Imperfections – deformation and microstructures in polycrystals

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8- Textures in metals

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a- Typical tests

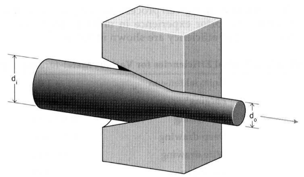
Typical tests

Textures in polycrystals
- Complex phenomenon
- Need for multi-scale modeling
- Very dependent on material history

If deformation experiment is too complicated
- Complex textures
- Difficult to understand

Therefore, we often rely on a short set of typical tests
- Compression
- Tension
- Rolling
- And others

Tensile test / wire drawing

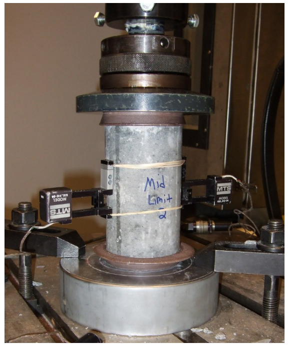


$$\epsilon = \begin{bmatrix} -\Delta/2 & 0 & 0 \\ 0 & -\Delta/2 & 0 \\ 0 & 0 & +\Delta \end{bmatrix}$$

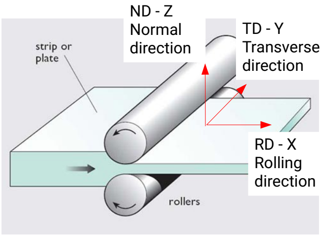
Images :
- Wikipedia
- A. Rollet

Compression

$$\epsilon = \begin{bmatrix} \Delta/2 & 0 & 0 \\ 0 & \Delta/2 & 0 \\ 0 & 0 & -\Delta \end{bmatrix}$$



Rolling



$$\epsilon = \begin{bmatrix} \Delta & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\Delta \end{bmatrix}$$

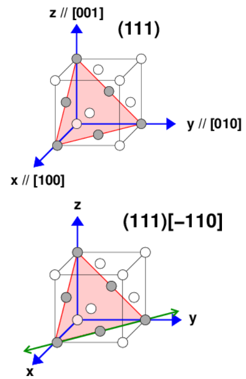
8- Textures in metals
b- Face centered cubic

Slip systems – fcc

Slip systems in fcc metals:
- slip direction: <110>
- slip plane: {111}

System: (111)[-110]

4 planes {111} : (111), $(\bar{1}11)$, $(1\bar{1}1)$, $(11\bar{1})$;
- For each: 3 directions <110>
- 12 systems, that can each operate in 2 directions (+ ou -).



Fcc – Compression Textures

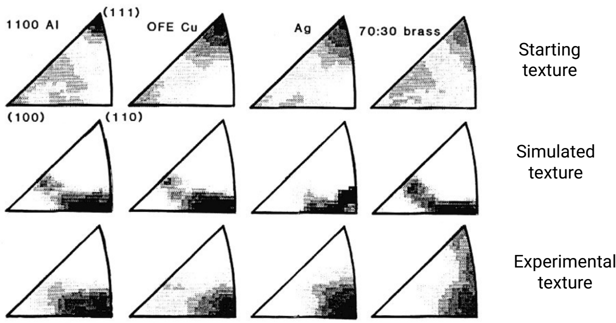
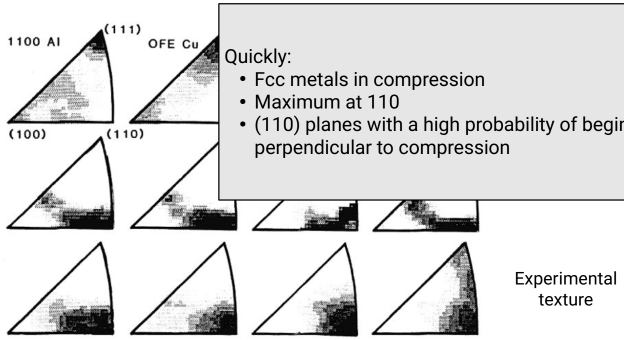


Image Kocks, Tomé, Wenk, 1998, Ch. 5

Fcc – Compression Textures

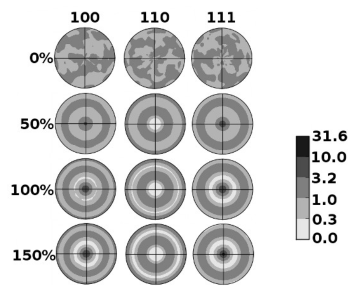


Quickly:
- Fcc metals in compression
- Maximum at 110
- (110) planes with a high probability of begin perpendicular to compression

