SALZGITTER MANNESMANN FORSCHUNG
Ein Unternehmen der Salzgitter Gruppe

Application of MTEX in Industrial Research

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Chemnitz, 17th March 2021

Outline

Introduction – Salzgitter Mannesmann Forschung

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SALZGITTER AG Stahl und Technologie | EUROPIPE | VDM Metals | vallourec | und weitere …

BU Strip Steel	BU Plate / Section Steel	BU Mannesmann



Markets

- OEM
- Automobile Component Supplier
- Trading and Steel Service-Center
- Cold Roller and Tube Manufacturer
- Construction Industry (Roof/Wall)

Markets

- Line Pipe
- Power Plants
- Automobile Industry
- Machinery and Plant Engineering
- Contruction Industry (Beams and Pilings)



Introduction – Salzgitter Mannesmann Forschung

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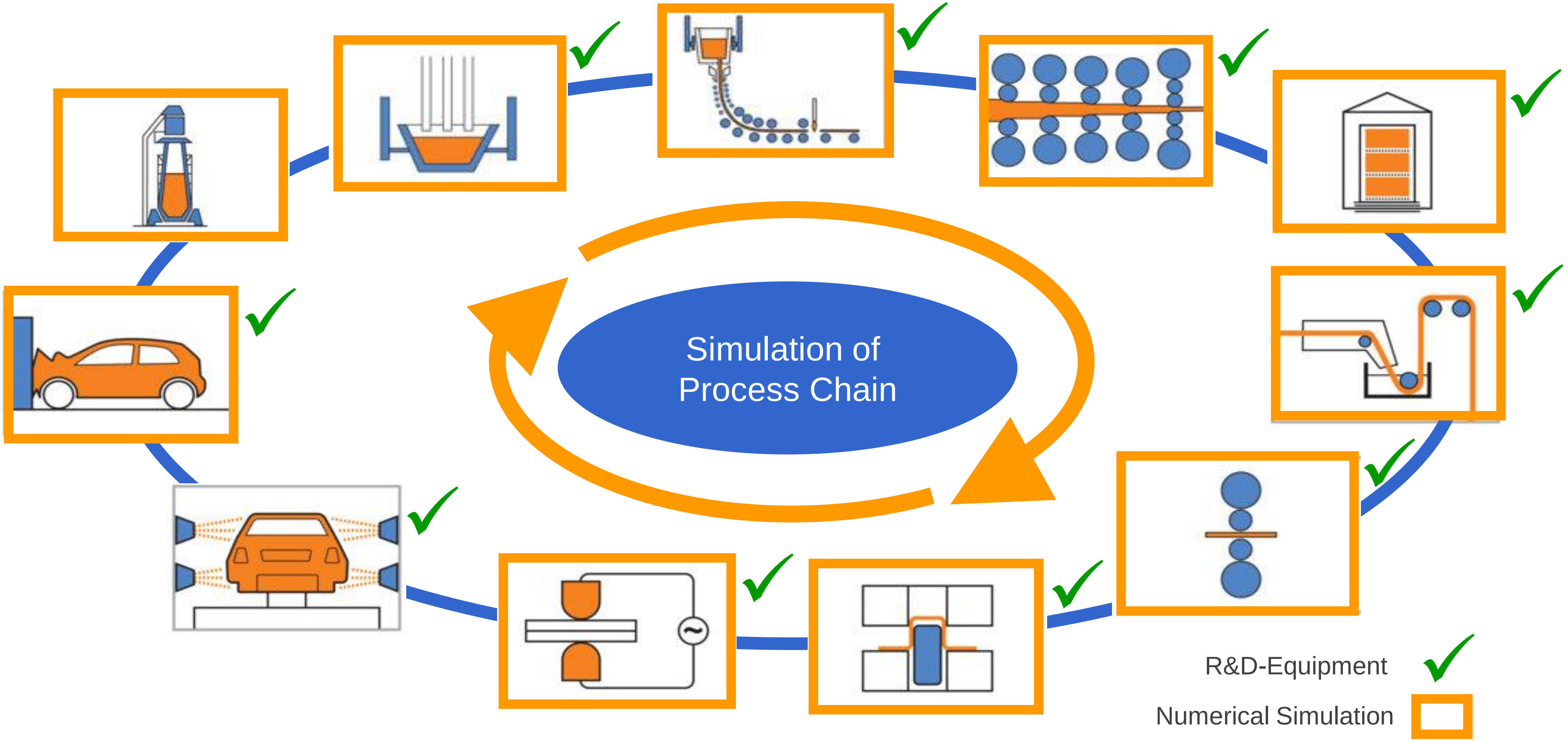

