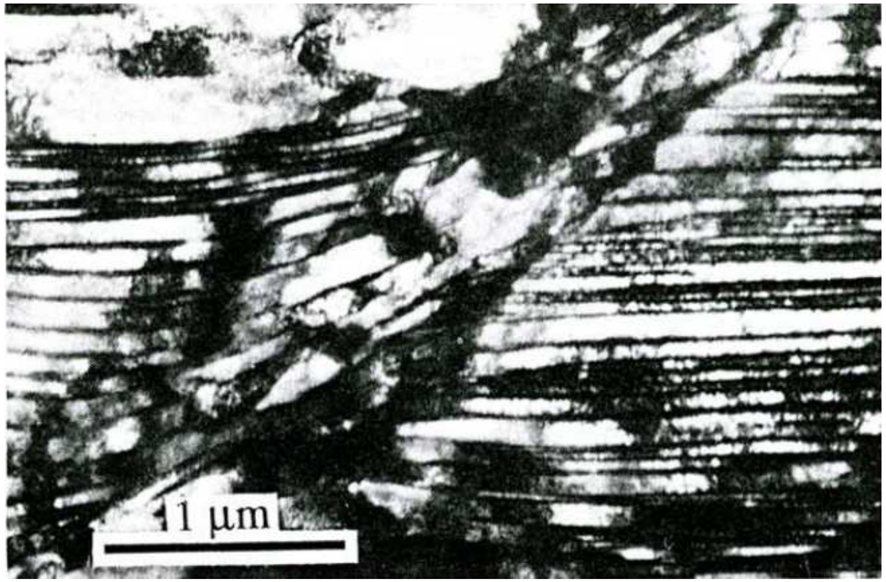
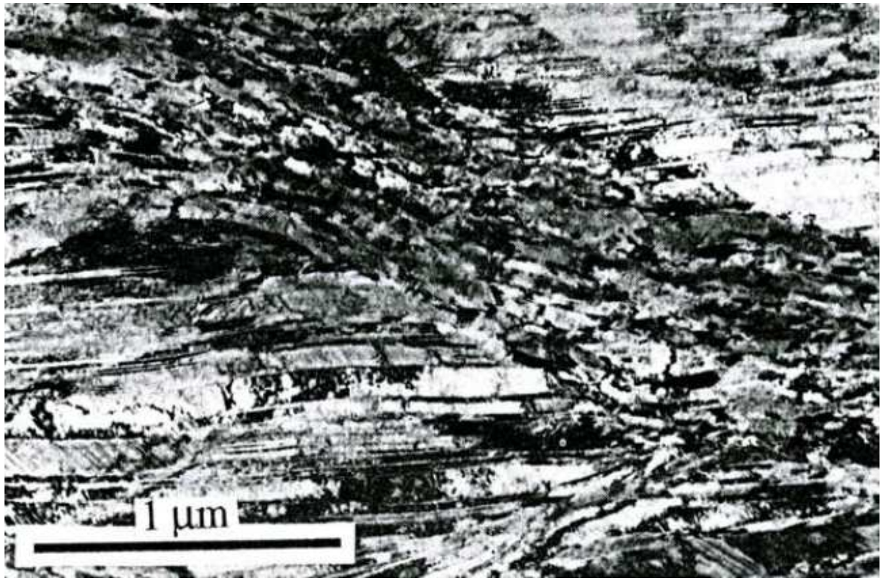
Shear bands in rolled metals

(110)[1-11] Cu single crystal
rolled 65% at 77K



Köhlhoff et al., 1988

70:30 brass
rolled 50% at RT



Duggan et al., 1978

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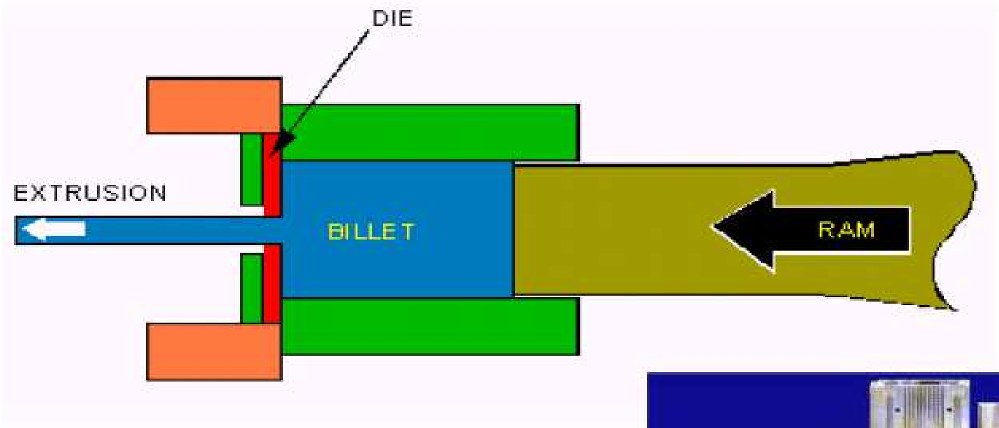
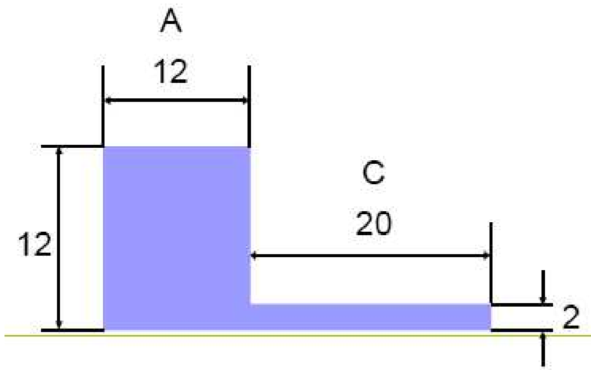
Extrusion of aluminium profiles





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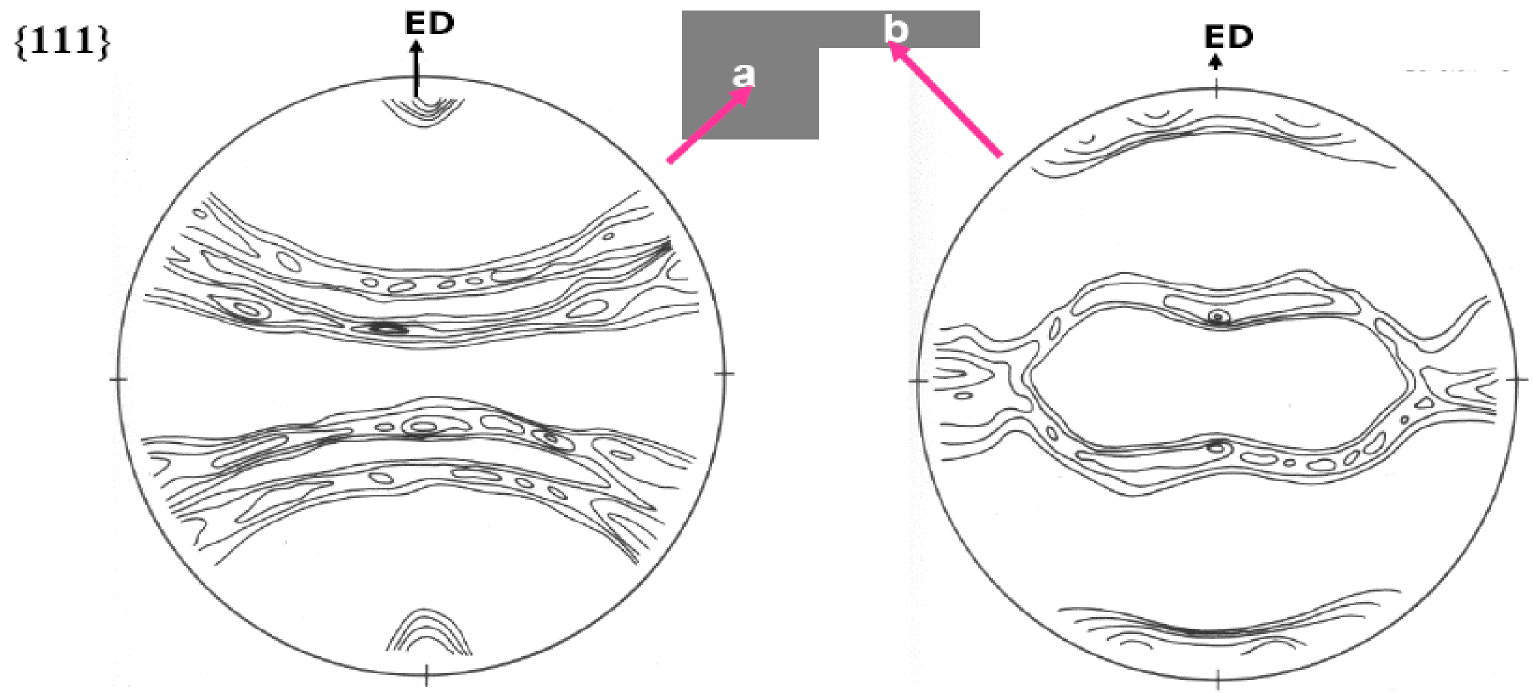
Texture variation in extruded Al alloy profiles