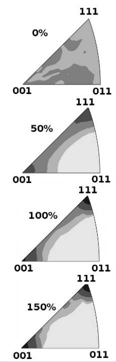
Image Kocks, Tomé, Wenk, 1998, Ch. 5

Fcc – Drawing Textures

Textures simulations for drawing of fcc metal



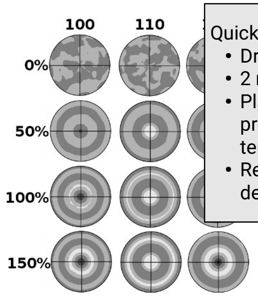
Pole figures (tension direction at the center)



Inverse pole figures of the tension direction

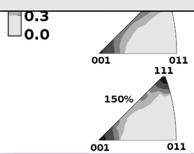
Fcc – Drawing Textures

Textures simulations for drawing of fcc metal



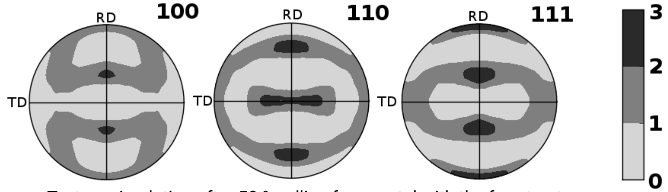
Pole figures (tension direction at the center)

Quickly:
- Drawing of fcc metals
- 2 maxima at 100 and 111
- Planes (100) and (111) with a high probability to be perpendicular to the tension direction
- Relative weight of 100 and 111 depends on the material.



Inverse pole figures of the tension direction

Fcc – Rolling texture



Texture simulation after 50 % rolling for a metal with the fcc structure

Rough characteristics :
- (110) planes // rolling plane
- <1$\bar{1}$2> // rolling direction

In reality, one often compares the obtained texture to classical cases (copper, brass, etc).

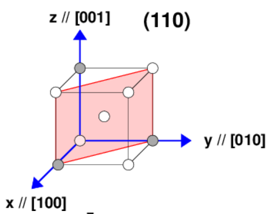
8- Textures in metals
c- Centered cubic

Slip systems – bcc

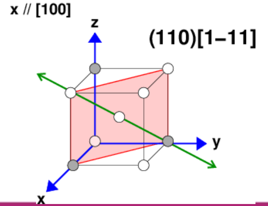
Slip systems in the bcc structure:
- Slip direction: <111>
- Slip plane: {110}

Slip system: (110)[1-11]

Other possible slip planes but slip direction is most-often <111>.



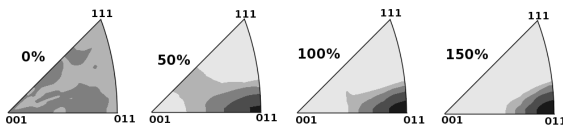
6 {110} planes: (110), (011), (101), (1$\bar{1}$0), (01$\bar{1}$), (10$\bar{1}$) ;
- For each: 2 <111> directions,
- 12 slip systems, each can operate in 2 directions (+ or -).

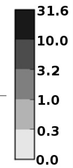


Bcc- Drawing and Compression

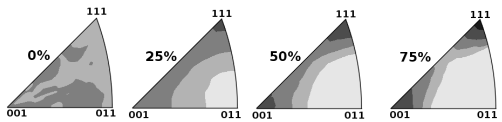
Simulation of drawing texture for a bcc metal

Same as fcc metal in compression





Simulation of a compression texture for a bcc metal



Same as drawing texture for fcc

Fcc/ bcc Comparison

Fcc in compression
~ bcc drawing
Fcc drawing
~ bcc in compression

Slip systems:
- Fcc : (111)[-110]
- Bcc : (110)[1-11]

Drawing textures:
- Fcc : 2 maxima, in 001 and 111, minimum in 011
- Bcc : maximum in 011

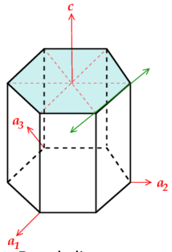
Compression textures:
- Fcc : maximum in 011
- Bcc : 2 maxima, in 001 and 111, minimum in 011

Rolling textures
- More complex.
- You can switch between fcc and bcc metals rolling textures by inverting the RD and ND directions in the projection.