Application of MTEX at SZMF

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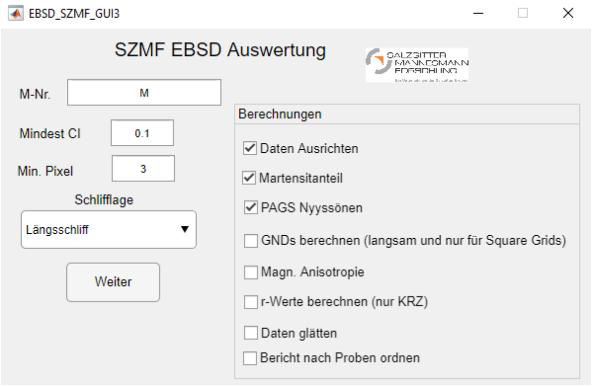
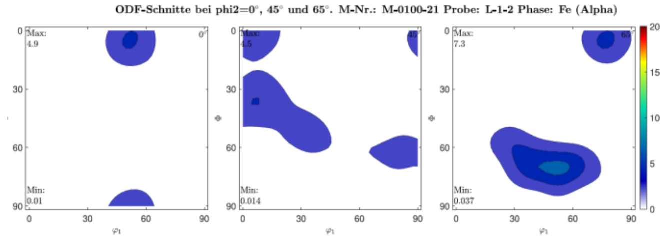
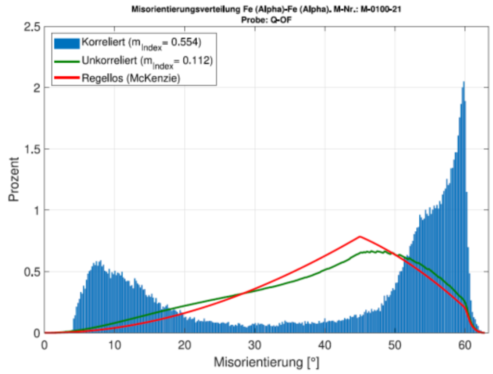
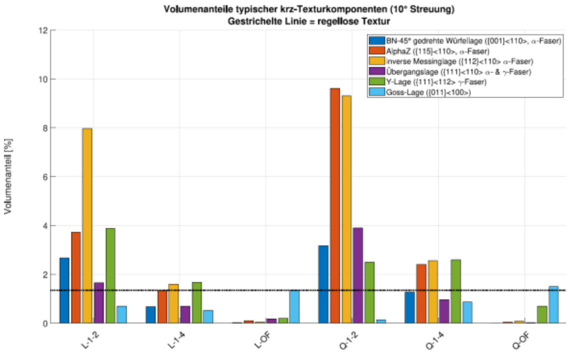
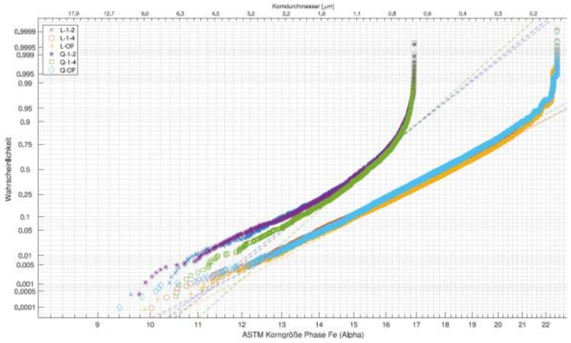
- In-depth and automated evaluation of XRD texture and EBSD measurements
- Sequential import → post-processing → evaluation → reporting











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- Introduction
- **Plastic Anisotropy**
- Texture Simulation 1 – Tensile Deformation
- Texture Simulation 2 – Hot Rolling
- Correlative Microscopy

Plastic Anisotropy – R-value (or Lankford coeff.)