(a) <111> / <100> fiber texture (b) plane strain texture

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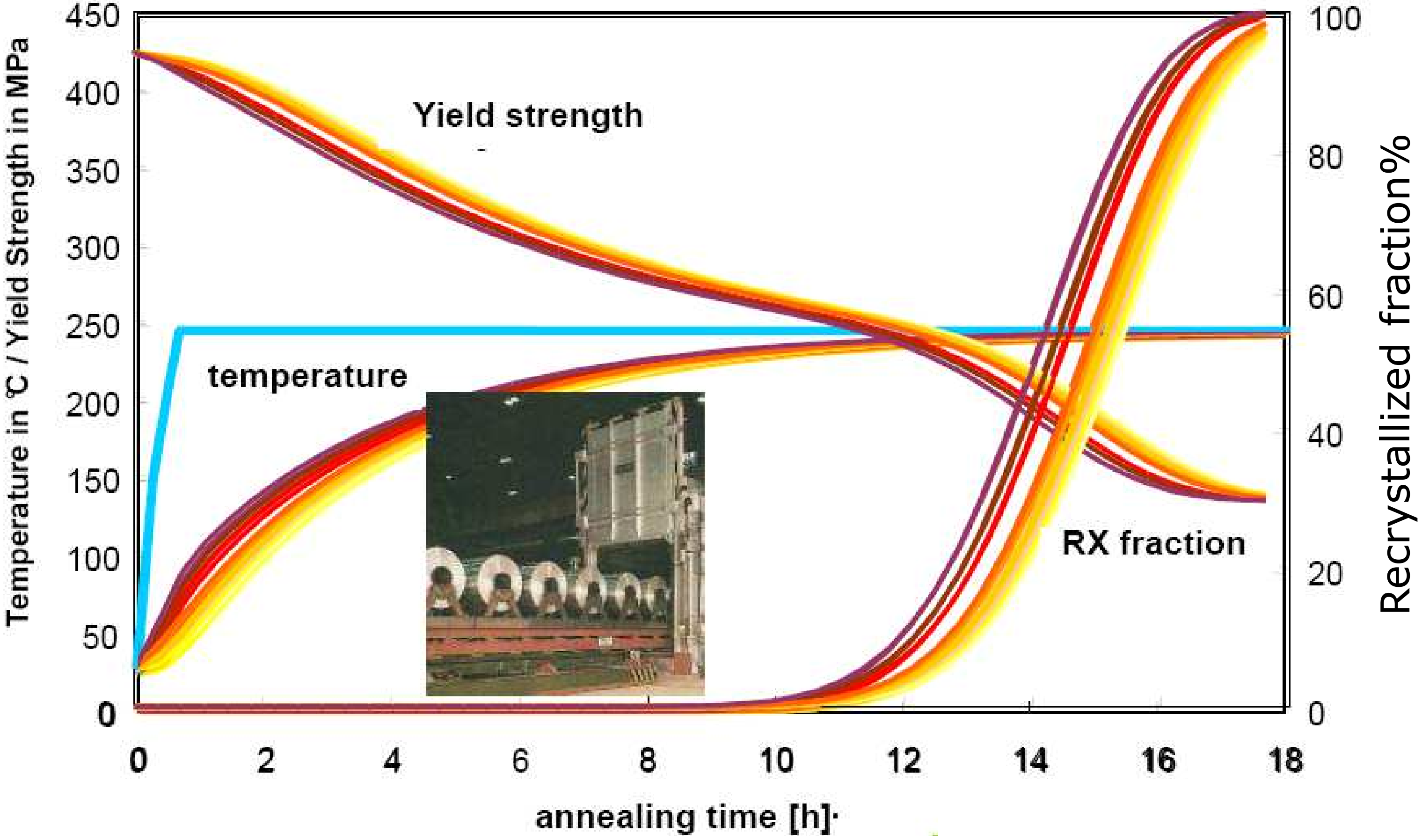
HYDRO

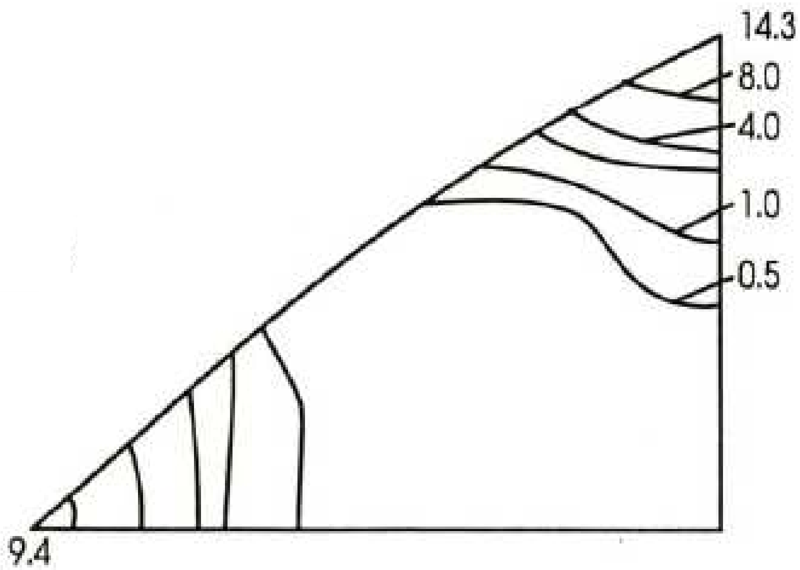
Temperature, recrystallization and strength evolution during coil annealing



Compression and tension textures in a-Fe

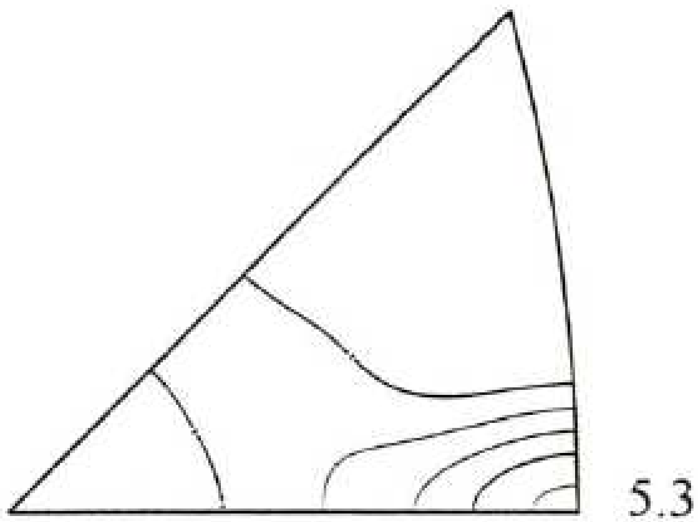
compression **tension**

[111]



[100] [110]

[111]



[100] [110]

Dillamore et al., 1974

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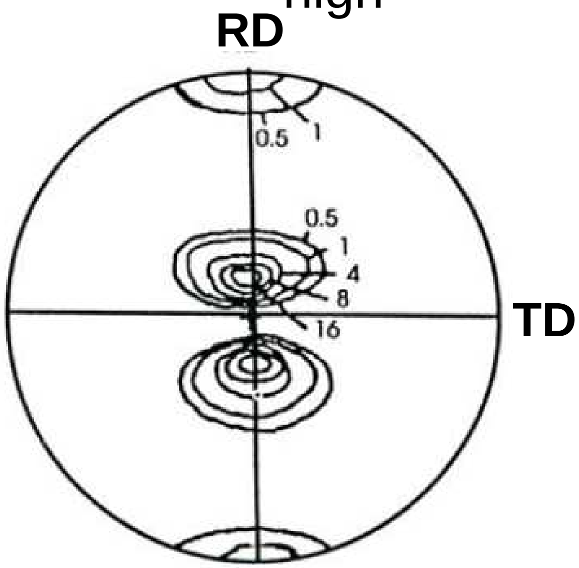
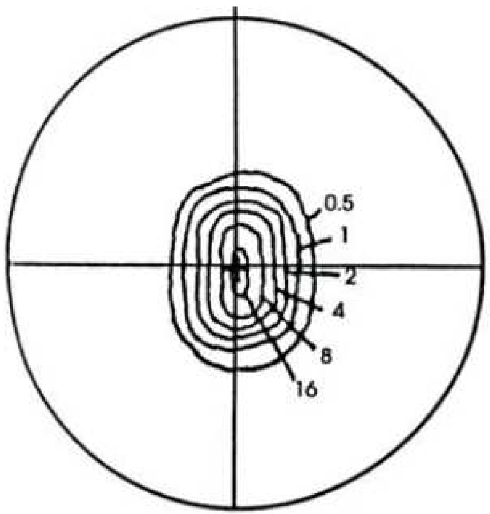
(0001) pole figures of rolled hexagonal metals

