



Max-Planck-Institut für Eisenforschung GmbH
Düsseldorf



MAX-PLANCK-GESELLSCHAFT

VDEh

Grundlagen der Kristallographie und Mikrostruktur von Stählen

Prof. Dr.-Ing. habil. Dierk Raabe
(raabe@mpie.de)

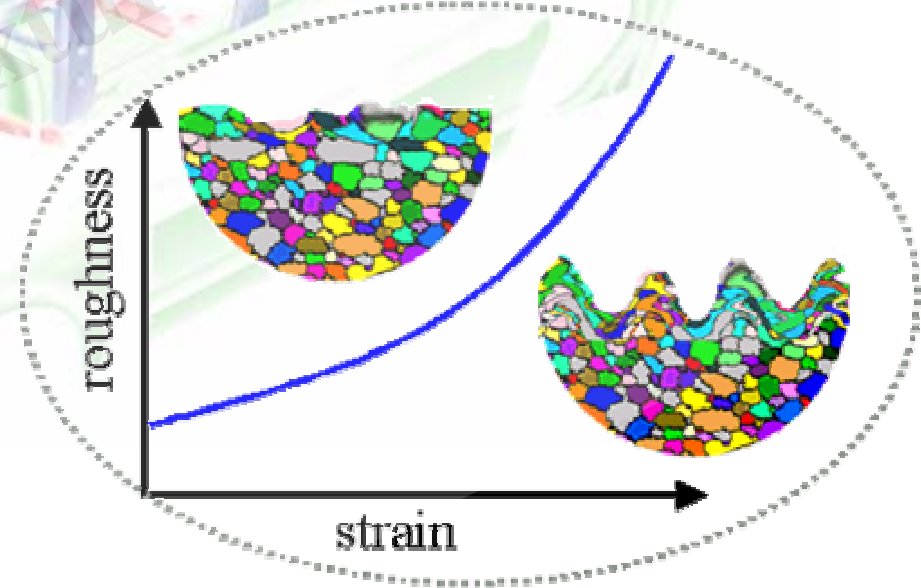
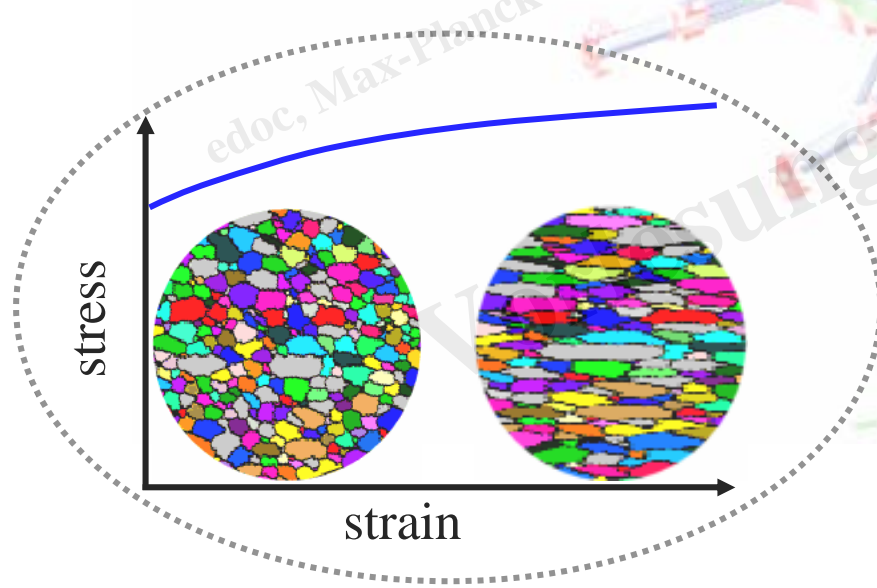
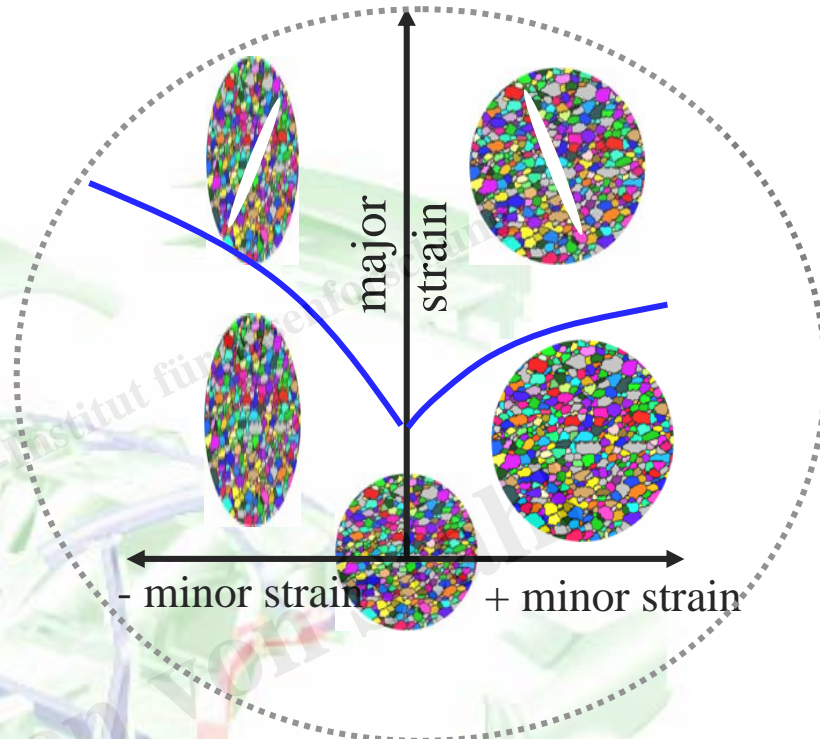
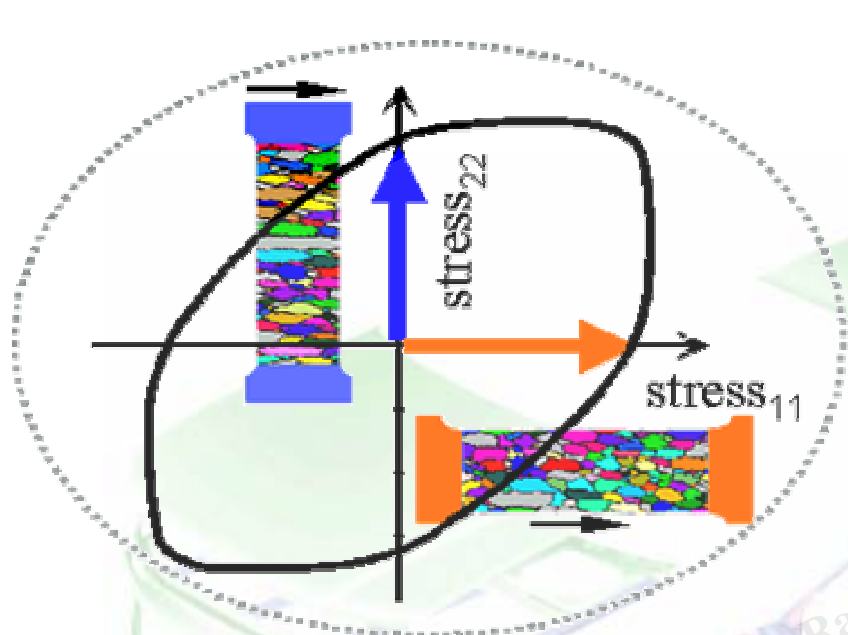
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1

Dierk Raabe
Steel Textures
Max-Planck-Institut

Abteilung Mikrostrukturphysik und Umformtechnik





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Grundbegriffe

Kristallographie

Textur

Anisotropie

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Vorlesung Texturen von Stahl

- **Mikrostruktur / Gefüge:** Gesamtheit aller Gitterfehler, die sich nicht im thermodynamischen Gleichgewicht befinden
- **Textur:** Volumengewichtete Gesamtheit aller Kristallorientierungen in einer Probe
- **OVF:** Orientierungsverteilungsfunktion, 3D Textur, quantitativ
- **Polfigur:** 2D Projektion der Orientierungsverteilungsfunktion, qualitativ
- **Isotropie:** Richtungsunabhängigkeit (*Tropos (gr.): Richtung*)
- **Anisotropie:** Richtungsabhängigkeit (Gefügezeiligkeit, Textur, etc.)
- **Fließort:** Gesamtheit aller Spannungszustände, bei denen plastisches Fließen auftritt
- **R-Wert:** Verhältnis von Breiten- zu Dickenabnahme an einer Stelle des Fließortes



Grundbegriffe

Kristallographie

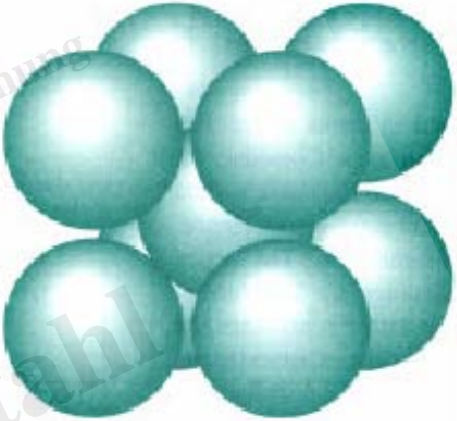
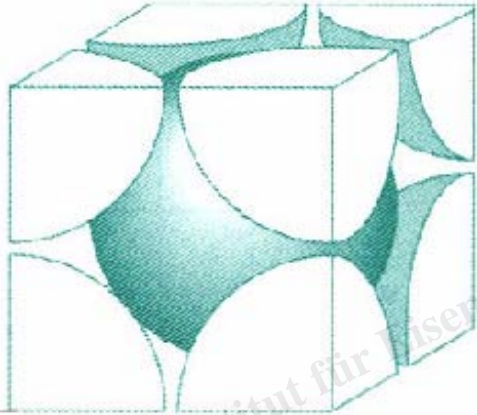
Textur

Anisotropie

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Vorlesung Texturen von Stahl



Fe, Cr, Mo, Ta, Nb, Mo, W



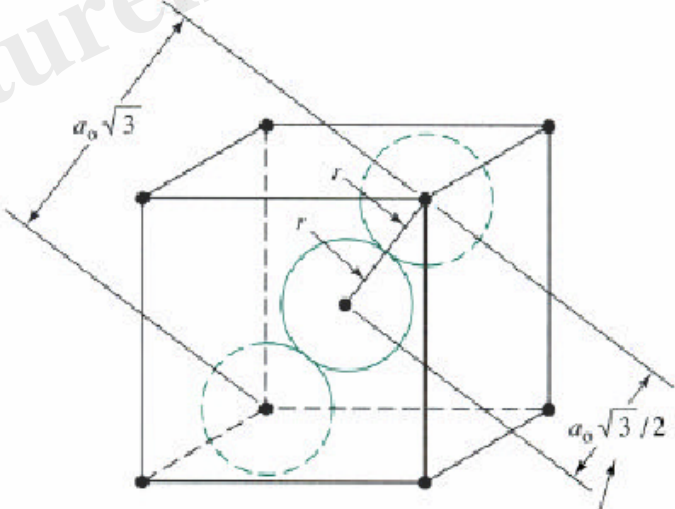
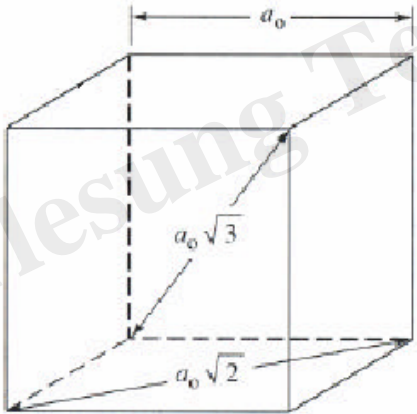
Atome pro Zelle = $(8 \times 1/8) + 1 = 2$

Koordinationszahl = $4 + 4 = 8$

atomare Packungsdichte = 0.68

$$4r = \sqrt{3}a$$

$$a = \frac{4}{\sqrt{3}}r$$



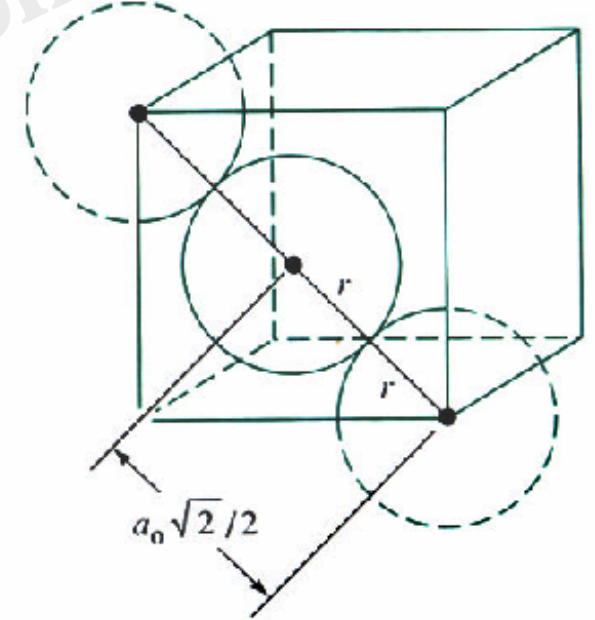
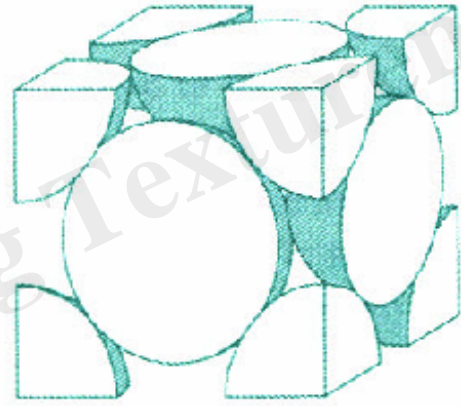
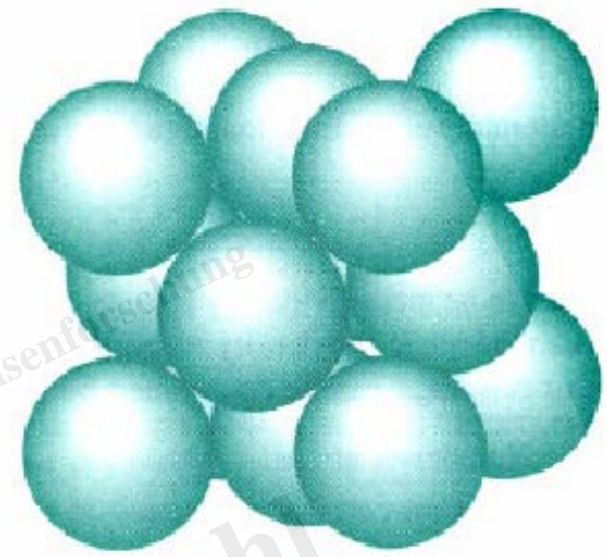
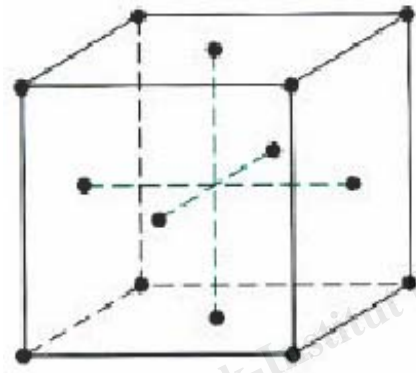
Fe, Al, Ni, Pt, Ir, Ag, Cu, Ag

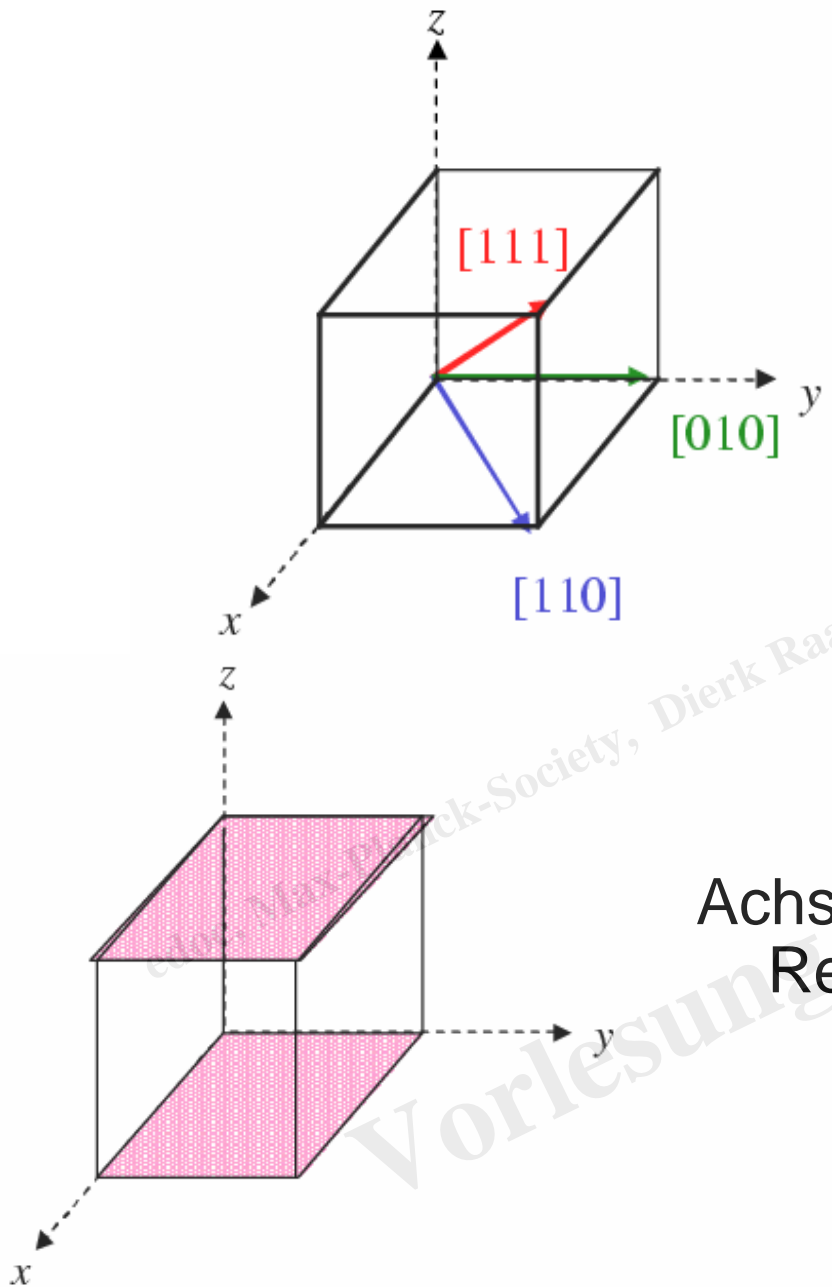
Atome pro Zelle
 $= (8 \times 1/8) + (6 \times 1/2) = 4$

Koordinationszahl
 $= 4 + 4 + 4 = 12$
atomare Packungsdichte
 $= 0.74$

$$4r = \sqrt{2}a$$

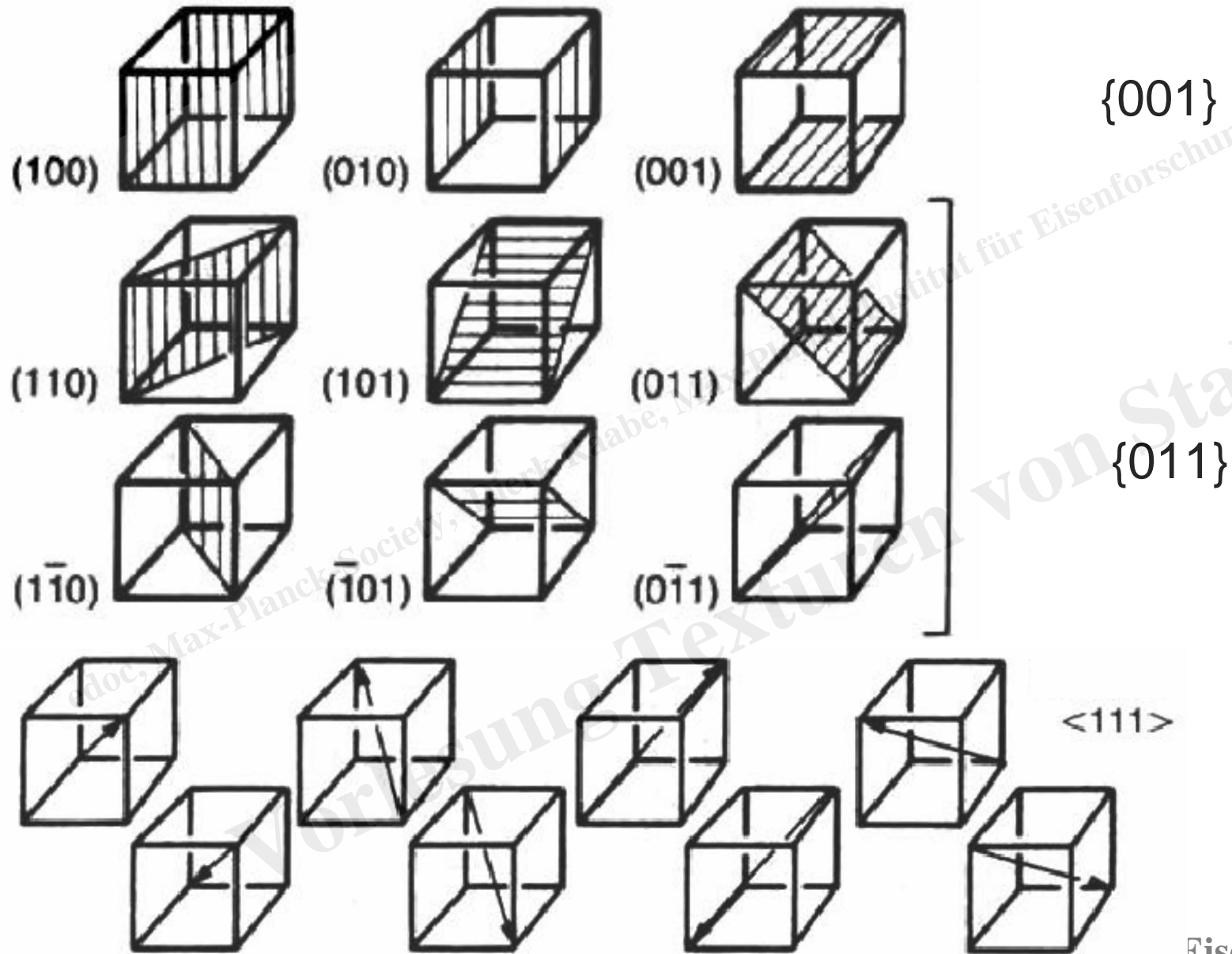
$$a = 2\sqrt{2}r$$





	x	y	z
Achsenabschnitte	∞	∞	1
Reziprokwerte	0	0	1
Indizes		(001)	

Familie



spezifisch

allgemein

Richtung

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Ebene

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Höherfeste IF-Stähle für sehr schwierige Ziehteile mit Streck- und Tiefziehbeanspruchung (z.B. Türinnenbleche, Seitenteile, Kotflügel)

Höherfeste Streckziehstähle für Bauteile, bei denen das Blech während der Umformung im Bereich des Stempelkontaktes möglichst nur aus der Dicke fließen soll, also bei flach gekrümmten Streckziehteilen (Türen, Hauben und Dächern)

Bake-Hardening-Stähle und phosphorlegierte Stähle für schwierige Tiefziehteile (Türen, Hauben, Dächern)

Mikrolegierte höherfeste Stähle für struktur- und crashrelevante Teile

Dualphasen-Stähle für Räder und schwierige Strukturteile (Längs- und Querträger); ebenso für streckgezogene Außenteile mit besonders hoher Beulfestigkeit (Türen, Dächer, Kofferdeckel)

Restaustenitstähle für Strukturteile mit besonders hohem Energieaufnahmevermögen (Säulen, Längs- und Querträger)

Martensitphasen-Stähle für Teile mit ausgeprägter Crashrelevanz (Säulen, Seitenaufprallträger, Stoßfänger)



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Vorlesung Texturen von Stahl

Grundbegriffe

Kristallographie

Textur

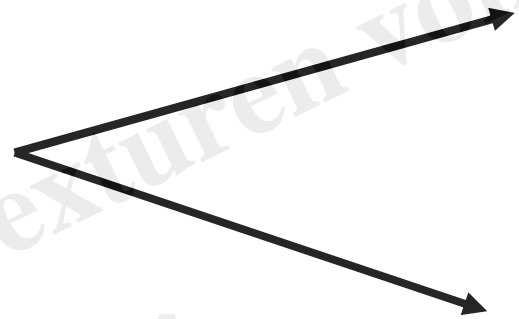
Grundlagen

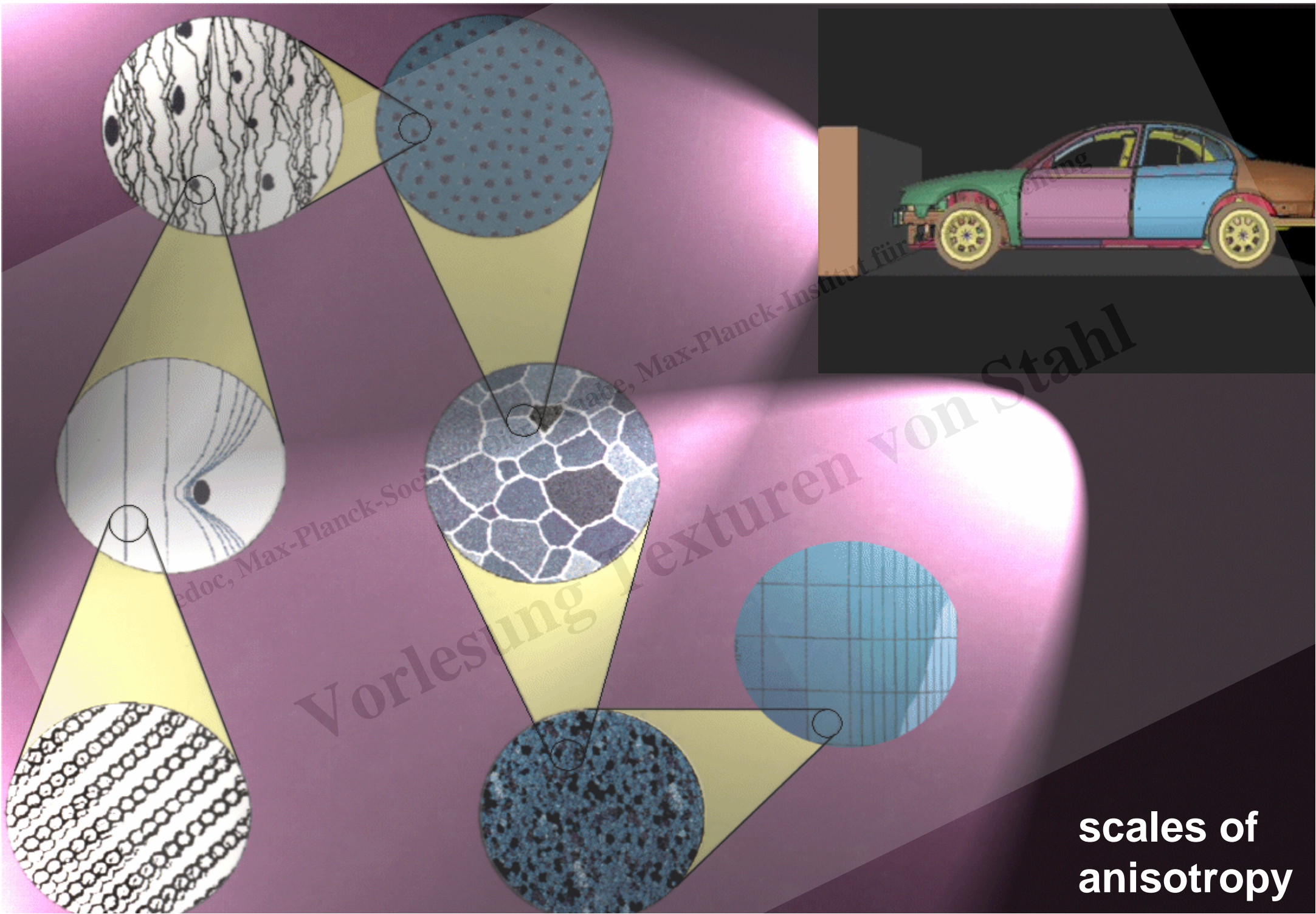
Anisotropie

Entstehung

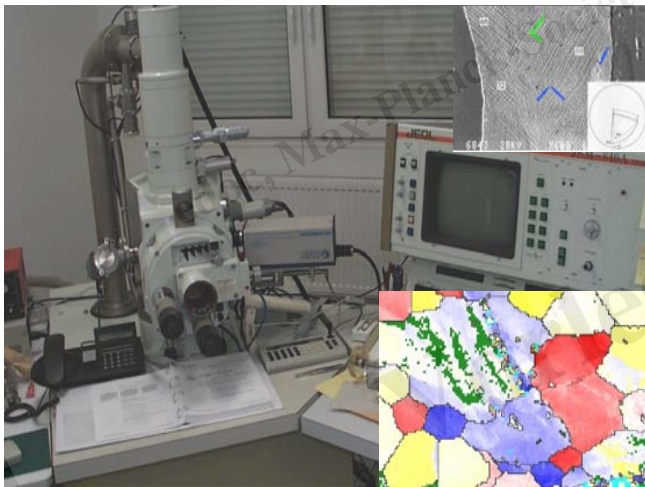
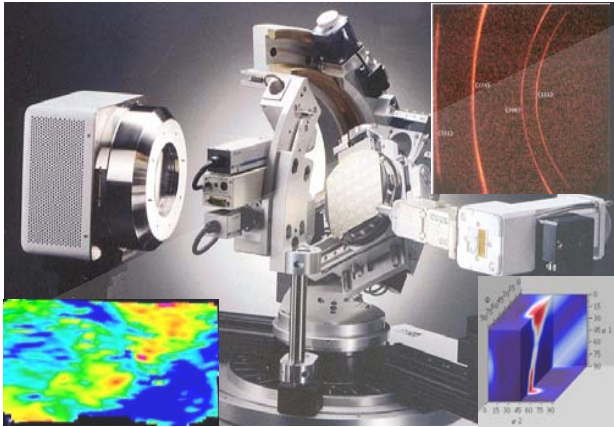
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Vorlesung Texturen von Stahl





**scales of
anisotropy**



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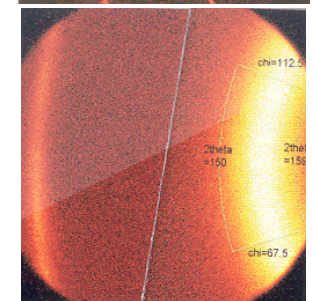
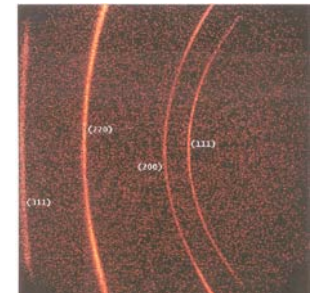
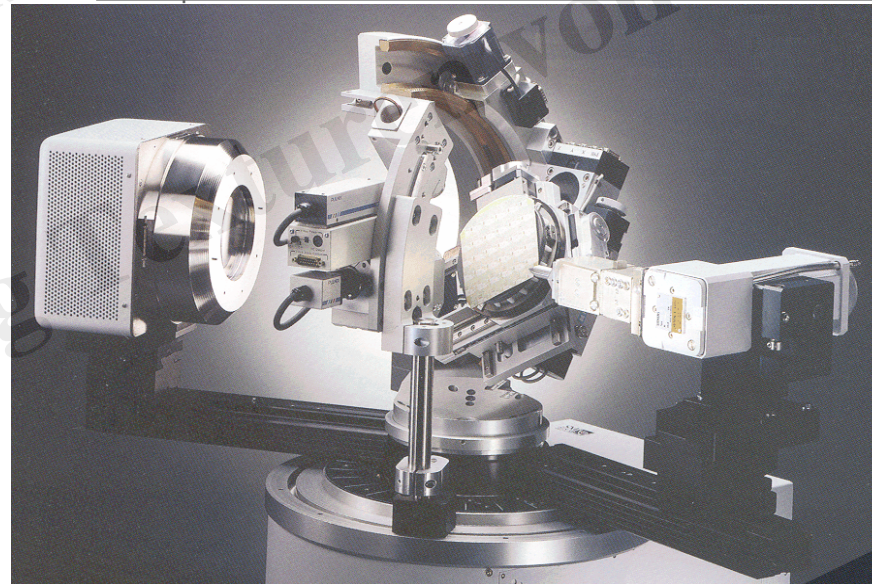
nano texture / TEM



micro texture / SEM



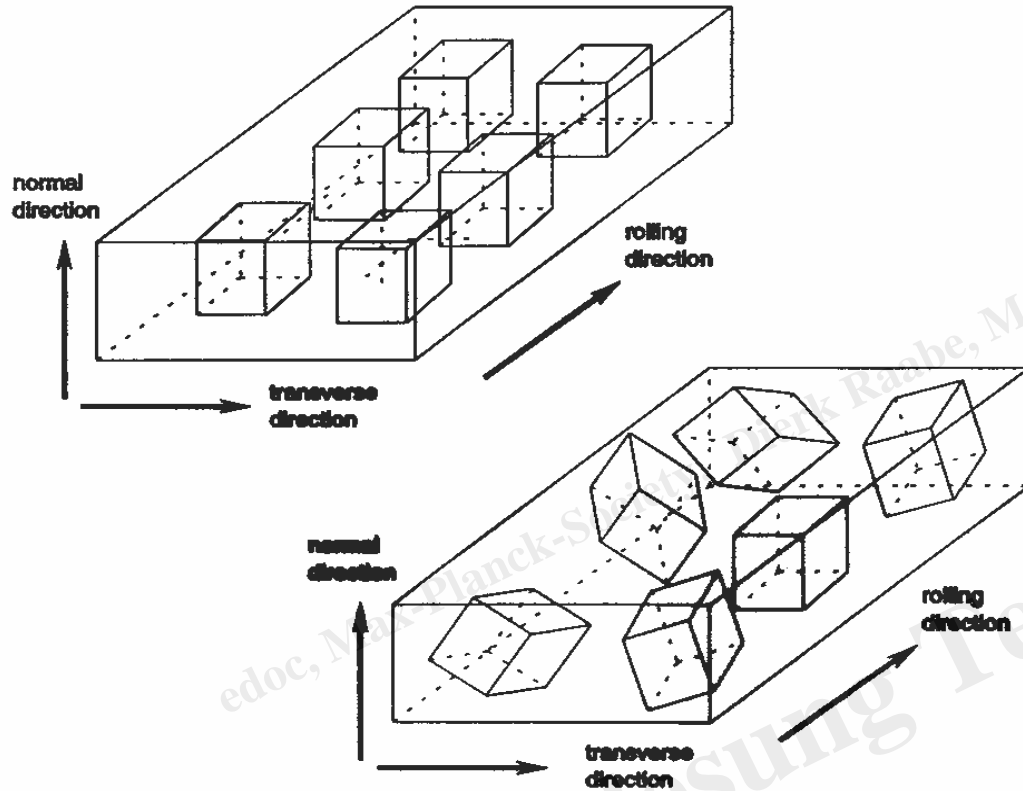
X-ray scanning microdiffraction goniometer