- In tensile tests the r-value is defined as: $$R = \frac{\epsilon_{\mathrm{y}}^{p}}{\epsilon_{\mathrm{z}}^{p}}$$
- According to [1] the R-value can be estimated from the crystallographic texture via Taylor simulation.
- Taylor simulation for different contraction ratios. The ratio wich leads to the least slip activity is assumed to be the R-value.
- The calculation is repeated for different tensile directions between RD and TD.
- Normal R-value (deep drawing): $$R = \frac{1}{4}\left(R_0 + 2\,R_{45} + R_{90}\right)\ .$$
- Planar anisotropy ΔR-value (earing): $$R_p = \frac{1}{2}\left(R_0 - 2\,R_{45} + R_{90}\right)\ .$$

[1] Bunge, H. J. (1994). *Texture analysis in materials science: mathematical methods*.

Plastic Anisotropy – MTEX Code

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```
% slip systems
sS = slipSystem.bcc(CS);

% sample orientations from odf
oris = calcOrientations(odf,1000);

% contraction ratios (smaller steps size --> better results)
q = 0:0.01:1;

% rotation of texture from RD to TD
rot = rotation('axis',zvector,'angle', 0:5:90.*degree);

for i=1: length(rot)

    %rotate all orientations
    oris_rot = rot(i)*oris;

    M_q = 0;

    for j = 1:length(q)

        % velc. Gradient Tensor with different contractions
        epsilon = velocityGradientTensor(diag([1 -q(j) -(1-q(j))]));

        % compute the mean Taylor factor
        M = calcTaylor(inv(oris_rot) * epsilon, sS.symmetrise,'silent');
        M_q(j) = mean(M);
    end

    % minimal Taylor factor determines actual amount of
     contraction
    [M_Min, id] = min(M_q);
    q_found(i) = q(id);

    % derive R-value from found contraction
    R_calc(i) = q_found(i)/(1-q_found(i));

end


% normal and delta R-Values
r_norm = (R_calc(1) + 2*R_calc(10) + R_calc(19))/4;
r_delta = (R_calc(1) - 2*R_calc(10) + R_calc(19))/2;
```

→ Calculation takes rather long and speed-up would be nice!

Plastic Anisotropy – Example

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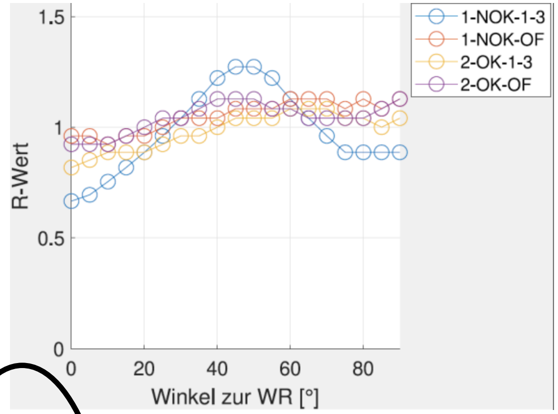
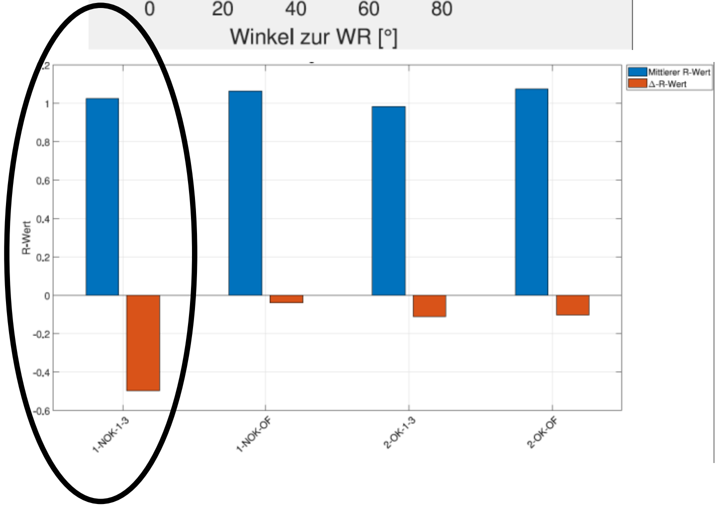
- Problem: Hot-rolled dual-phase steel batch showed earing during manufacturing.
- EBSD measurements at surface (shear texture) and 1/3 sheet thickness (rolling texture)
- The not-OK sample had at 1/3 thickness stronger α- and γ-fibre texture, smaller grain size and higher ΔR-value.
- Problem was caused by unsufficient recrystallization during the last hot rolling steps.
- Increase of finish rolling temperature solved the problem!





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Texture Simulation 1 – Tensile Deformation

Paper Review

- An „awesome“ discovery was presented in a low quality draft:

  „Tensile deformation leads to a further increase of texture intensity in Cube textured pure fcc Ni“

- What says the MTEX Taylor simulation to this?

Texture Simulation 1 – MTEX Code

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```
% fcc crystal symmetry & slip systems
CS = crystalSymmetry('m-3m', [3.6599 3.6599 3.6599], 'mineral', 'Iron fcc', 'color', 'light green');
sS = slipSystem.fcc(CS);

% cube orientation
cube = orientation.byEuler(0,0,0,CS);

% start with sharp cube texture
odf_start = 0.9*unimodalODF(cube,CS,deLaValleePoussinKernel('HALFWIDTH',5*degree)) + 0.1*uniformODF(CS);

% get orientations from odf
ori = calcOrientations(odf_start,10000);

% initial cube fraction --> 77.7%
vol_cube_start = volume(ori,cube,10*degree)

% tensile strain tensor
epsilon = 0.3 * strainTensor(diag([1 -0.5 -0.5]));

for i=1:5
  % compute the Taylor factors and the orientation gradients
  [M,~,W] = calcTaylor(inv(ori) .* epsilon./5, sS.symmetrise);
  % rotate the individual orientations
  ori = ori .* orientation(-W);
end

% cube fraction after deformation --> 86.5%
vol_cube_def = volume(ori,cube,10*degree)
```