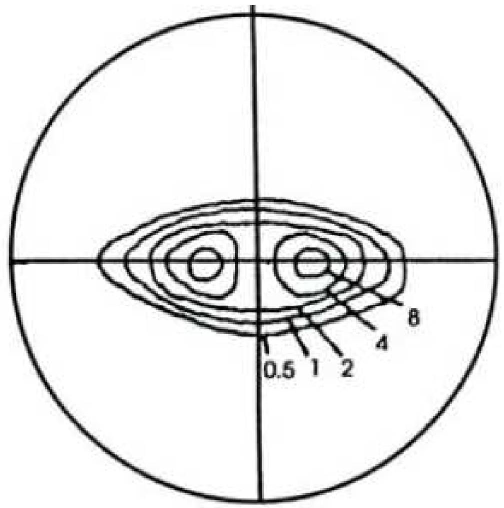
Zn
c/a = 1.856
high



Mg
c/a = 1.624
ideal =1.633

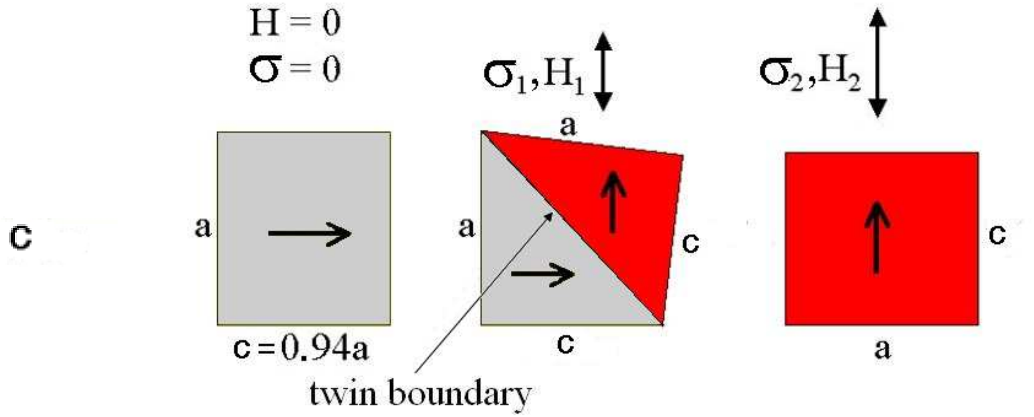


Ti
c/a = 1.588
low



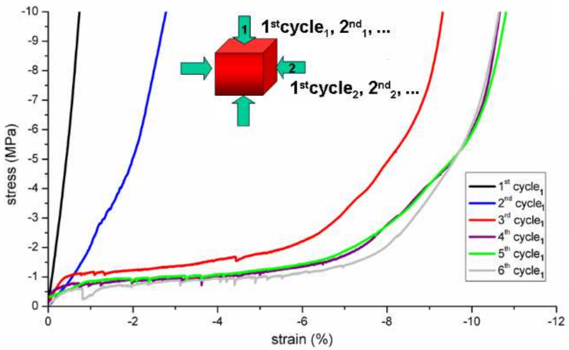
Hatherly & Hutchinson, 1979

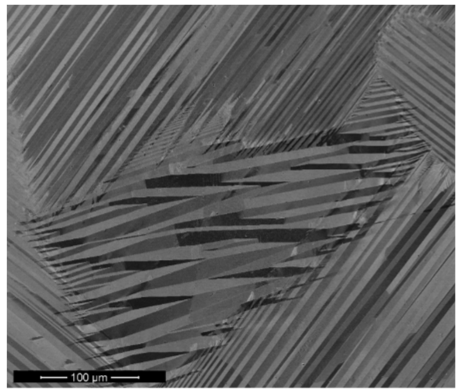
Magnetic field-induced strain



Requirements:

- ❑ high magnetocrystalline anisotropy
- ❑ highly mobile twin boundaries
  - ➢ Low twinning stress
  - ➢ Training process





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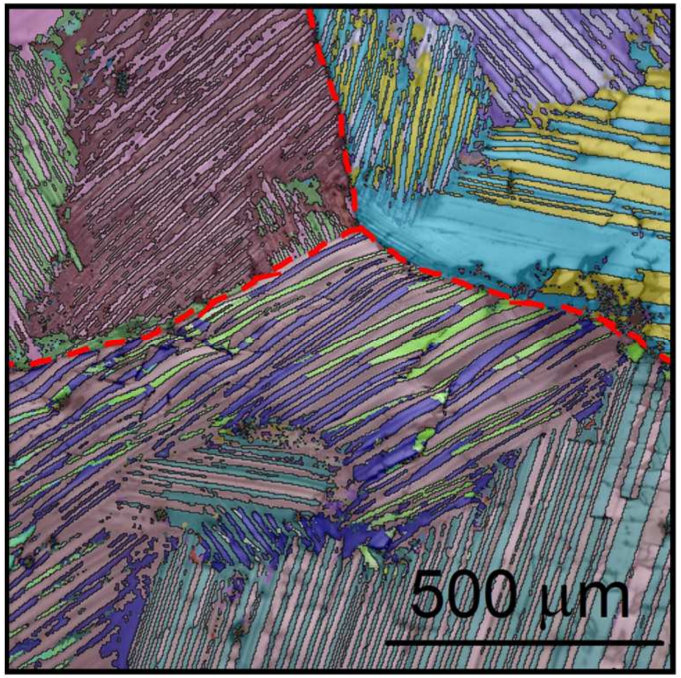
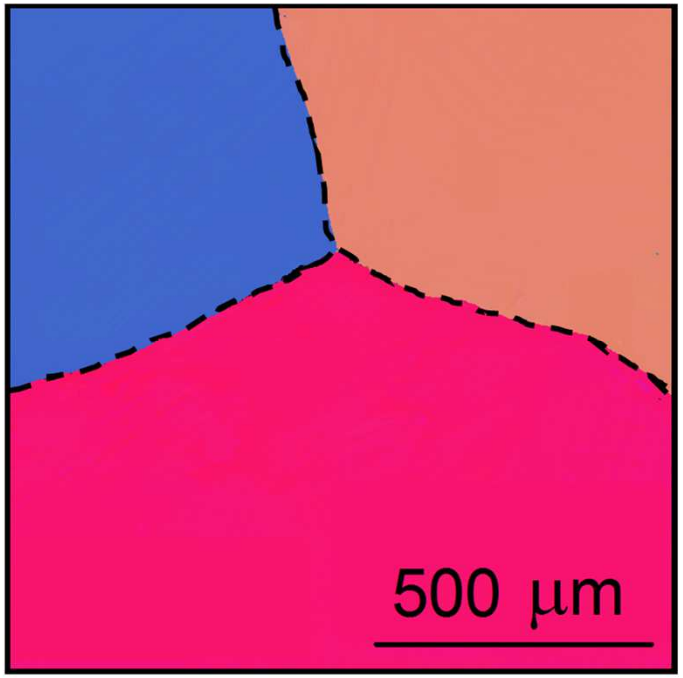
Texture inheritance

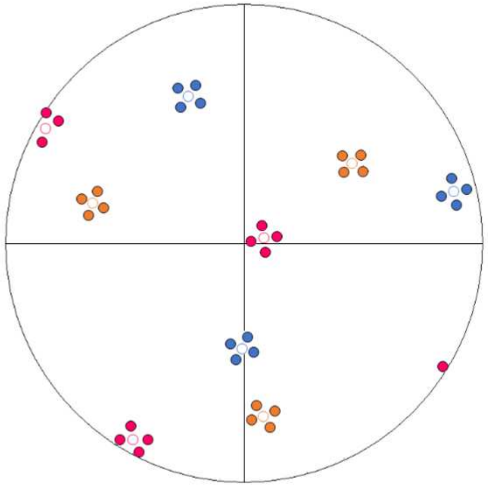
Martensite (RT)



Austenite (110°C)



(001) pole figure



○ austenite
● martensite

EBSD mapping, All Euler color coding

Orientation description

- {hkl}<uvw>
- Pole figures
- Euler Angles
- Axis angle pair Rodriques-Frank vector
- Quaternions

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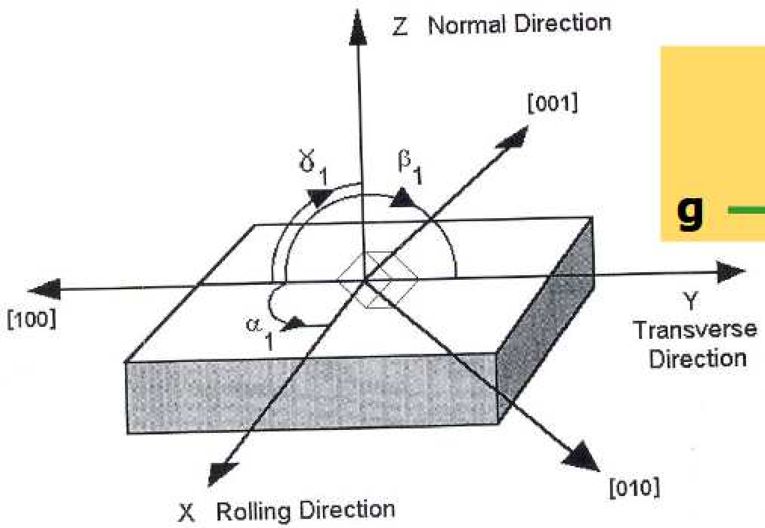
Orientation matrix



$$C_c = g\, C_s$$

g → orientation matrix

$$g = \begin{pmatrix} \cos\alpha_1 & \cos\beta_1 & \cos\gamma_1 \\ \cos\alpha_2 & \cos\beta_2 & \cos\gamma_2 \\ \cos\alpha_3 & \cos\beta_3 & \cos\gamma_3 \end{pmatrix} = \begin{pmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} & g_{32} & g_{33} \end{pmatrix}$$

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Coordinate systems

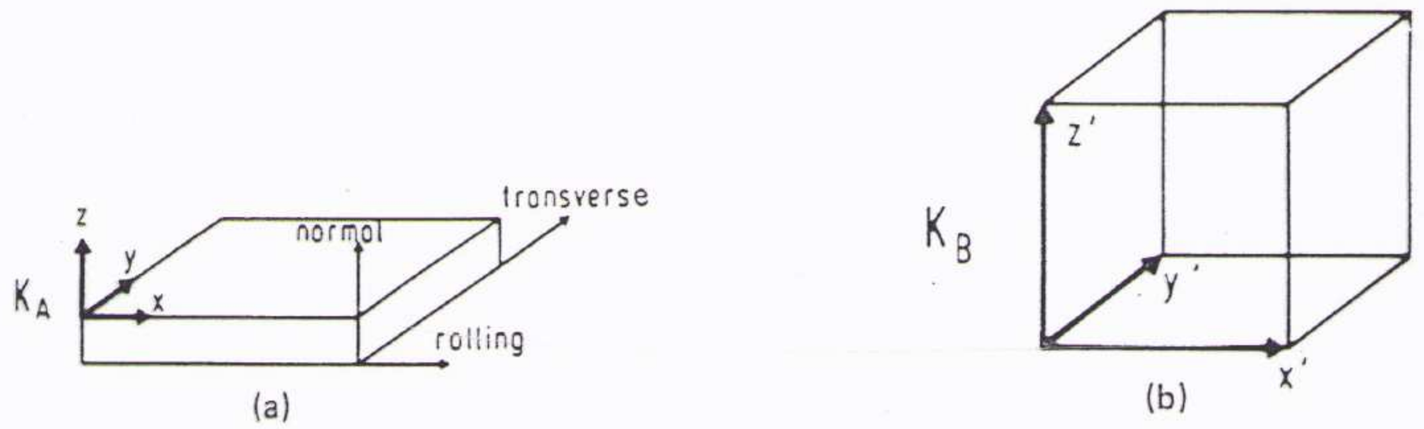

Fig. 2 (a) Possible choice of the sample coordinate system K_A in a metal sheet

(b) Possible choice of the crystal coordinate system K_B in the cubic system.