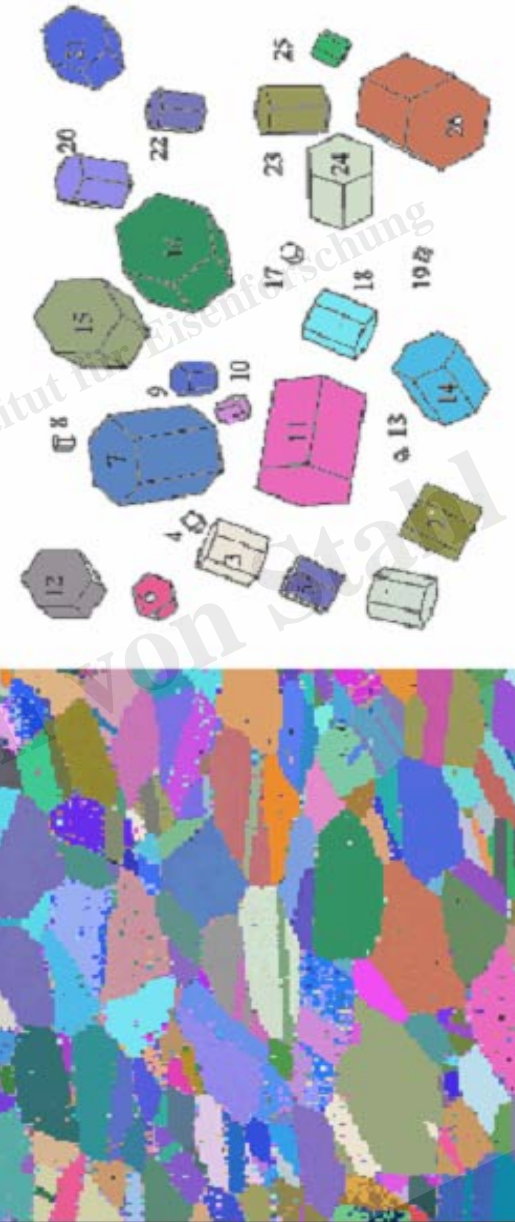
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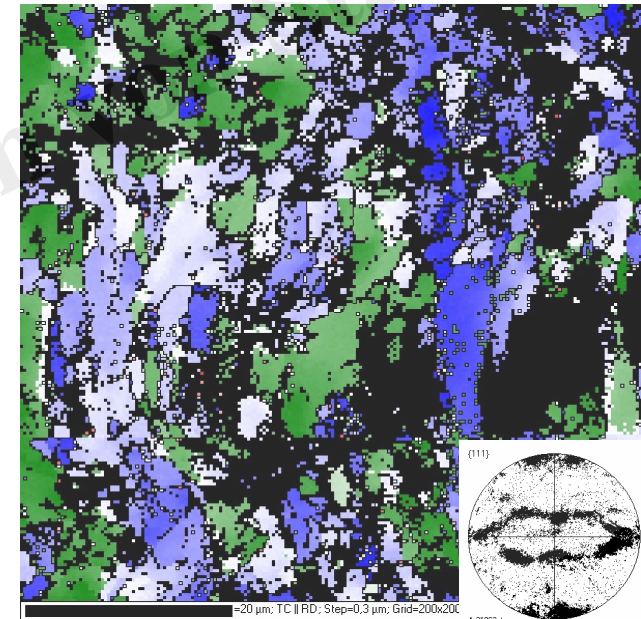
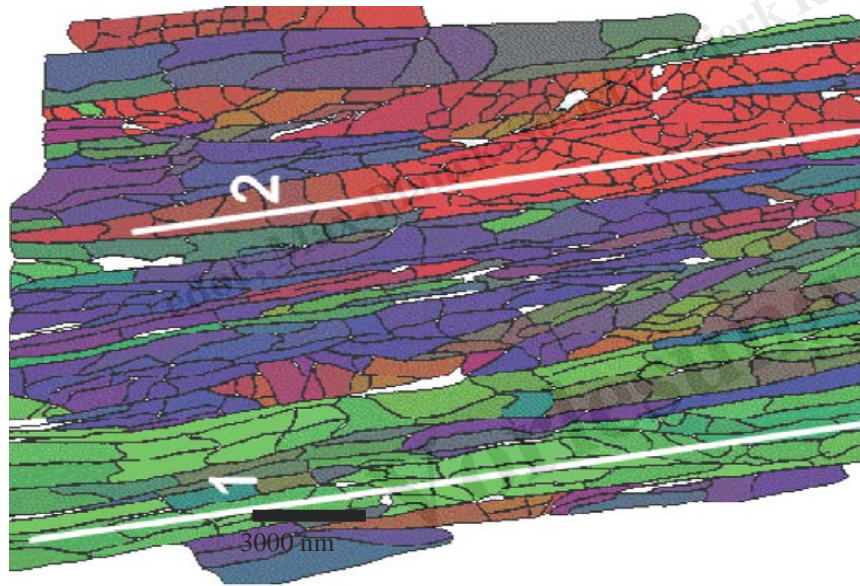
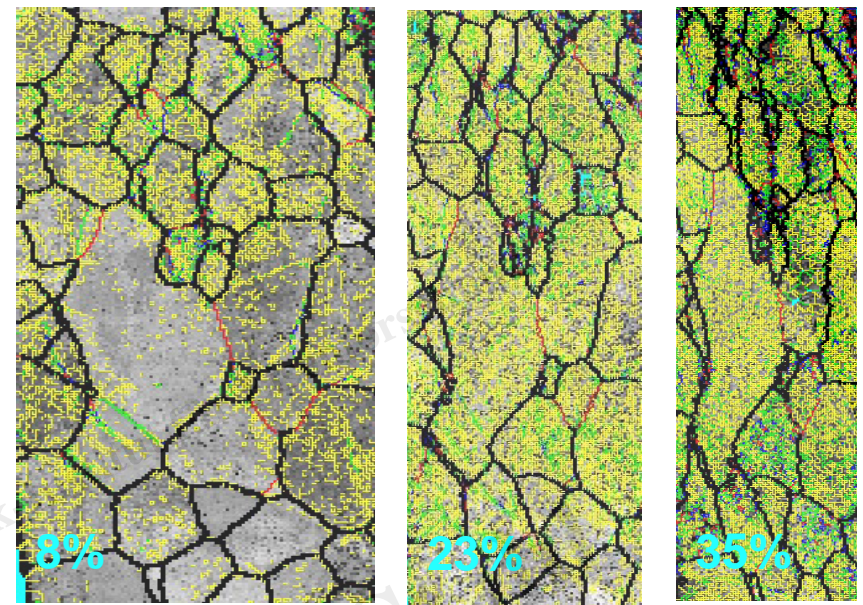
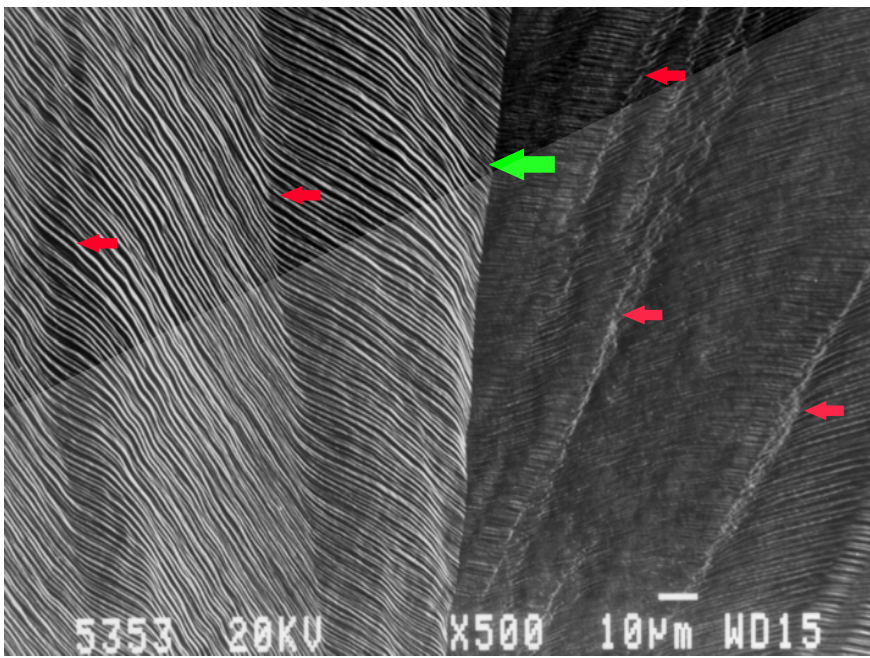


Scharfe Texture

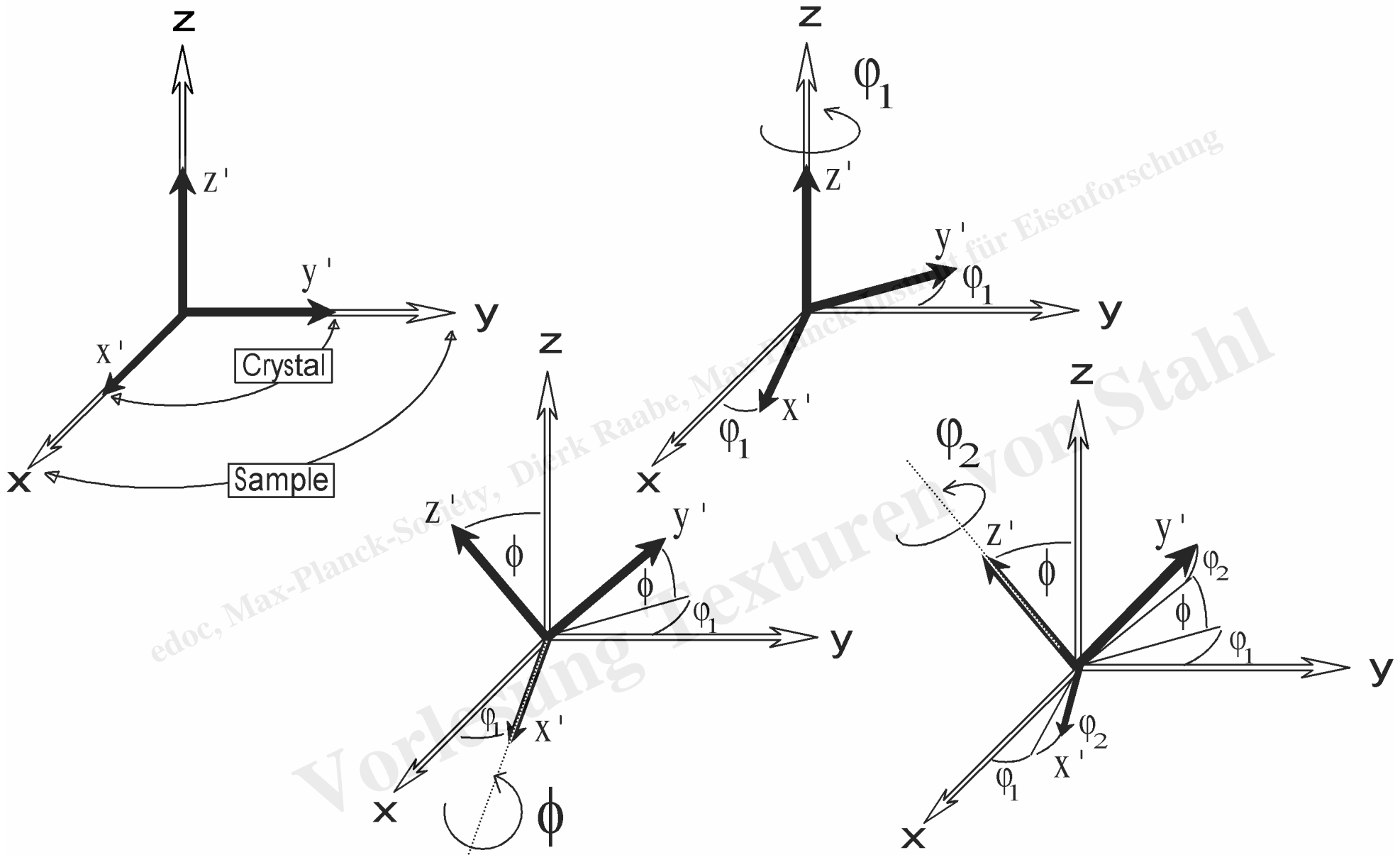


Regellose Textur





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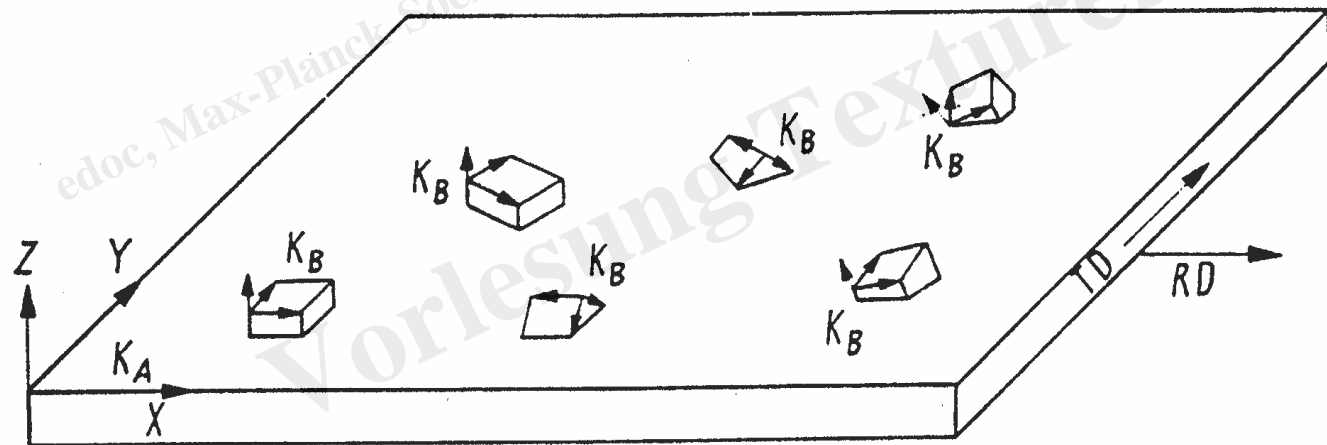
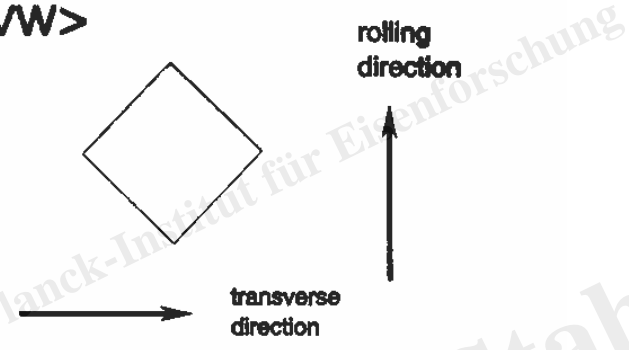


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Miller Indices $\{hkl\}\langle uvw \rangle$

$\{001\}\langle 110 \rangle$

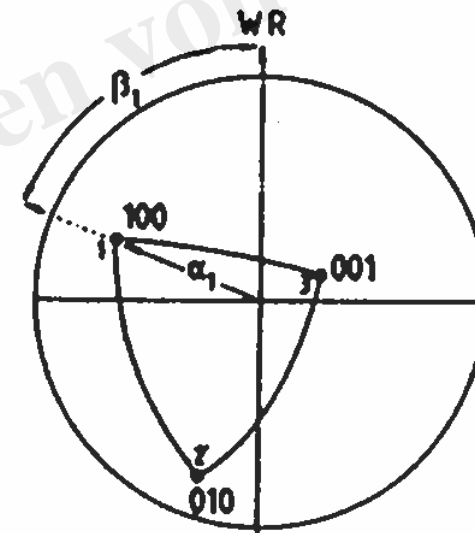
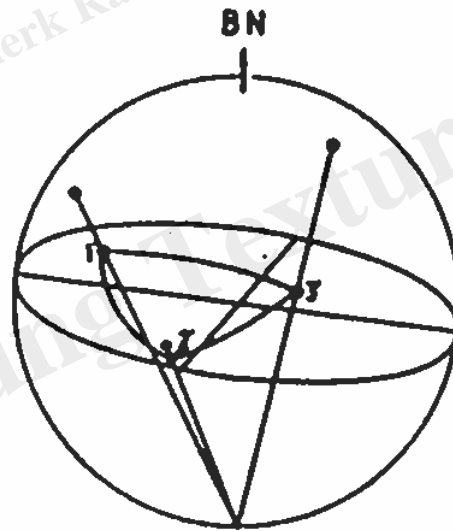
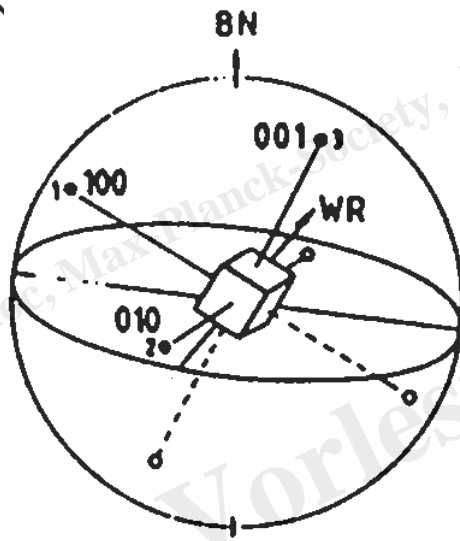
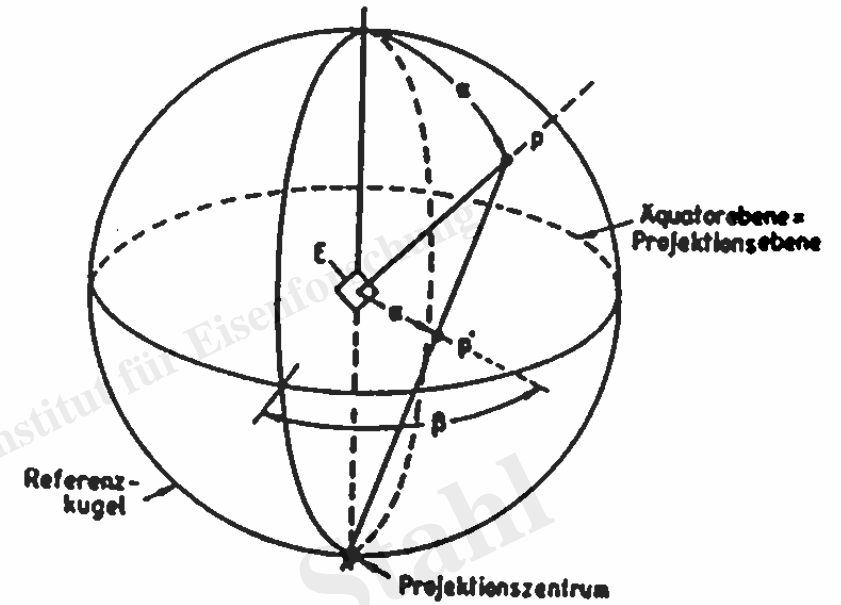
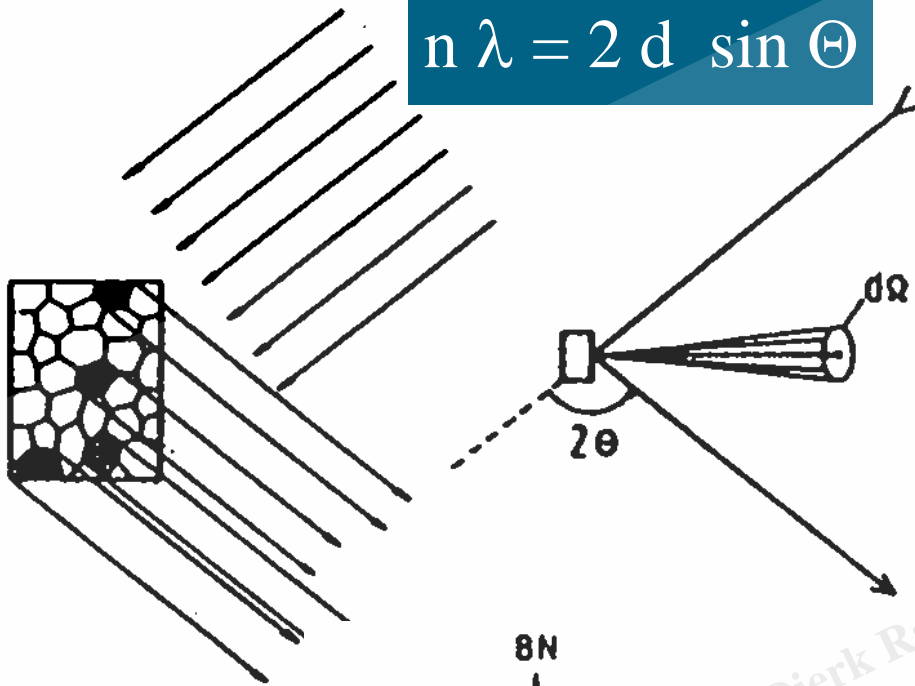
$\varphi_1 \Phi \varphi_2$



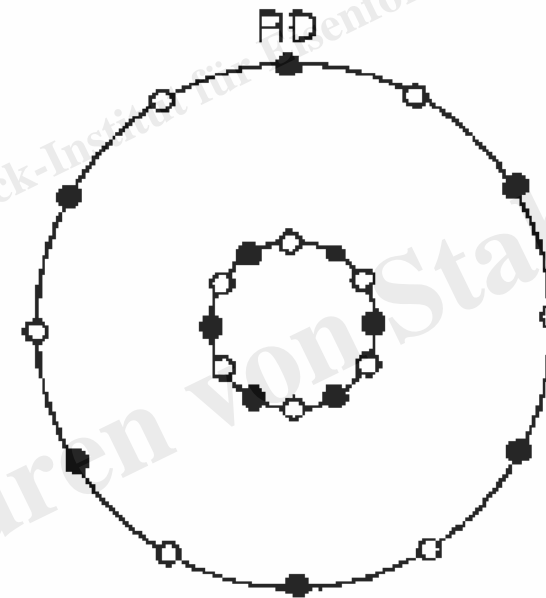
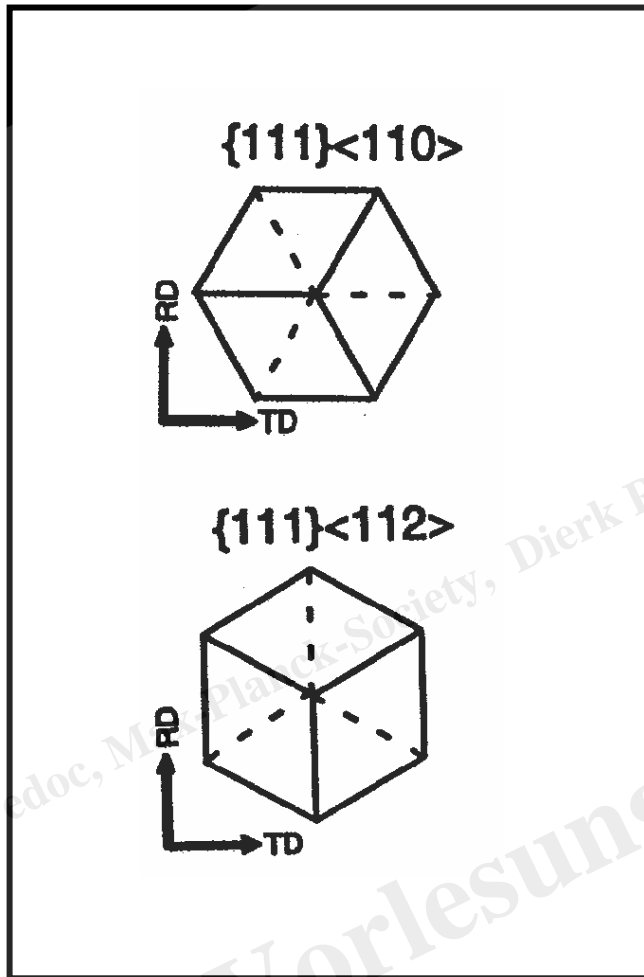
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$$n \lambda = 2 d \sin \Theta$$

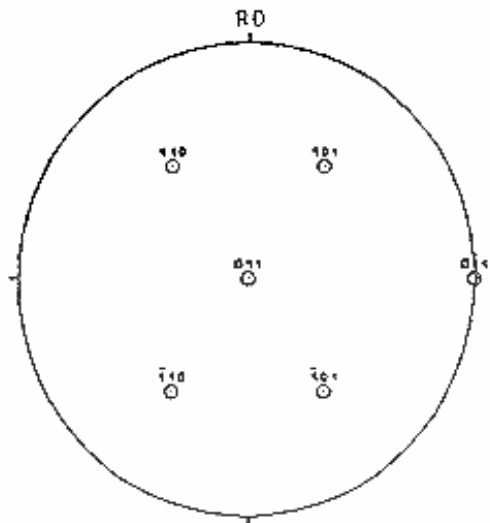


γ – Faser

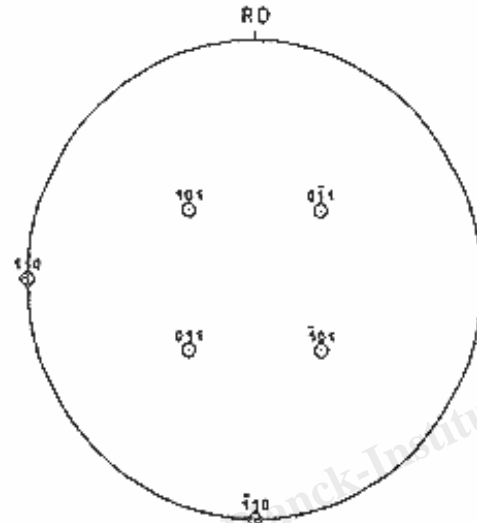


γ -Faser mit $\langle 111 \rangle \parallel \text{ND}$

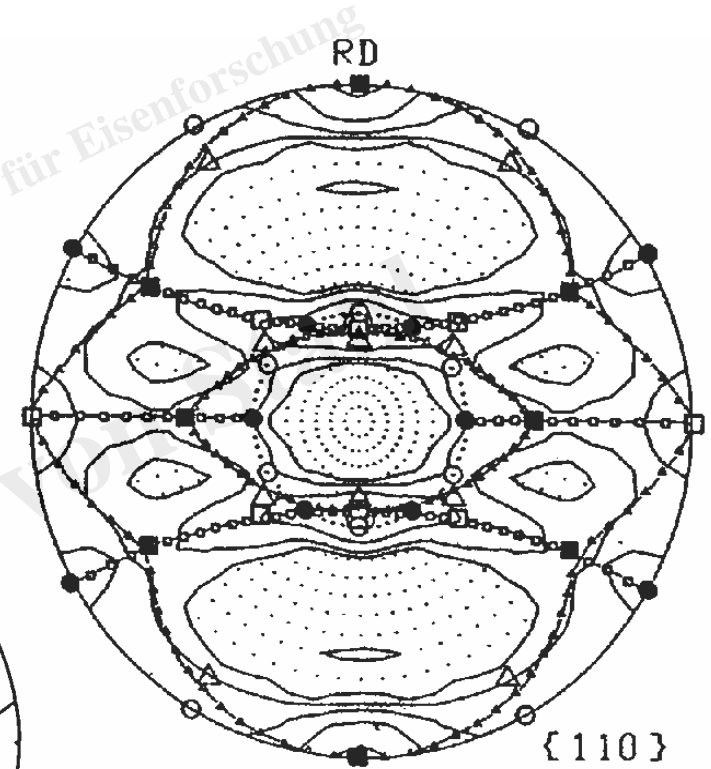
- $\{111\}\langle 112 \rangle$
- $\{111\}\langle 110 \rangle$



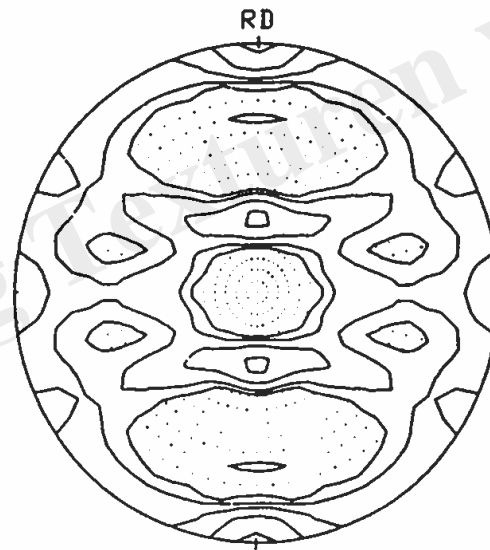
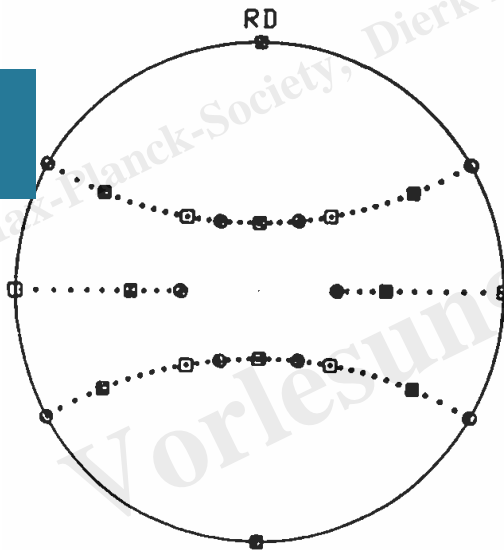
$\{011\} \langle 100 \rangle$

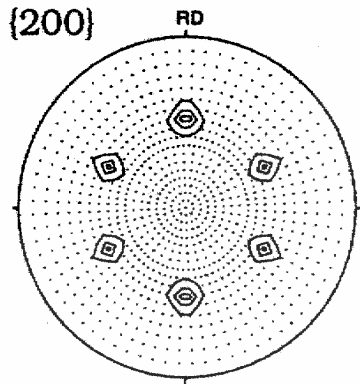


$\{001\} \langle 110 \rangle$

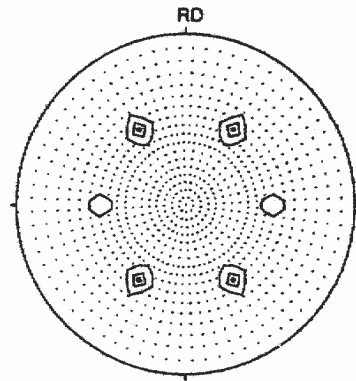


α – Faser

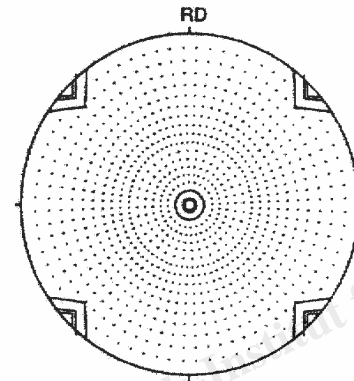




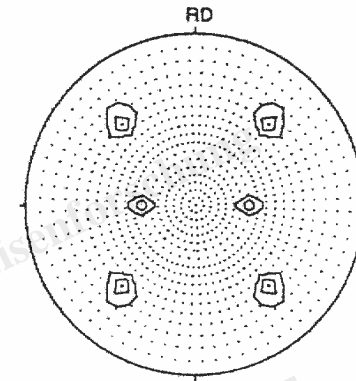
a) $\{111\}\langle 112\rangle$



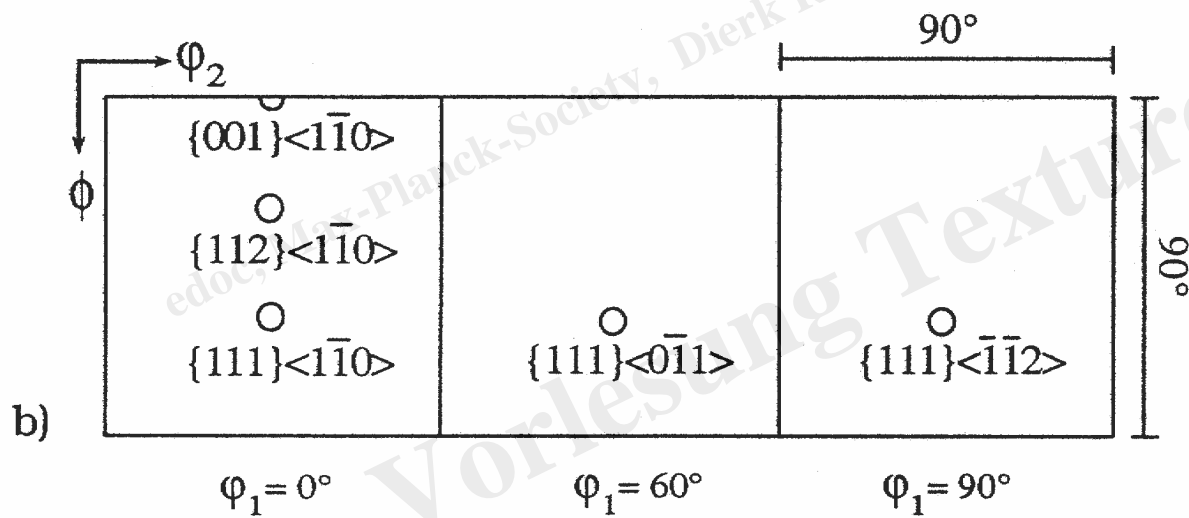
$\{111\}\langle 110\rangle$



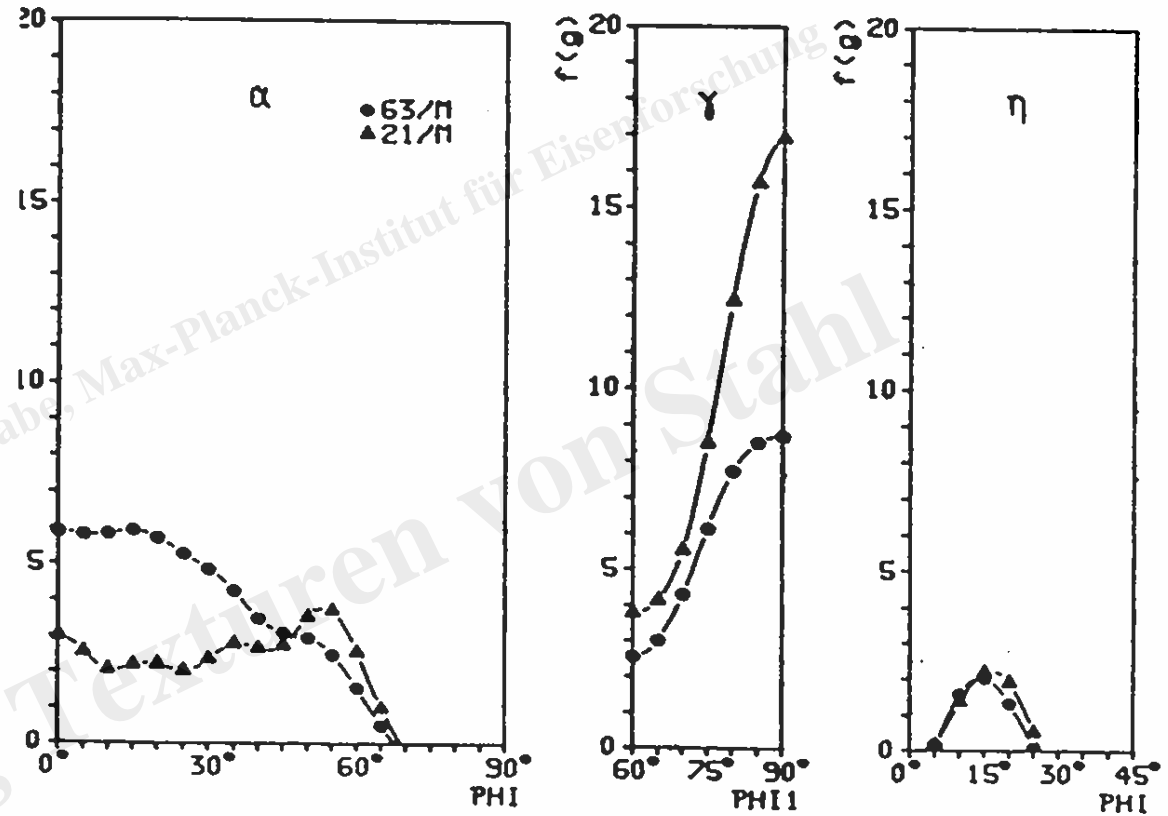
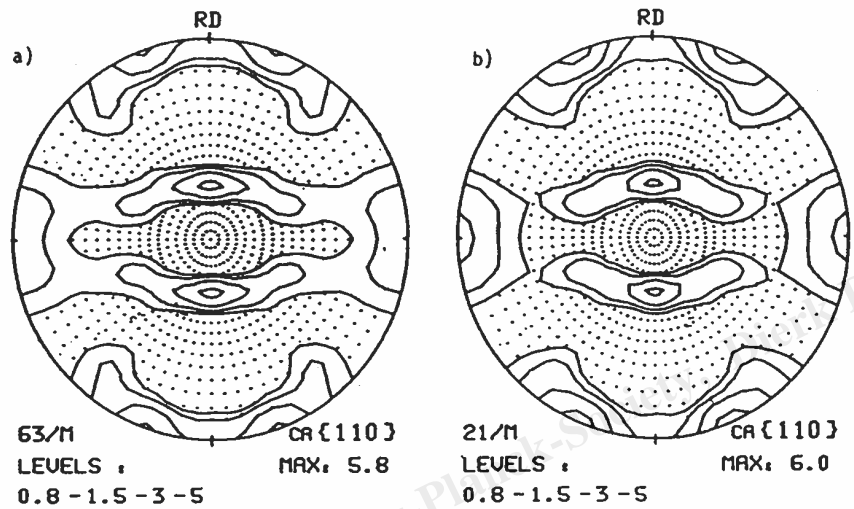
$\{001\}\langle 110\rangle$