→ Increase in Cube texture intensity is in agreement with Taylor theory (minimization of slip activity)

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Texture Simulation 2 – Hot Rolling

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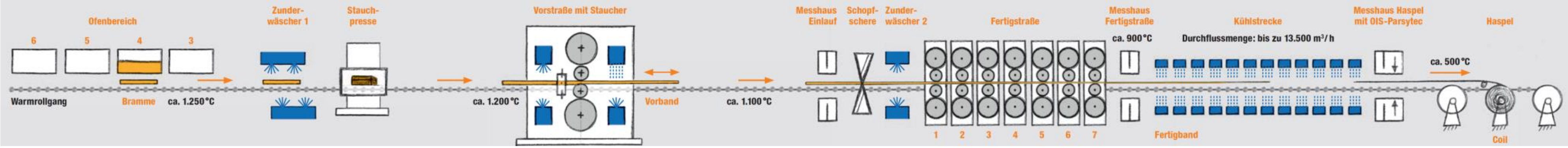
- During Hot Rolling a lot happens in a short time:
  - Deformation
  - Recrystallization (Dynamic & Static)
  - Recovery (Dynamic & Static)
  - Phase Transformation
  - Grain Growth
  - Precipitation
  - …



Texture Simulation 2 – Hot Rolling - Deformation

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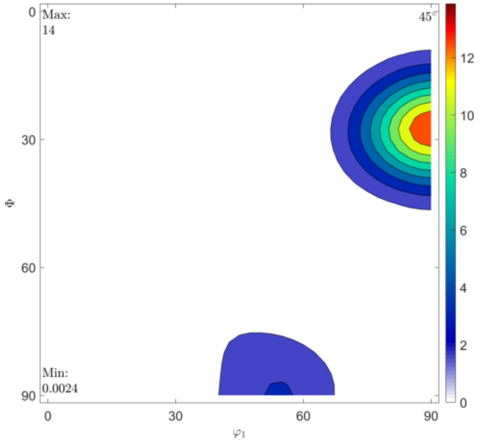
- Simple model for the prediction of hot rolling textures in steel
- Deformation, Recrystallization, Phase Transformation (fcc → bcc)

Hot Deformation

- FCC slip system {111} <110>
- Initial texture is random
- Plane strain without shear deformation
- Simulation in 11 steps up to ε = 3.7

Result

- Typical fcc rolling texture. β-fiber with more Copper orientation than Brass orientation.