$$K_A \text{---} g \longrightarrow K_B$$

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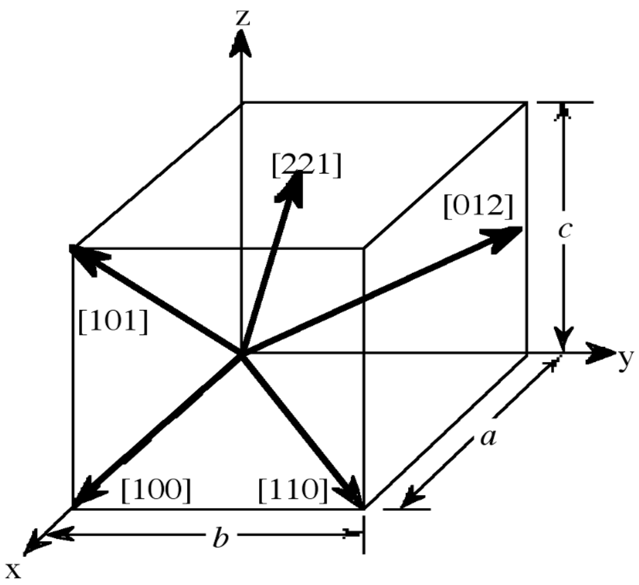
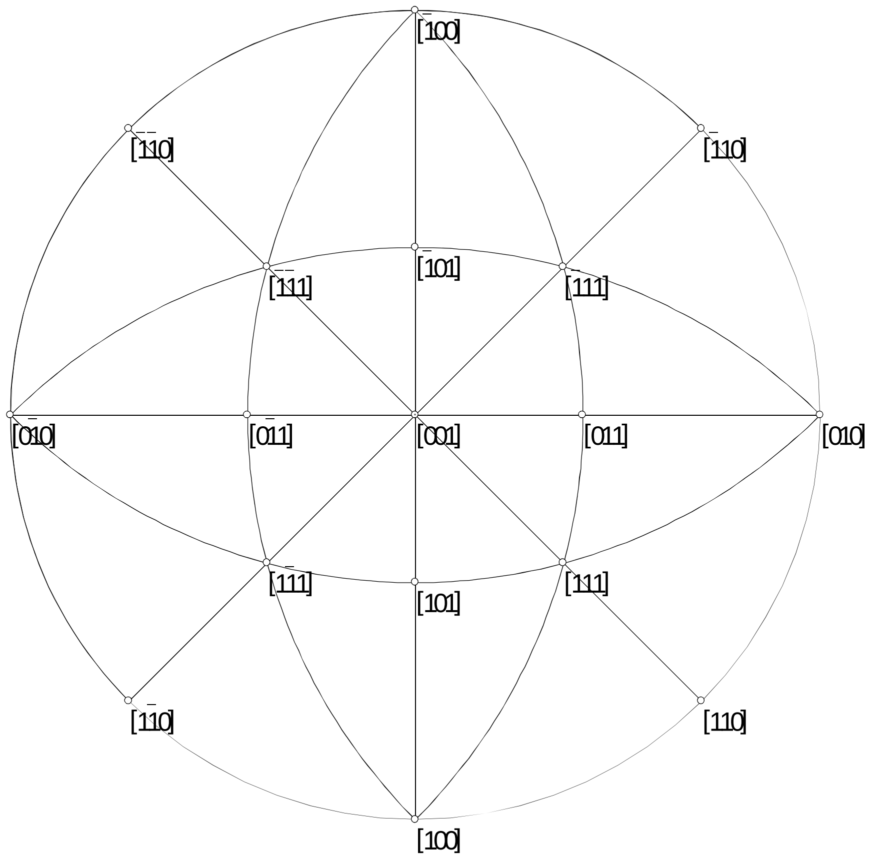
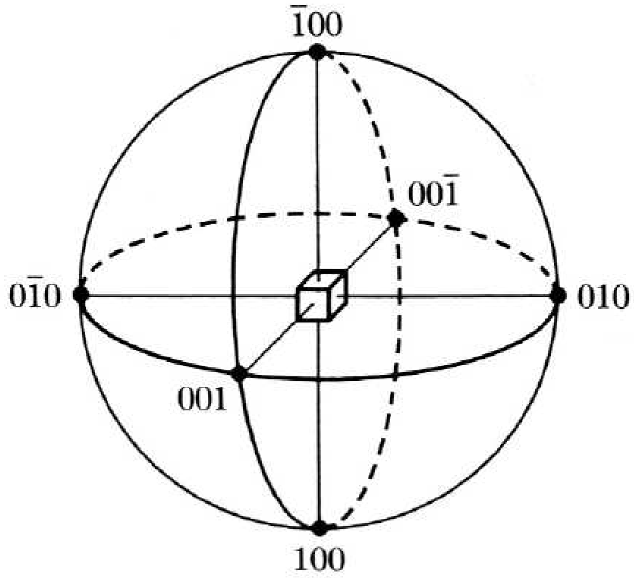
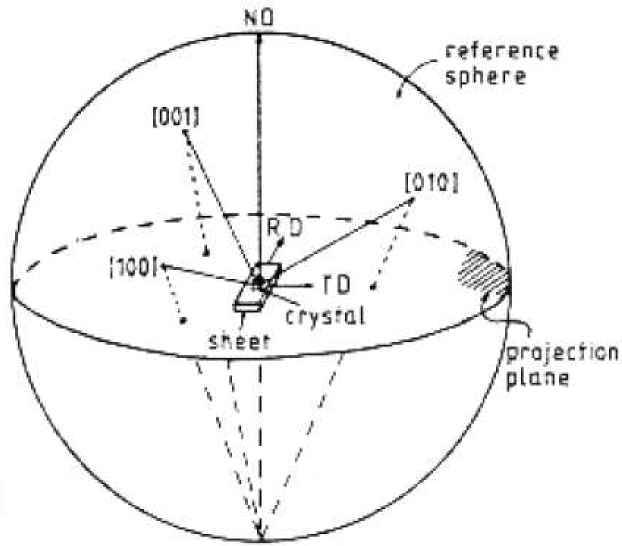
Crystallographic directions