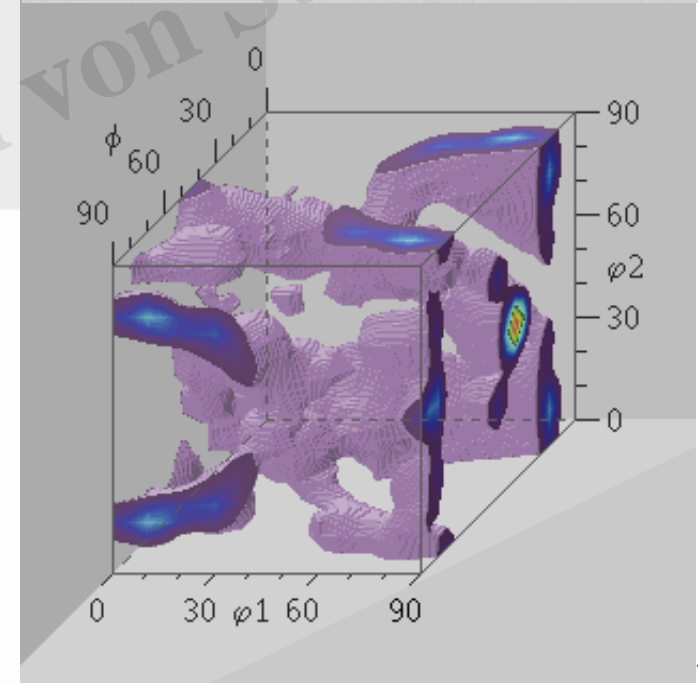
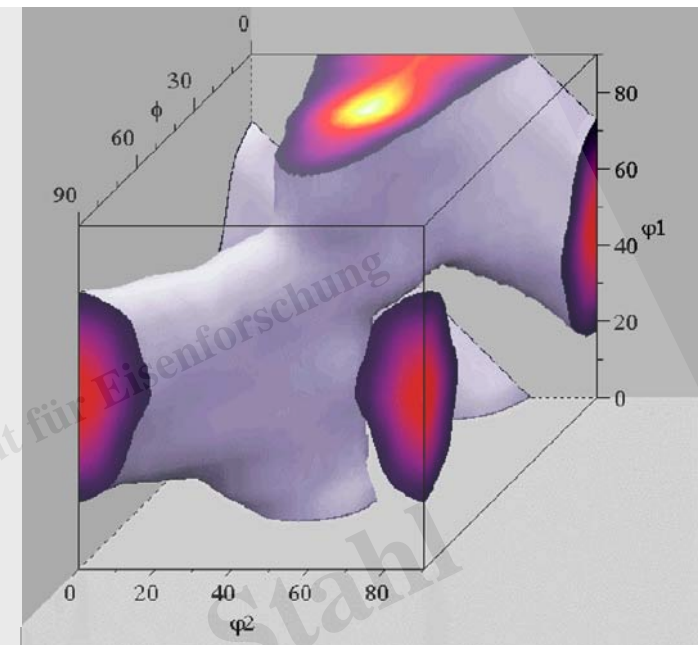
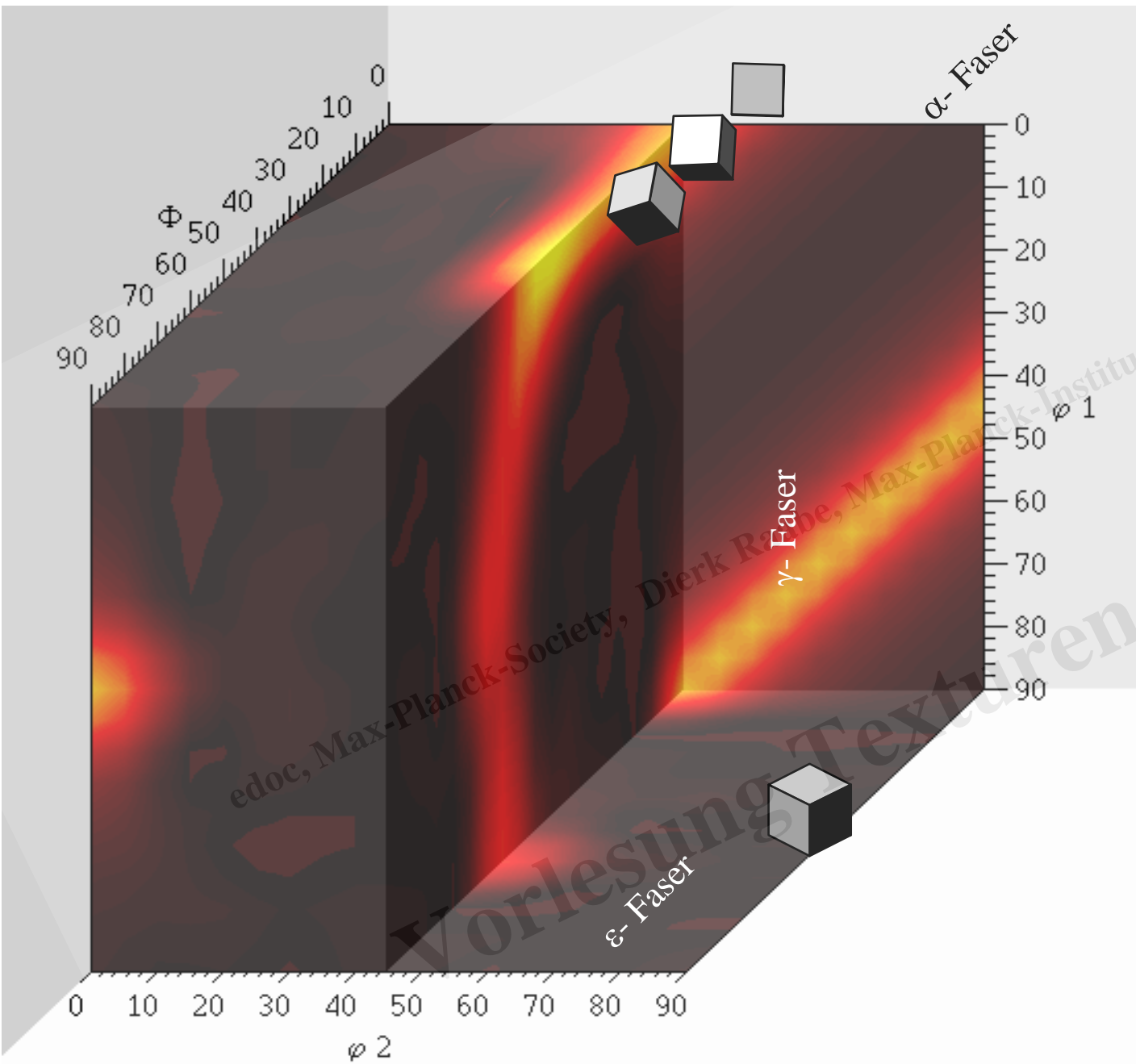


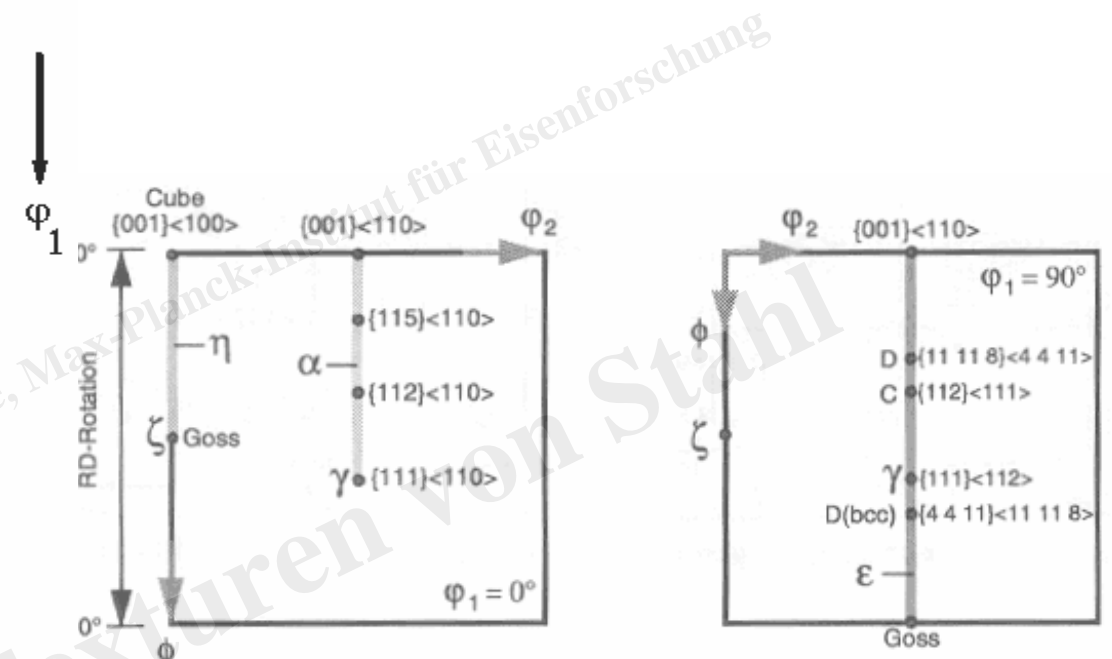
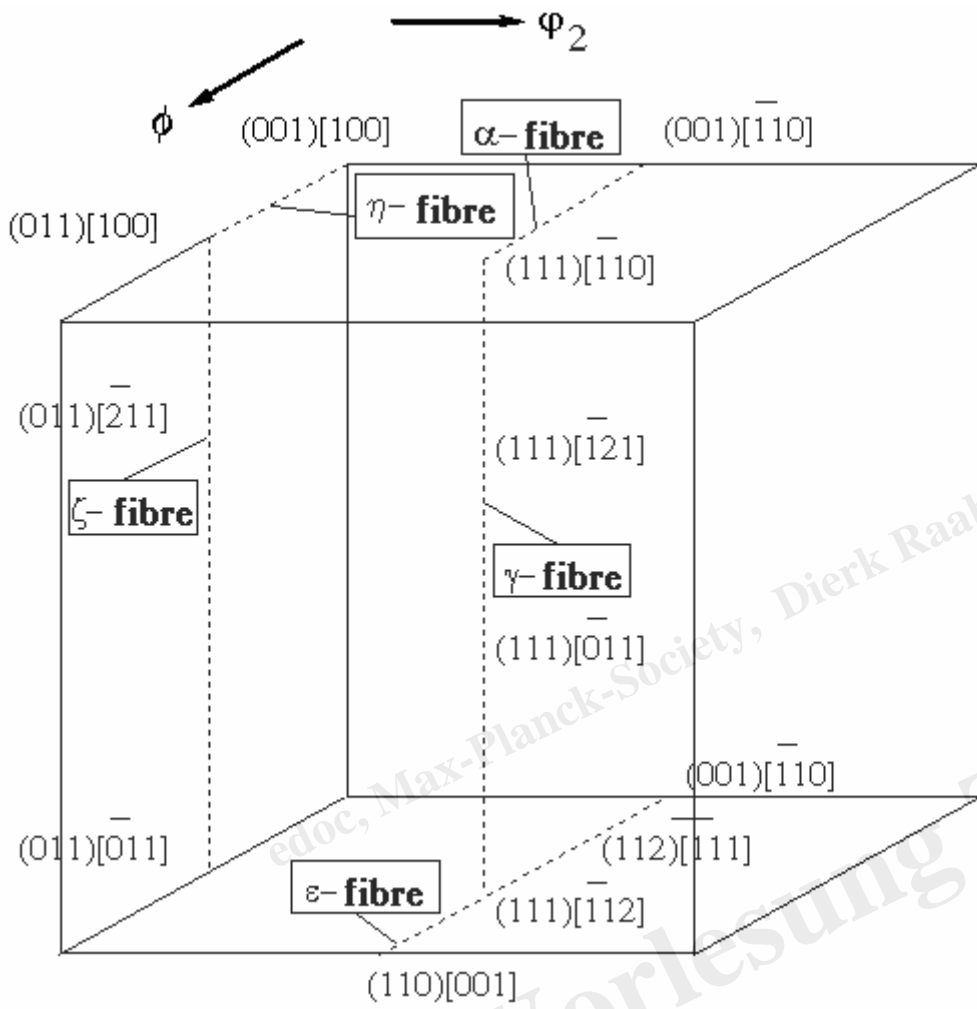
$\{112\}\langle 110\rangle$

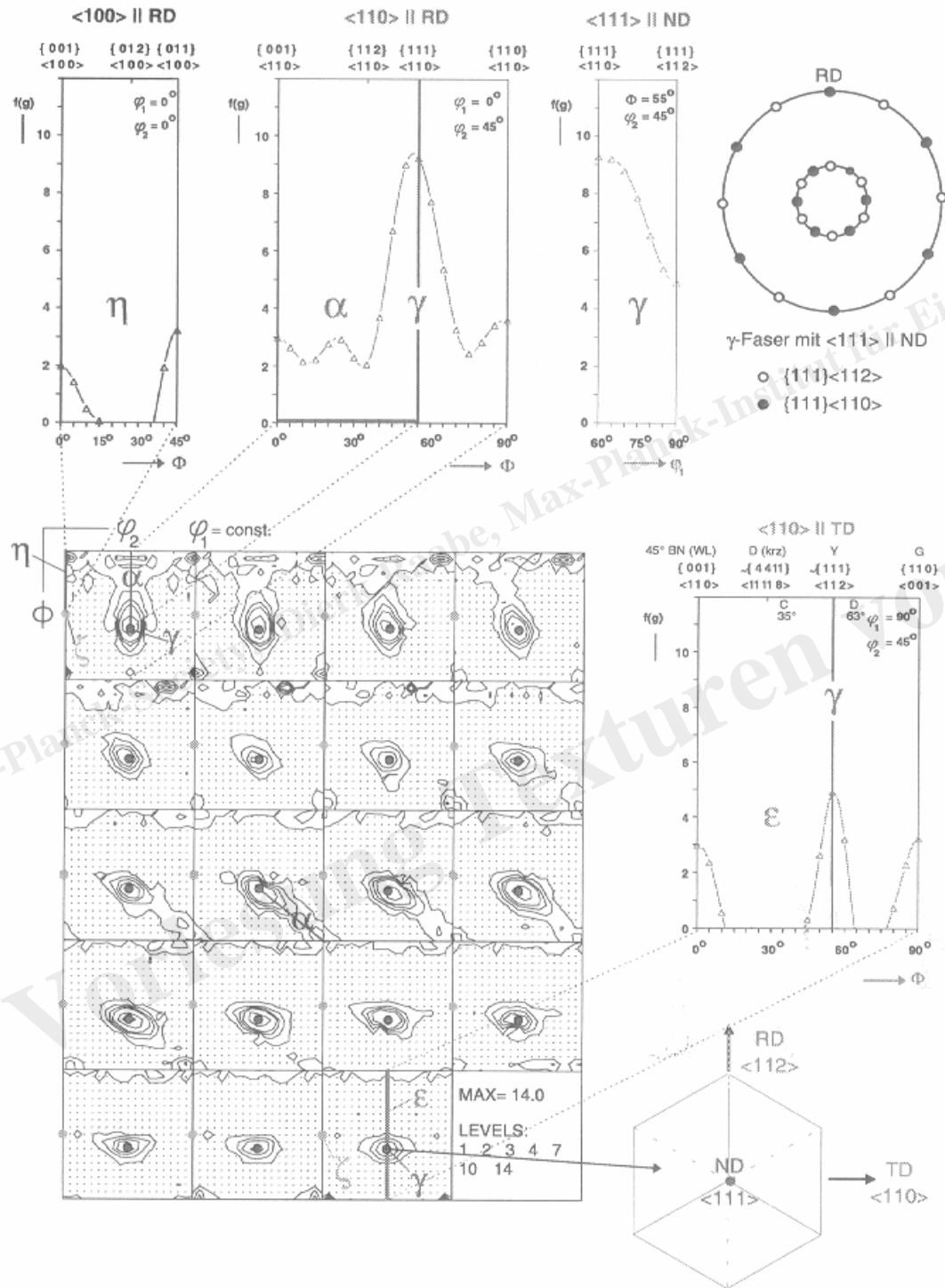


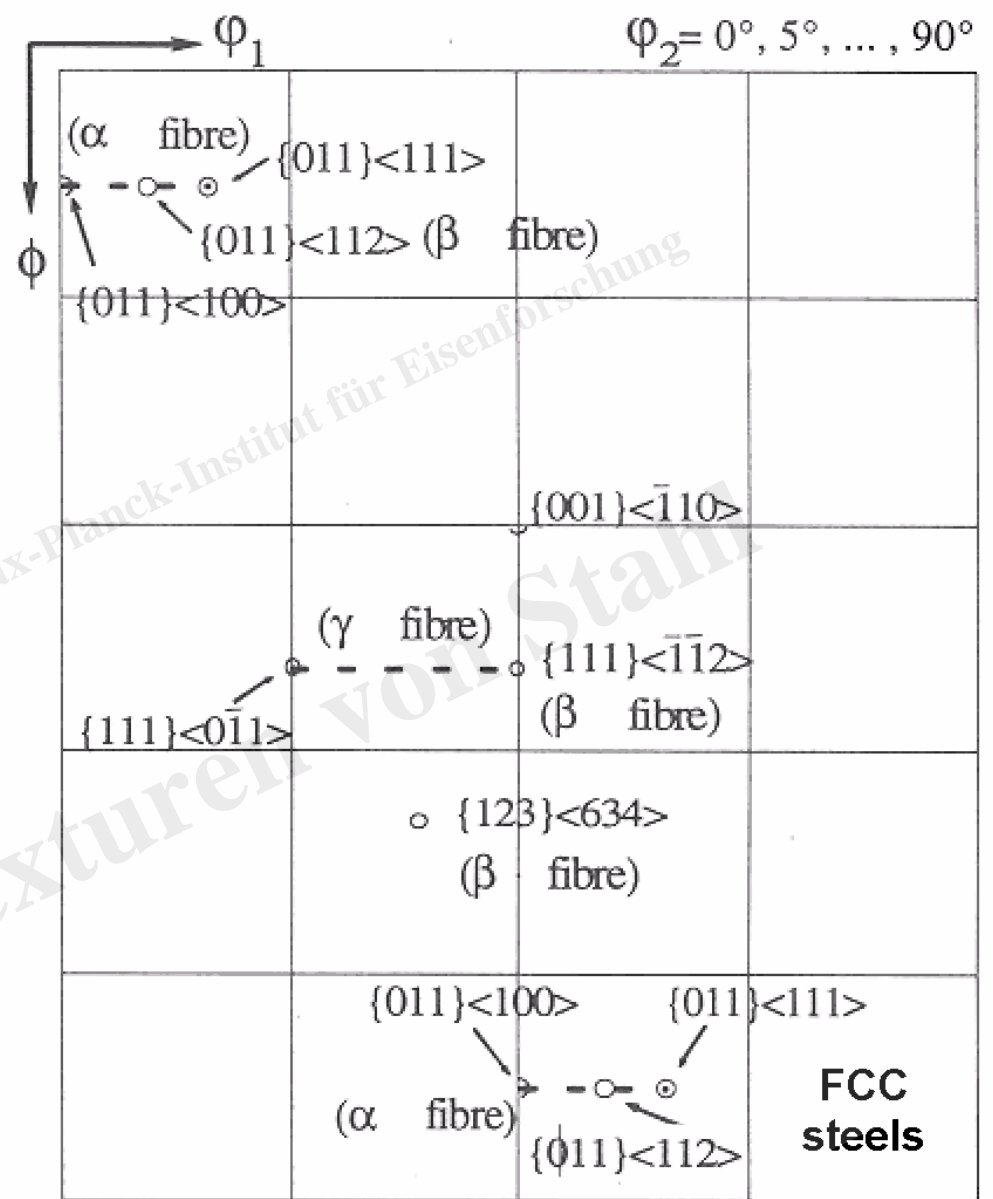
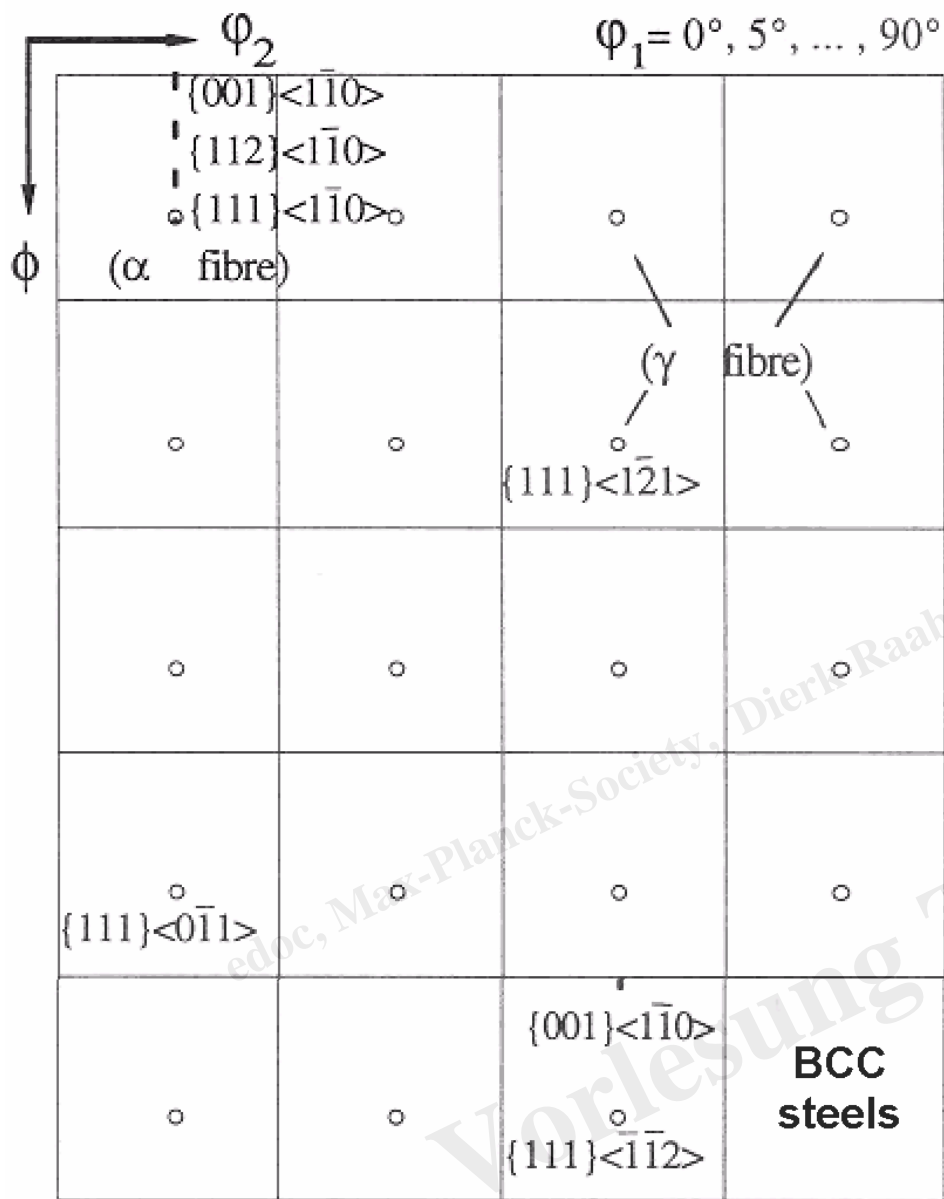
b)





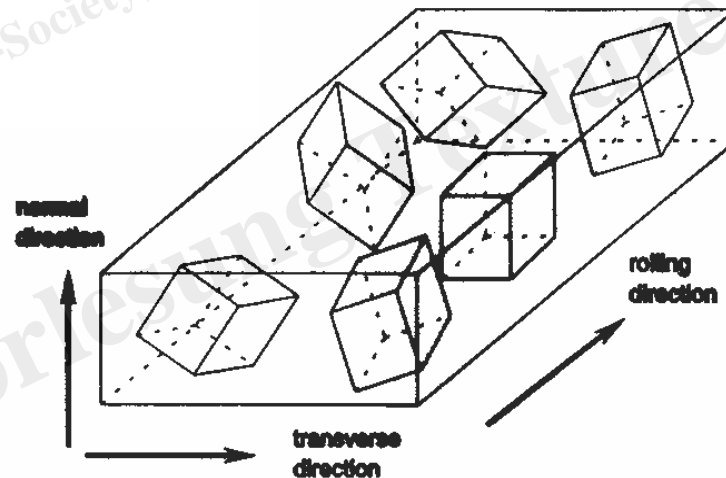




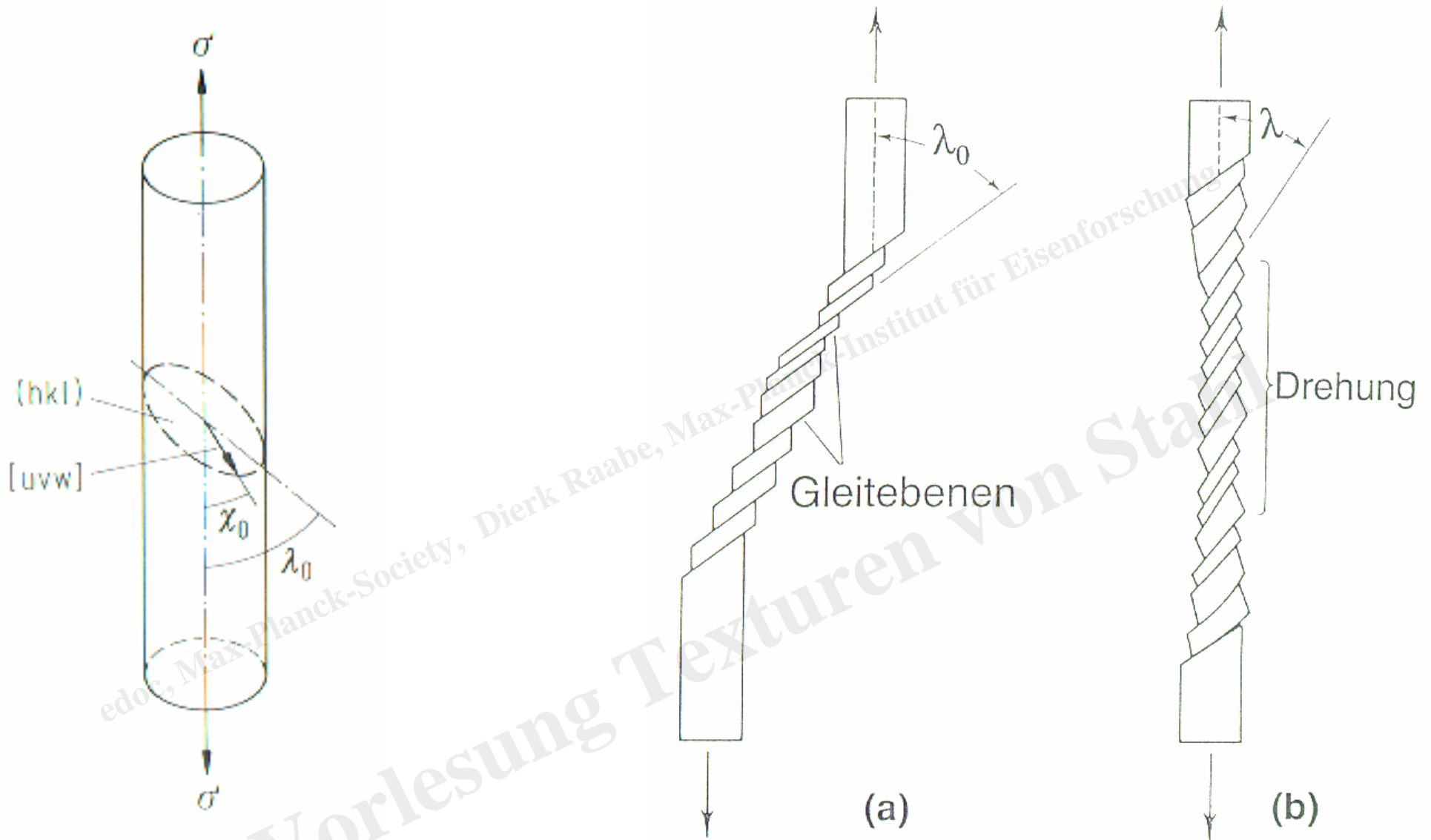


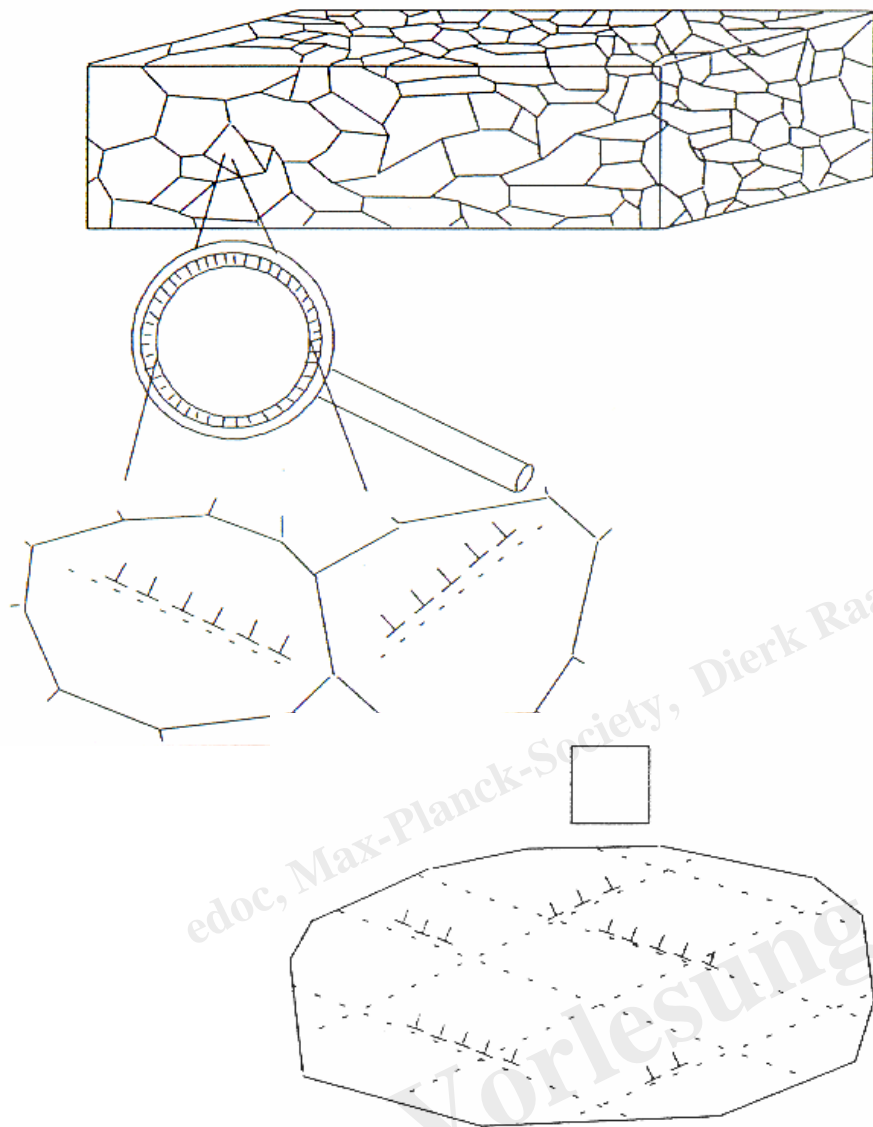
Fiber	Fiber axis	Relevant texture components on the fiber
α -fiber	$\langle 110 \rangle // RD$	$\{001\}\langle 110 \rangle - \{112\}\langle 110 \rangle - \{111\}\langle 110 \rangle$ (incomplete fiber)
γ -fiber	$\langle 111 \rangle // ND$	$\{111\}\langle 110 \rangle - \{111\}\langle 112 \rangle$
η -fiber	$\langle 001 \rangle // RD$	$\{001\}\langle 100 \rangle - \{011\}\langle 100 \rangle$
ζ -fiber	$\langle 011 \rangle // ND$	$\{011\}\langle 100 \rangle - \{011\}\langle 211 \rangle - \{011\}\langle 111 \rangle - \{011\}\langle 011 \rangle$
ε -fiber	$\langle 110 \rangle // TD$	$\{001\}\langle 110 \rangle - \{112\}\langle 111 \rangle - \{111\}\langle 112 \rangle - \{011\}\langle 100 \rangle$
θ -fiber	$\langle 001 \rangle // ND$	$\{001\}\langle 100 \rangle - \{001\}\langle 110 \rangle$