Texture Simulation 2 – Hot Rolling - Recrystallization

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- Recrystallization (RX) mechanisms are Oriented Nucleation and Oriented growth.

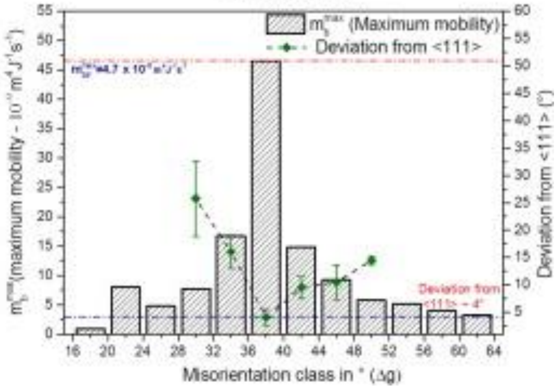
Oriented Nucleation

- Orientations with high Taylor factor (= high disclocation density) nucleate first.
- → Create ODF from inital orientations of deformation step and use Taylor factors as weights.

Oriented Growth

- Highly mobile 38°-<111> ∑7 grain boundaries in fcc determine growth.
- → Rotation of simulated deformation texture after deformation step by 38°-<111>

Experimental



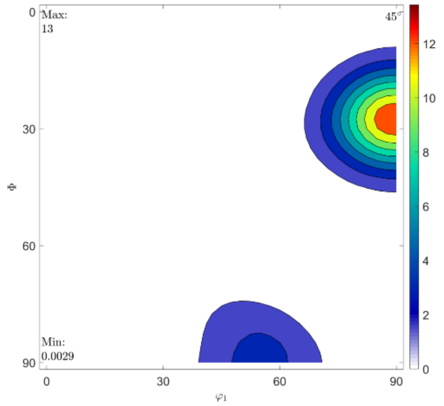
Basu, I., et al., *Mat. Char.* 117 (2016): 99-112.

Texture Simulation 2 – Hot Rolling - Recrystallization

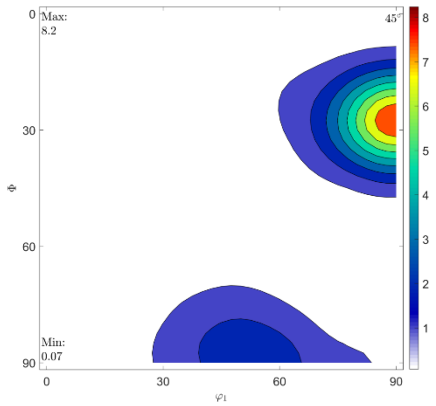
- Mixing of simulated deformation ODF with Taylor-ODF and rotated ODF after each deformation step (mixing ratio = RX factor).

Result

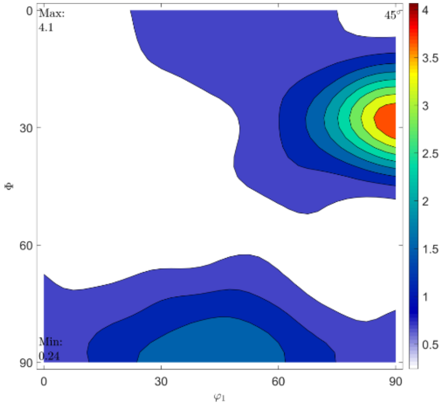
- Decrease in texture intensity (mainly Copper orientation), strengthening of RX cube texture



