Texture simulations in magnesium and its alloys

B. Sulkowski

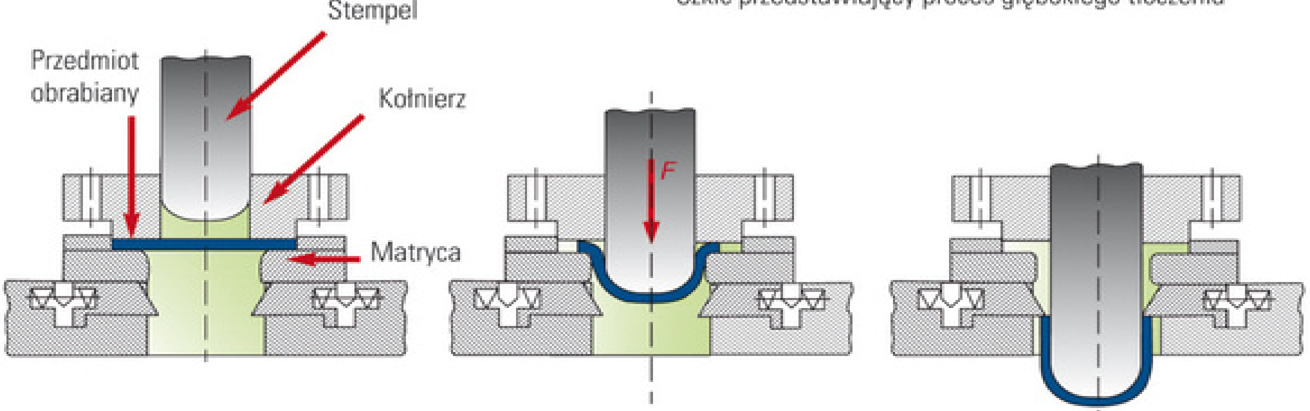
Akademickie Centrum Komputerowe CYFRONET AGH,
ul. Nawojki 11, 30-098 Kraków
b.sulkowski@cyfronet.pl

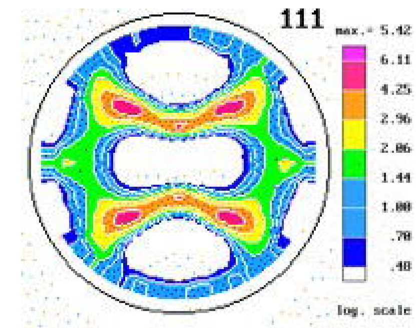
Overview

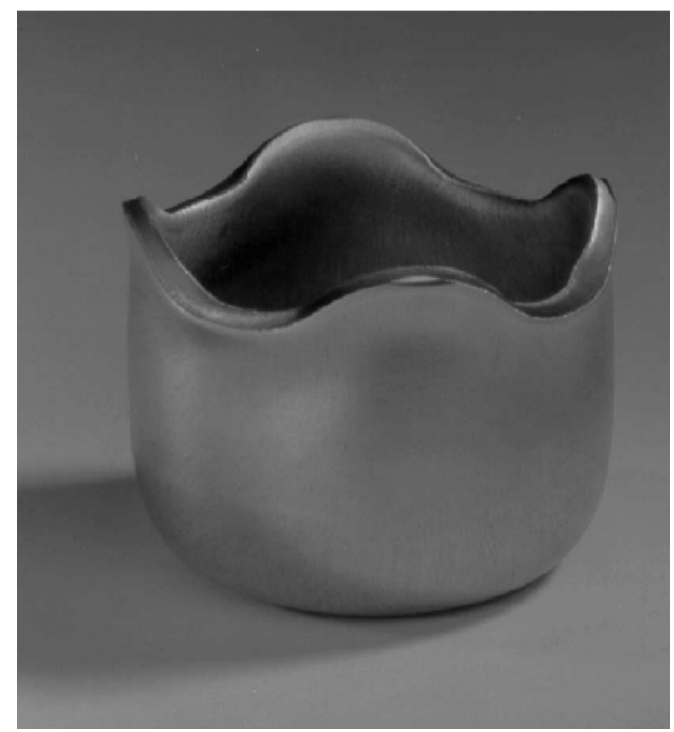
- Introduction
- Structure, mechanial and texture investigations of AZ61 and AZ91 magnesium alloys
- Texture simulations
- Texture simulations results
- Conclusions

Stamping of metals

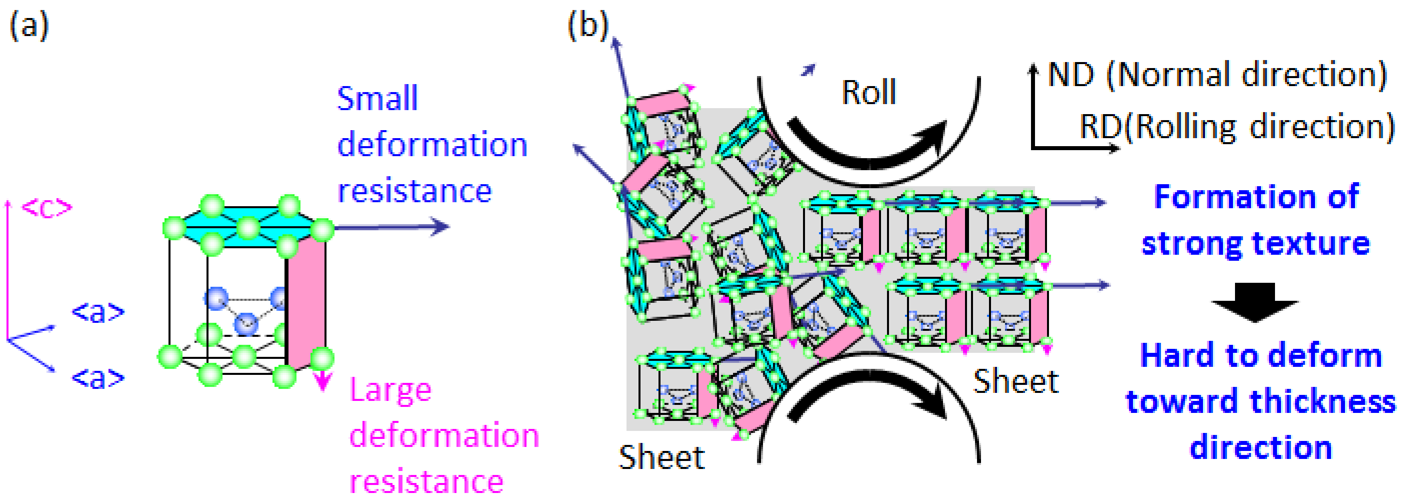
Szkic przedstawiający proces głębokiego tłoczenia