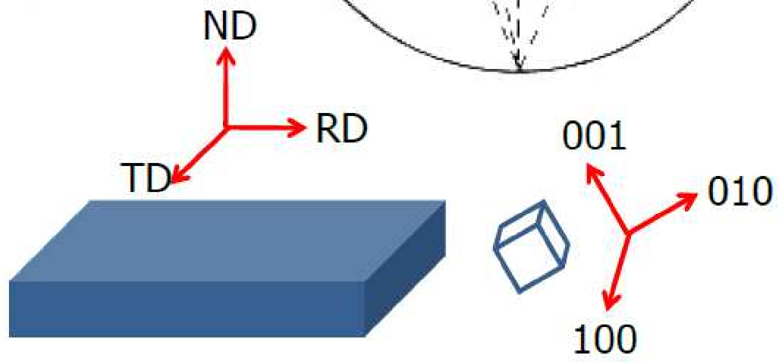




Stereographic projection







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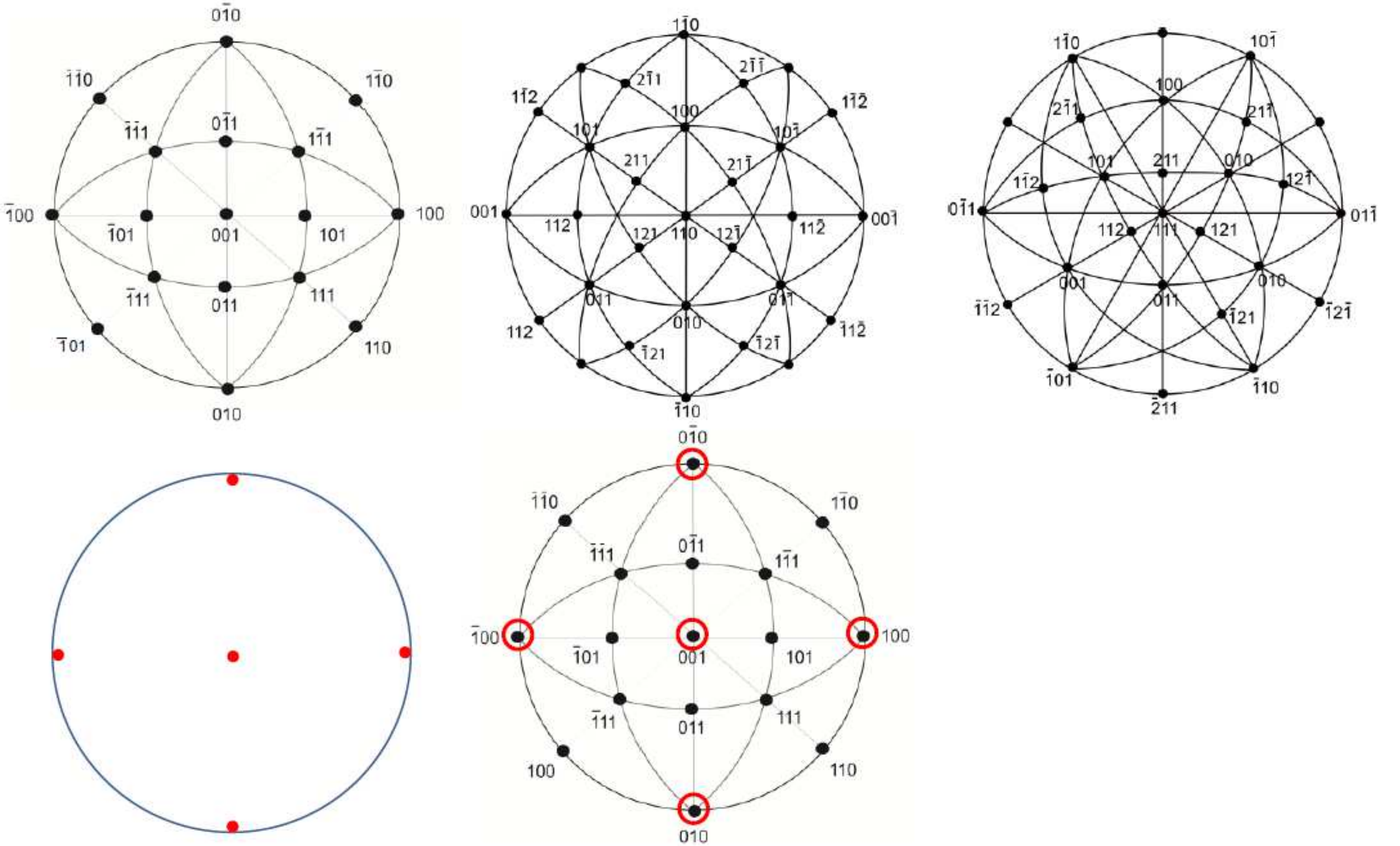
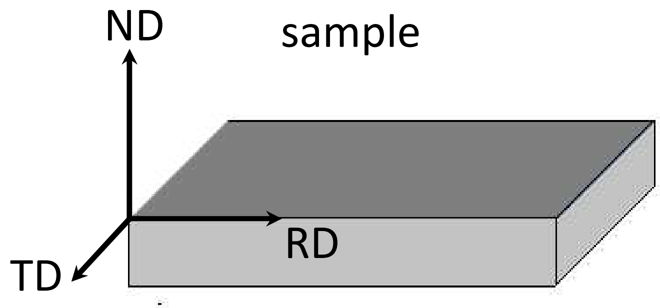
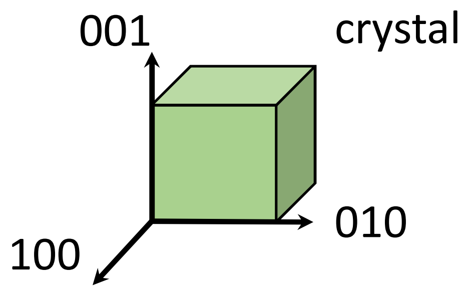
Pole figures

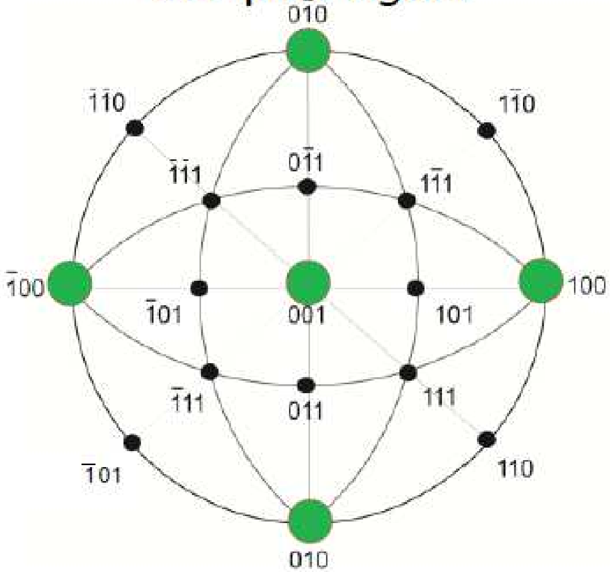


Coordinate systems

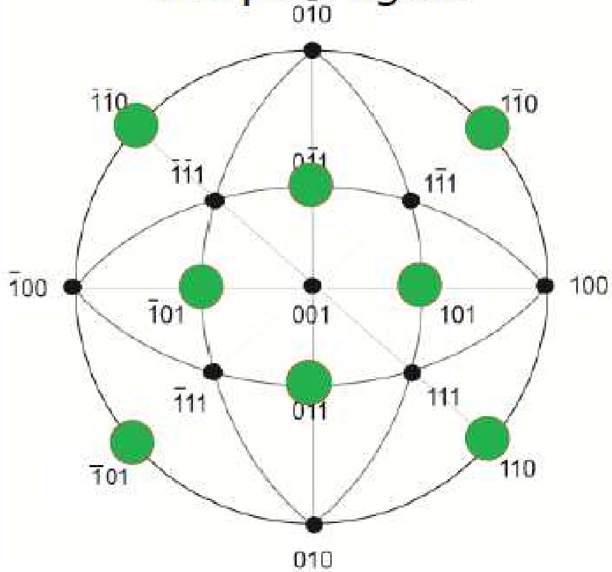




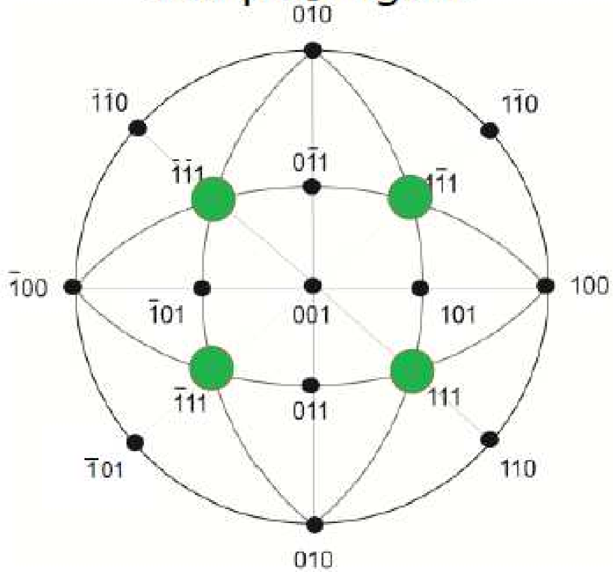
100 pole figure



101 pole figure



111 pole figure



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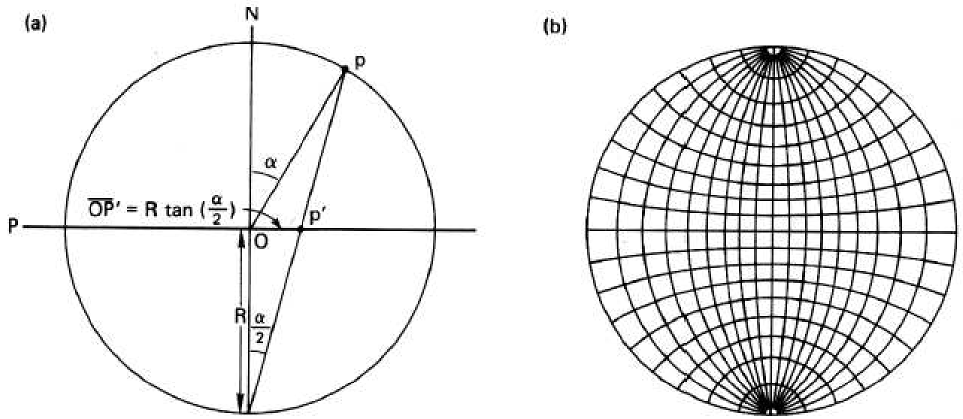
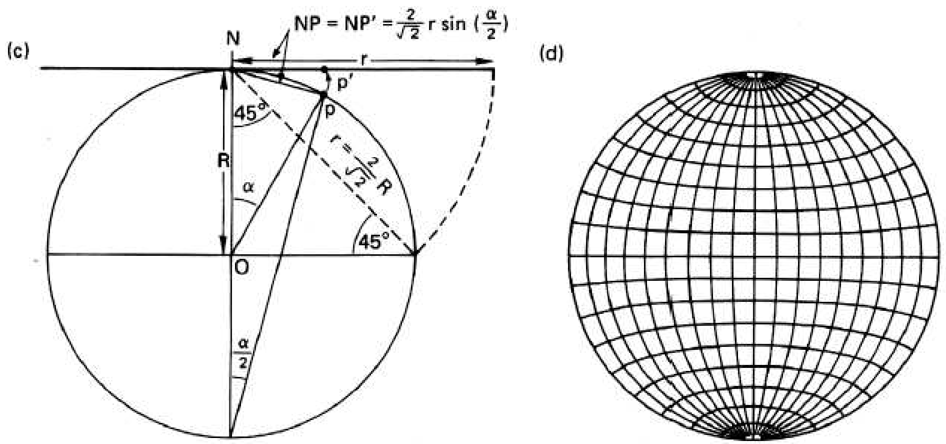
Stereographic projection