RX = 0.0



RX = 0.2



RX = 0.5

Texture Simulation 2 – Hot Rolling – Phase Transformation

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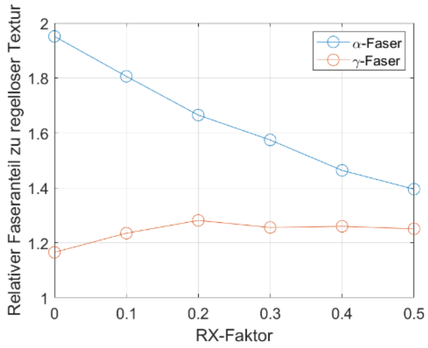
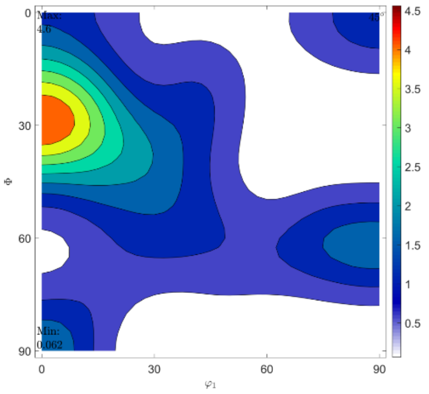
Assumptions

- FCC → BCC orientation relationship is Greninger-Troiano
- No variant selection (does not have much effect?)

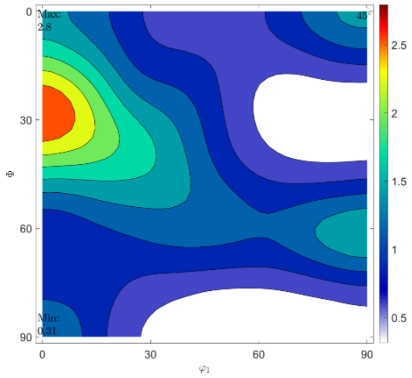


Results

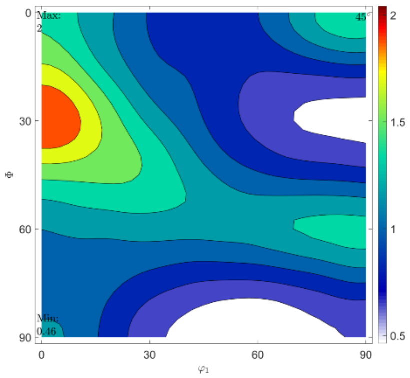
- Typical bcc rolling texture with more α- than γ-fibre
- Decreasing texture intensity and strengthening of γ-fibre with increasing RX.



RX = 0.0



RX = 0.3

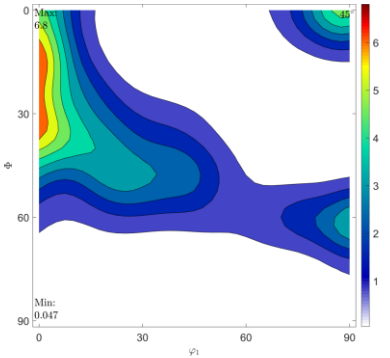


RX = 0.5

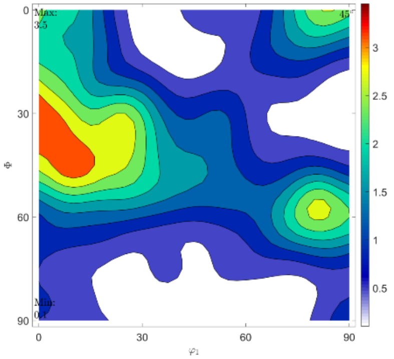
Texture Simulation 2 – Hot Rolling – Comparison

Less RX | More RX

Experiment (M_0132_19)

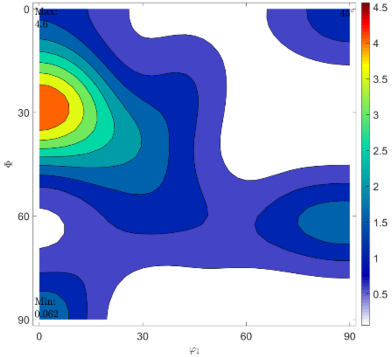


ΔR = -0.90

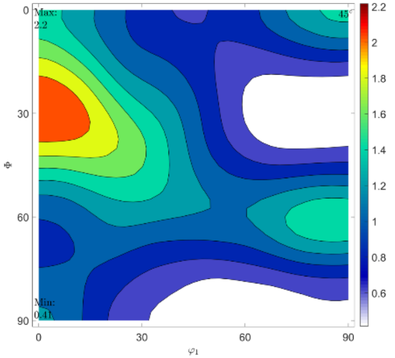


ΔR = -0.46

Simulation



ΔR = -0.24



ΔR = -0.08

Model reproduces correct trend only from crystallography!