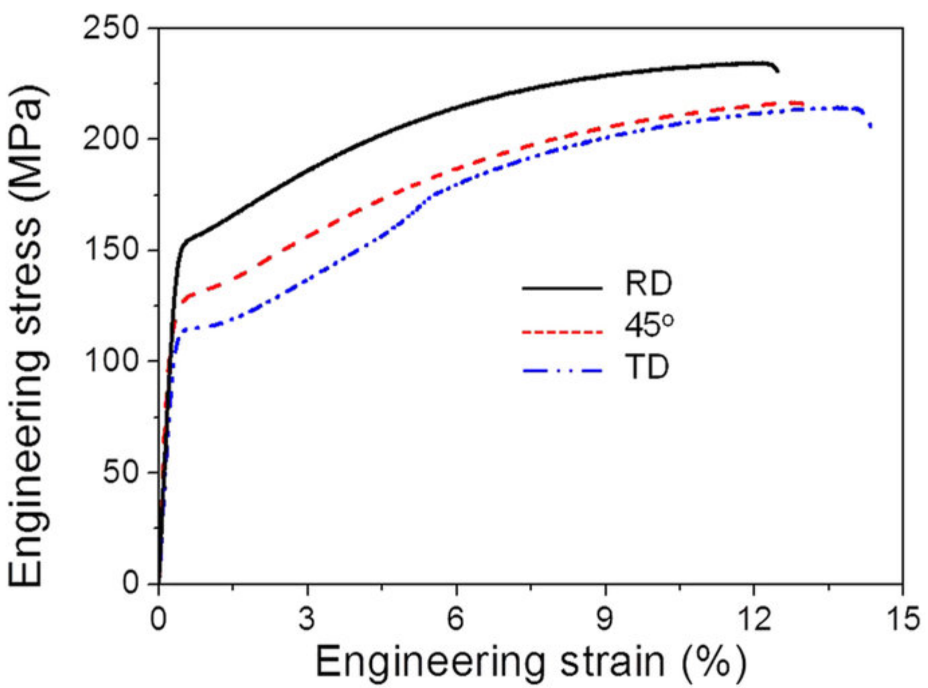






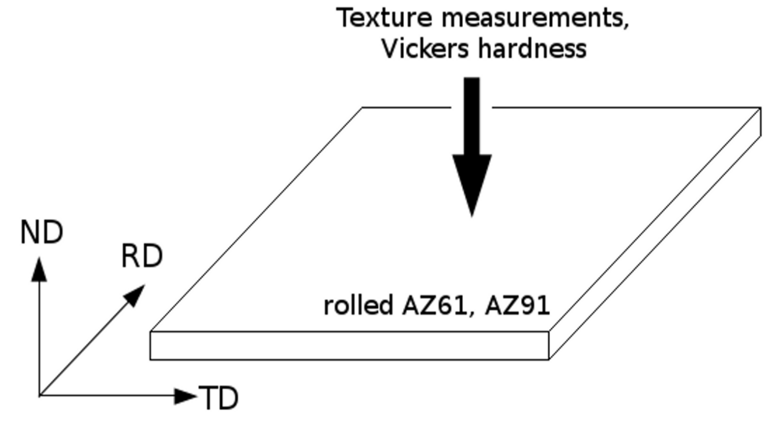
Mechanical anistropty of hcp metals

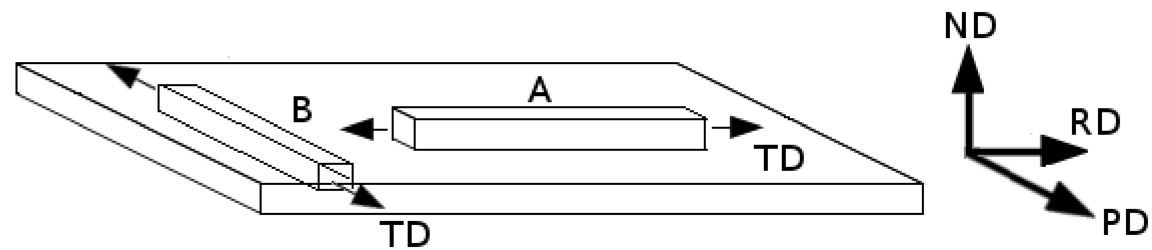




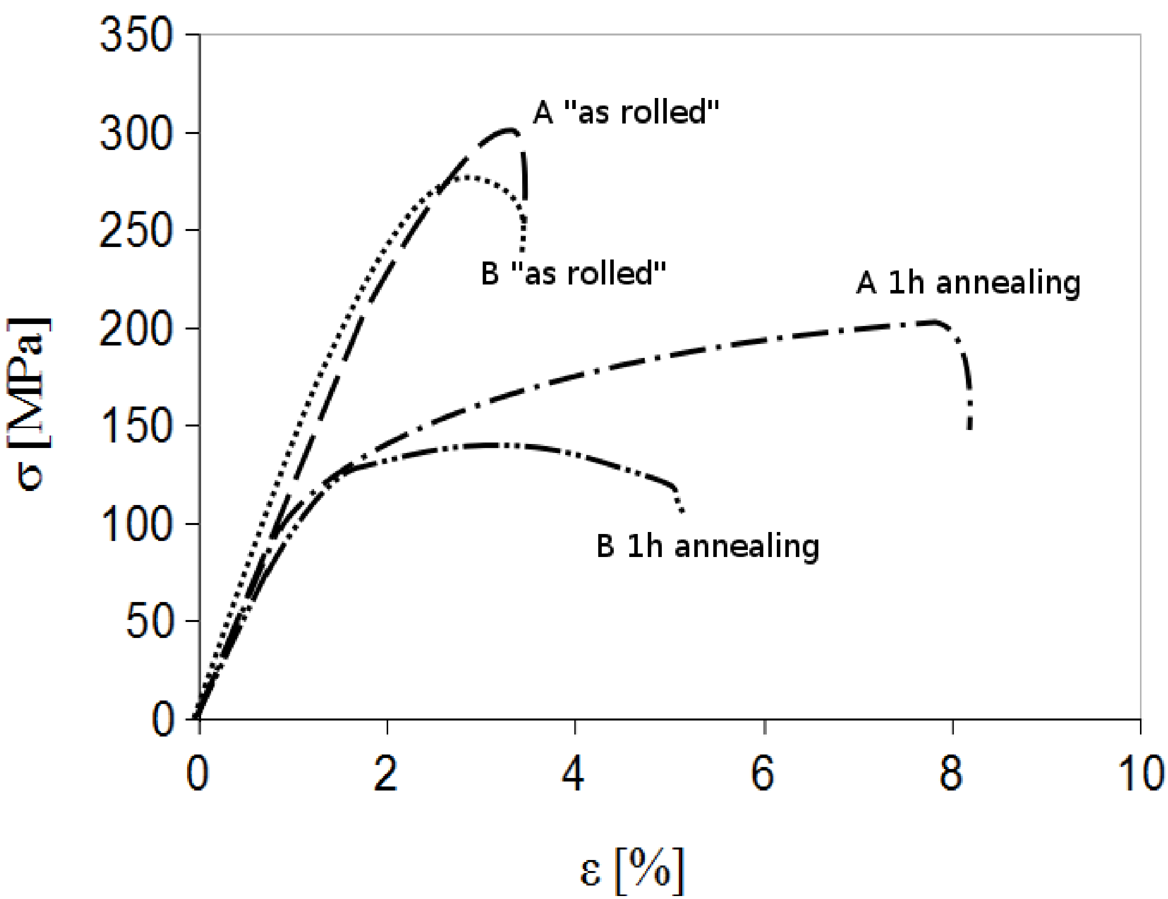
Investigations

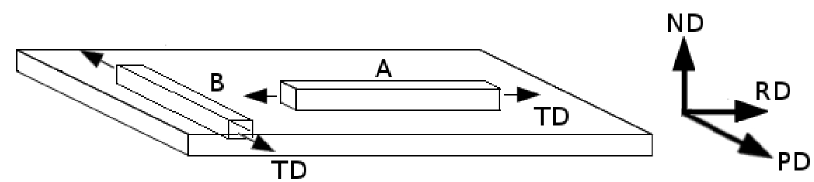
- AZ61 and AZ91 magnesium alloys
- Rolling with large thickness reduction, up to 90%.
- Rolling conditions:
  - strain rate equal to 1.6 s^{-1}
  - temperature 450°C
  - three routes with intermediate annealing