RD: rolling direction, ND: normal direction, TD: transverse direction



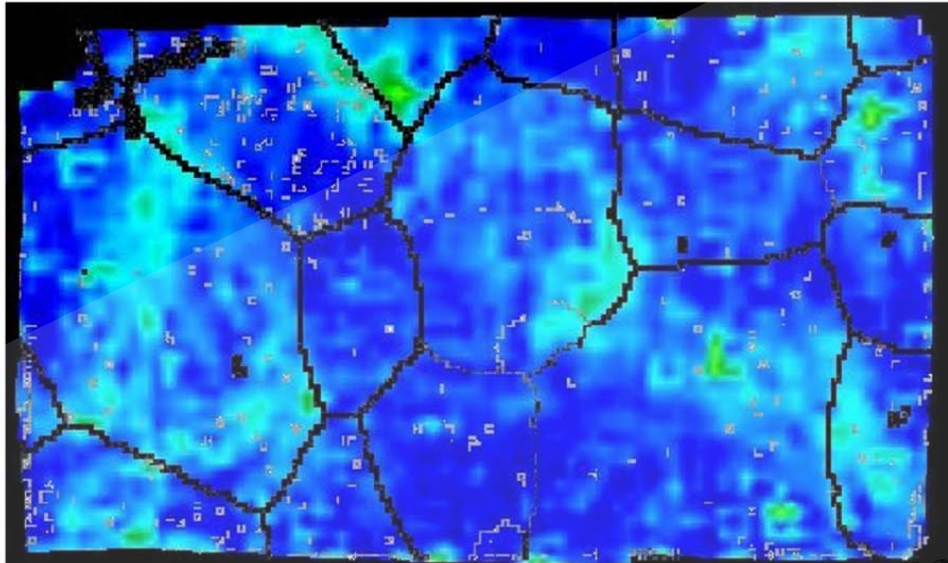
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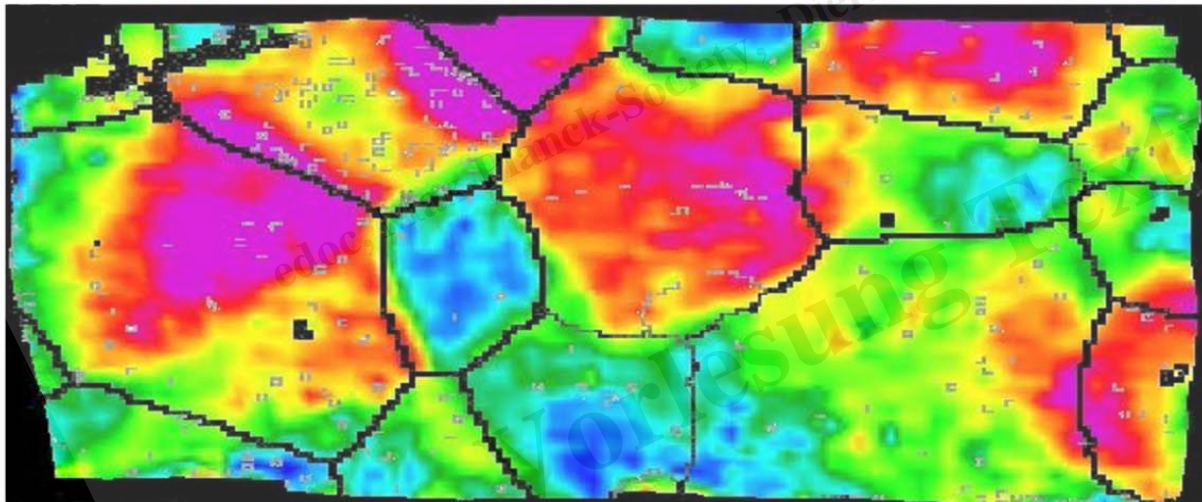
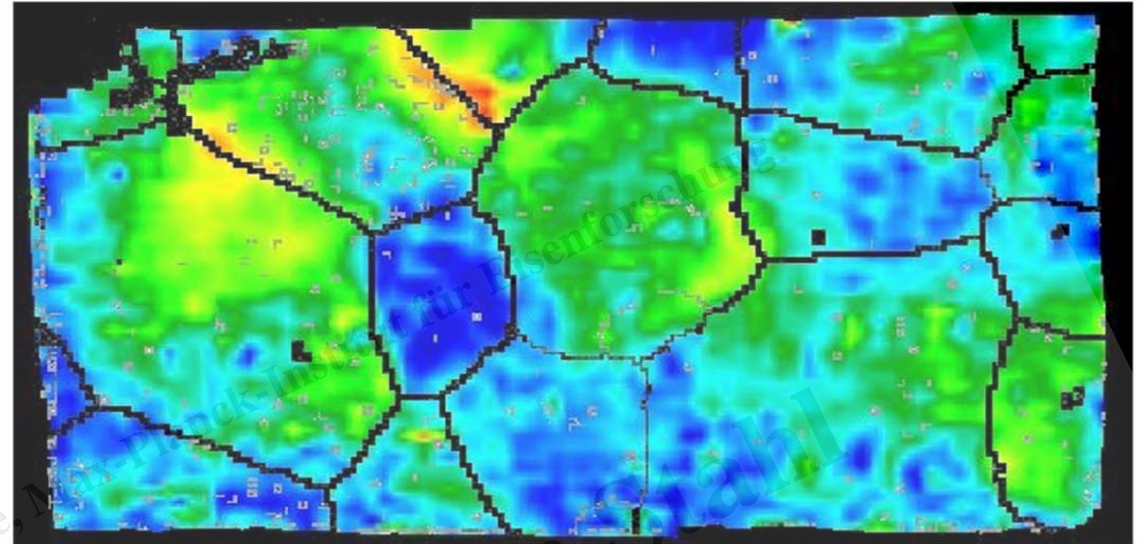


$$\epsilon_{ij} = \frac{1}{2} \sum_{s=1}^5 (n_i^s b_j^s + n_j^s b_i^s) \gamma^s$$

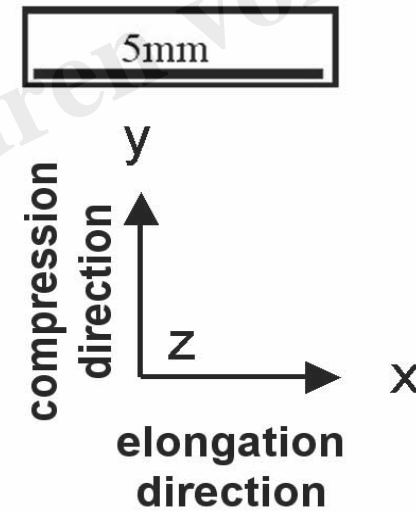
3%



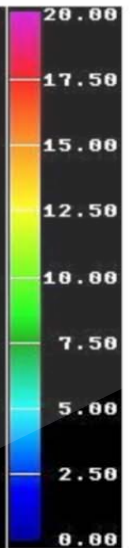
8%

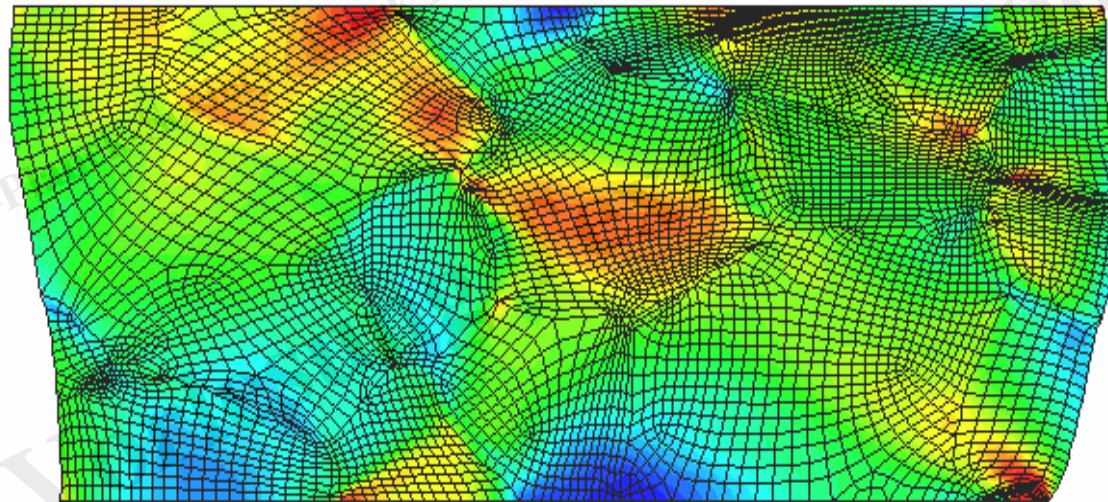
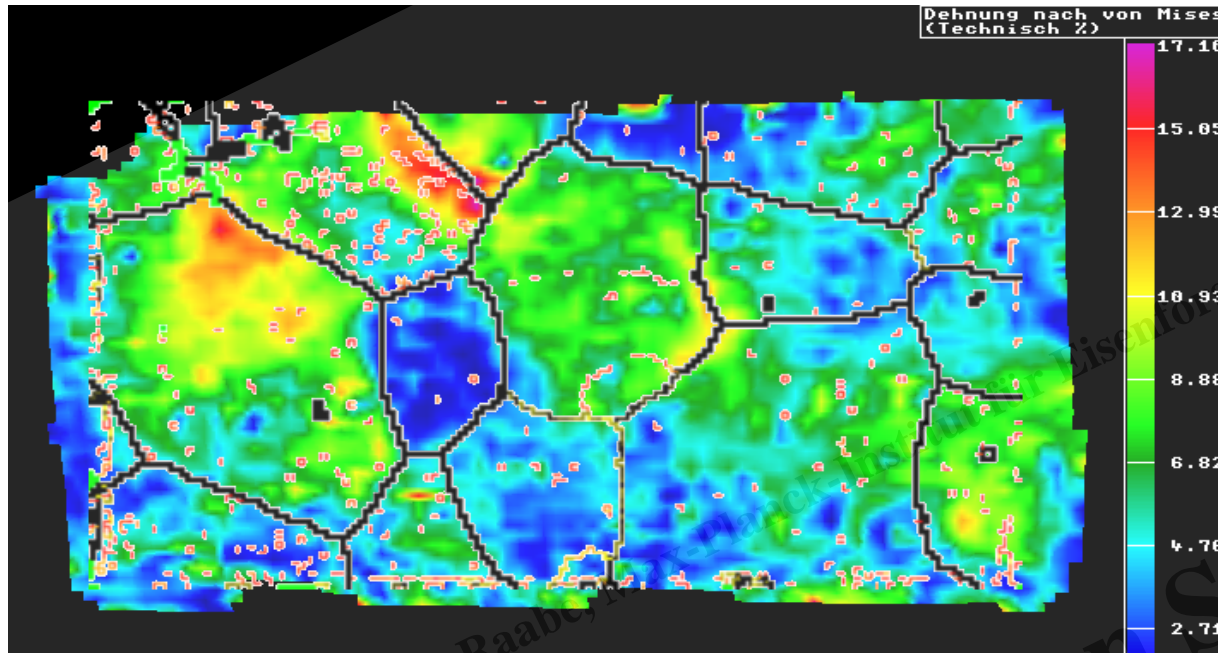
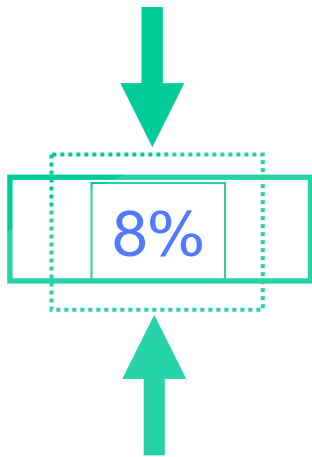


15%

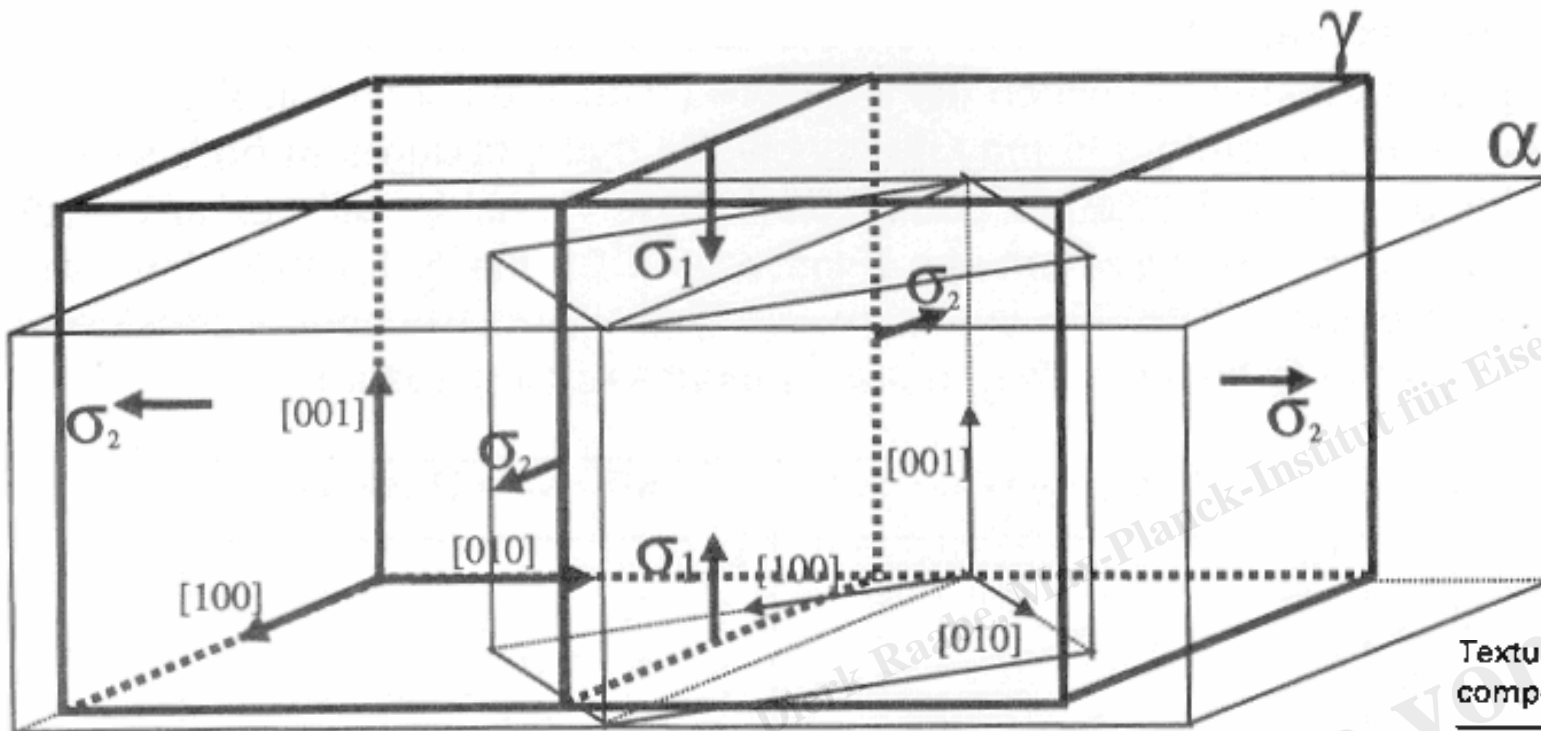


accumulated
von Mises
strain





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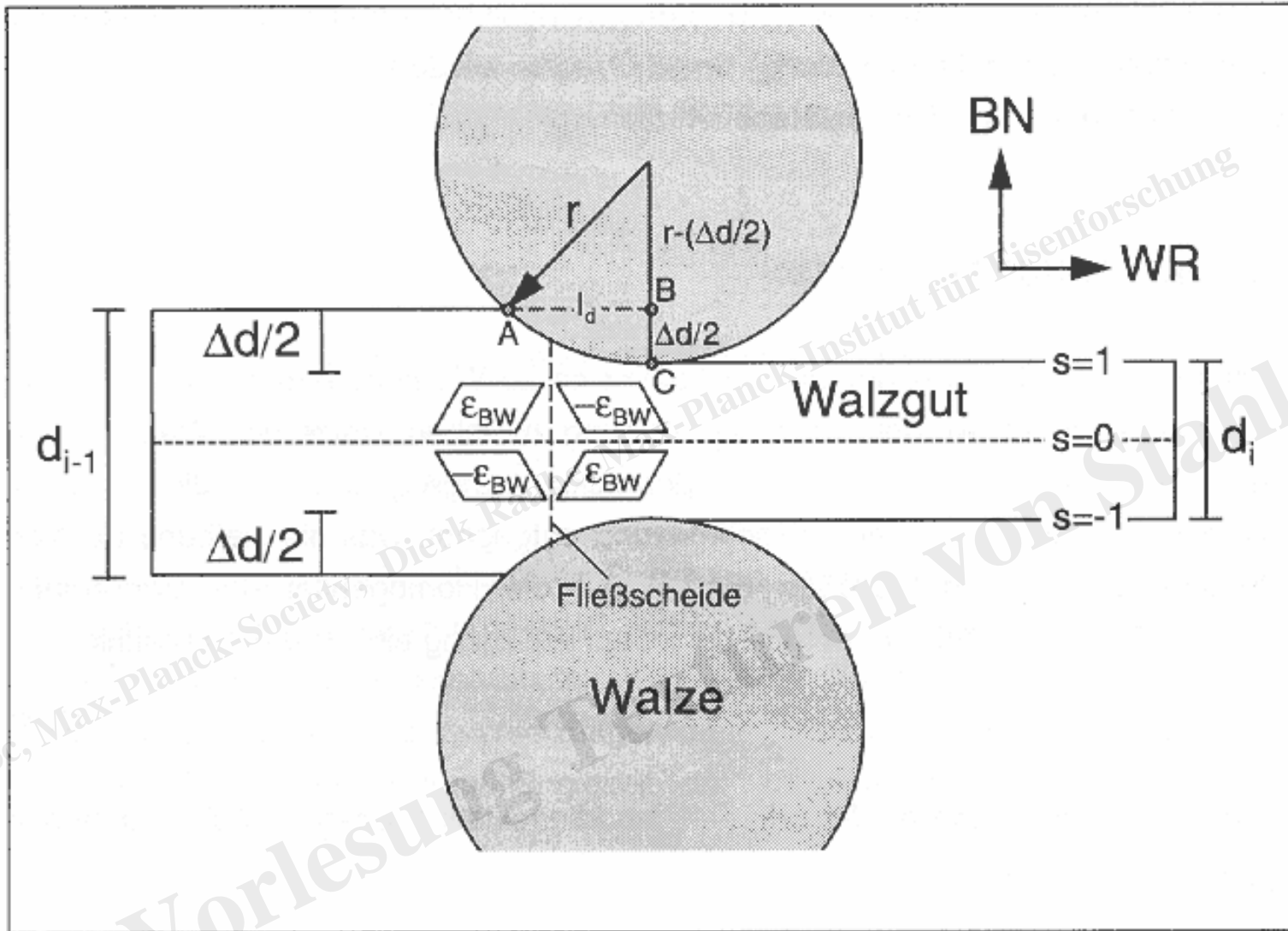
Umwandlung

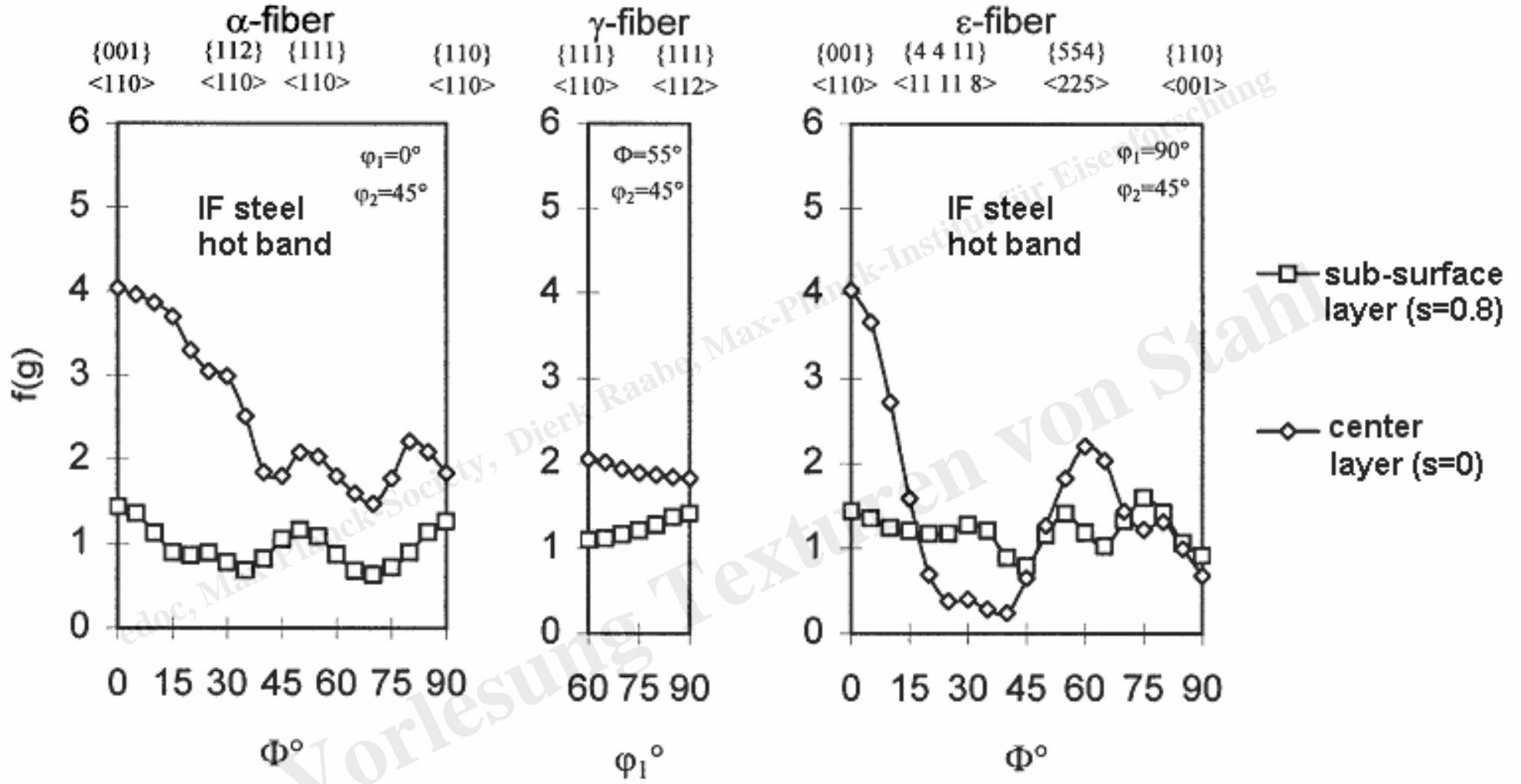
Texture component	Origin
$\{332\}\{113\}_\alpha$	$\{110\}\{112\}_\gamma$, rolled γ texture component (brass component)
$\{113\}\{110\}_\alpha$	$\{112\}\{111\}_\gamma$, rolled γ texture component (copper component)
$\{100\}\{011\}_\alpha$	$\{100\}\{001\}_\gamma$, recrystallised γ texture component (cube component)

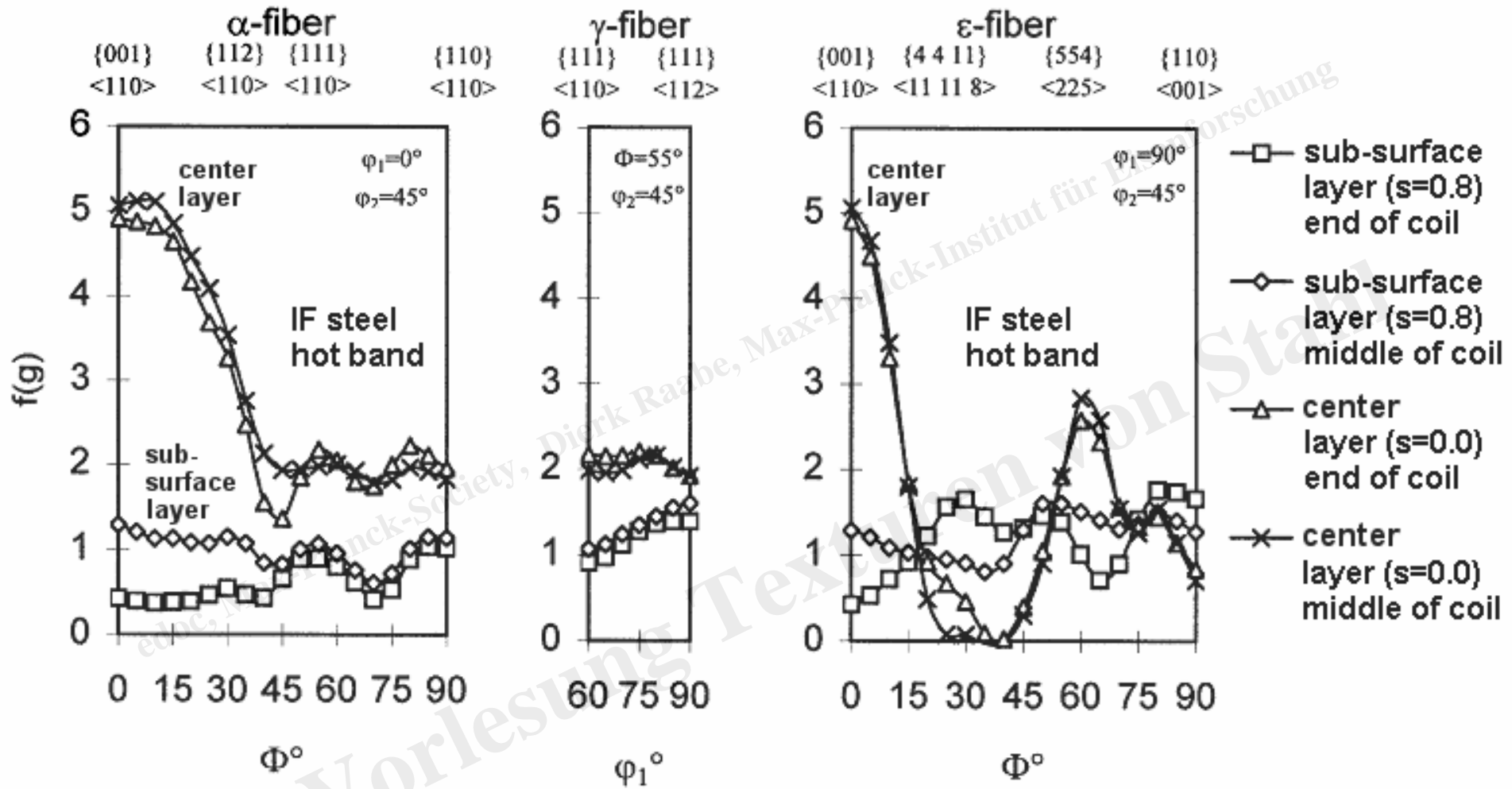
Major transformation texture components inherited by α from γ in controlled rolled steels

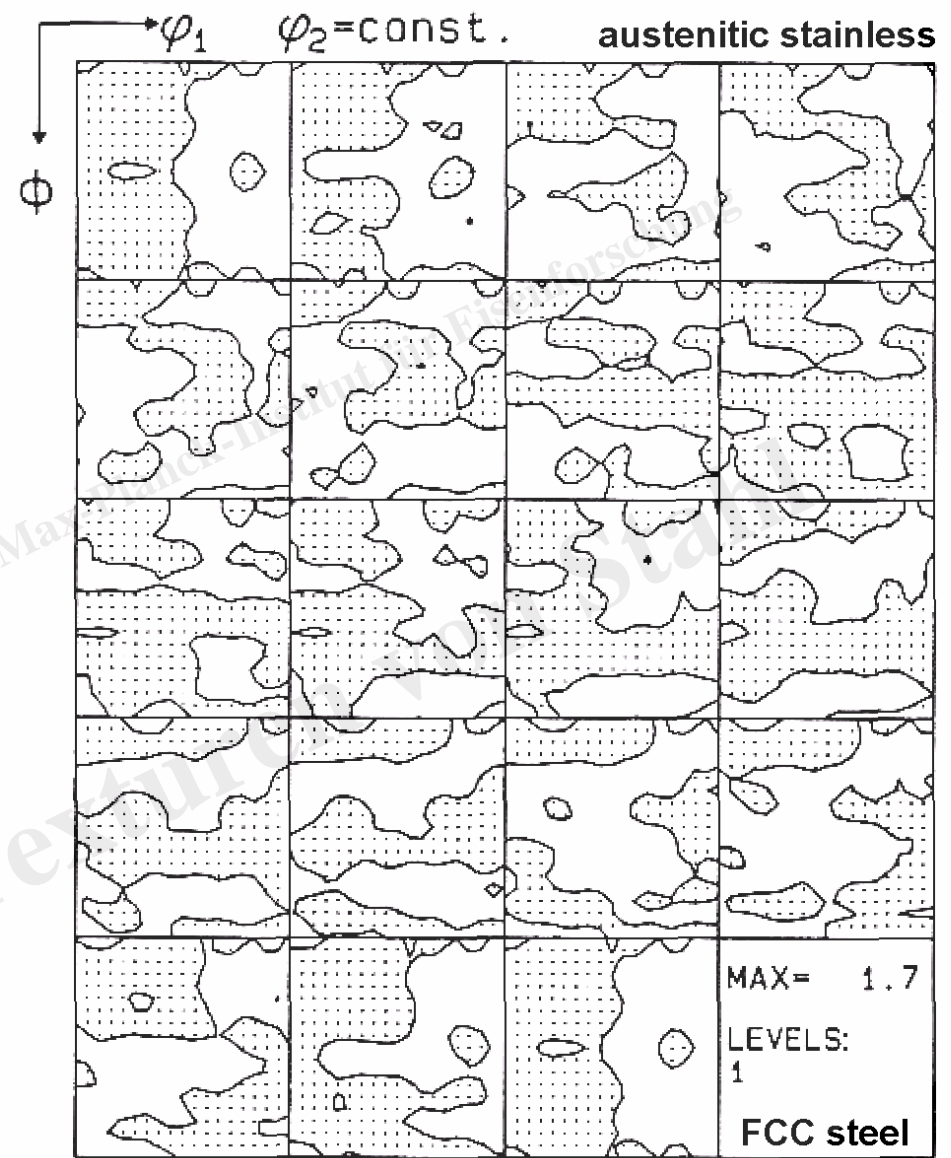
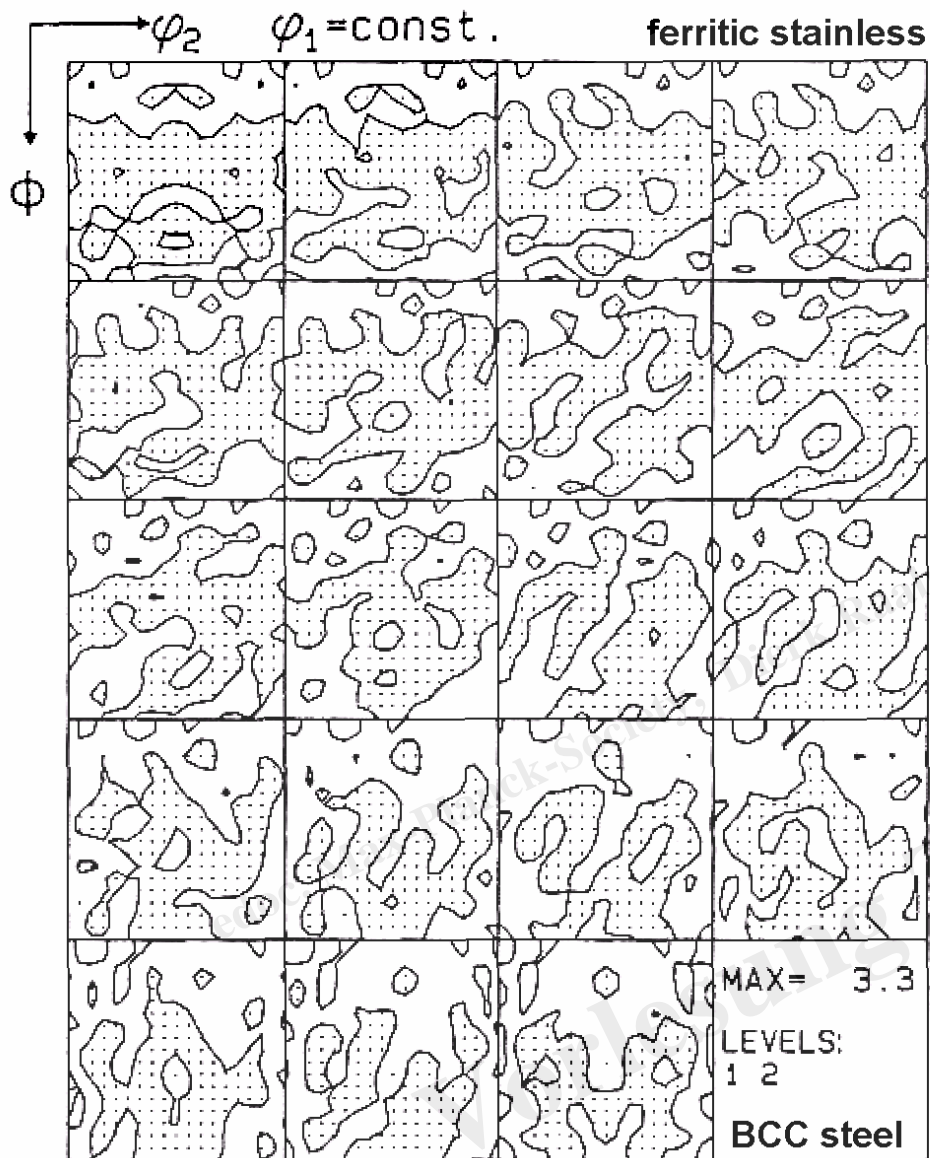
Texture component	Origin	\bar{R}	ΔR
$\{332\}\langle 113\rangle_{\alpha}$	$\{110\}\langle 112\rangle_{\gamma}$ rolled γ texture component (brass component)	2.7	1.9
$\{113\}\langle 110\rangle_{\alpha}$	$\{112\}\langle 111\rangle_{\gamma}$ rolled γ texture component (copper component)	1.0	-1.7
$\{100\}\langle 011\rangle_{\alpha}$	$\{100\}\langle 001\rangle_{\gamma}$ recrystallised γ texture component (cube component)	0.4	-0.8