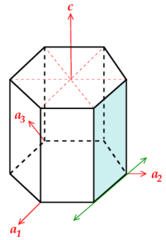
8- Textures in metals
c- Hexagonal closed packed

Hcp Slip Systems: <$11\bar{2}0$>

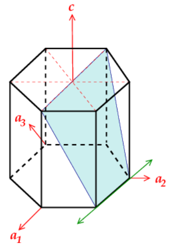
Slip slip systems with <$11\bar{2}0$> Burgers vector
also called <a>



Basal slip
(0001)[$11\bar{2}0$]
3 equivalent systems



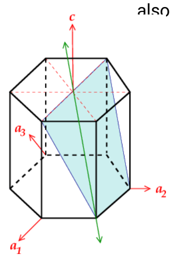
Prismatic slip
($01\bar{1}0$)[$11\bar{2}0$]
3 equivalent systems



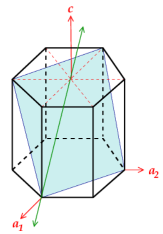
Pyramidal <a> slip
($01\bar{1}1$)[$11\bar{2}0$]
6 equivalent systems

Hcp Slip Systems: <$11\bar{2}3$>

Slip slip systems with <$11\bar{2}3$> Burgers vector
also called <c+a>



Pyramidal <c+a> slip
First order
($10\bar{1}1$)[$11\bar{2}3$]
12 equivalent systems

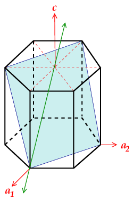


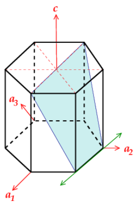
Pyramidal <c+a> slip
Second order
($11\bar{2}2$)[$11\bar{2}3$]
6 equivalent systems

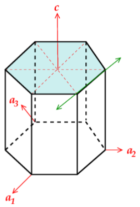
c/a > 1.633

Hexagonal metals with c/a > 1.633

- Cd, Zn
- Basal slip
- Pyramidal <a> slip
- Pyramidal <c+a> second order
- Twins





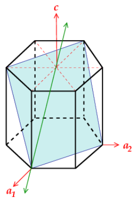


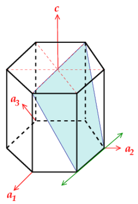
Notes :
- Basal slip is dominant
- Twinning is very important

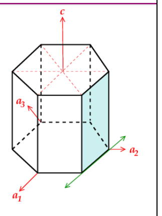
c/a < 1.633

Hexagonal metals with c/a < 1.633

- Zr, Ti, Hf ;
- Prismatic slip,
- Pyramidal <a> slip,
- Pyramidal <c+a> second order,
- Twins.







Notes:
- You can also have basal slip
- Twinning is very important

Hcp – Compression / Extrusion Texture

Pure Titanium

Extrusion:
- Maximum at 10-10

Compression:
- Maximum close to 0001
- 25° of 0001, ~ <11-24>

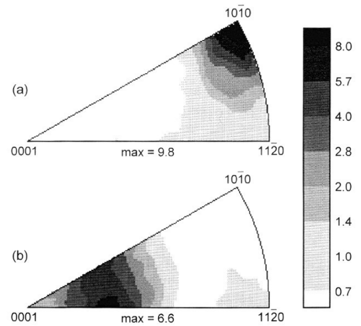


Fig. 20. Inverse pole figures of pure titanium: (a) extruded to a von Mises equivalent strain of 1.75 (extrusion-axis inverse pole figure), (b) forged and cross-rolled to a von Mises equivalent strain of 1.98 (plate normal inverse pole figure).

Comparison Titanium / Zirconium

General rule for hcp metals:
- Complex behavior due to activity of twinning modes
- Simple consideration on slip systems not always relevant

Compression Zr

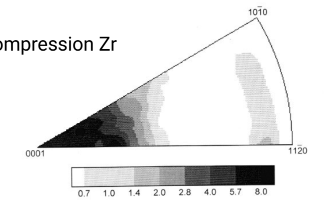
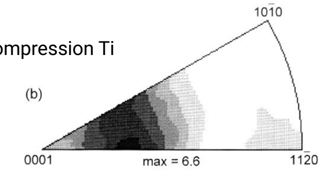


Fig. 21. Inverse pole figure (plate normals) for forged and cross-rolled zirconium.

Compression Ti



Hcp – Rolling Textures

c/a > 1.633:

0001 splits in two components in the plane between rolling normal and rolling direction

c/a = 1.633:

0001 perfectly aligned with rolling plane normal

c/a < 1.633:

0001 split in two components in the plane formed by the transverse and normal directions

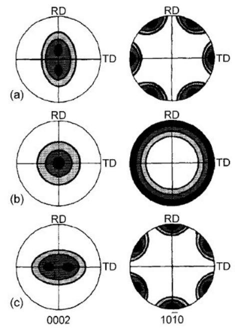


Fig. 22. Schematic rolling textures in hcp metals with *c/a* ratios of (a) greater than 1.633, (b) approximately equal to 1.633 and (c) less than 1.633. 0002 and 10$\bar{1}$0 pole figures. [Tenckhoff 1988].