- Structure investigations
- Vickers microhardness measurements
- Texture measurements
- Tensile tests





Work hardening curves from tensile tests of investigated AZ61 after hot rolling (dashed lines) and annealing for 1 hour (full and dotted lines).

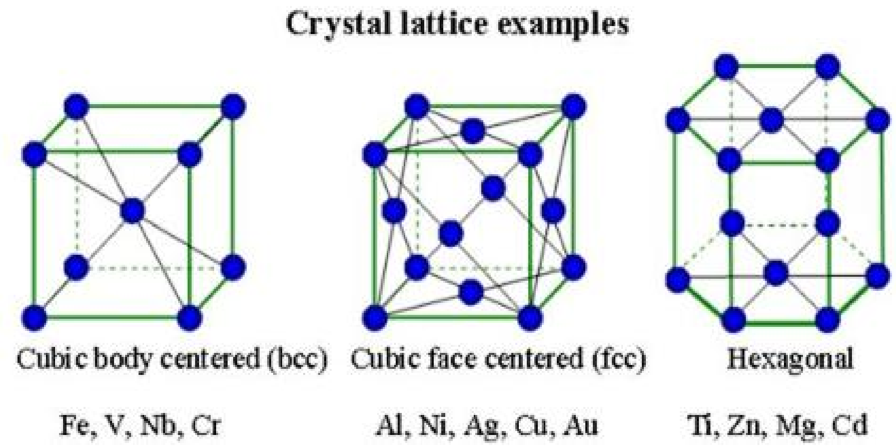


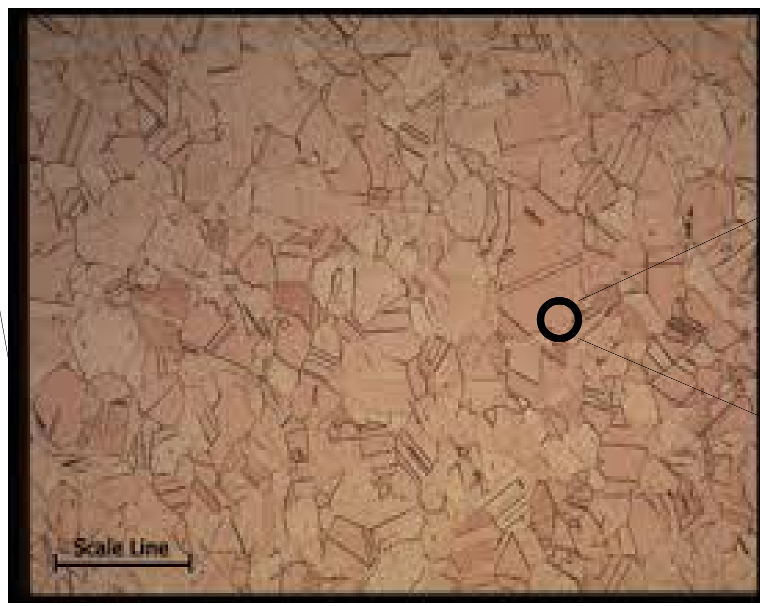


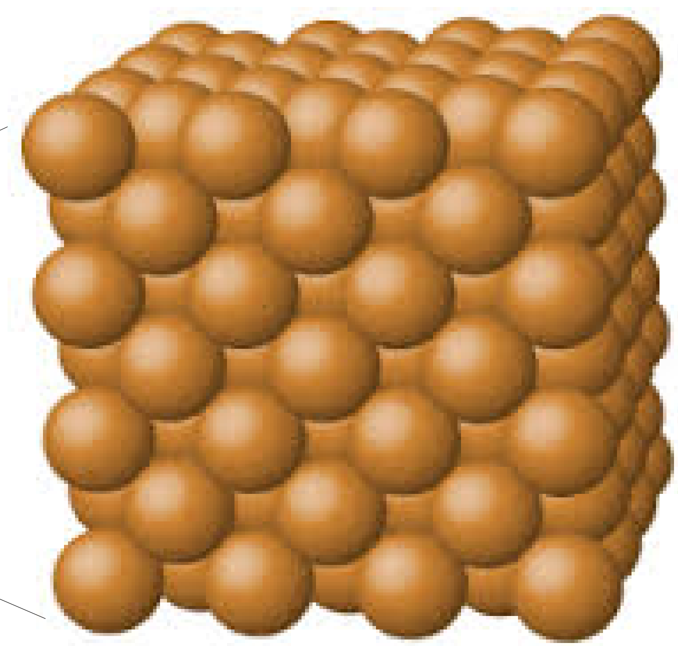
The sketch showing samples with TD || RD and TD ⊥ RD cut for tensile tests