Texture Simulation 2 – Hot Rolling – Outlook

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- More realistic deformation and RX path from MatCalc simulations
  - MatCalc can simulate many material properties, but not texture.
- Recovery? Cross slip?
- Active slip systems at high temperatures?
- Variant selection during phase transformation (s. Da Costa Viana 1996)
- Simulation of shear texture close to sheet surface
- …

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Correlative Microscopy

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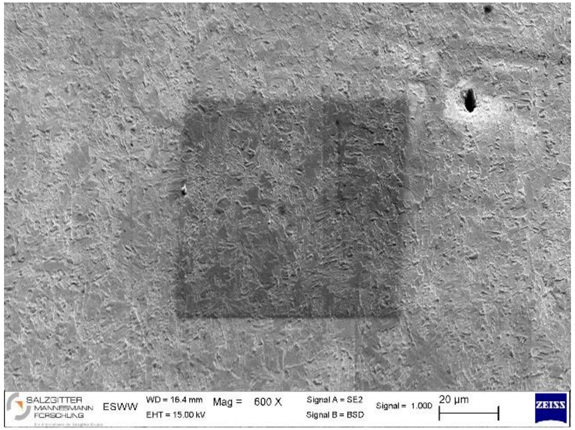
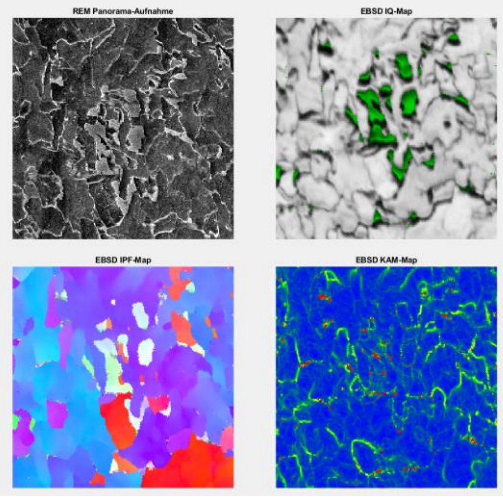
- Correlative Microscopy with EBSD and SEM
- Electropolishing (A2) causes topography contrast (different carbon content of steel phases)
- After EBSD measurements the carbon contamination makes it easy to find the same area
  → High resolution SEM panorama image
- By cropping and rotation the SEM and EBSD images can be rather well aligned





Correlative Microscopy – MTEX Code

```
% load images
img1 = imread('SEM_panorama.bmp');
img2 = imread('EBSD_Phase.bmp');
img3 = imread('EBSD_IPF.bmp');
img4 = imread('EBSD_KAM.bmp‘);

% stretch gray value histogram
img1 = rgb2gray(img1);
img1 = imadjust(img1);

% make subplots
figure
subplot(2,2,1);
% adjust image size
imshow(img1, 'XData',[1 4096], 'YData',[1 4096])
axes1 = gca;
title('SEM')

subplot(2,2,2);
imshow(img2)
axes2 = gca;
title('EBSD IQ-Map')
```

```
subplot(2,2,3);
imshow(img3)
axes3 = gca;
title('EBSD IPF-Map')

subplot(2,2,4);
imshow(img4)
axes4 = gca;
title('EBSD KAM-Map')

% link axes of subplots
linkaxes([axes1,axes2,axes3,axes4],'xy');

% adjust margins between subplots
ha=get(gcf,'children');
set(ha(1),'position',[.35 .1 .4 .4])
set(ha(2),'position',[.1 .1 .4 .4])
set(ha(3),'position',[.35 .55 .4 .4])
set(ha(4),'position',[.1 .55 .4 .4])

set(gcf,'units','normalized','Position',[0 0 1 1])
saveas(gcf,'SEM_EBSD_linked.fig‘)
```

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Summary

- Calculation of plastic anisotropy is very useful but still very slow.
- Simulation of texture development during tensile deformation fits to experiment.
- Simple model for the texture development during hot rolling of steel.
- „linkaxes“ is a helpful function for correlating images.

- MTEX was extremely useful for these evaluations!

No matter what you have planned ...

Thank you for your attention!