Angle true



Area true



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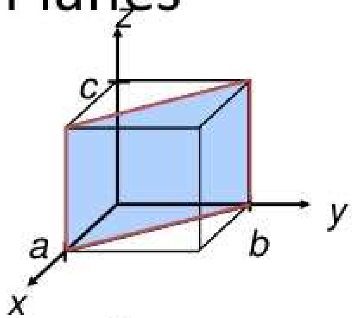
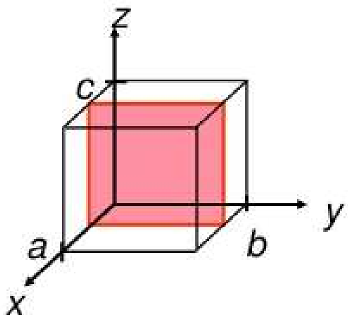
Crystallographic planes

Crystallographic Planes

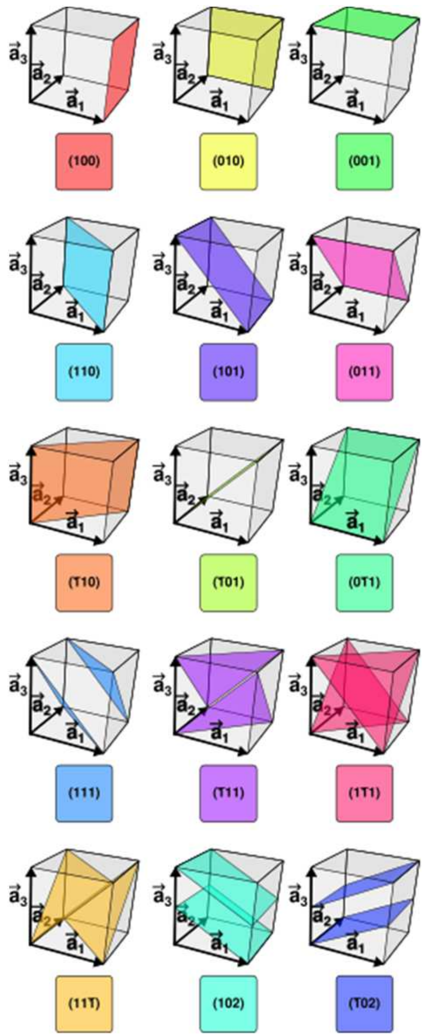
example	a	b	c
1. Intercepts	1	1	∞
2. Reciprocals	1/1	1/1	1/∞
	1	1	0
3. Reduction	1	1	0
4. Miller Indices	(110)		



example	a	b	c
1. Intercepts	1/2	∞	∞
2. Reciprocals	1/½	1/∞	1/∞
	2	0	0
3. Reduction	2	0	0
4. Miller Indices	(100)		



51



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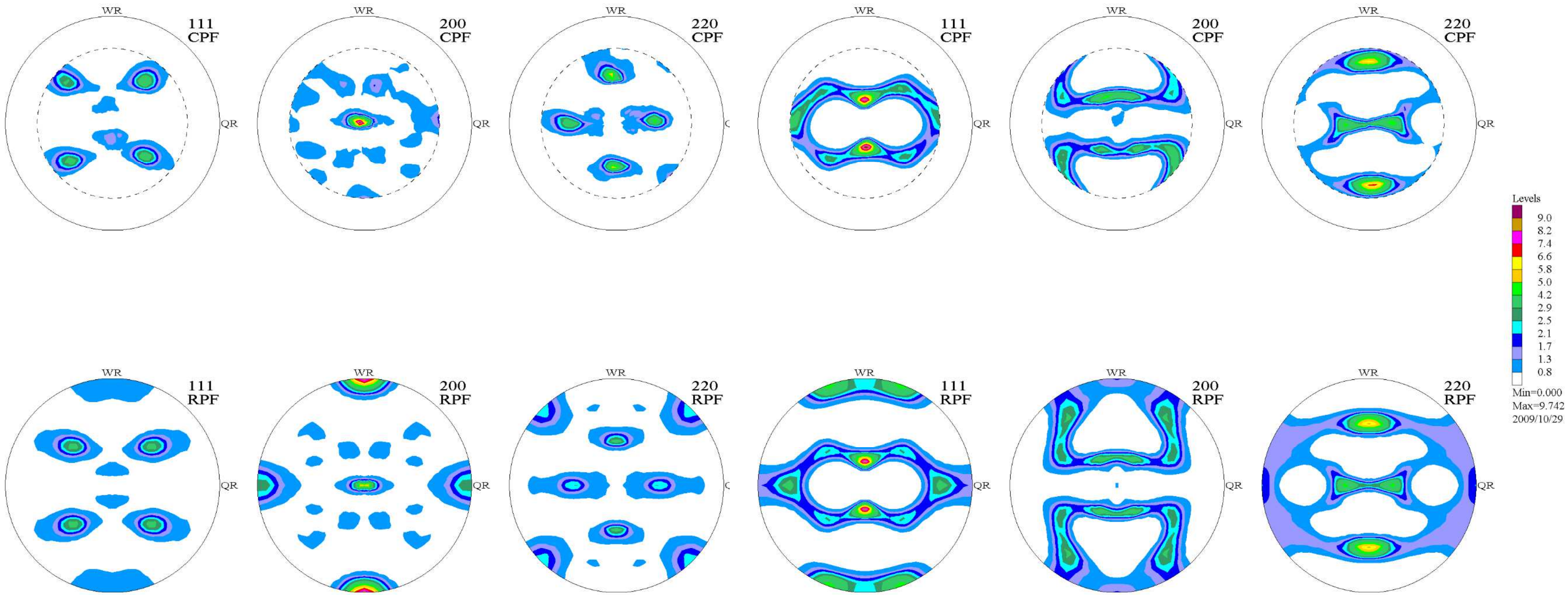
Experimental pole figures

annealing rolling



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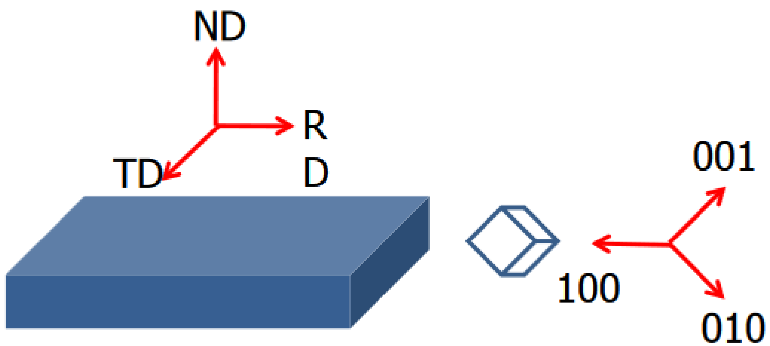
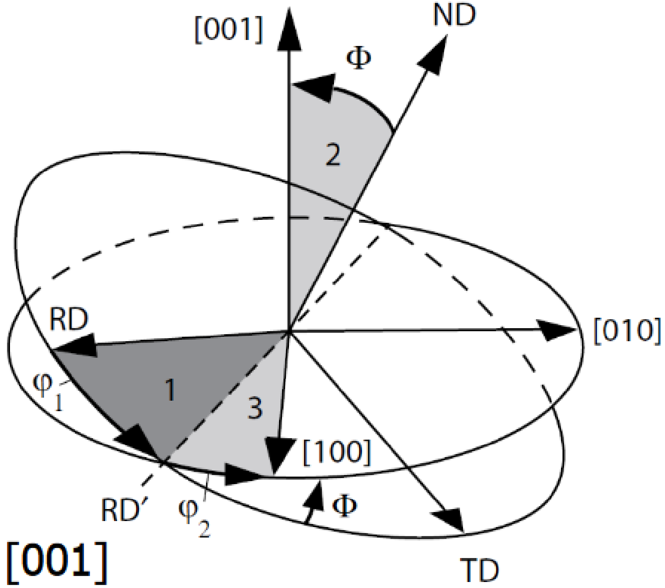
Euler Angles





- Rotate φ_1 about ND so that RD is perpendicular to plane containing ND and [001]

  RD → RD′ and TD → TD′

- Rotate Φ about RD′ so that ND and [001] coincide

  ND → [001] and TD′ → TD″

- Rotate φ_2 about ND so that crystal and sample frame coincide

  RD′ → [010] and TD″ → [100]