Texture simulations

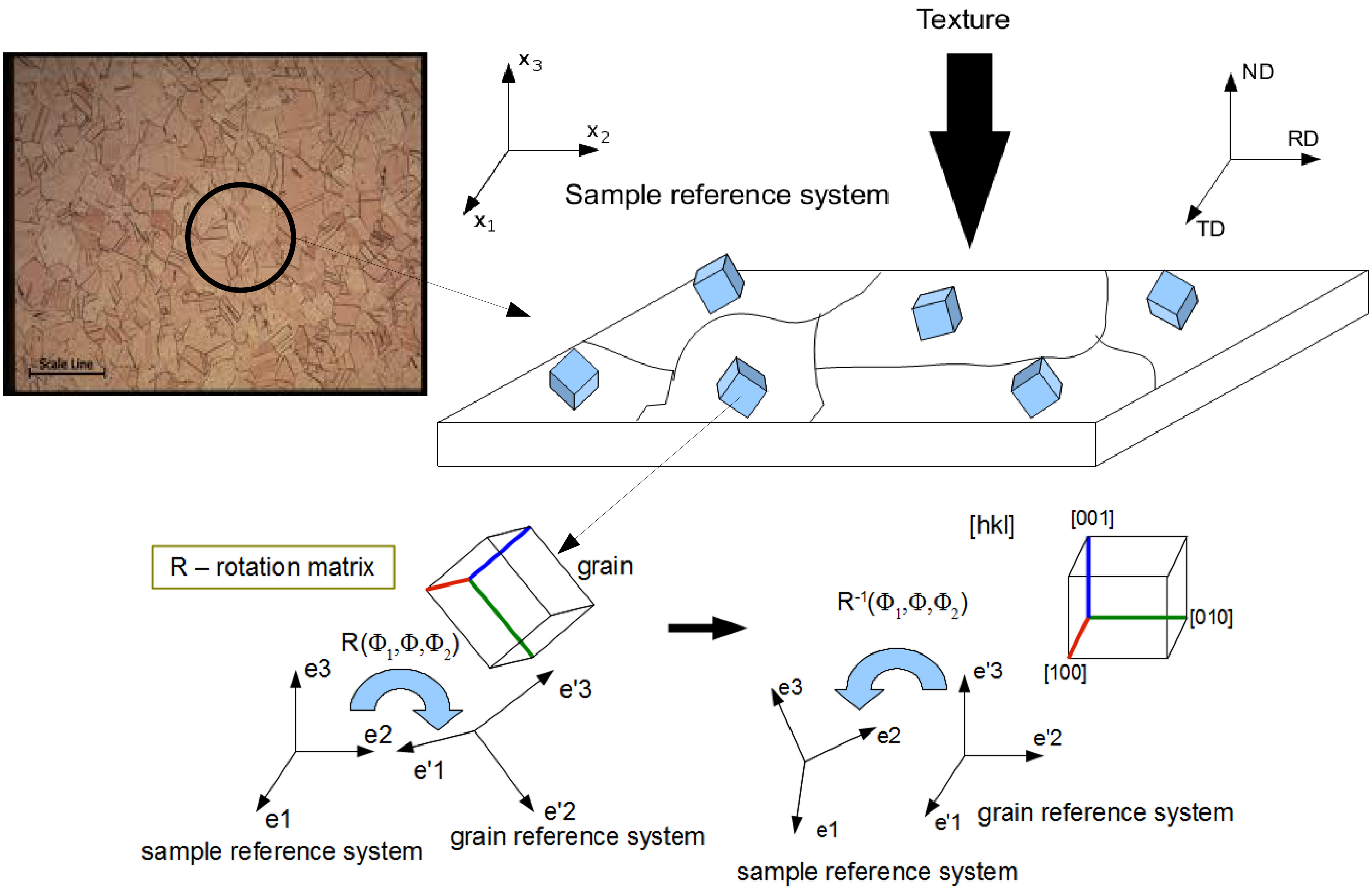
The structure of metals



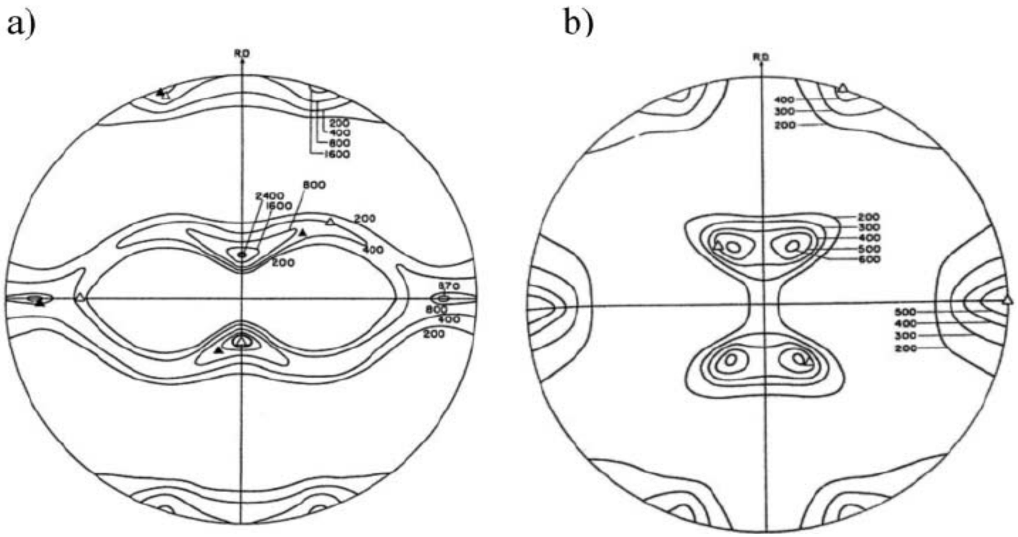




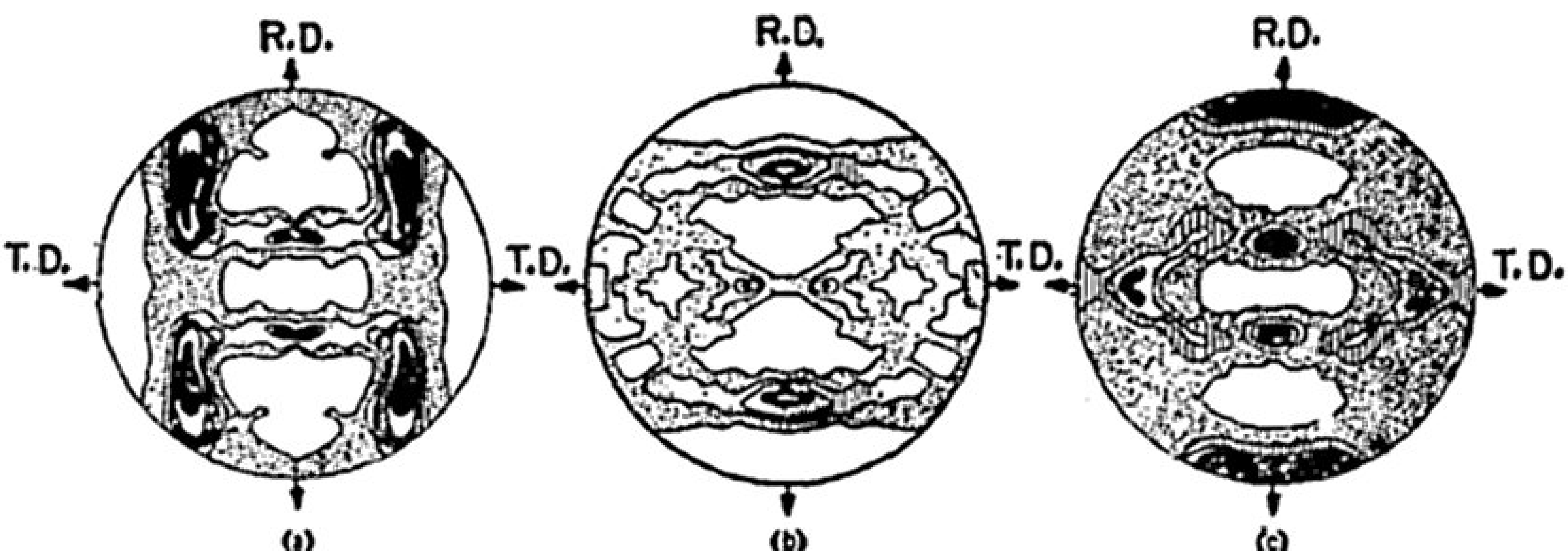
What is a texture in metals?



Example of textures



Copper type texture after rolling of Cu



Brass type texture after rolling

Modeling of texture

Sachs versus ***Taylor***

- Diagrams illustrate the difference between the Sachs iso-stress assumption of single slip in each grain (a, c and e) versus the Taylor assumption of iso-strain with multiple slip in each grain (b, d).

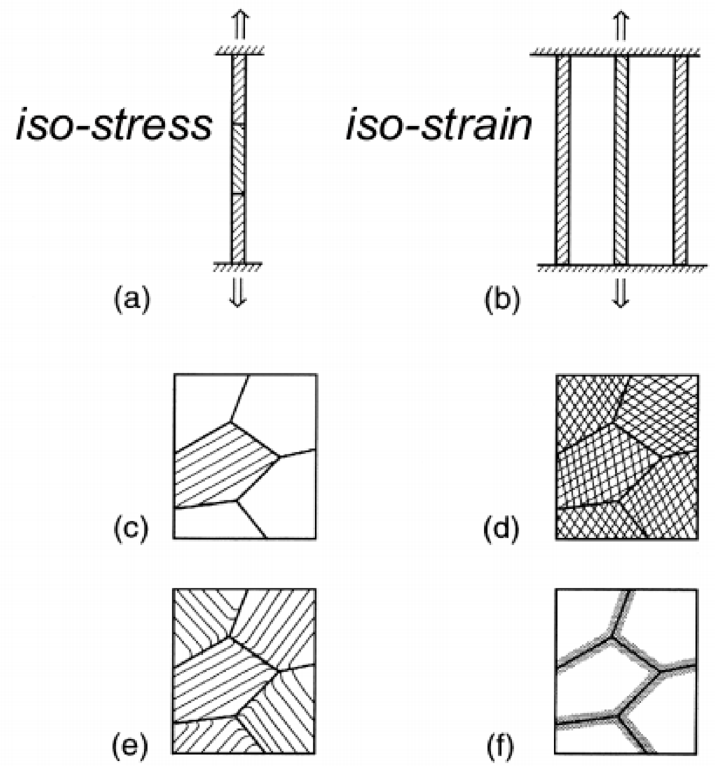
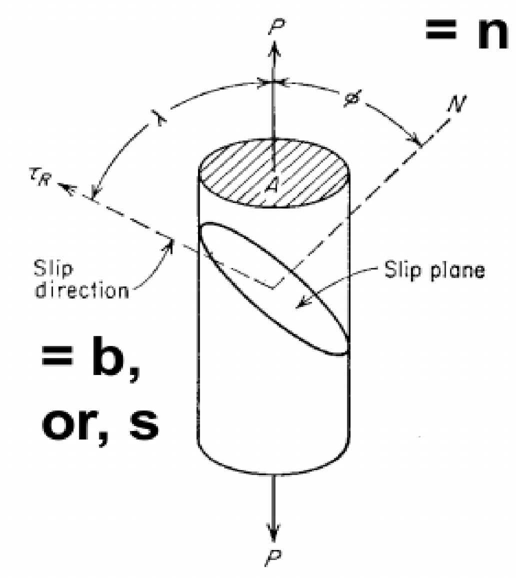


Fig. 23. Schematic description of various polycrystal plasticity models: (a) a true lowe bound for a linear serial polycrystal; (b) the Sachs model (independent parallel grains) (c) a true lower bound for a 3-D polycrystal (only one grain deforms at any instant); (d a true upper bound (also the Taylor model); (e) the Kochendörfer model (single sli plus bending); (f) the Ashby model (polyslip plus 'geometrically necessar dislocations').