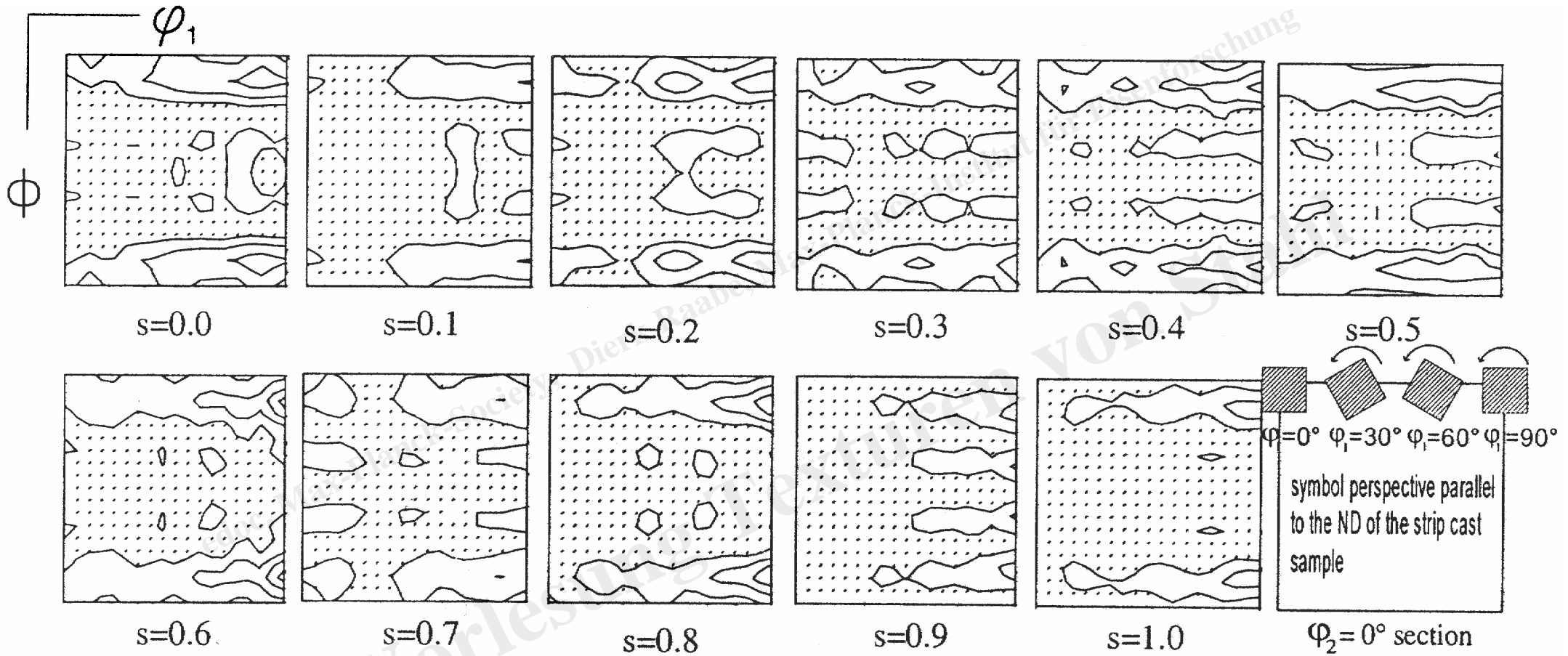


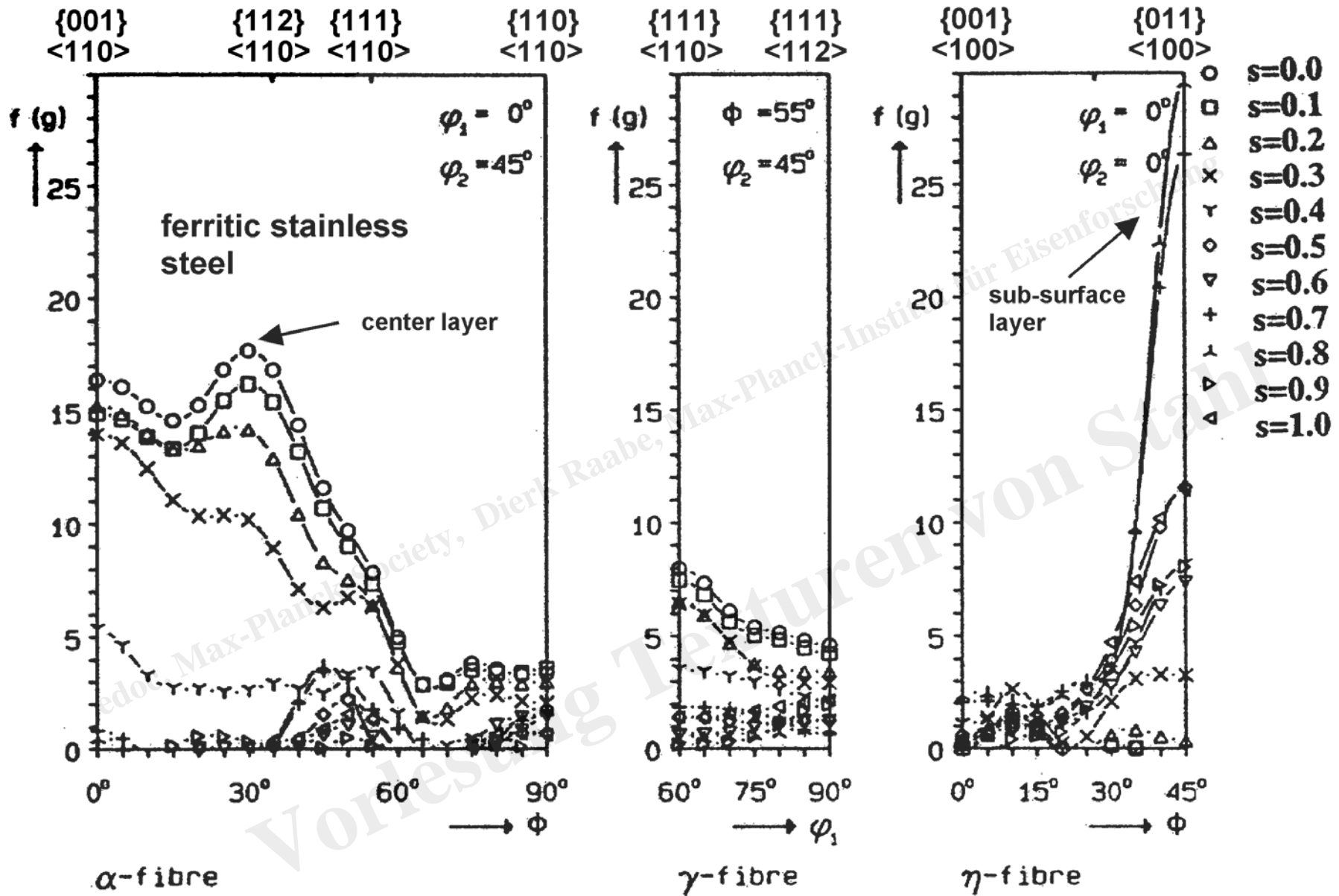


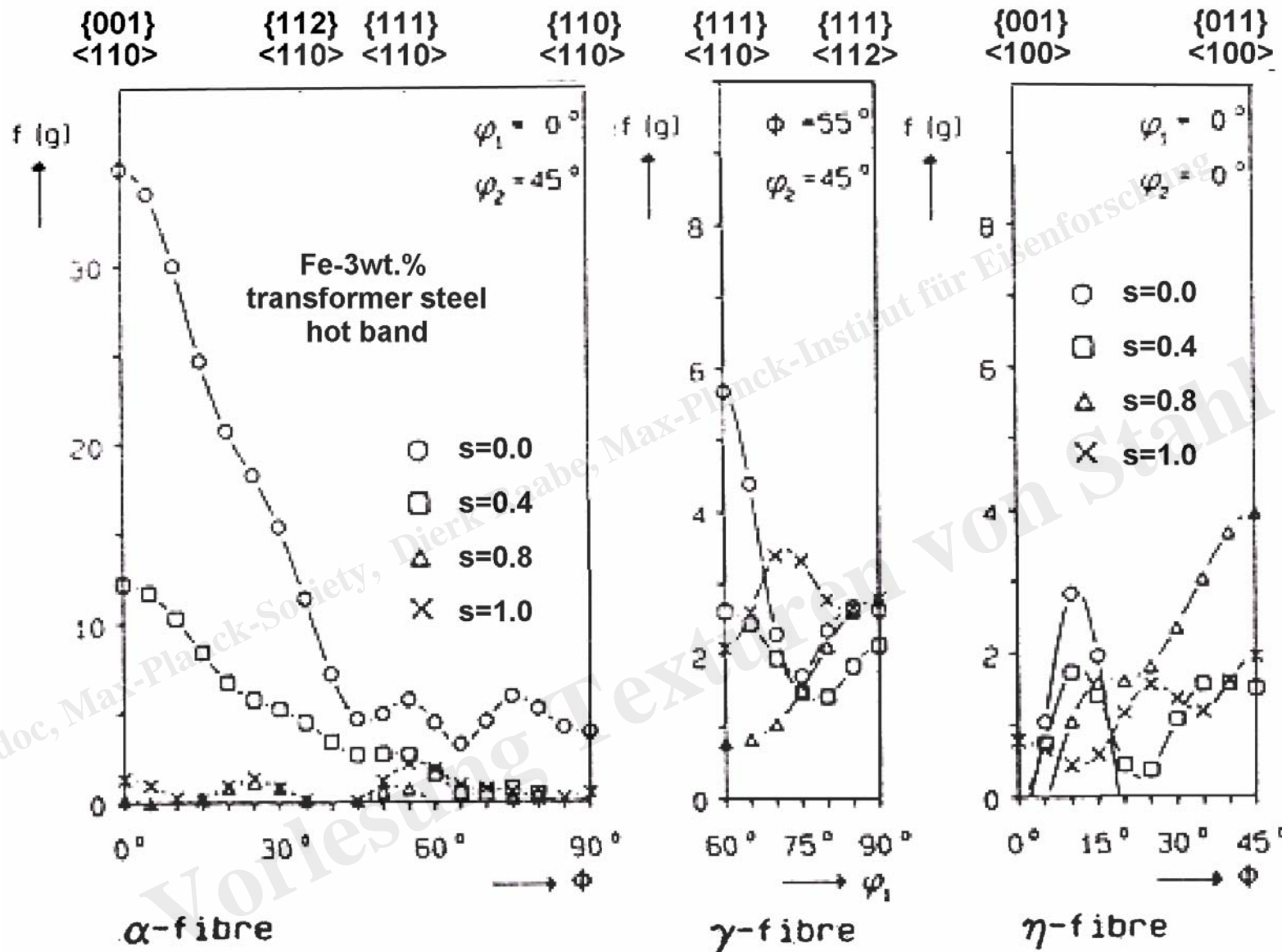




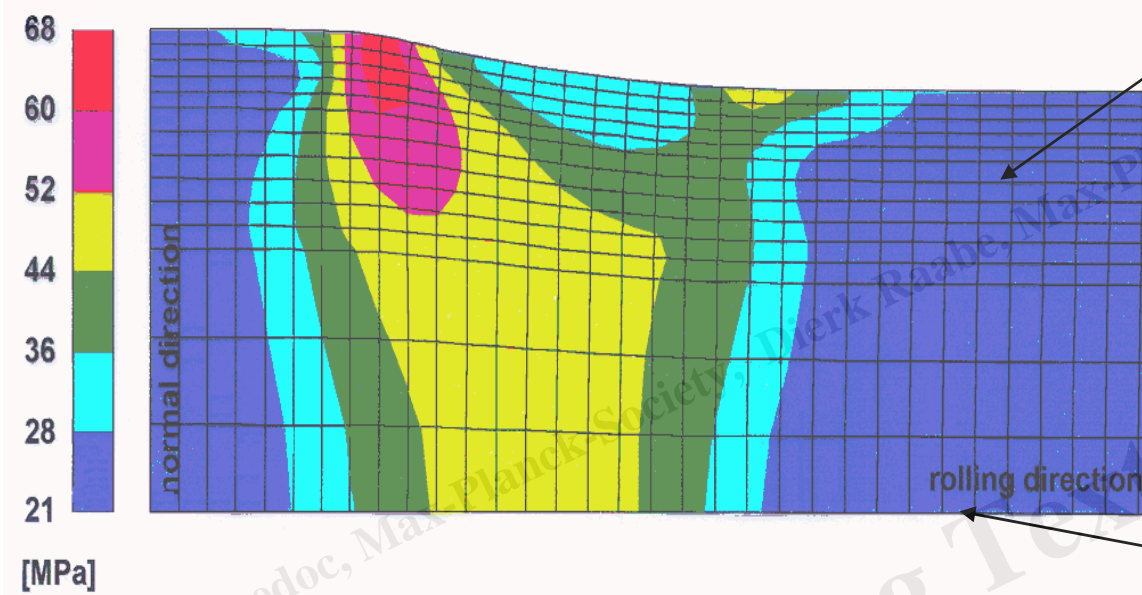
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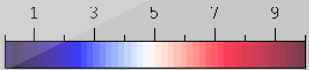
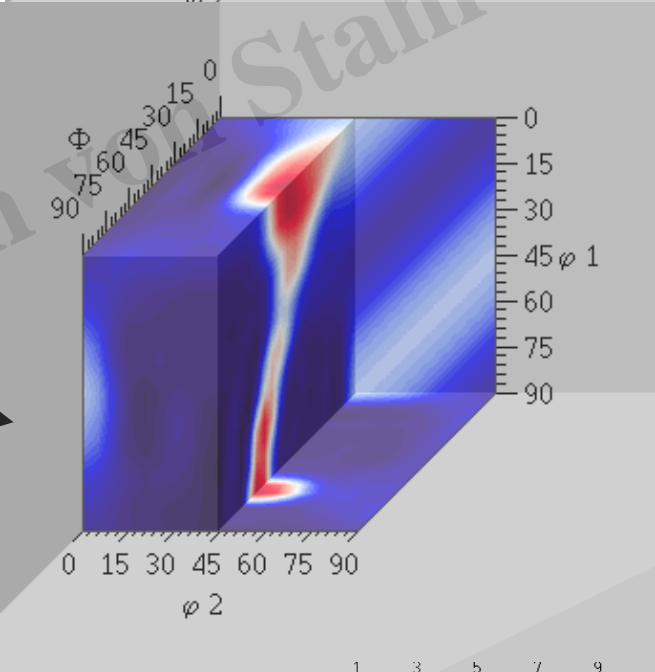
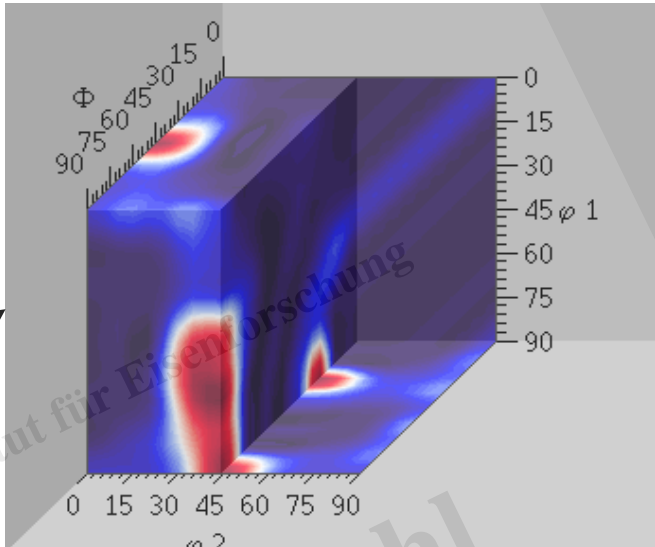




Oberfläche

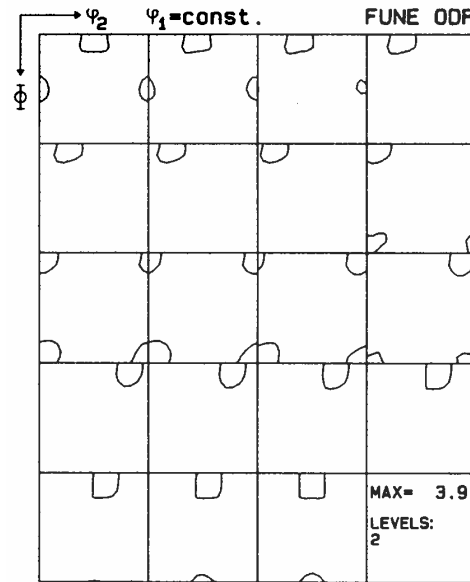


Mitte

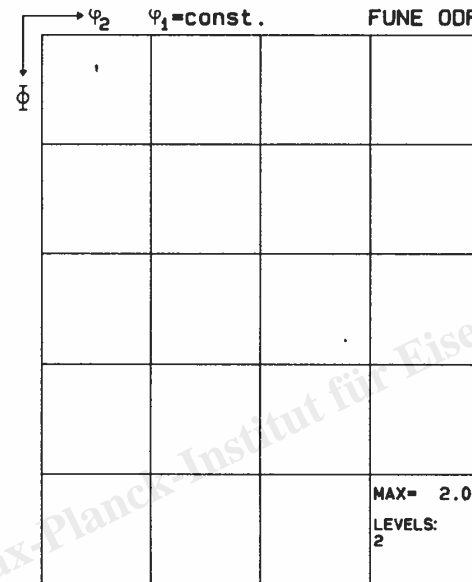


Mitte

low-C



low-c, s=0



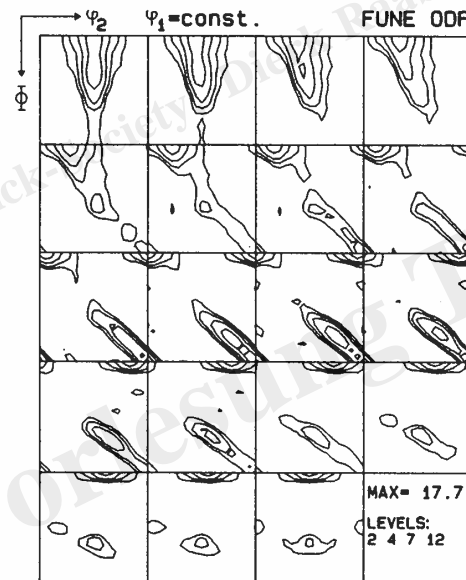
low-C, s=0.8

Oberfläche

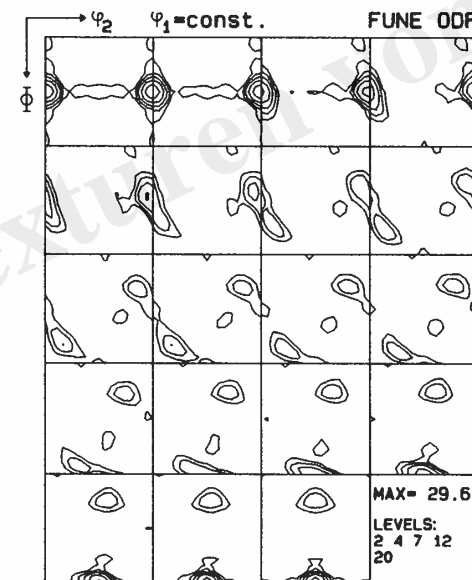
low-C

Mitte

Fe-Cr



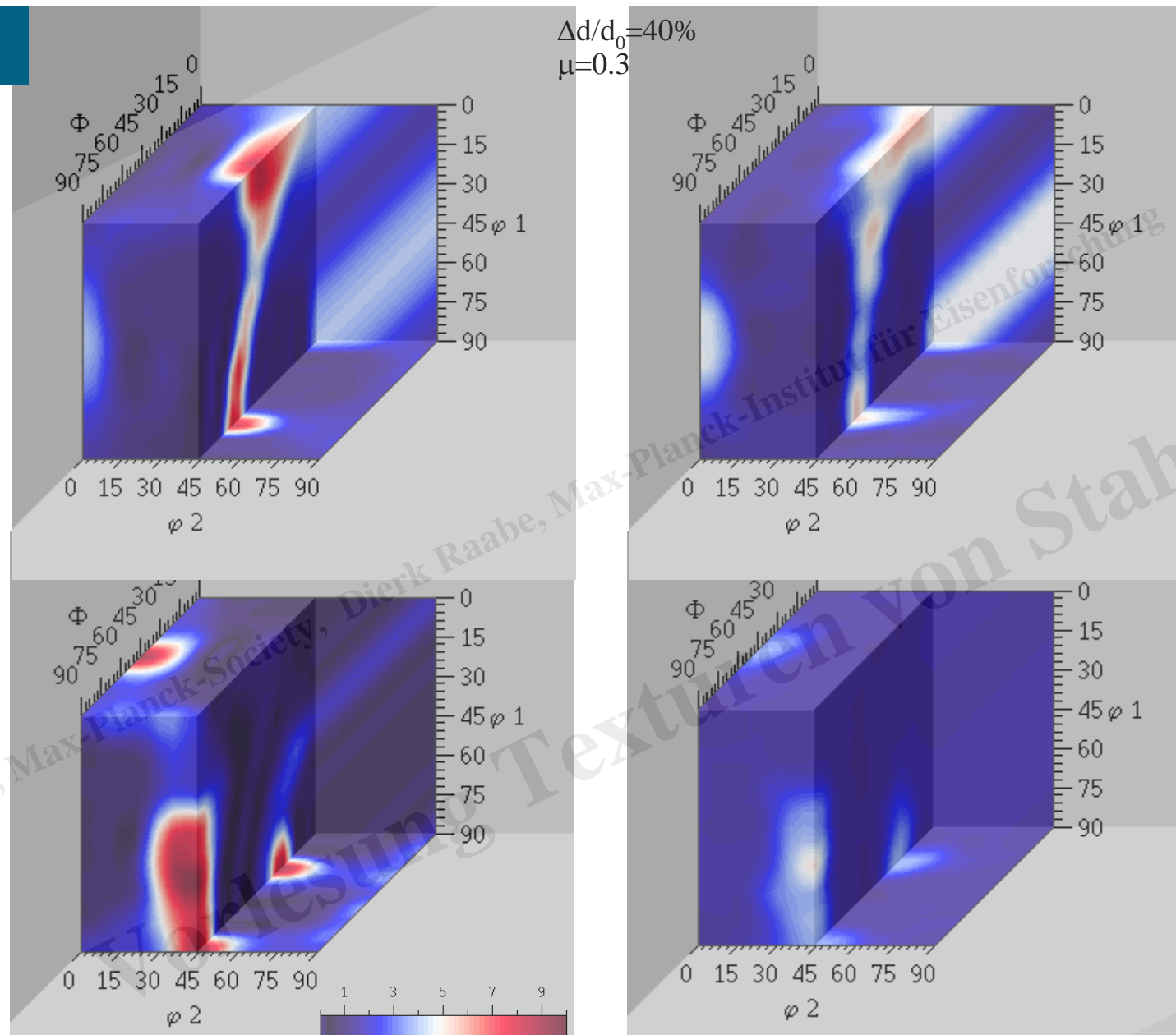
Fe-16%Cr, s=0



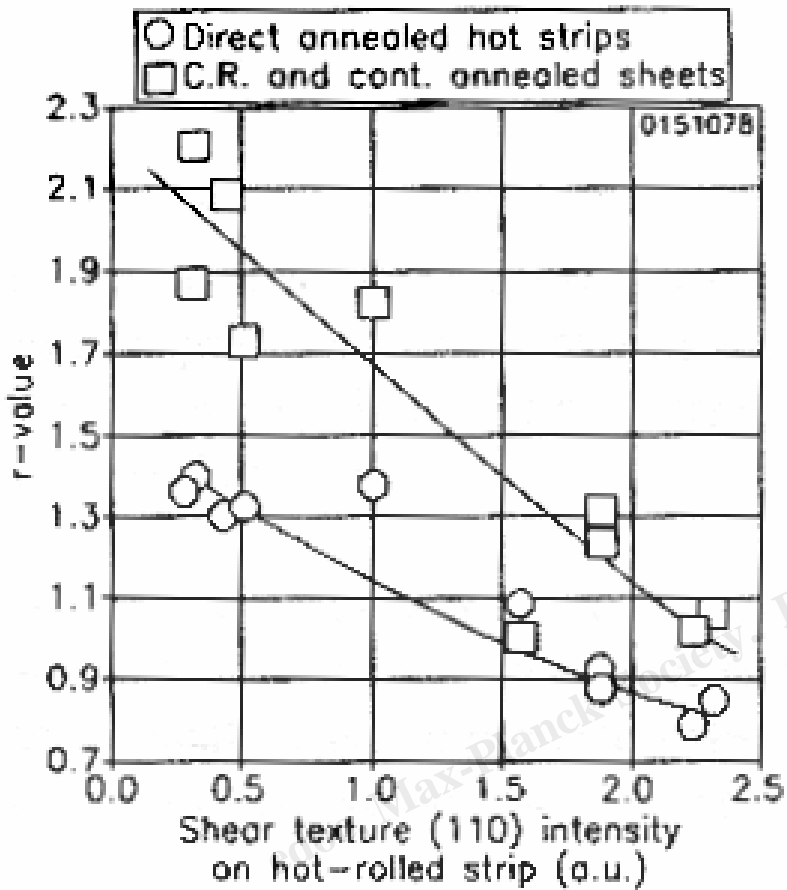
Fe-16%Cr, s=0.8

Oberfläche

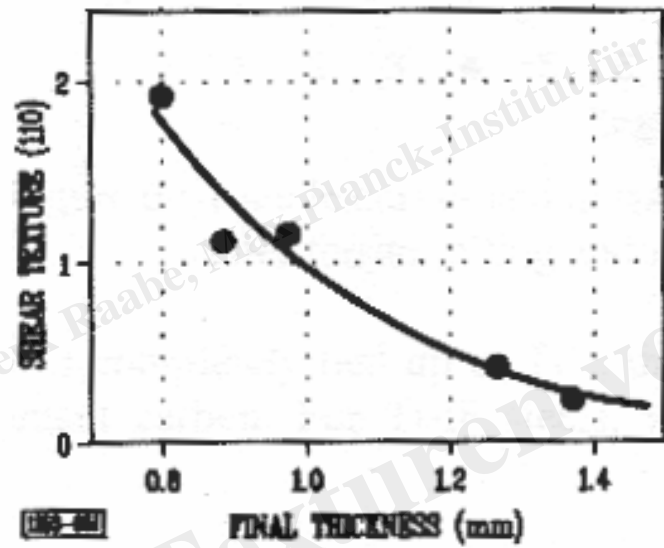
Fe-Cr



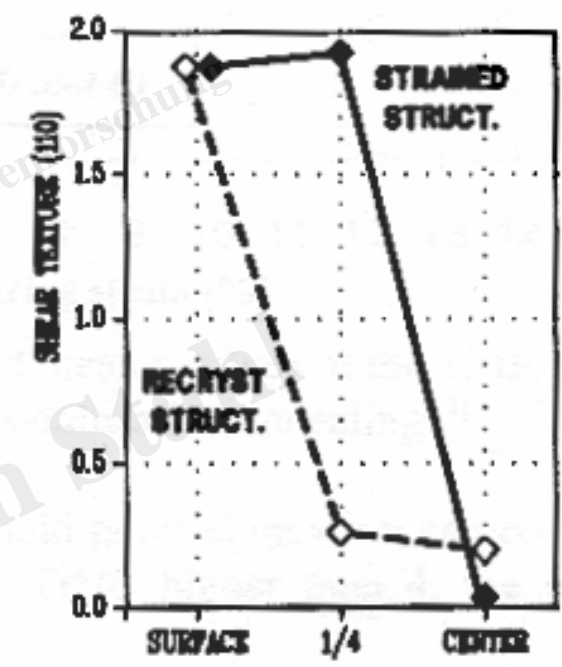
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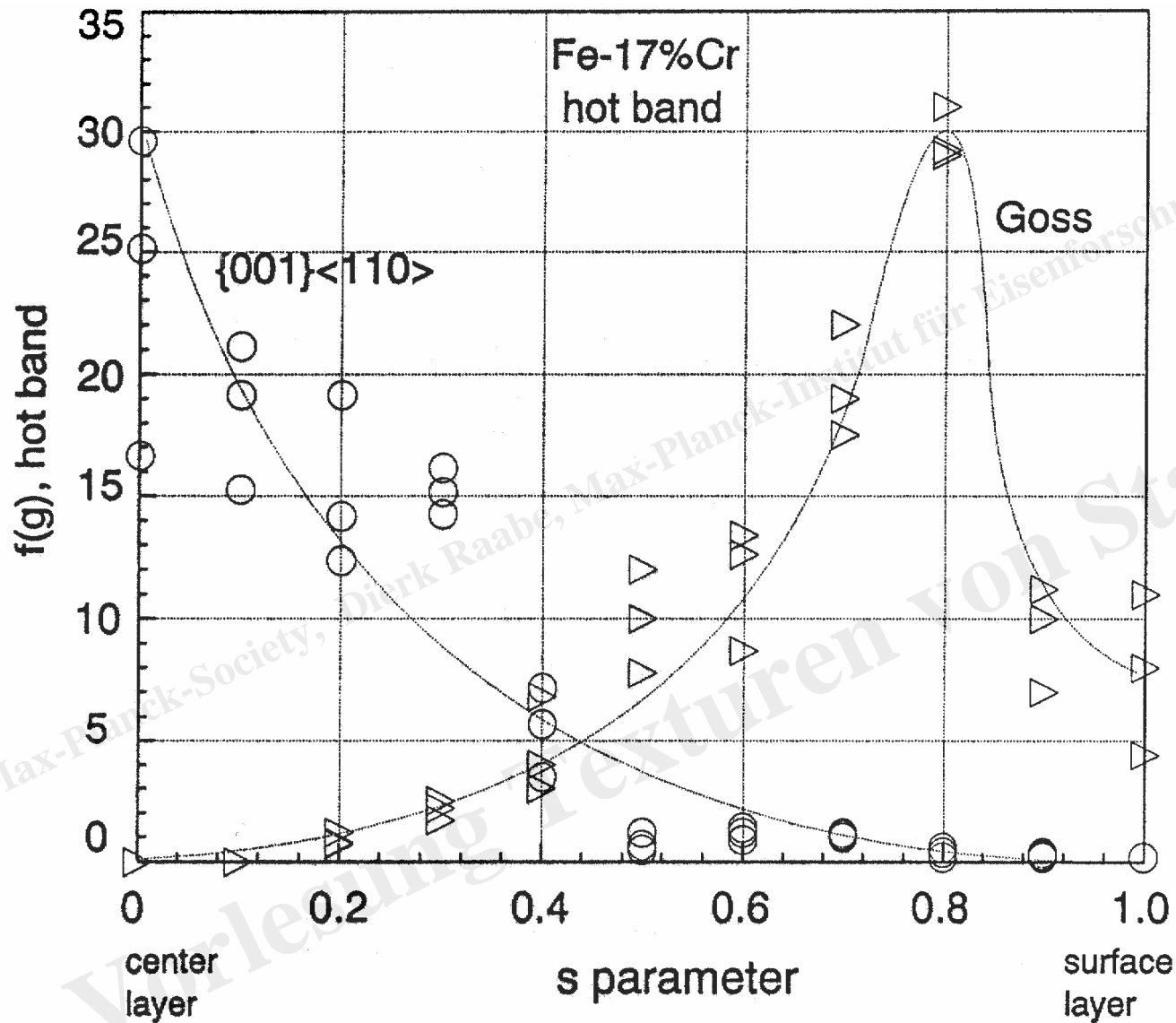


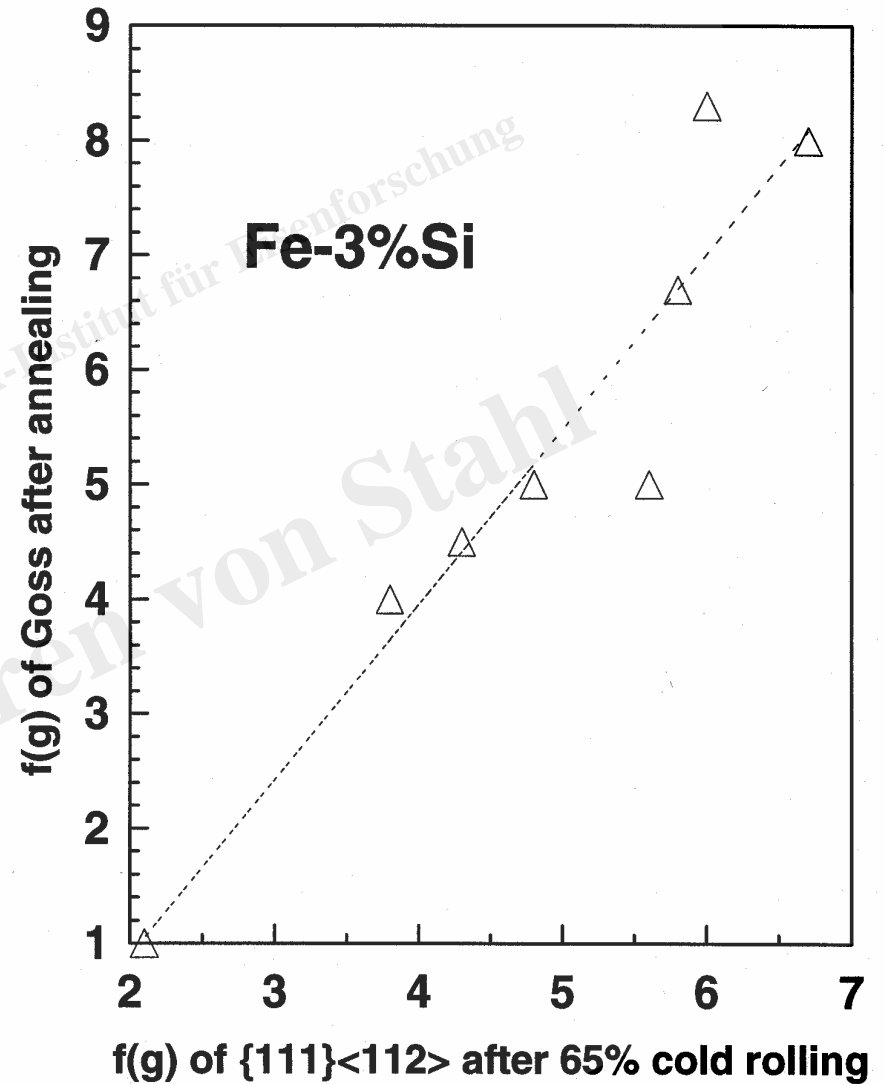
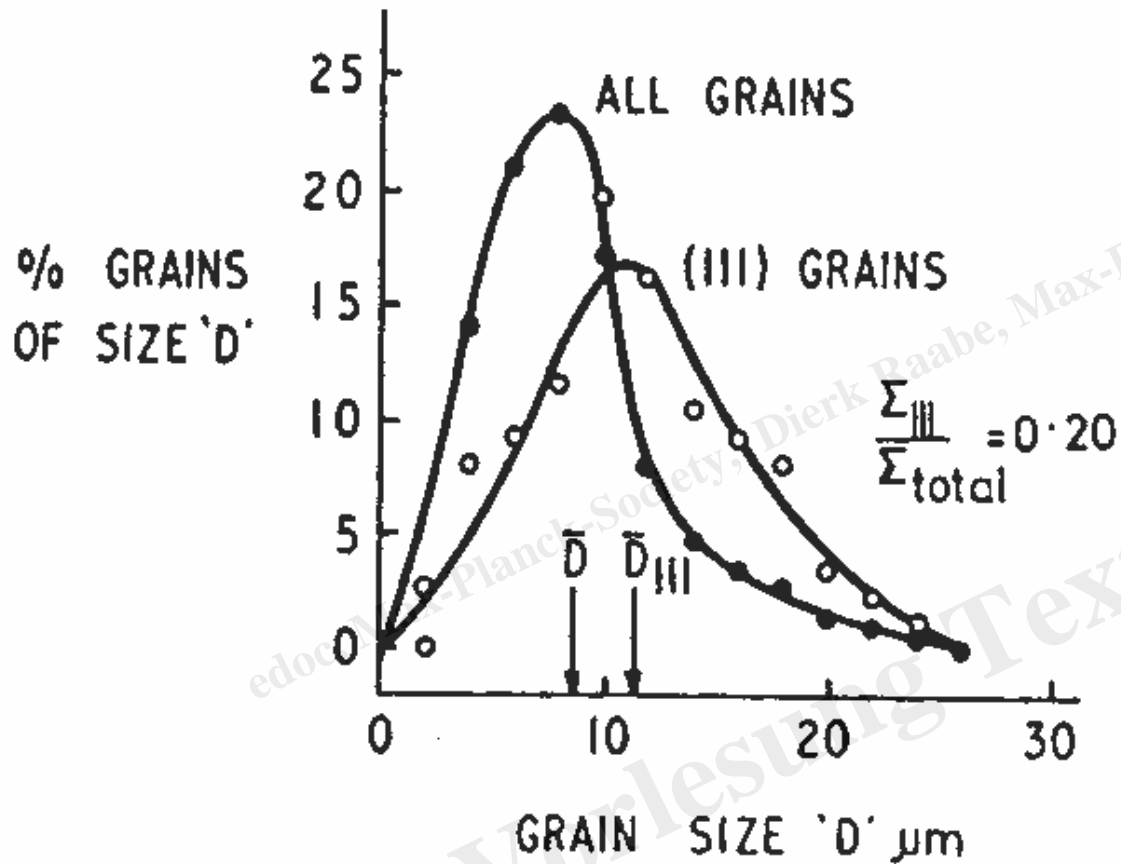
Effect of the shear texture intensity on the r-value