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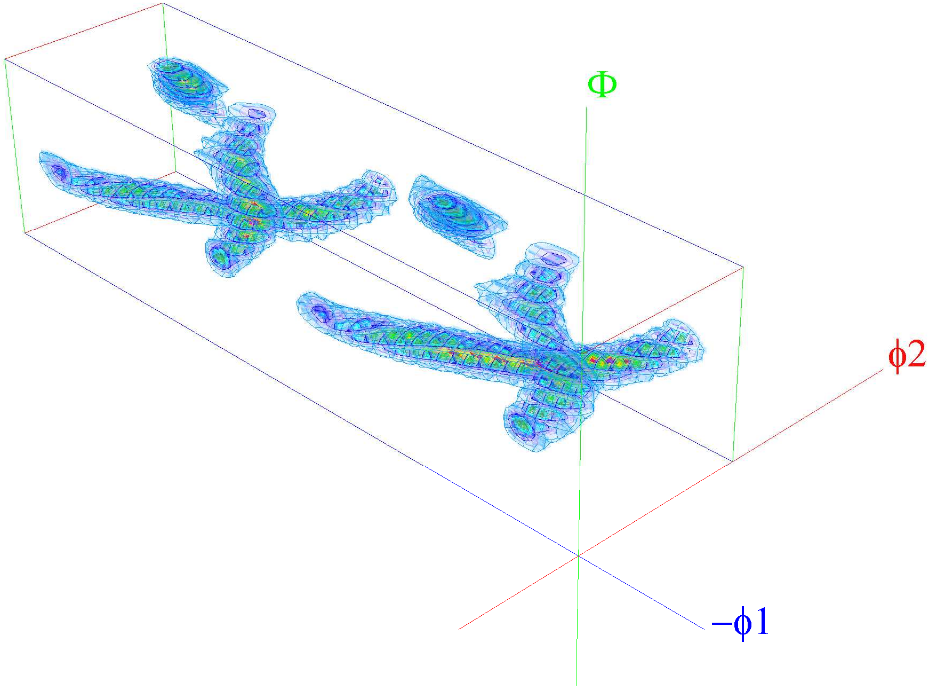
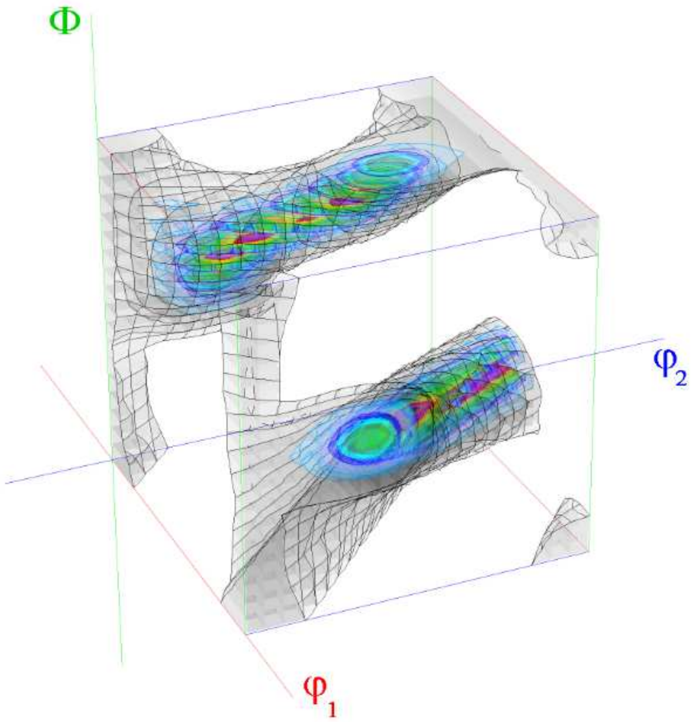
Orientation distribution function

$$\frac{dV}{V} = f(\varphi_1, \phi, \varphi_2)\frac{1}{8\pi^2}\sin\phi d\varphi_1 d\phi d\varphi_2$$