Modeling of texture by Taylor model

•Finding independent five active slip systems

Given :
- **Slip system -** c_3; $\dot{\gamma}_{c3}$
- **Unit vector in the slip direction –** $n = \frac{1}{\sqrt{3}}(-1,1,1)$
- **Unit normal vector to the slip plane –** $b = \frac{1}{\sqrt{2}}(1,1,0)$



P is a *unit vector* in the loading direction

The contribution of the c_3 system is given by

$$\frac{1}{2}(bn+nb)\dot{\gamma}_{c3} = \frac{\dot{\gamma}_{c3}}{2\sqrt{6}}\begin{bmatrix} -2 & 0 & 1 \\ 0 & 2 & 1 \\ 1 & 1 & 0 \end{bmatrix}$$

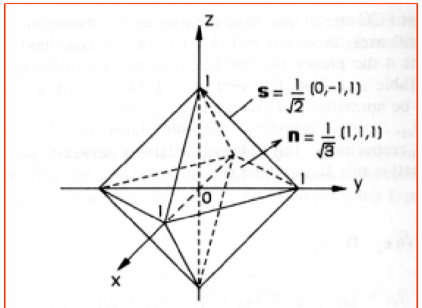


Fig. 11.1 Crystal axes and slip systems

Minimal internal or maximum external work criterion

(Taylor or Taylor-Bishop method)

$$m_{ij}^{(\alpha)} = b_i^{(\alpha)} n_j^{(\alpha)}$$

$$\sum_{\alpha=1}^{n} \tau_c \dot{\gamma}_\alpha \le \sum_{\alpha=1}^{n} \tau_\alpha^* \dot{\gamma}_\alpha^*$$