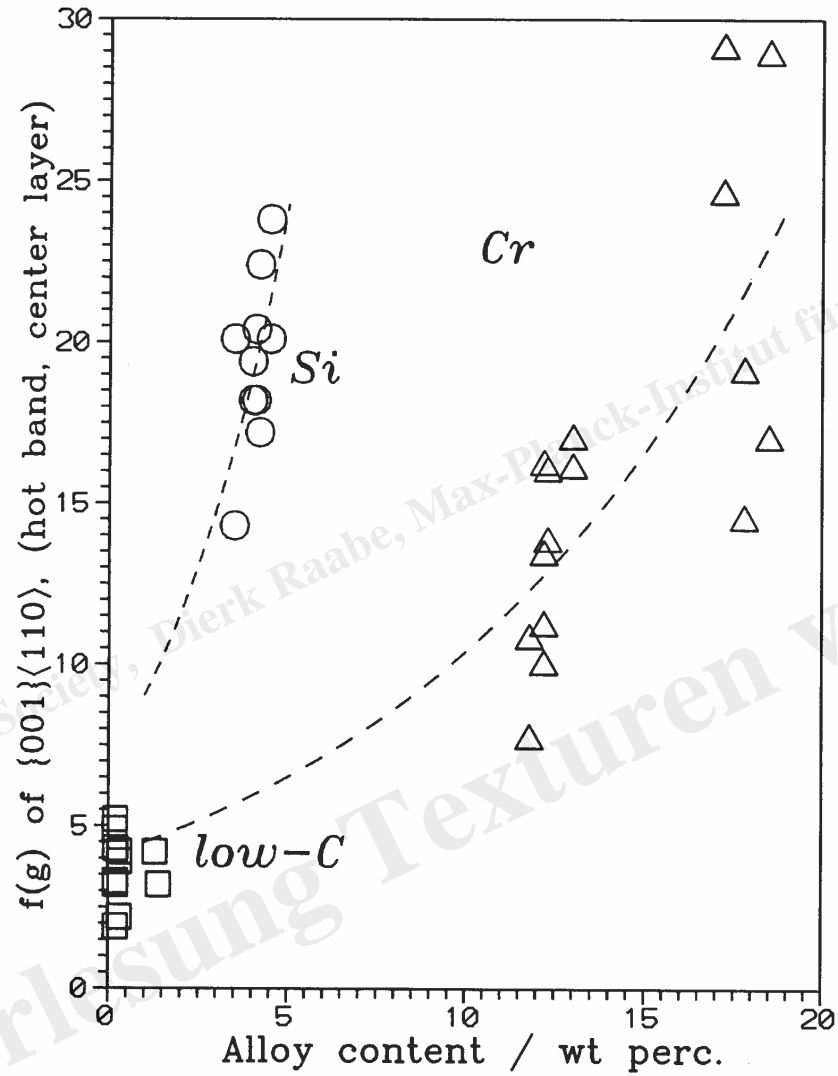


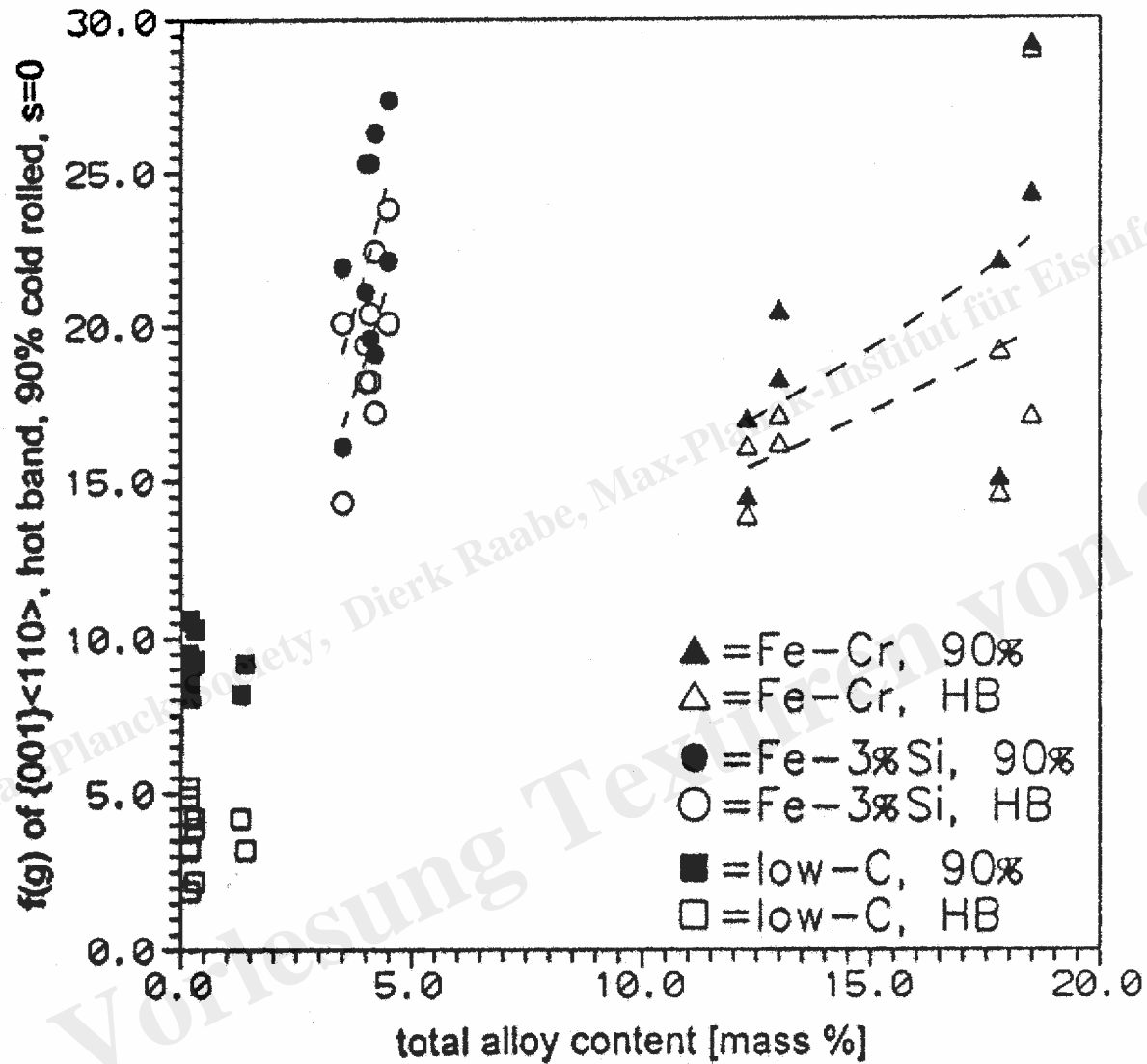
Evolution of the shear texture intensity
Effect of the final thickness
Evolution from strain to recrystallised ferrite (0.8 mm)

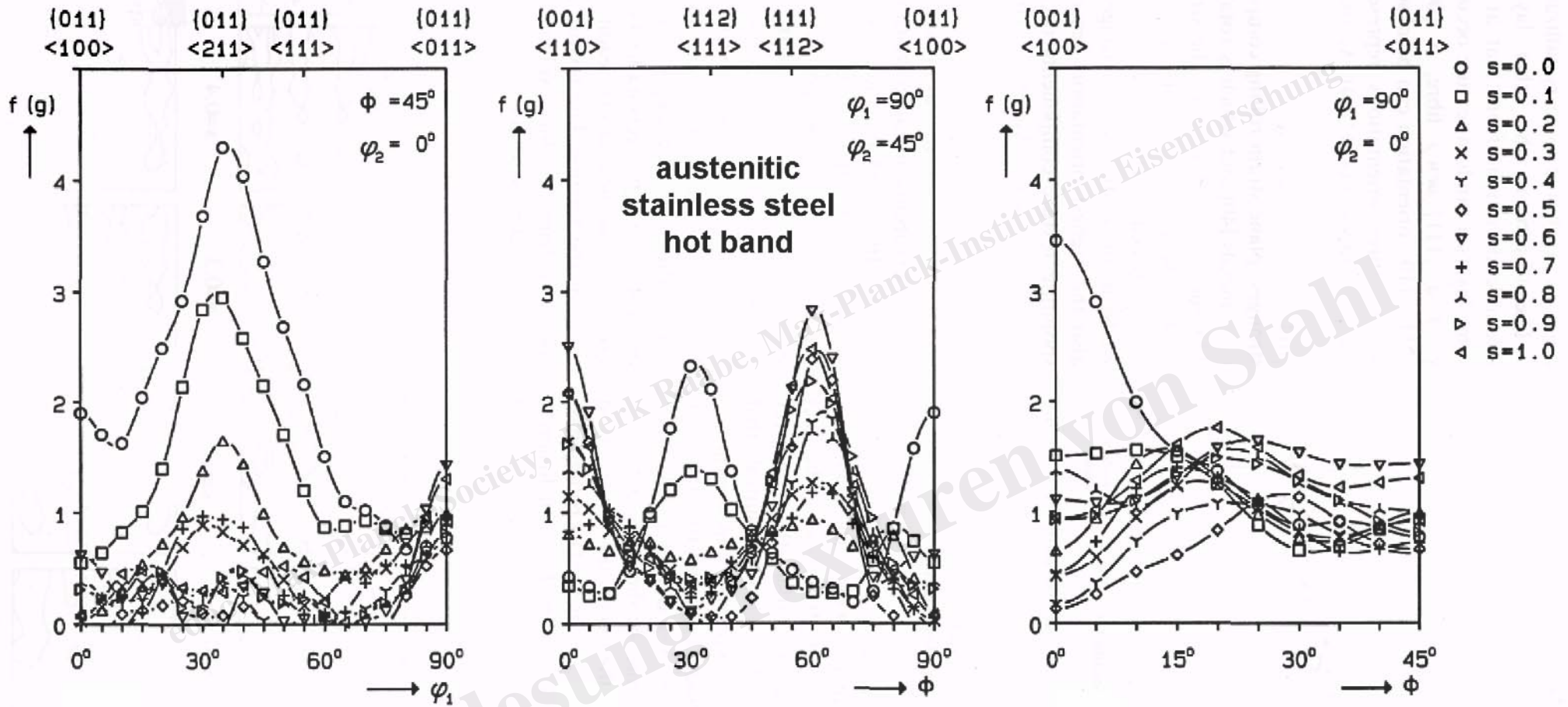


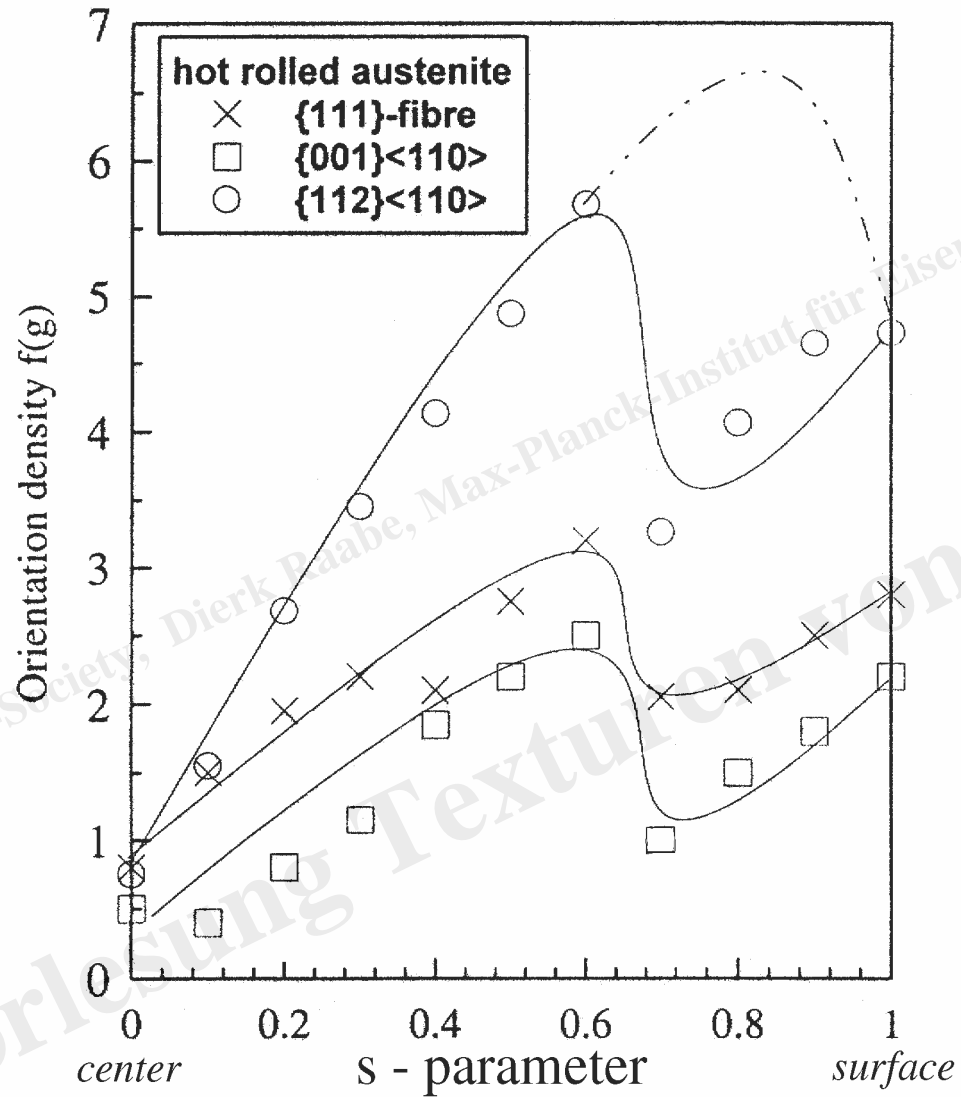


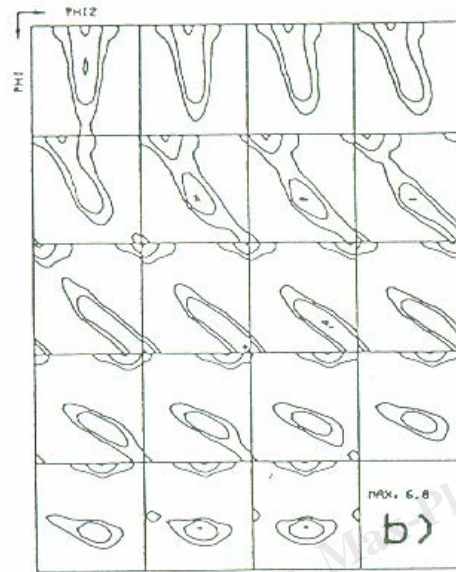
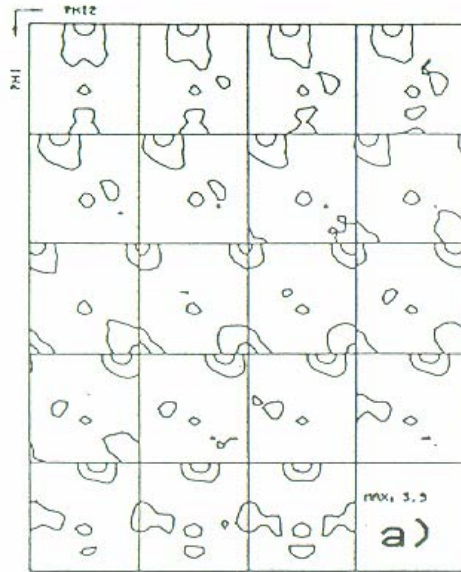






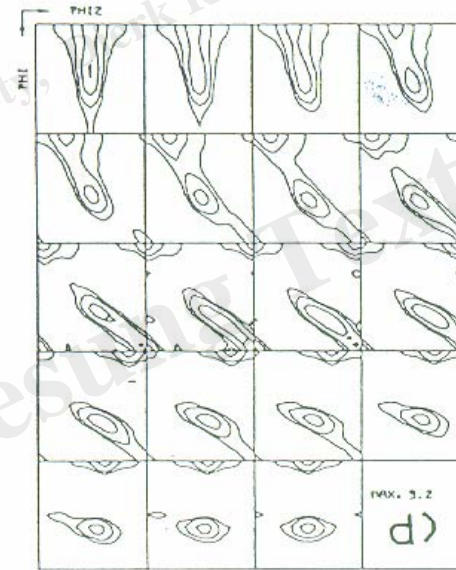
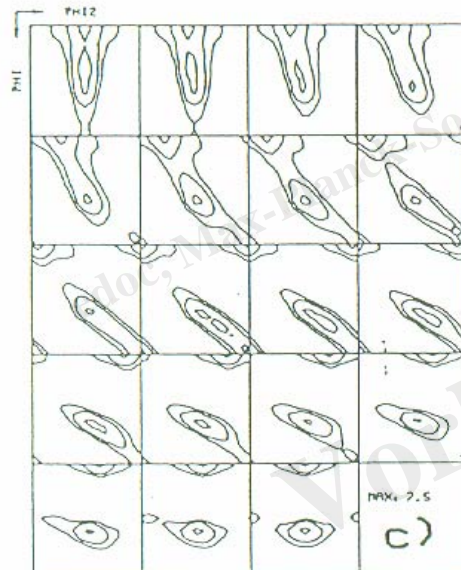




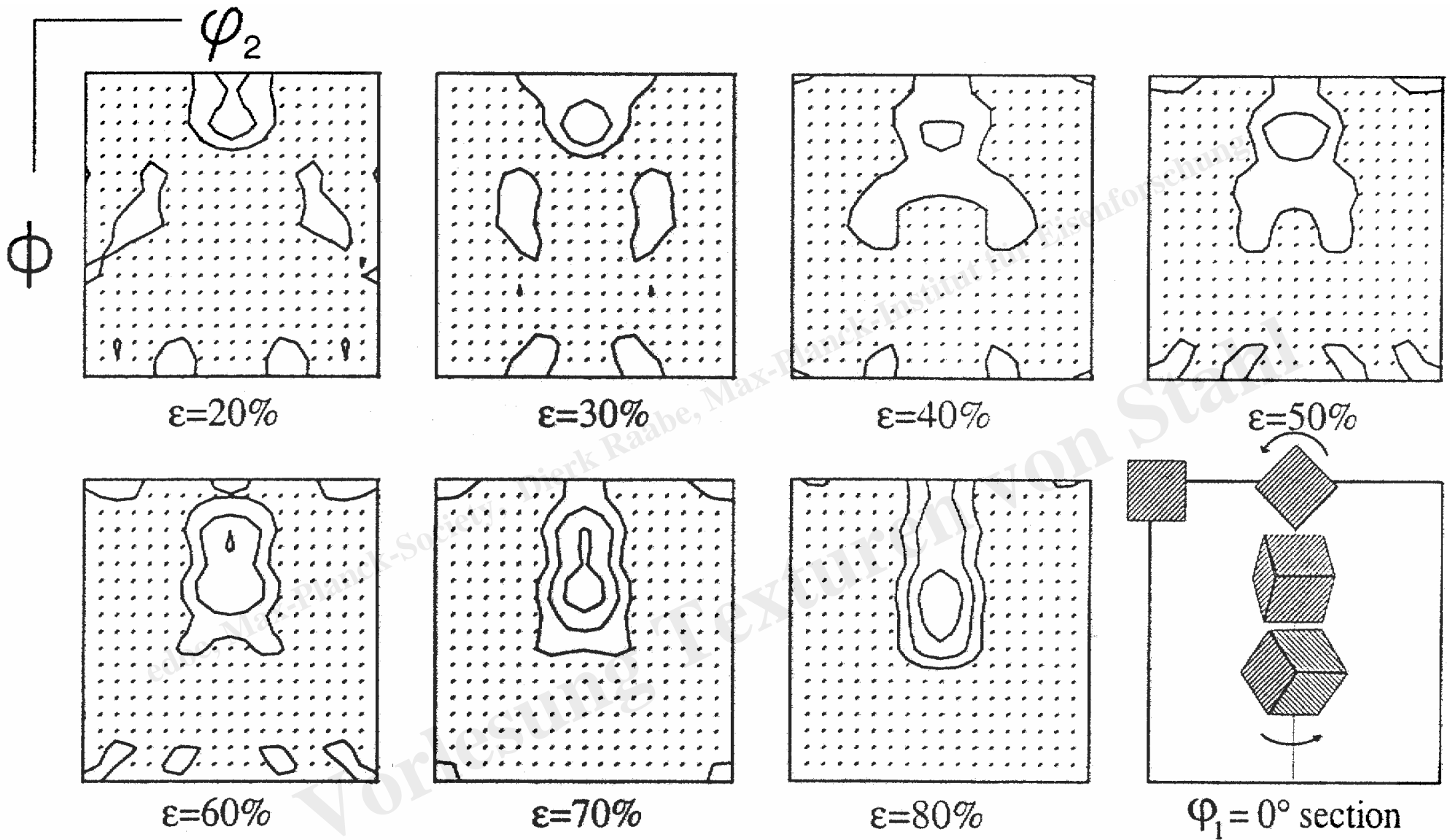


Levels: 1.5-3-6-9
PHI1 = CONST

- a) H. B.
- b) 60% C. R.
- c) 70% C. R.
- d) 80% C. R.
- e) 90% C. R.



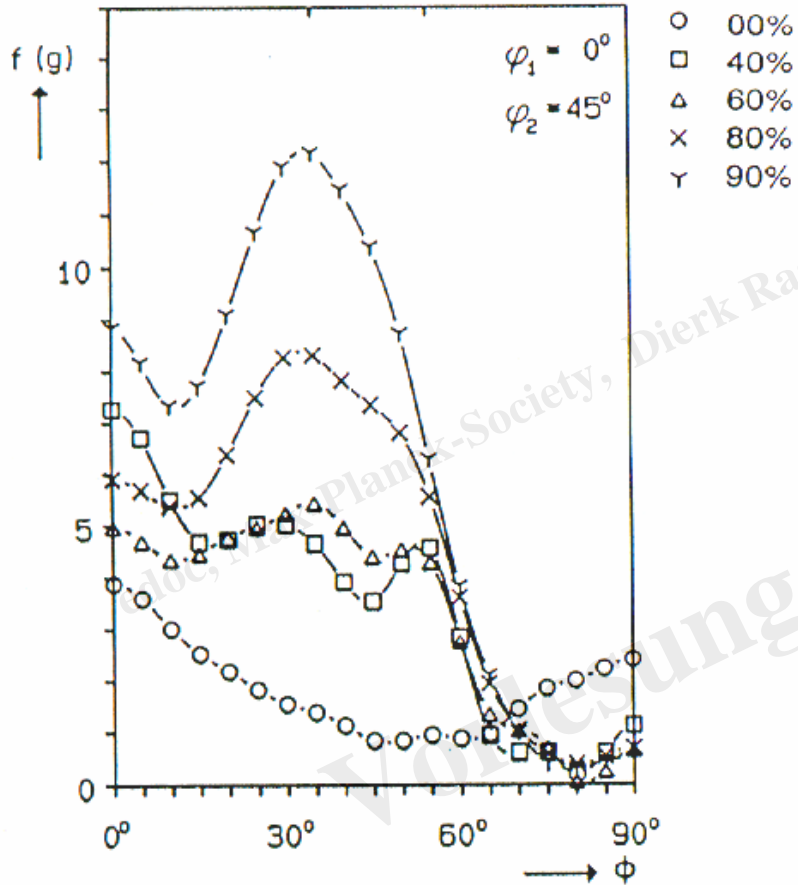
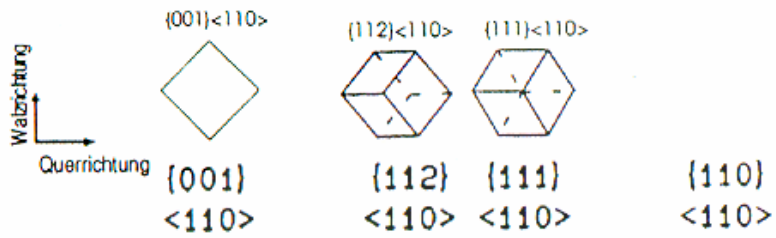
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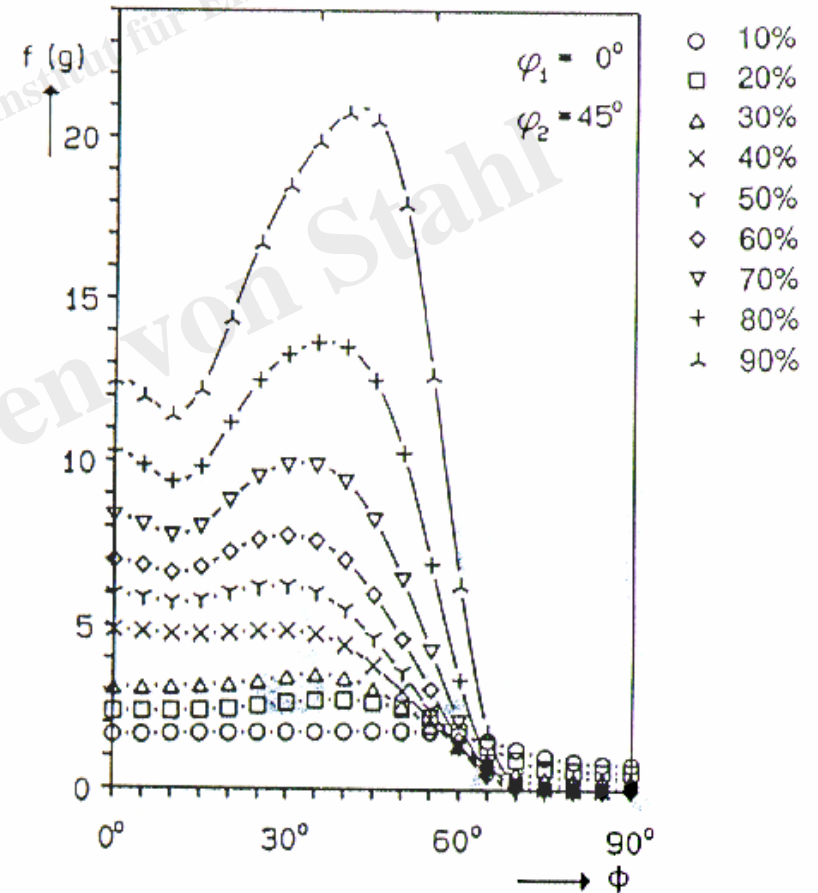
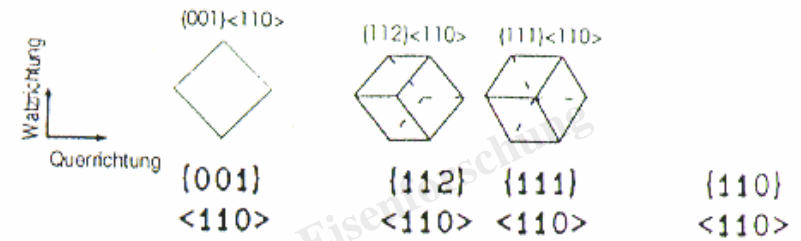
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Experiment



Simulation



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low C, kein IF

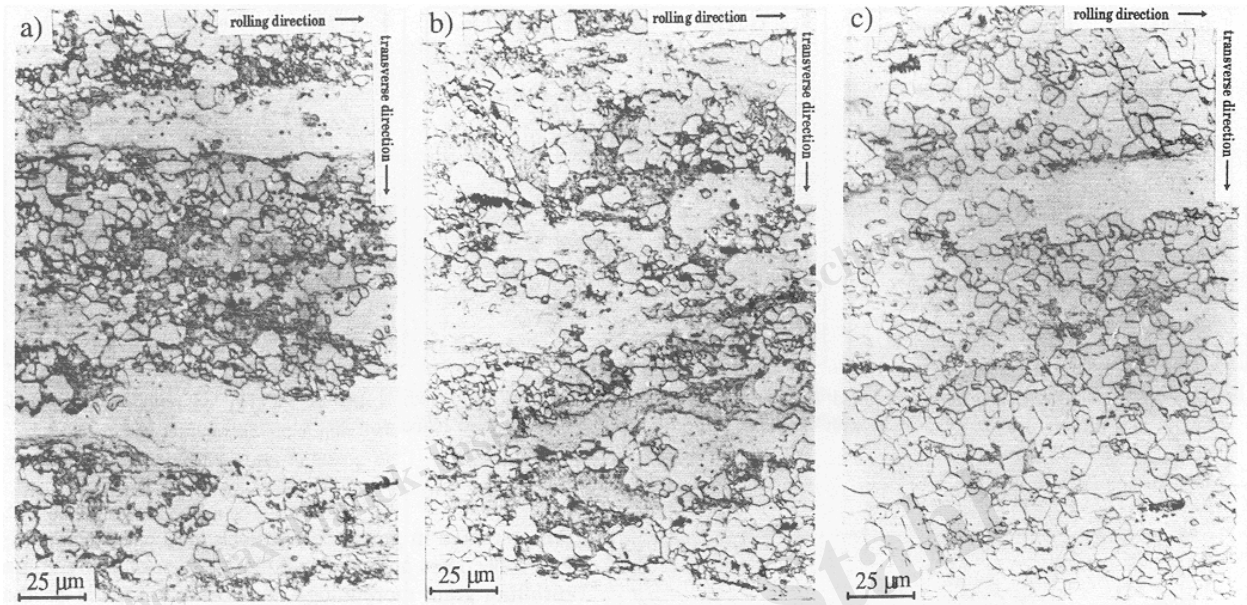
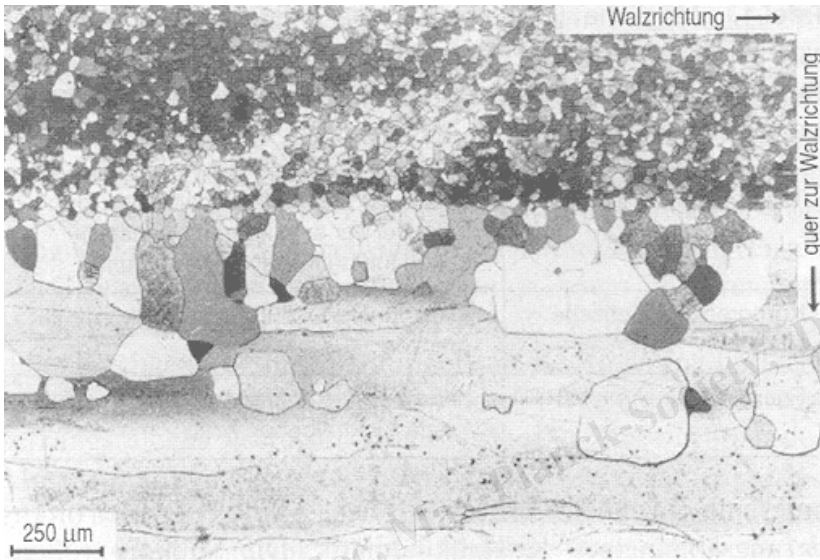


Figure 11. Flat sections of the rolled and annealed polycrystals the texture of which was shown in figure 10; a) 5 s, b) 6 s, c) 7 s at 1000 K