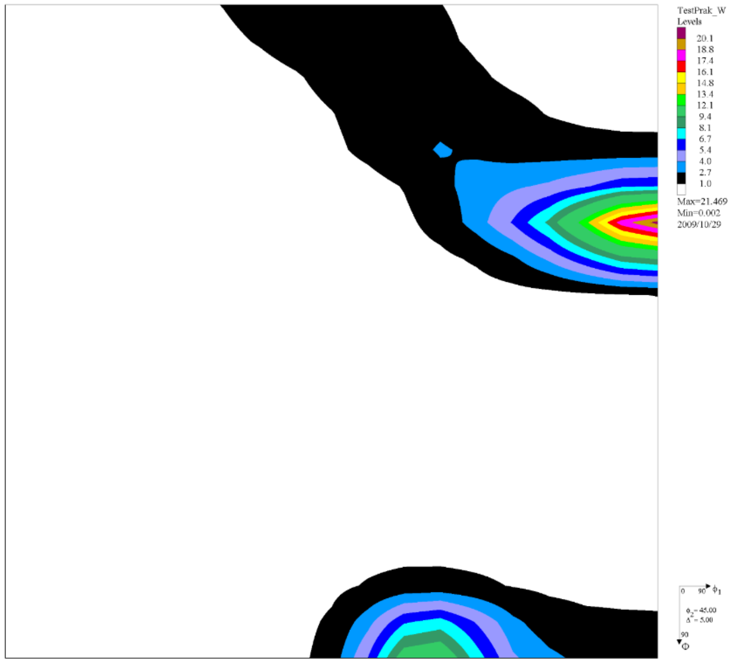


Orientation distribution function

ODF

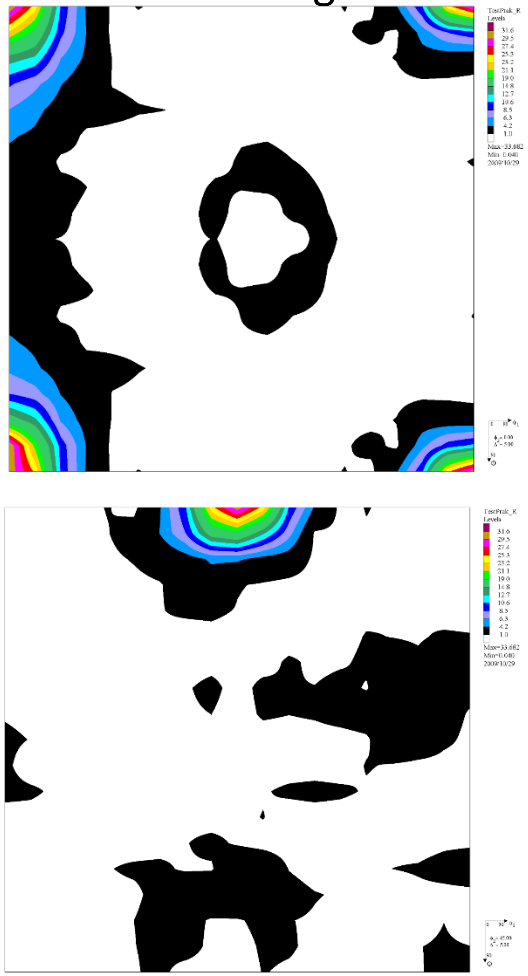


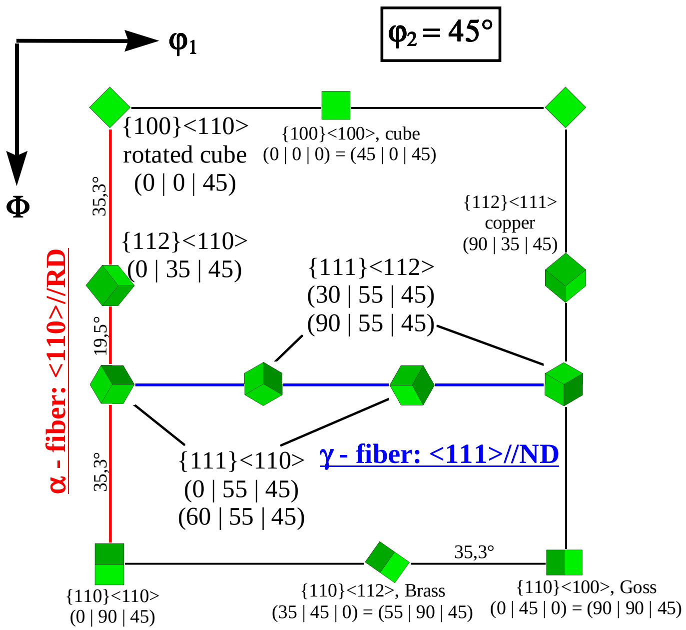
ODF section



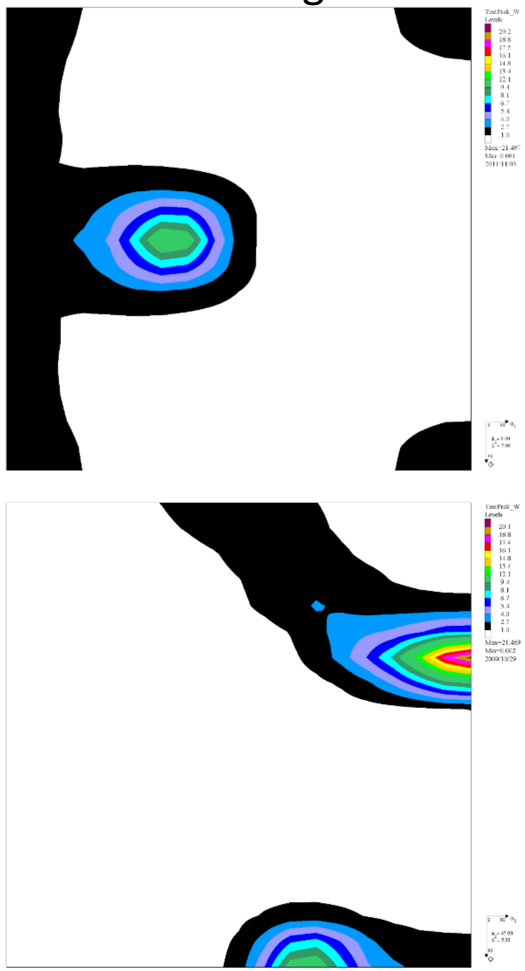
Key figure

Annealing





Rolling



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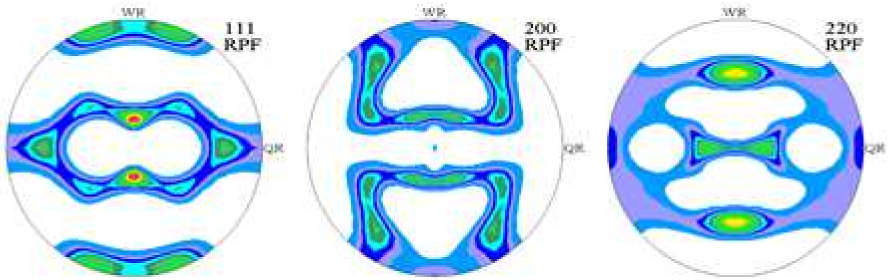
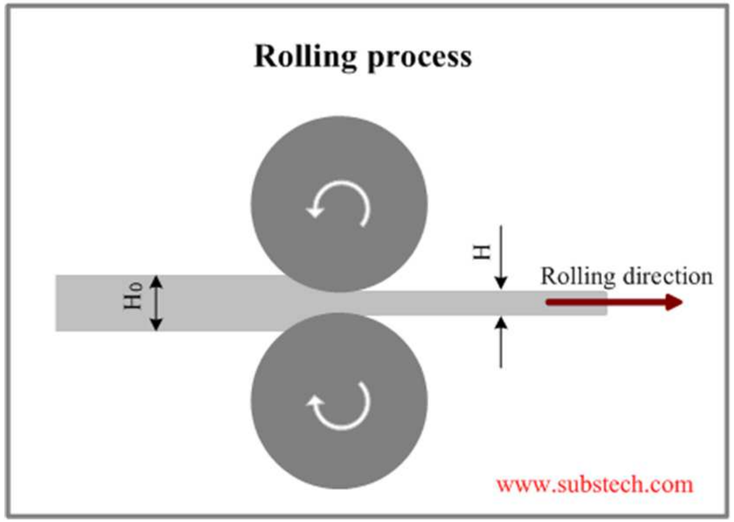
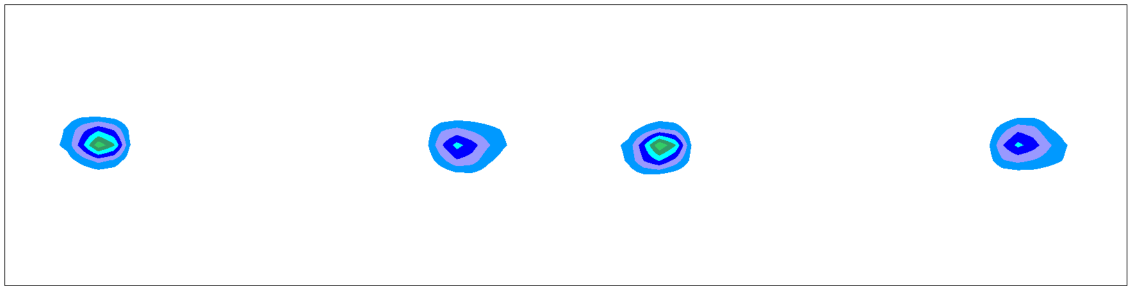
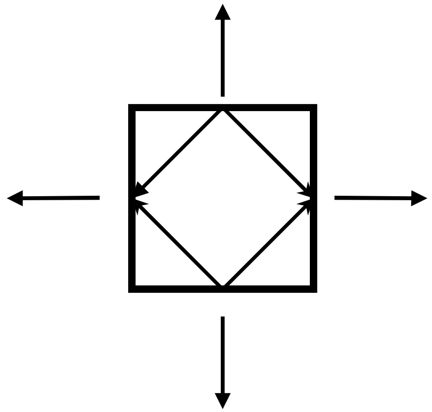
Sample symmetry (orthorhombic)

- Rolling









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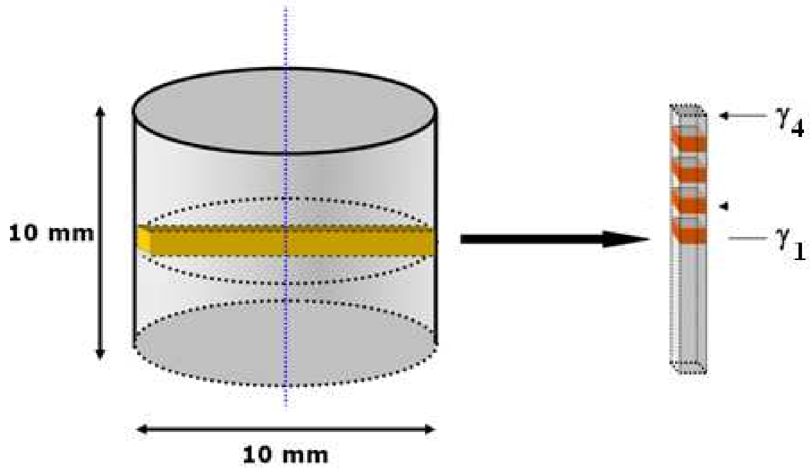
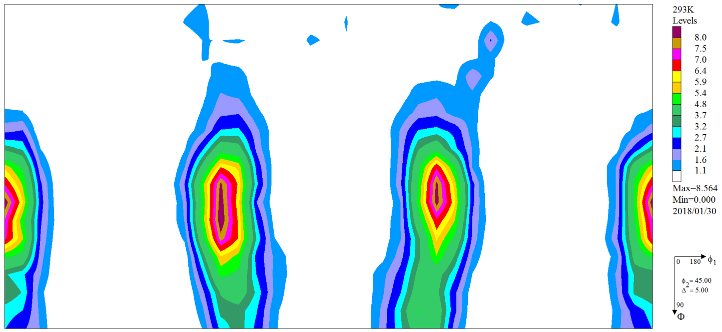
Sample symmetry – monoclinic

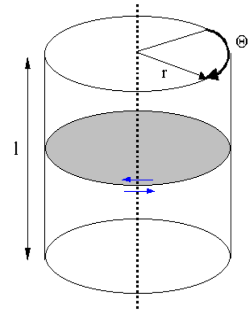


High Pressure Torsion (HPT)

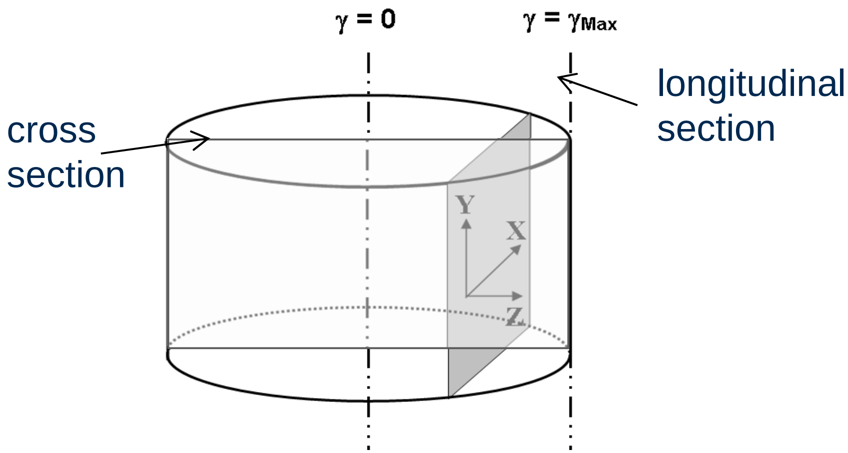


shear strain

$$\gamma = \frac{\Theta}{l} \cdot r$$



Microstructure – EBSD: *longitudinal and cross sections*



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Sample symmetry - triclinic

ECAP

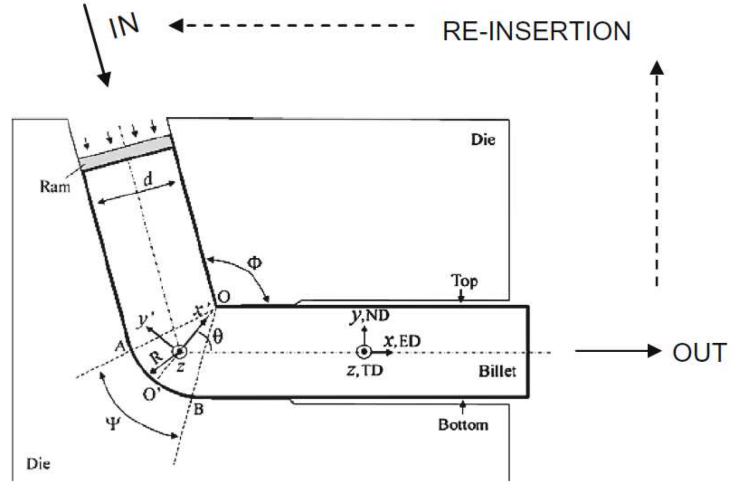
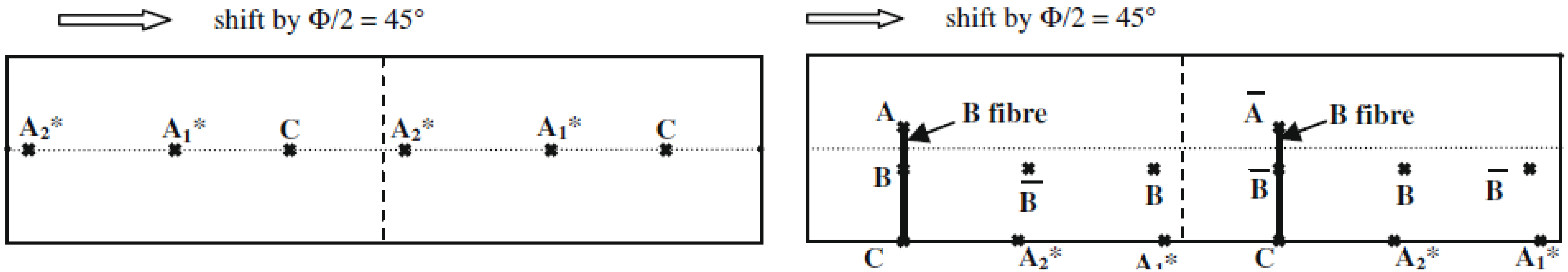


Fig. 1. ECAE die geometry and coordinate system employed in this paper [6].



I.J. Beyerlein, L.S. Tóth / Progress in Materials Science 54 (2009) 427–510

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