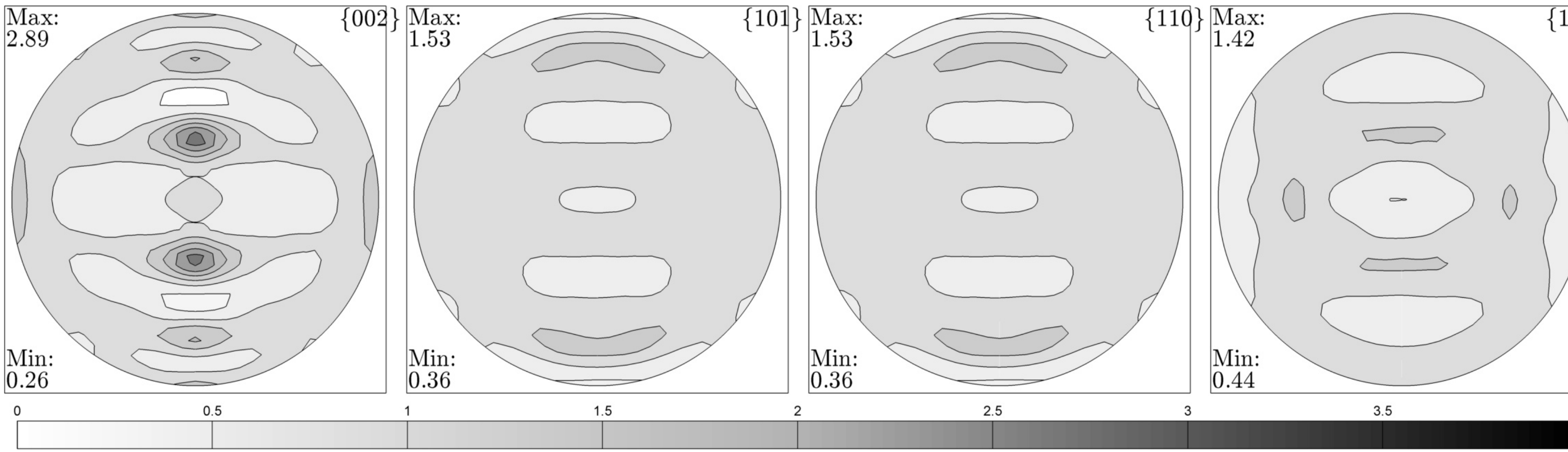
Modeling of texture by Taylor model

- Construct deformation matrix from active slip systems

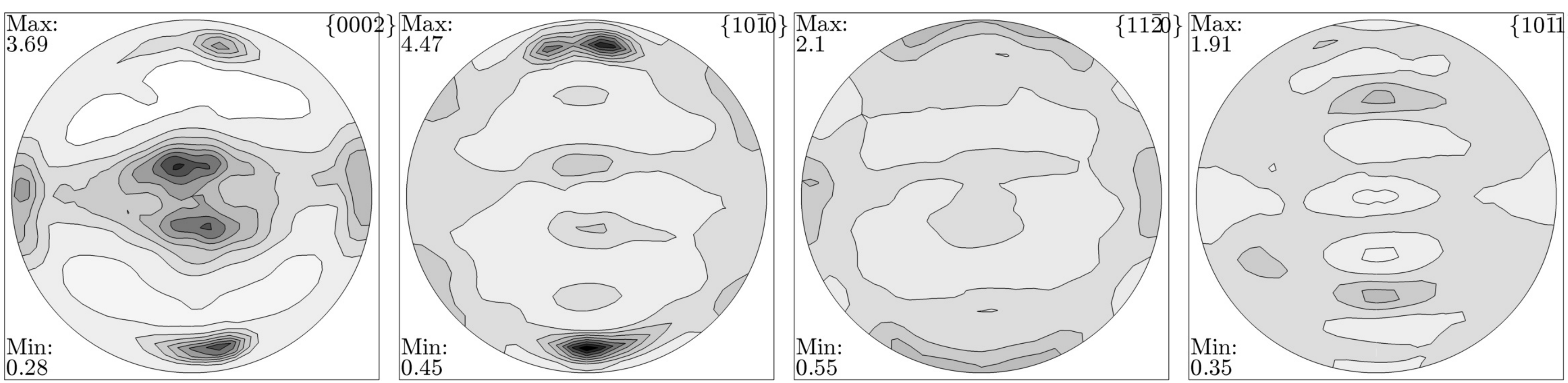
$$D = D^p = \sum_{\alpha=1}^{n} m_\alpha \dot{\gamma}_\alpha$$

- Anti-Symmetric part of deformation matrix gives information about change in orientation
- Update actual orientation of grain
- Repeat until last step of deformation