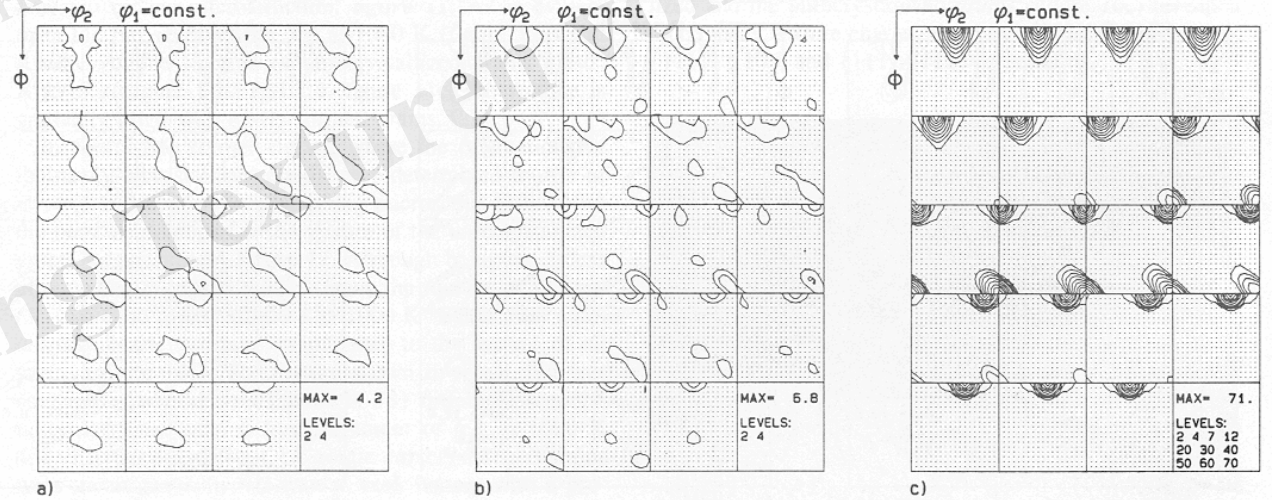
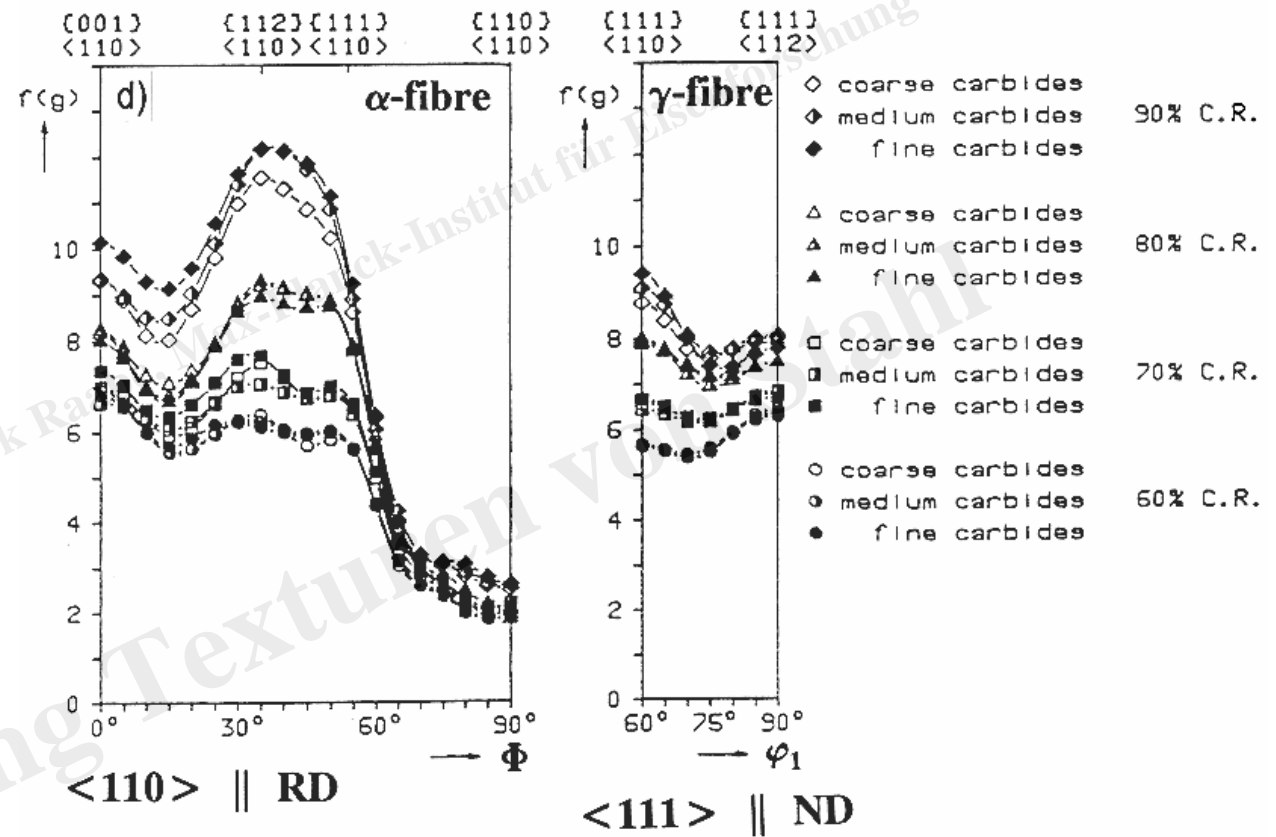
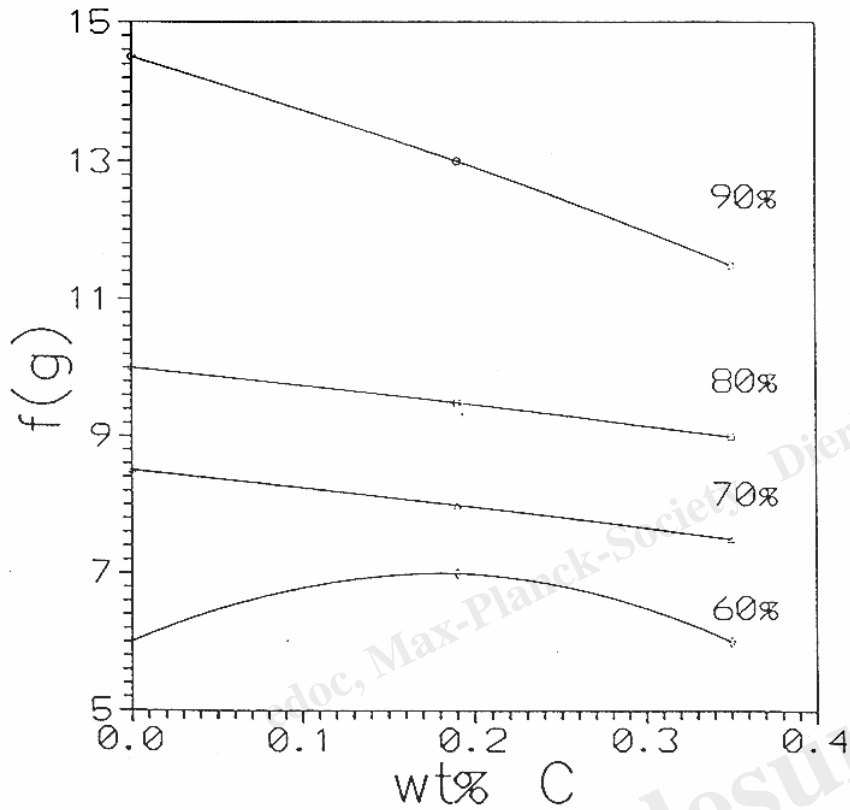
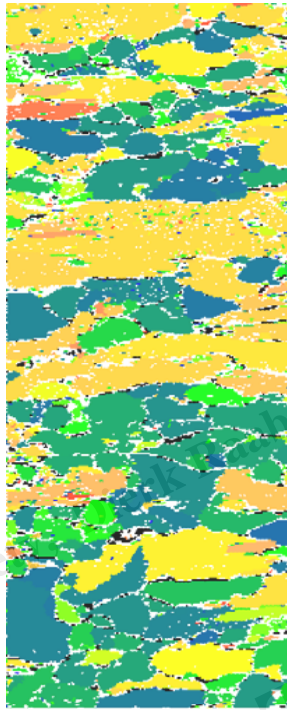


Figure 12. ODFs of the unrecrystallized grains within 90 % rolled and annealed polycrystals (1000 K). Single orientations determined by employment of electron diffraction in the scanning microscope [27;28]. Calculation of the ODF by use of the Gauss method [29]; a) 5 s, b) 6 s, c) 7 s at 1000 K

Einfluß der Karbiddispersion



verformter/erholter Gefügebereich



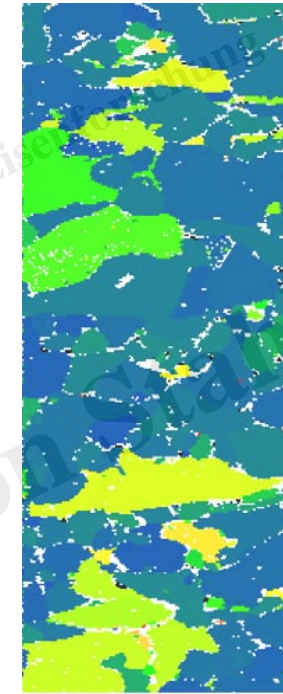
35.00 μm = 35 steps

Gray Scale Map Type: <none>

Color Coded Map Type: Grain Average Misorientation

	Min	Max	Total Fraction	Partition Fraction
	0.068528	4.98609	0.838	0.838

teilkristallisierter Gefügebereich



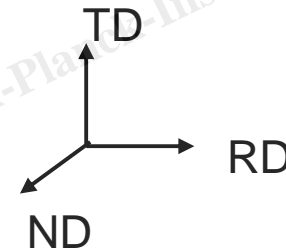
25.00 μm = 25 steps

Gray Scale Map Type: <none>

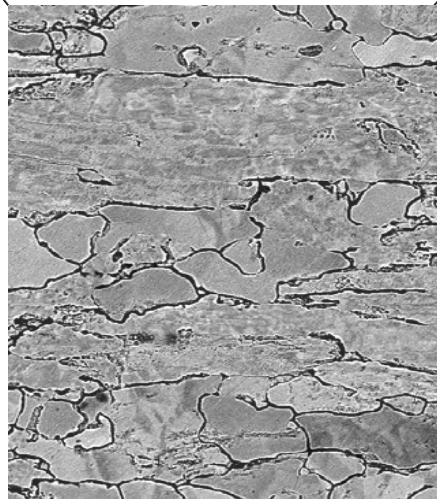
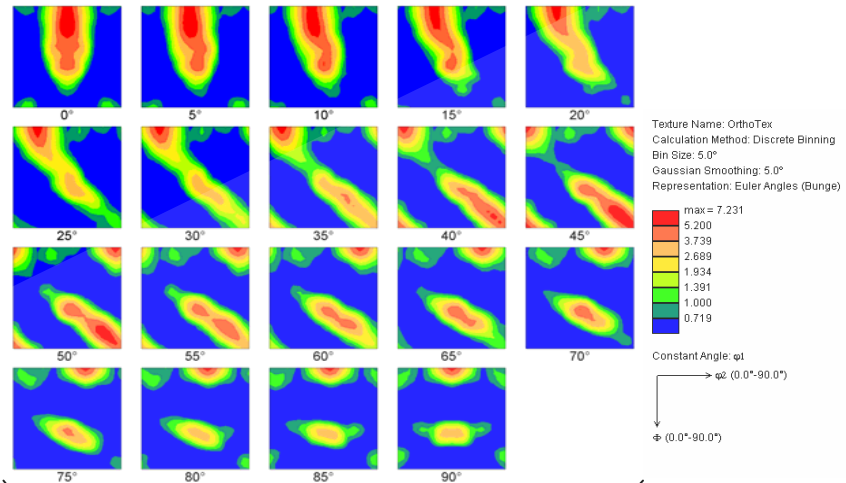
Color Coded Map Type: Grain Average Misorientation

	Min	Max	Total Fraction	Partition Fraction
	0.0791294	4.83229	0.938	0.938

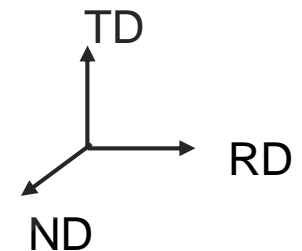
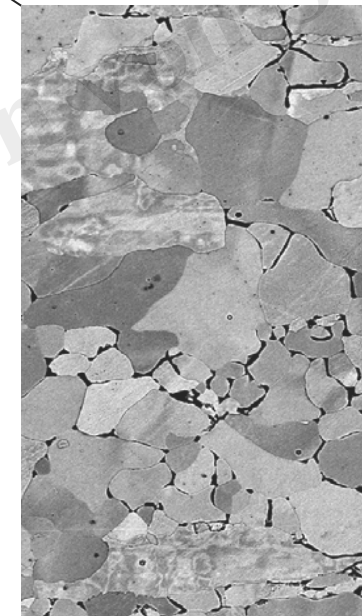
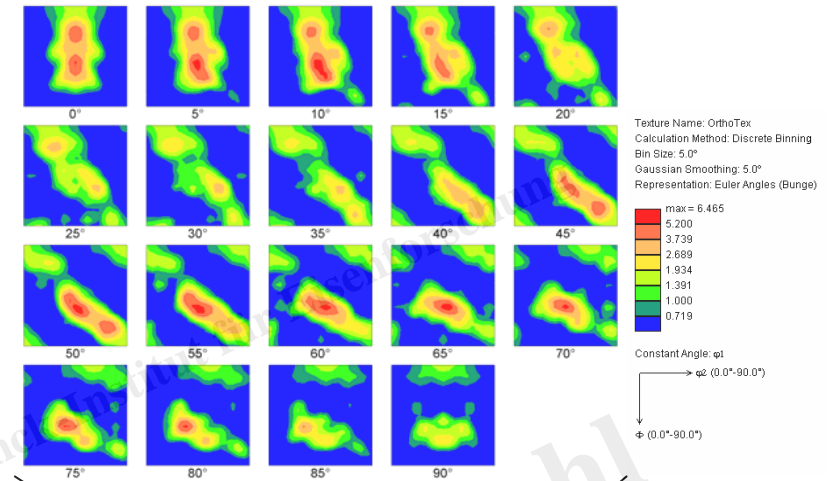
Misorientierung
innerhalb der einzelnen
Körner



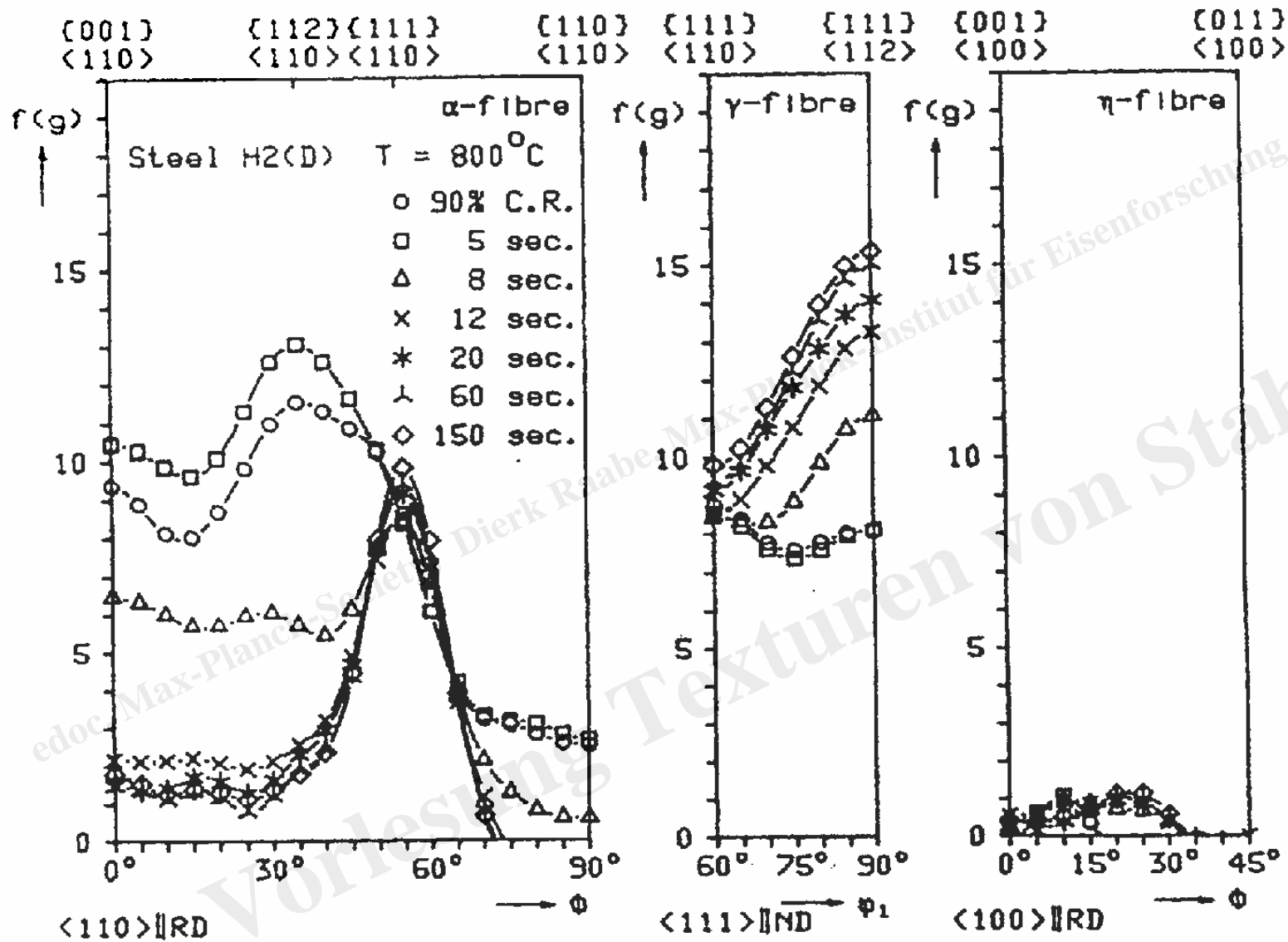
verformter/erholter Gefügebereich



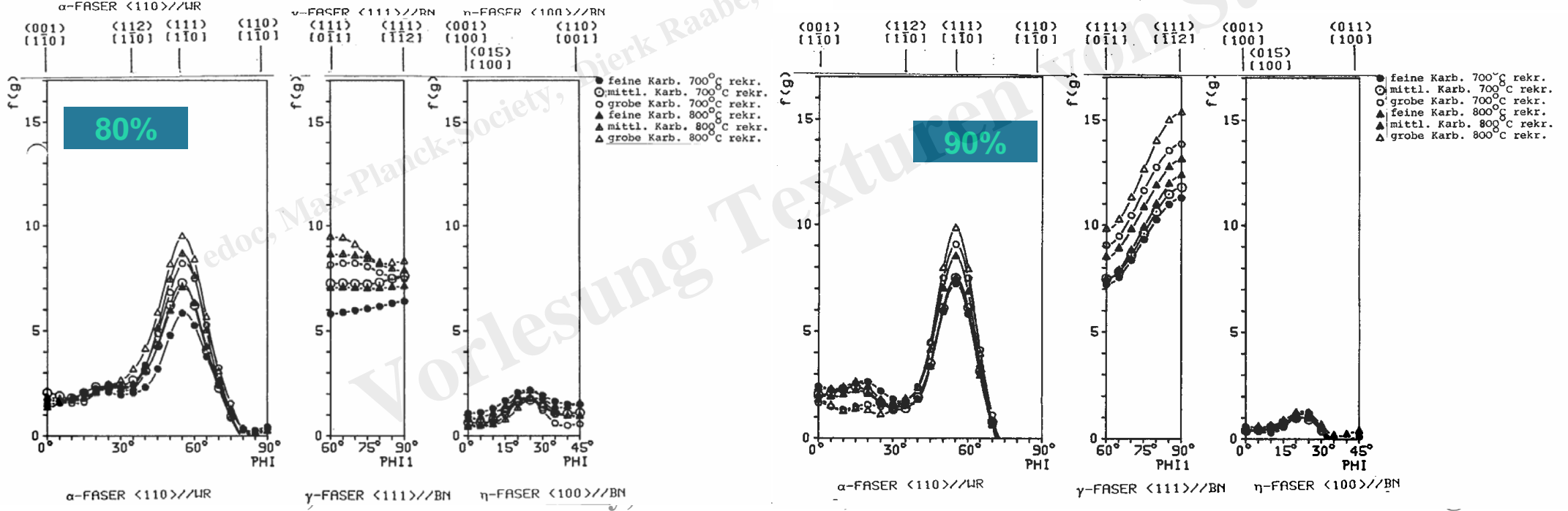
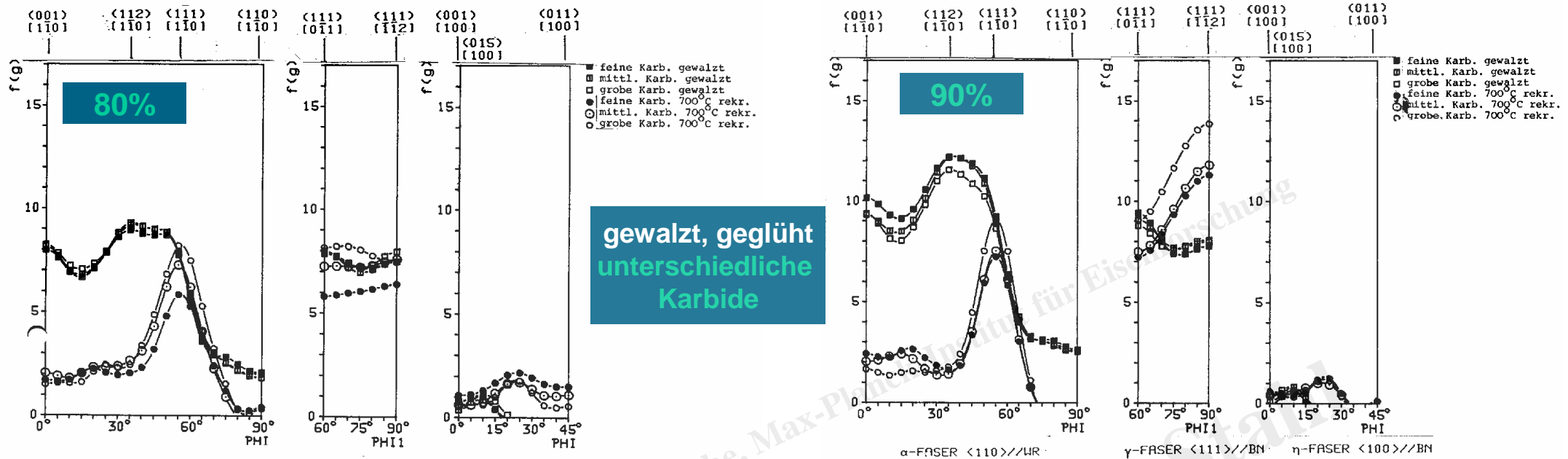
teilkristallisierter Gefügebereich



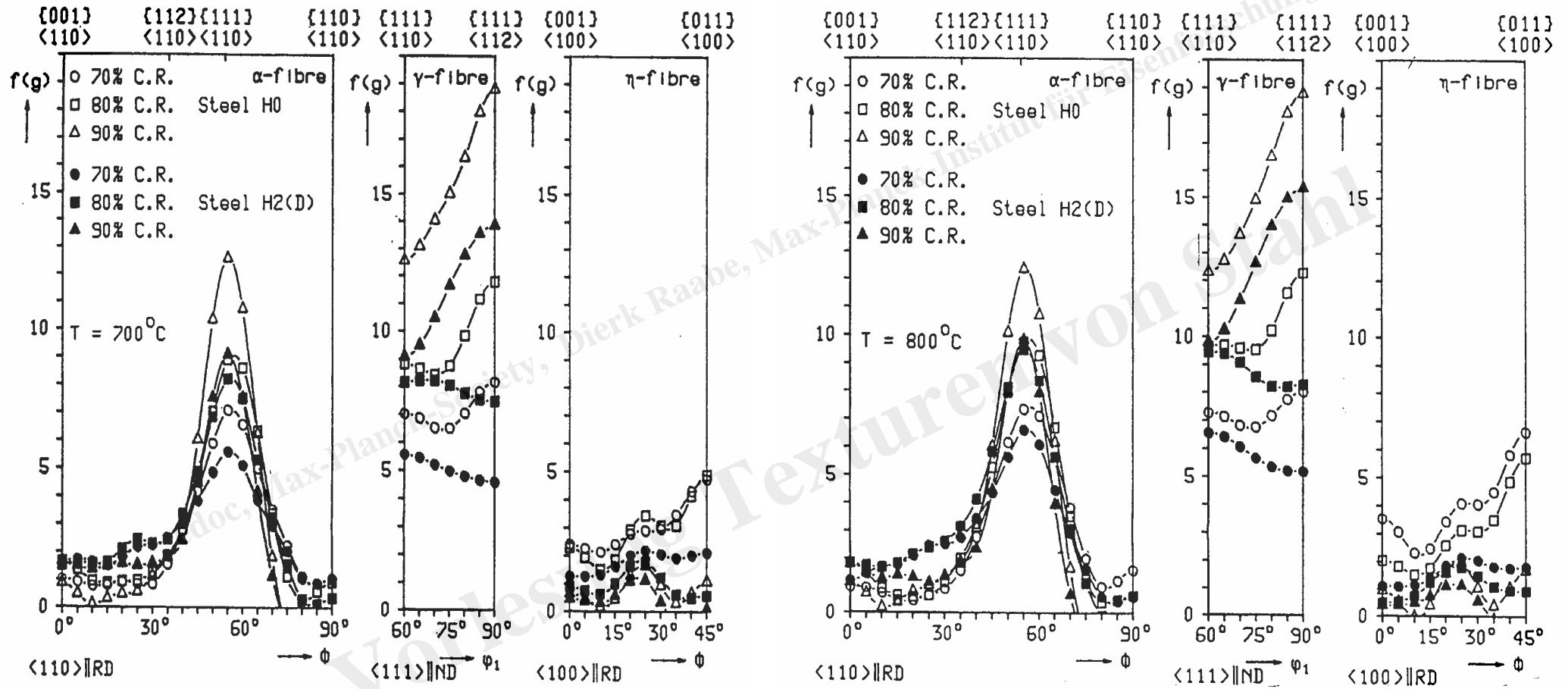
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low C, kein IF



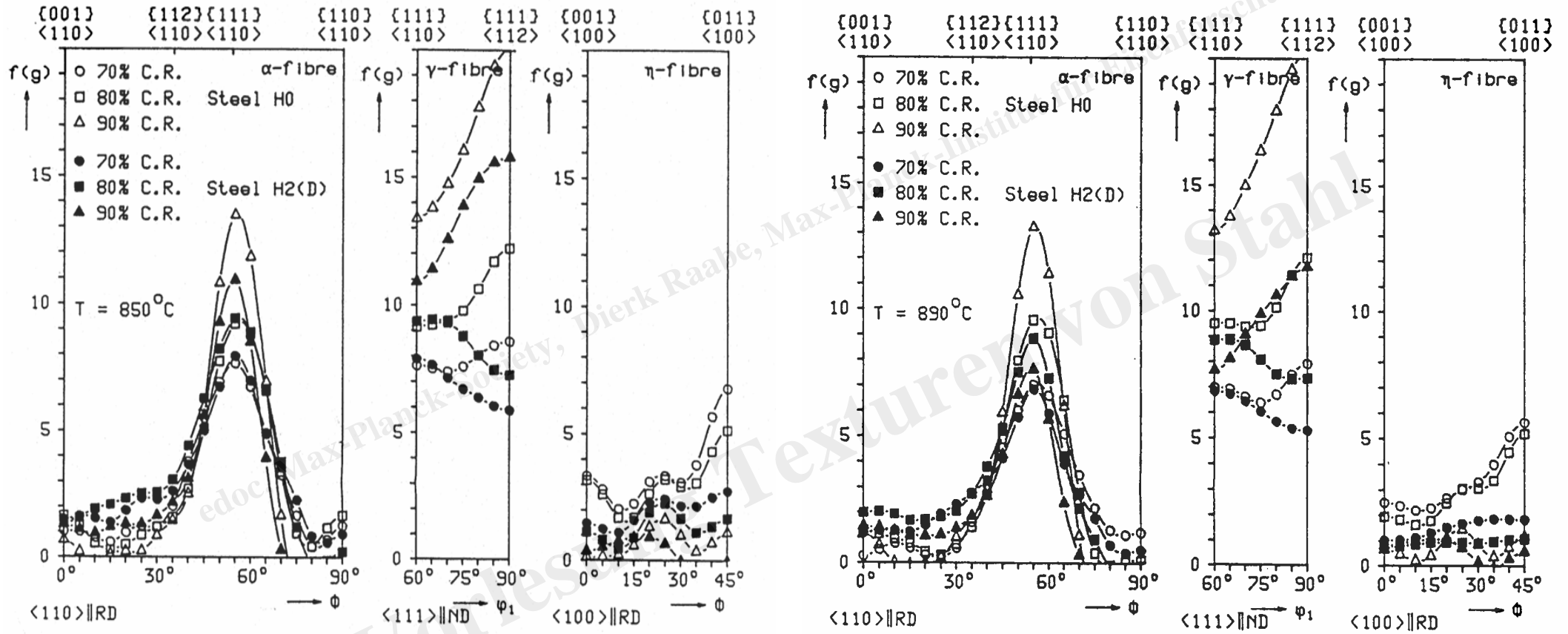
low C, kein IF



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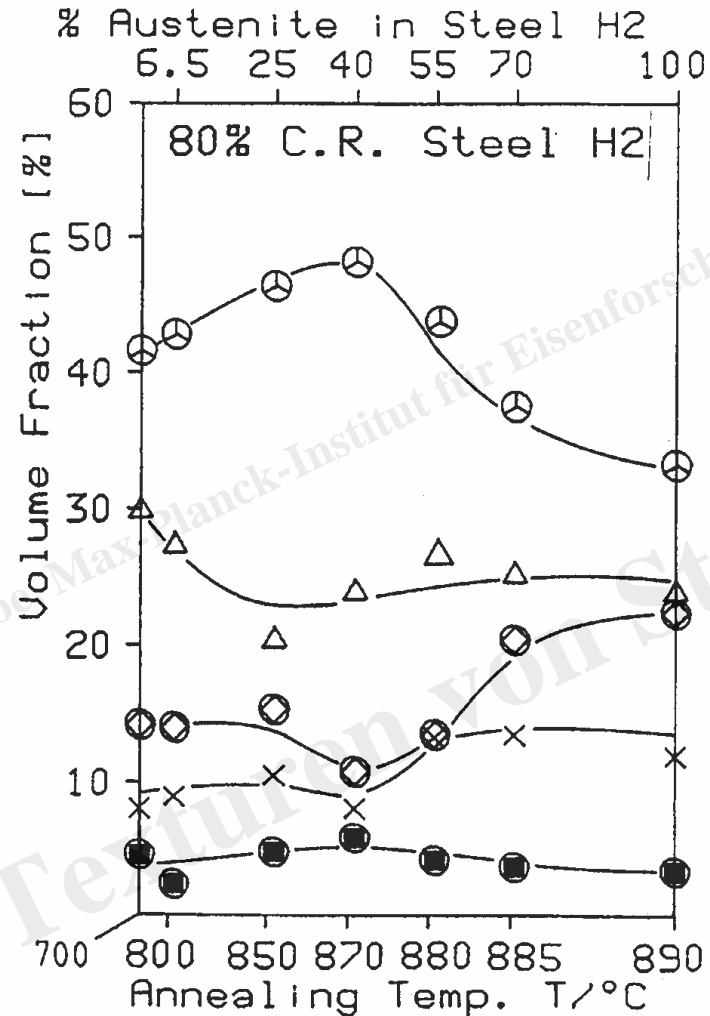
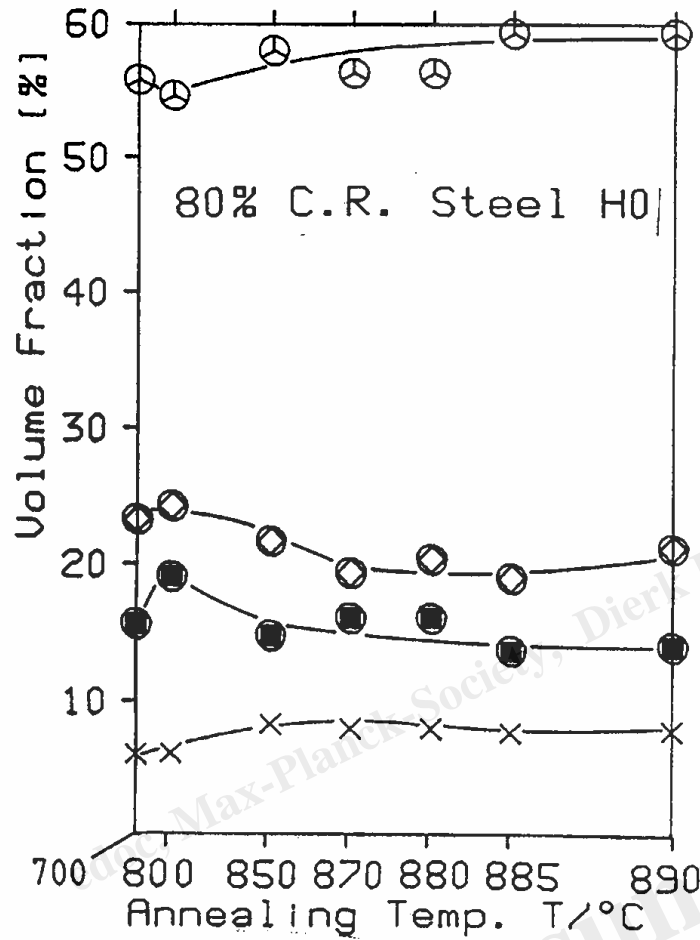


low C, kein IF



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- ⊙ γ- Fibre
- ⊙ α- Fibre
- η- Fibre
- △ ~ {557} < 493 >
- × Background

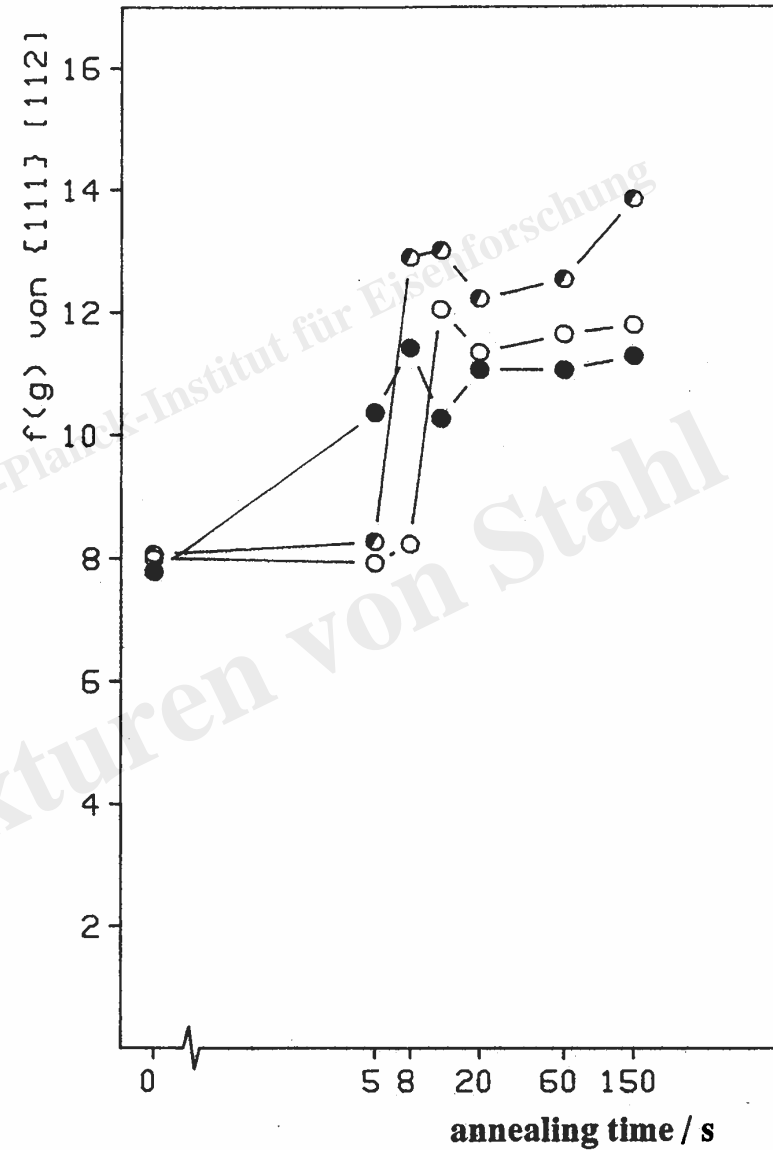
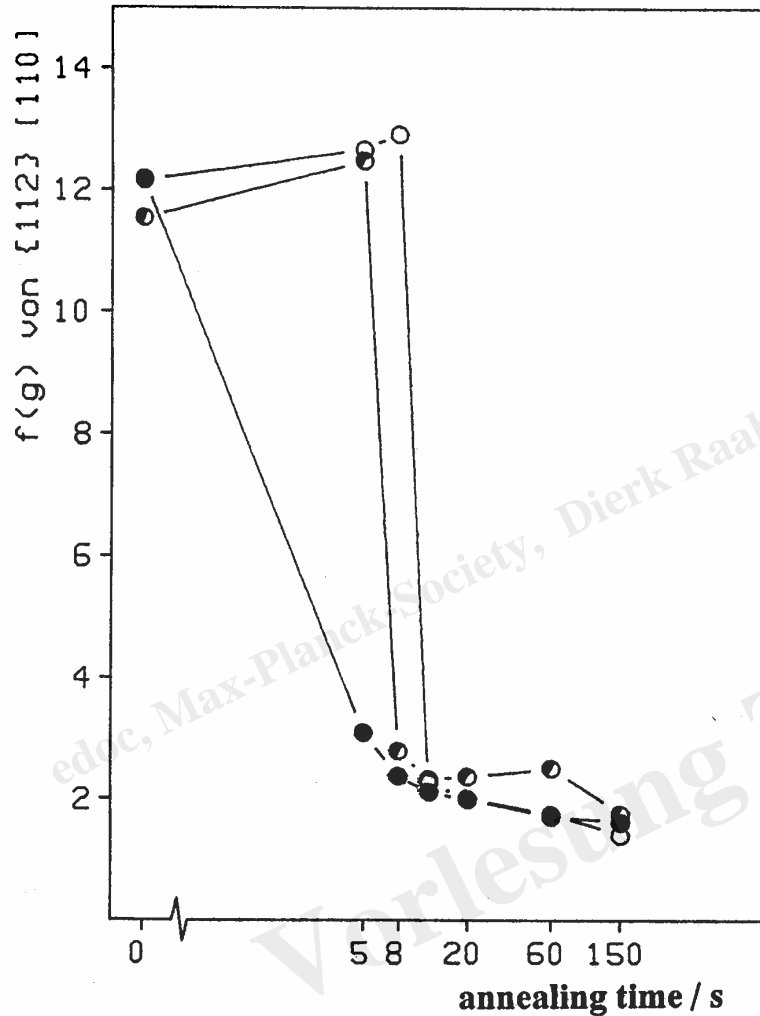
Bild 6

Entwicklung der Volumenanteile der Texturkomponenten mit zunehmender Glüh­temperatur.