Texture simulations results of afte rolling up to 80% of thickness reduction

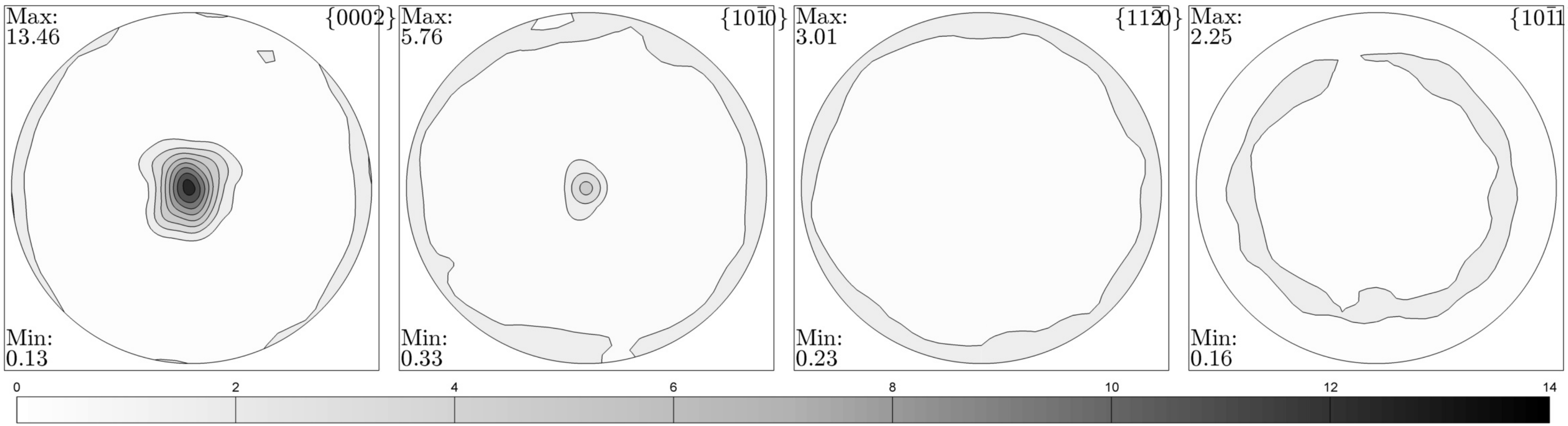


Simulations results, deformation in soft slip systems

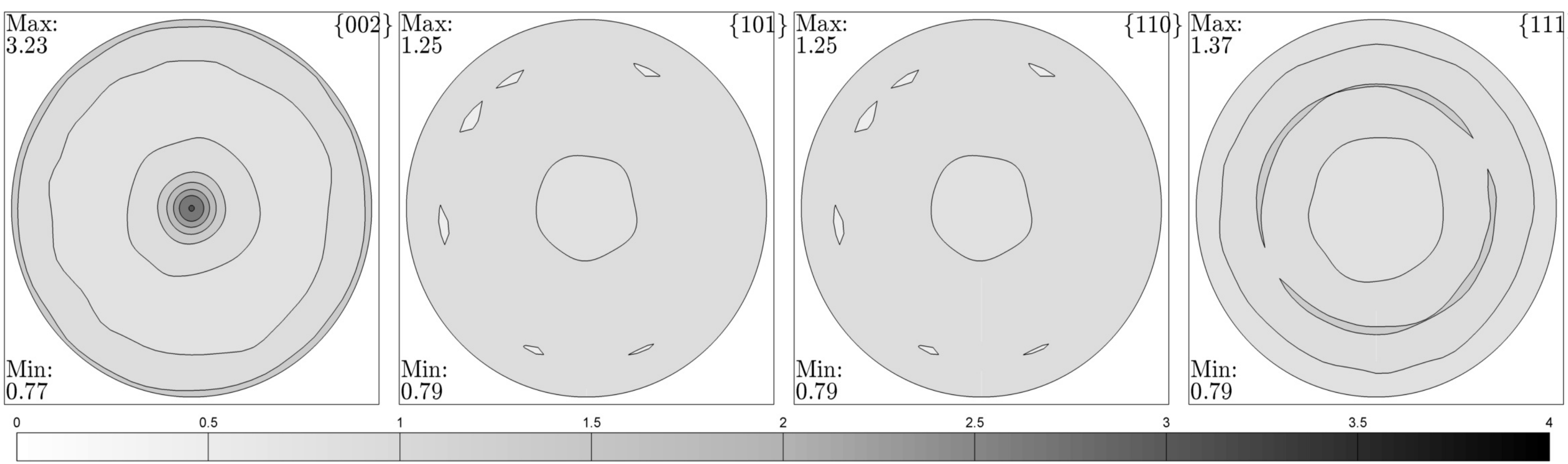


Measured texture for AZ61 after rolling

Texture simulations results of afte rolling up to 80% of thickness reduction

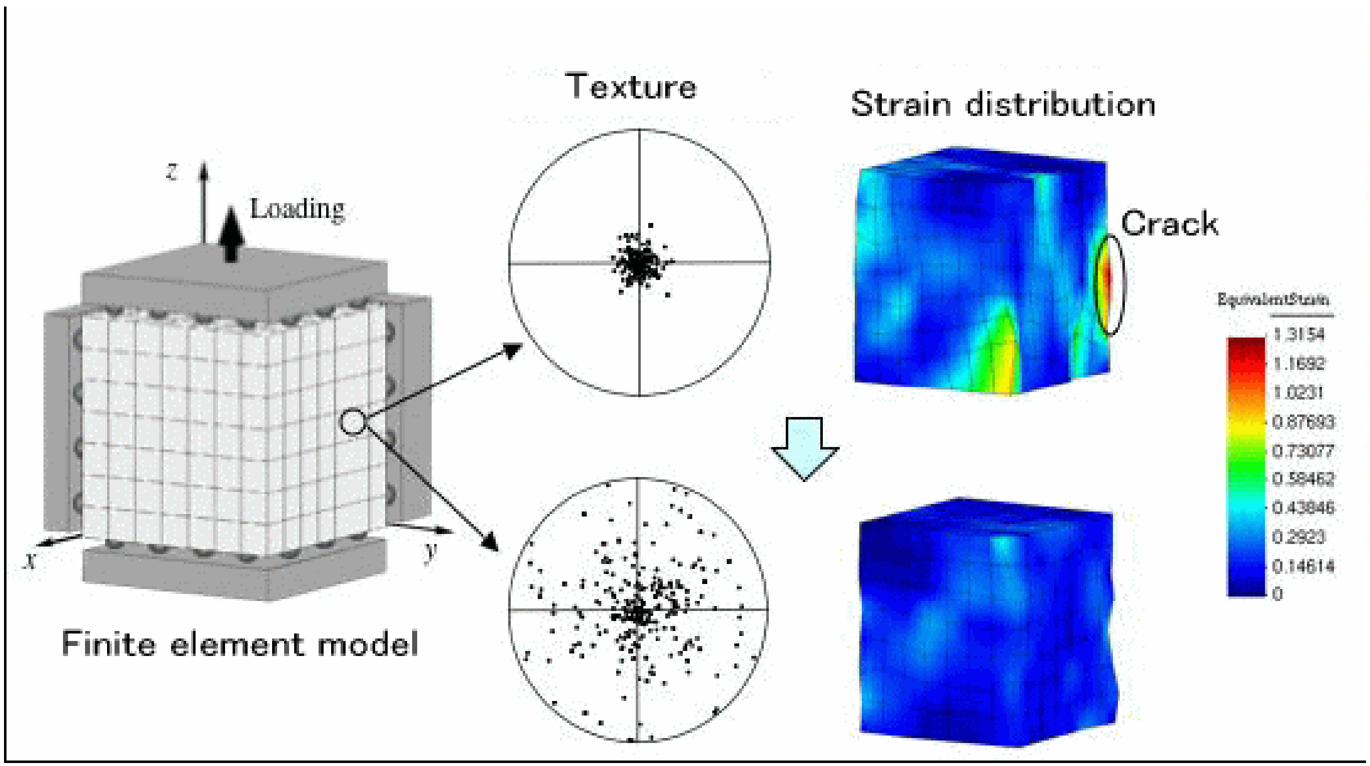


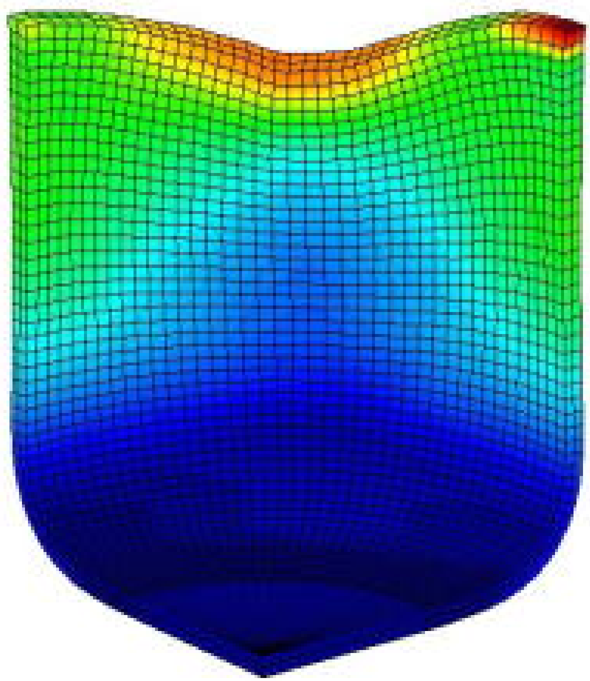
Simulations results, deformation in soft slip systems



Measured texture for AZ91 after rolling

Texture effect in processing of metals - simulations





Results of simulations

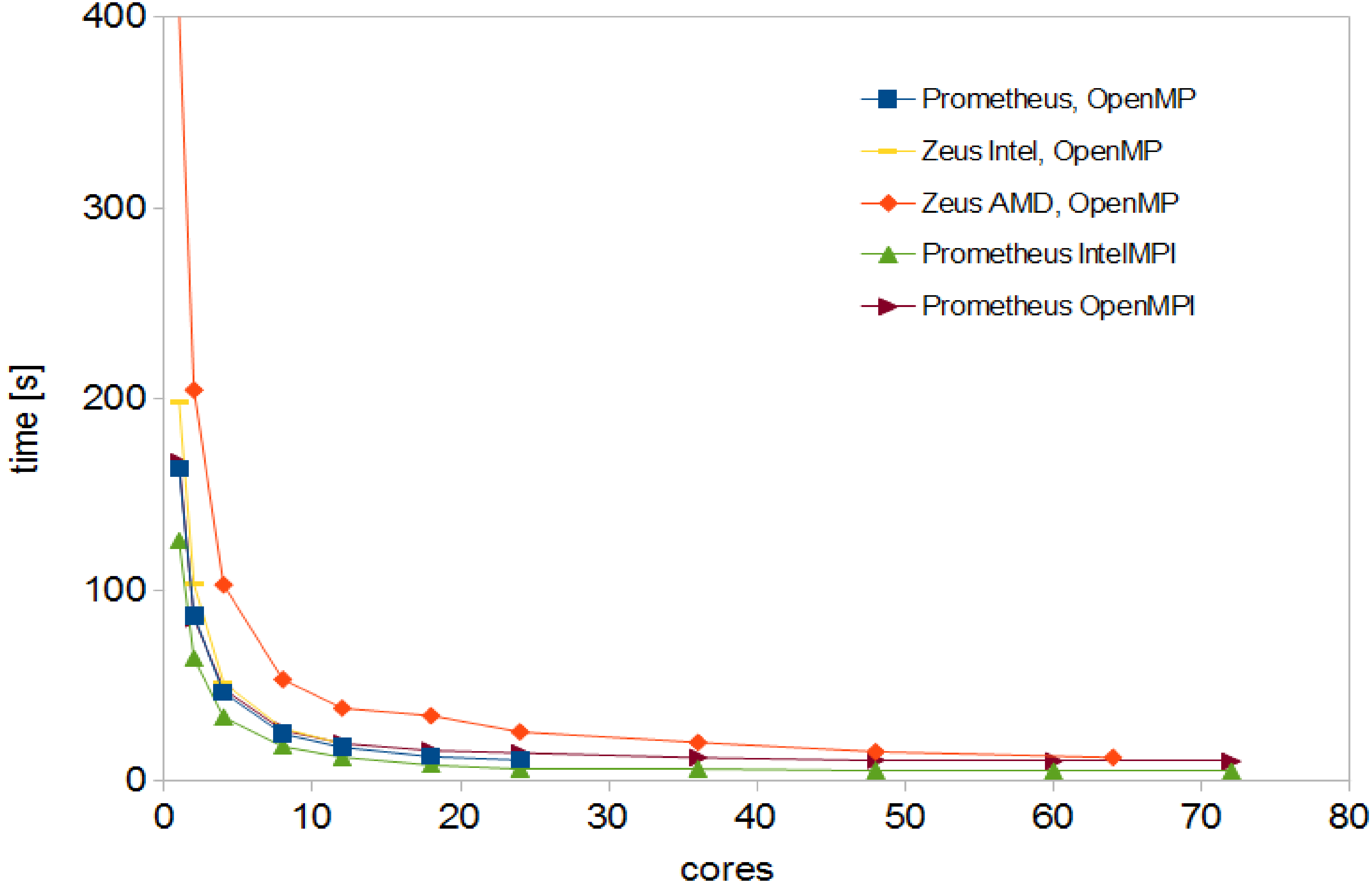
- Modeling of textures for: magnesium and copper
- Strain tensor: rolling
- Deformation: 80%
- Deformaton step: 0.025
- Initail sample size: 100 000 elements
- Multi slip, Taylor model
- Supercoumpter Zeus:

  Intel(R) Xeon(R) CPU X5650 2.67GHZ

  AMD Opteron(TM) Processor 6276
- Supercomputer Prometheus:

  Intel(R) Xeon(R) CPU E5-2680 v3 2.50GHz
- Software:OpenMP, OpenMPI, IntelMPI

Efficiency of calculations



Conclusions

•After hot rolling of AZ61 and AZ91 at 450°C and at a high strain rate, twins formed in grains, which had an impact on the increase of hardness

•During annealing, in general, the average size of grains increased. However, in the case of AZ61 after annealing for 15 minutes a decrease in the average grain size was observed

•The texture after hot rolling of AZ61 and AZ91 was a basal type texture with additional components. Those components are strong $\{11\bar{2}0\}$ fibre and $\{0\bar{1}\bar{1}3\}\langle 2\bar{1}\bar{1}0\rangle$ for AZ91 and strong $(0001)\langle 10\bar{1}0\rangle$ component for AZ61

•During annealing the texture changed in both cases of AZ61 and AZ91. The basal component disapeared and new components appeared. It was weak $(0001)\langle 11\bar{2}0\rangle$ and $\{11\bar{2}0\}$ fiber for AZ61 and strong $(0001)\langle 11\bar{2}0\rangle$ for AZ91

•The texture changes may have an impact on the plastic and mechanical properties of deformed and annealed magnesium alloys