(a) Stahl H0, 80% kaltgewalzt und geg­löh­tert.

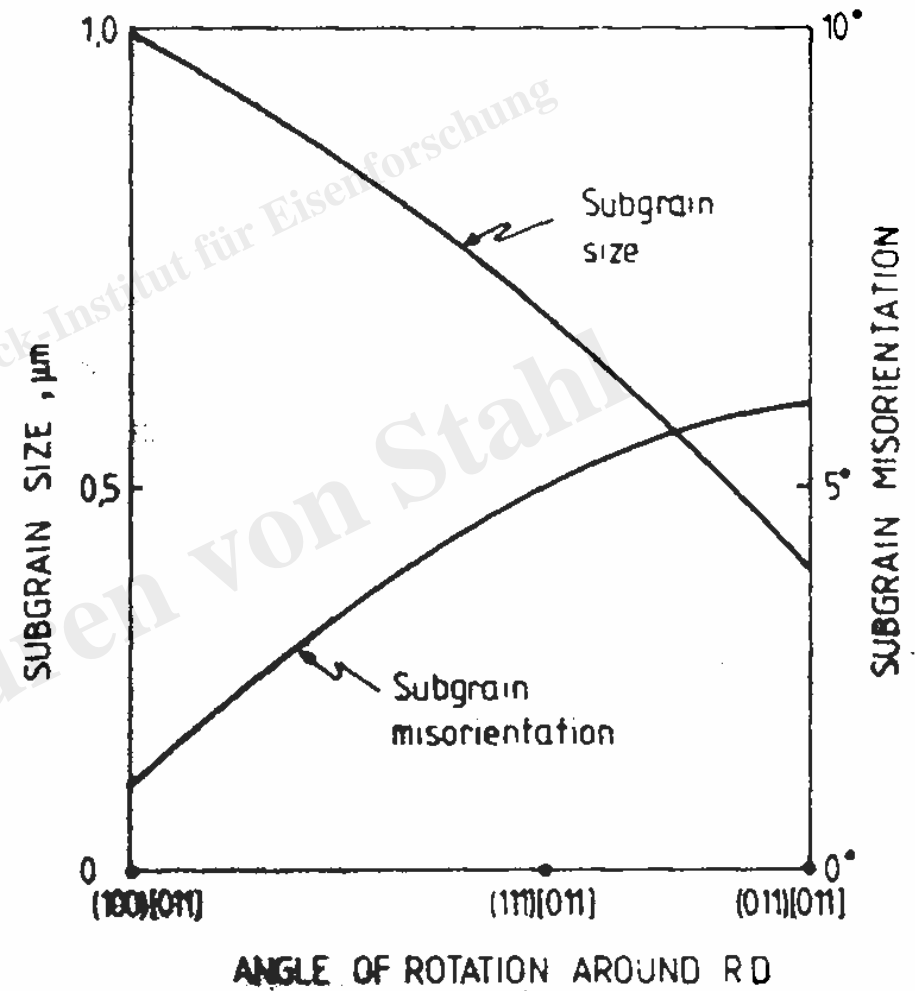
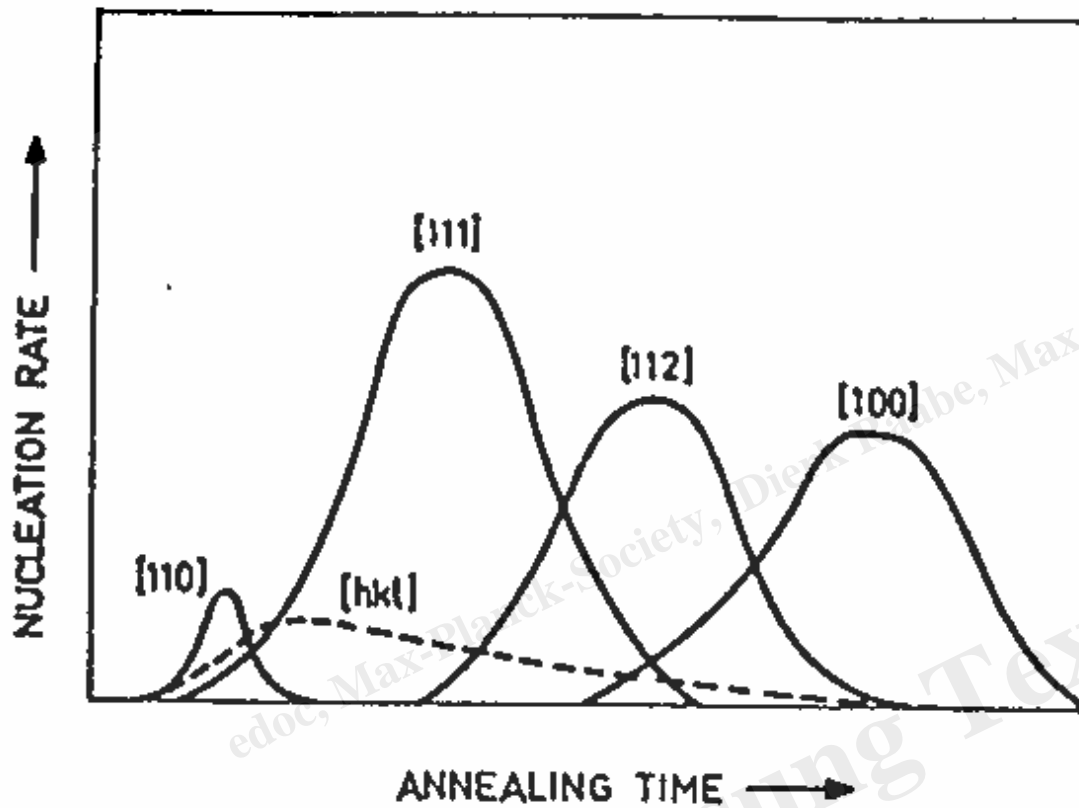
(b) Stahl H2, 80% kaltgewalzt und geg­löh­tert.

low C, kein IF



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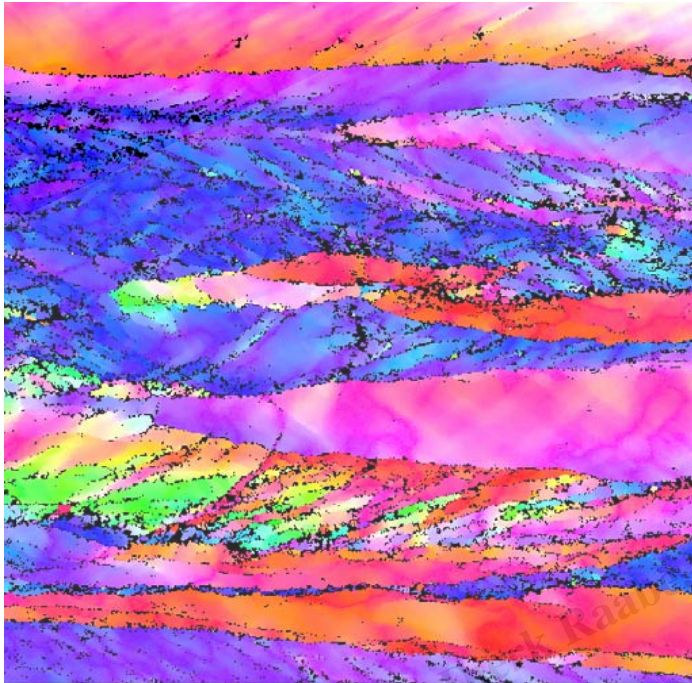
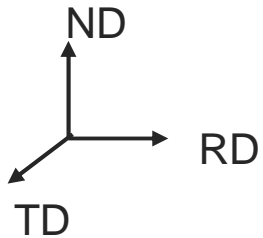
Walzhartes Gefüge



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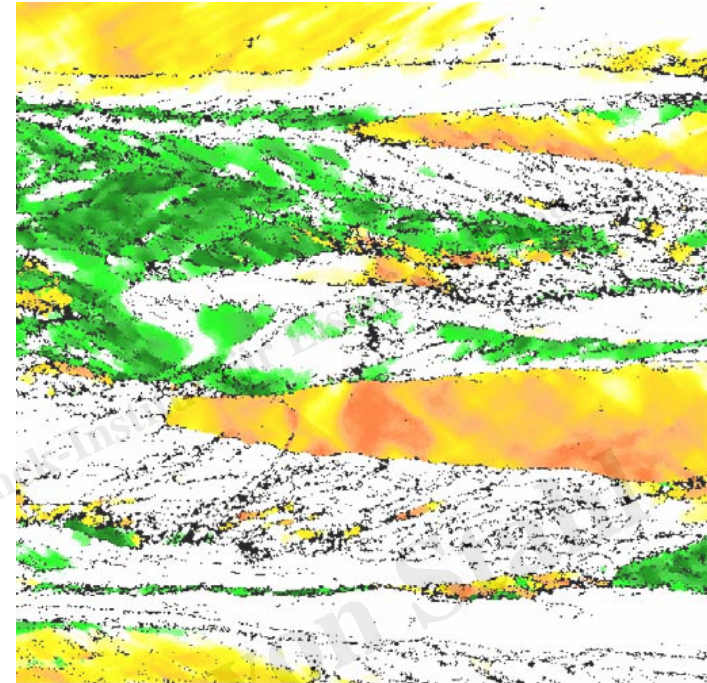
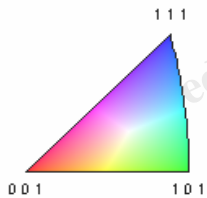
walzhart



9.00 μm = 90 steps IPF [001]

Color Coded Map Type: Inverse Pole Figure [001]

Iron (Alpha)



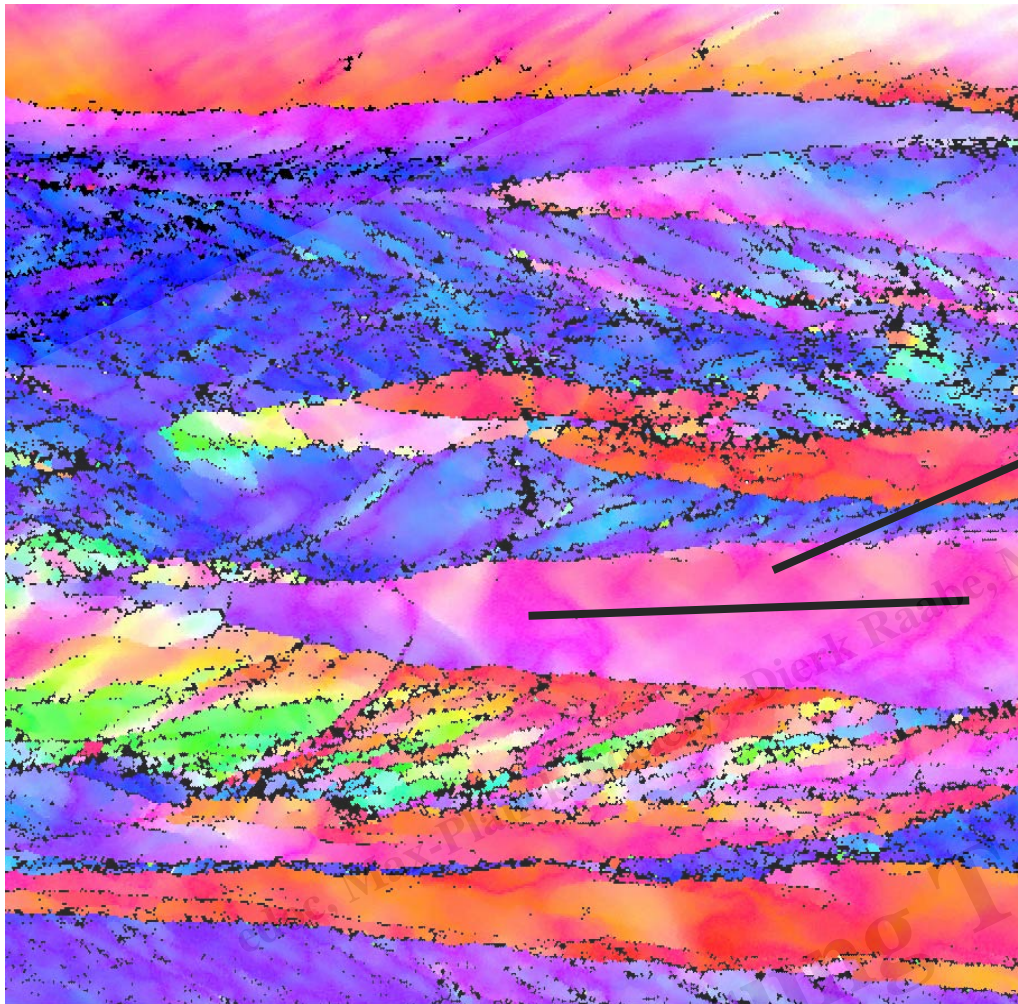
9.00 μm = 90 steps Direction

Direction	Min	Max	Total Fraction	Partition Fraction
$\langle 110 \rangle [100]$	0°	10°	0.276	0.276
$\langle 111 \rangle [001]$	0°	10°	0.183	0.183

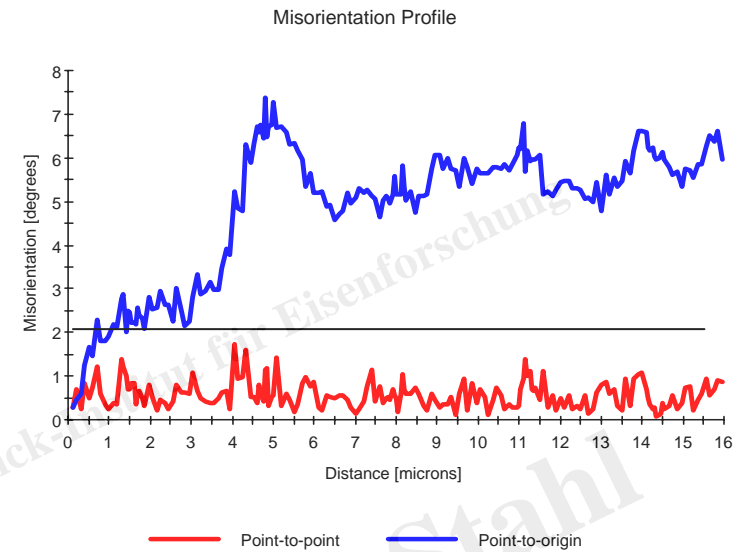
qualitative Aufteilung des Gefüges:

1. Alpha-Faser
2. Gamma-Faser
3. Gebiete mit Subkornstruktur

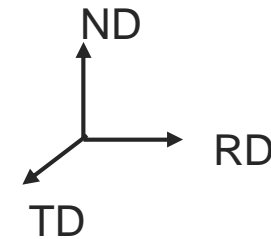
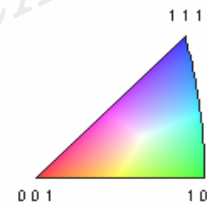




9.00 μm = 90 steps IPF [001]



Color Coded Map Type: Inverse Pole Figure [001]
Iron (Alpha)

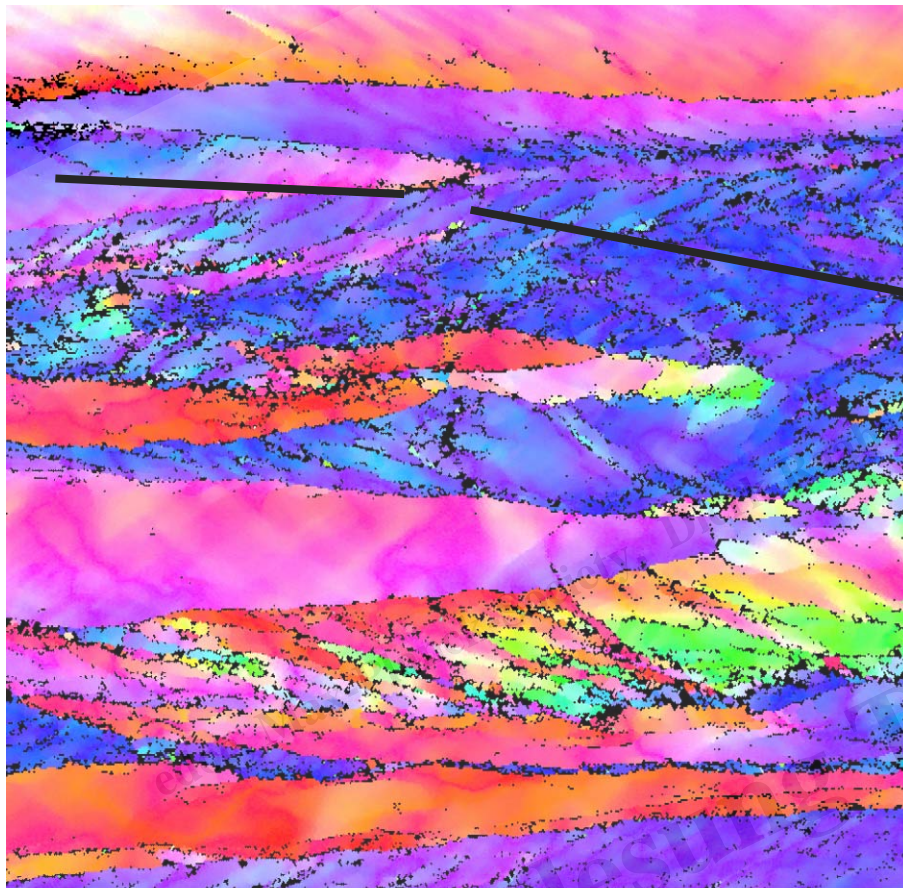


walzhart

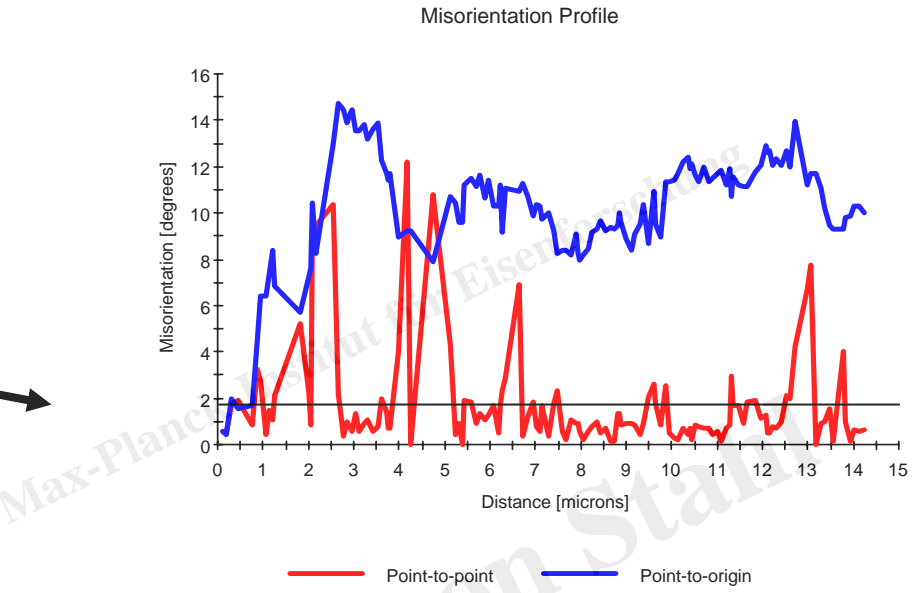
- Alpha-Faser zeigt kontinuierlichen Orientierungsgradienten

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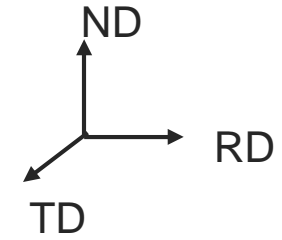
walzhart



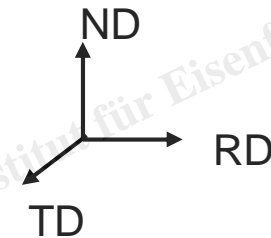
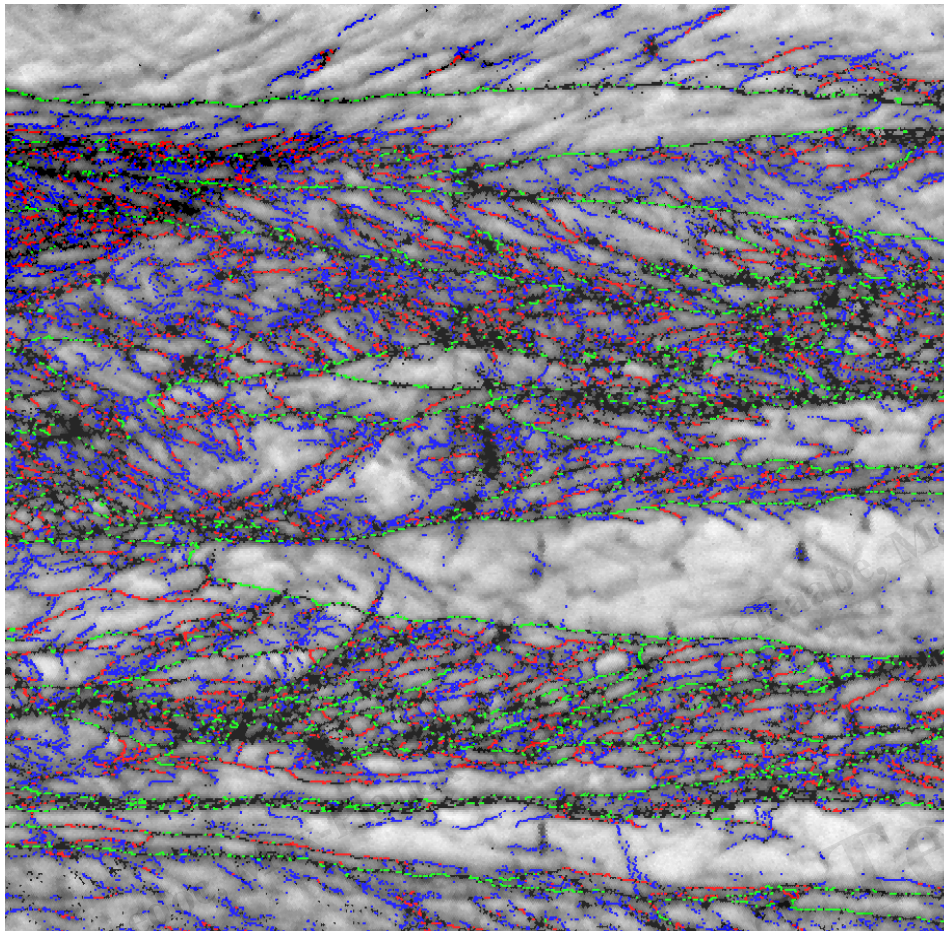
Color Coded Map Type: Inverse Pole Figure [001]
Iron (Alpha)



Color Coded Map Type: Inverse Pole Figure [001]
Iron (Alpha)



- in der Gamma-Faser zeigt die Orientierung diskrete Sprünge
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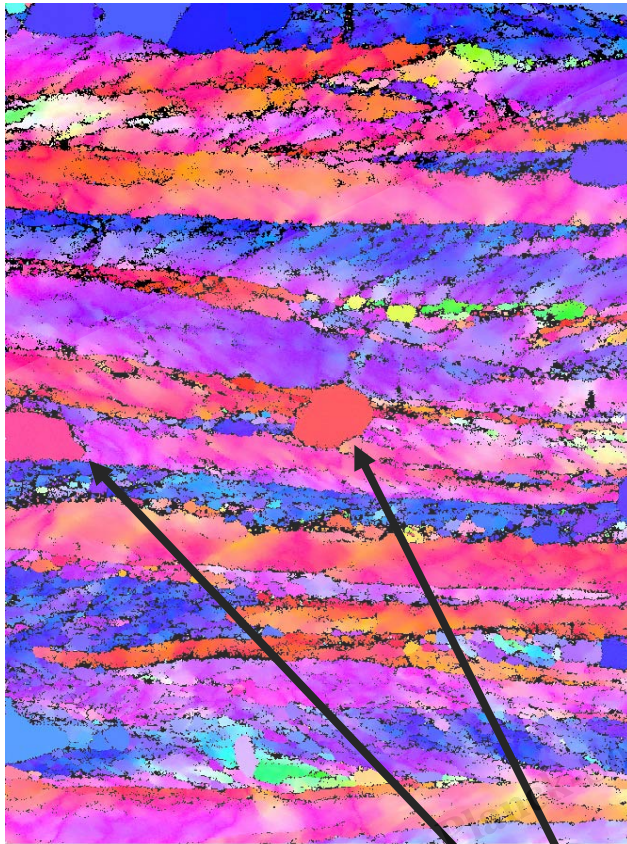


Boundaries: Rotation Angle

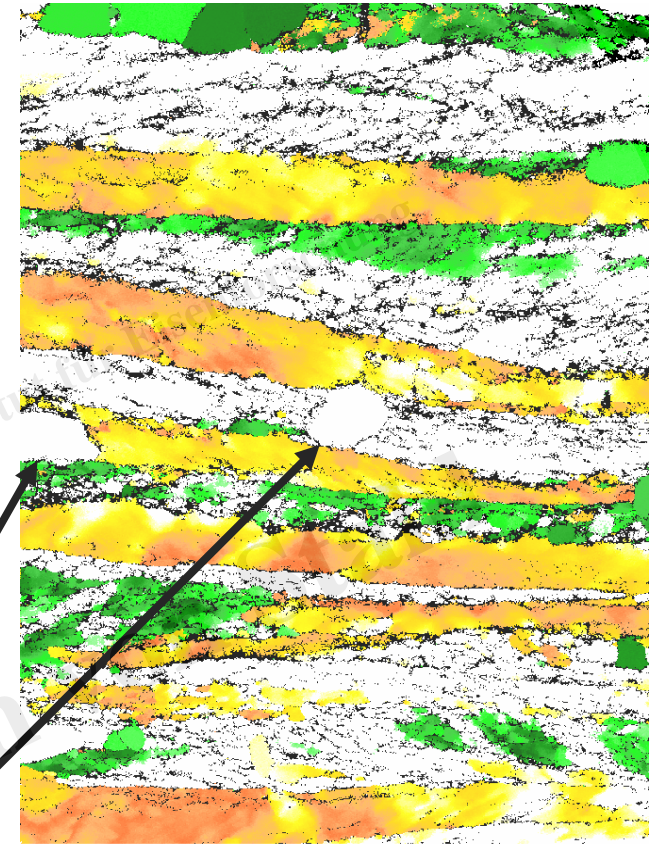
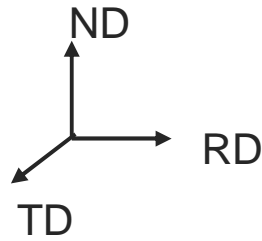
	Min	Max	Fraction
—	2°	5°	0.487
—	5°	15°	0.248
—	15°	180°	0.265

9.00 μm = 90 steps Boundary levels: 2° 5° 15° IQ 18...167.9

- Subkörner bilden teilweise Großwinkelkorngrenzen



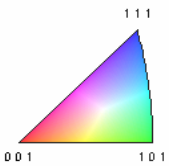
680°C; 3min



10.00 μm = 100 steps IPF [001]

Color Coded Map Type: Inverse Pole Figure [001]

Iron (Alpha)



10.00 μm = 100 steps Direction

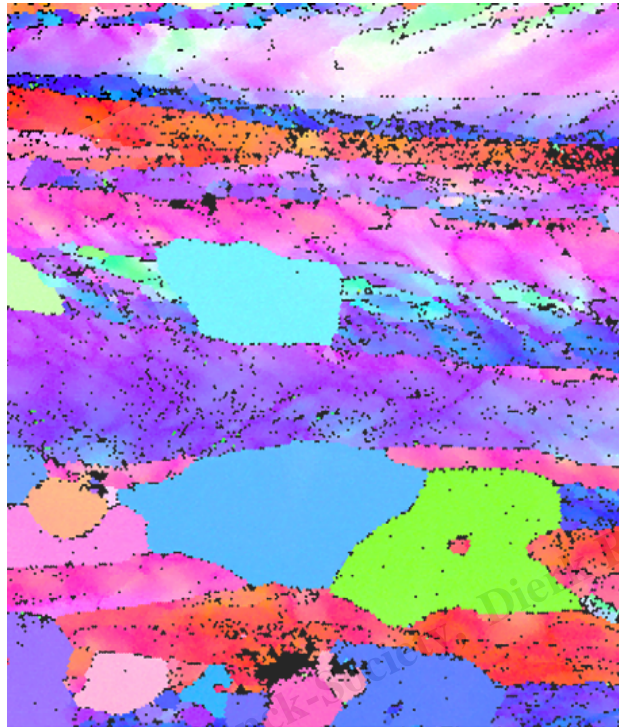
Color Coded Map Type: Crystal Direction

Direction	Min	Max	Total Fraction	Partition Fraction
<1 1 0> [1 0 0]	0°	10°	0.367	0.367
<1 1 1> [0 0 1]	0°	10°	0.154	0.154

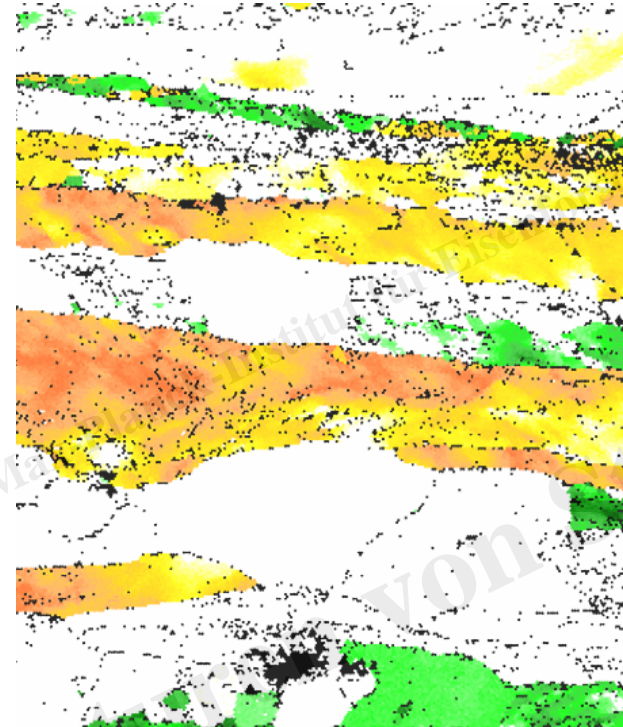
- beginnende Rekristallisation

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700°C; 3.5min

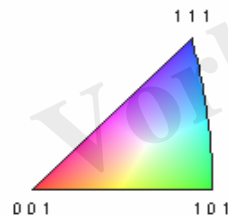
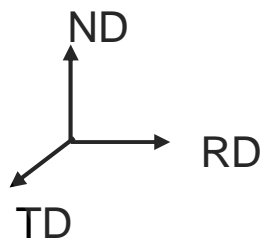


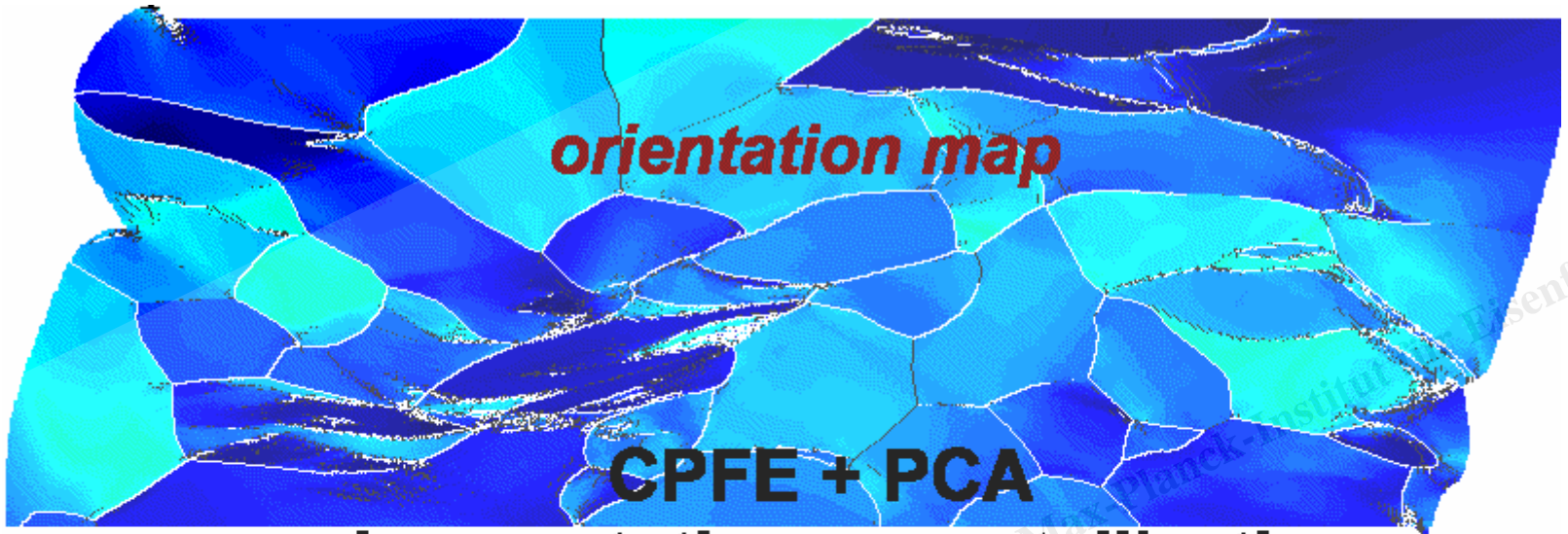
7.50 μm = 50 steps IPF [001]
 Color Coded Map Type: Inverse Pole Figure [001]
 Iron (Alpha)



7.50 μm = 50 steps Direction
 Color Coded Map Type: Crystal Direction

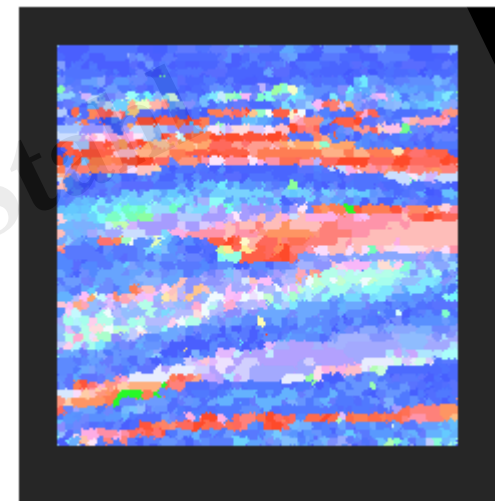
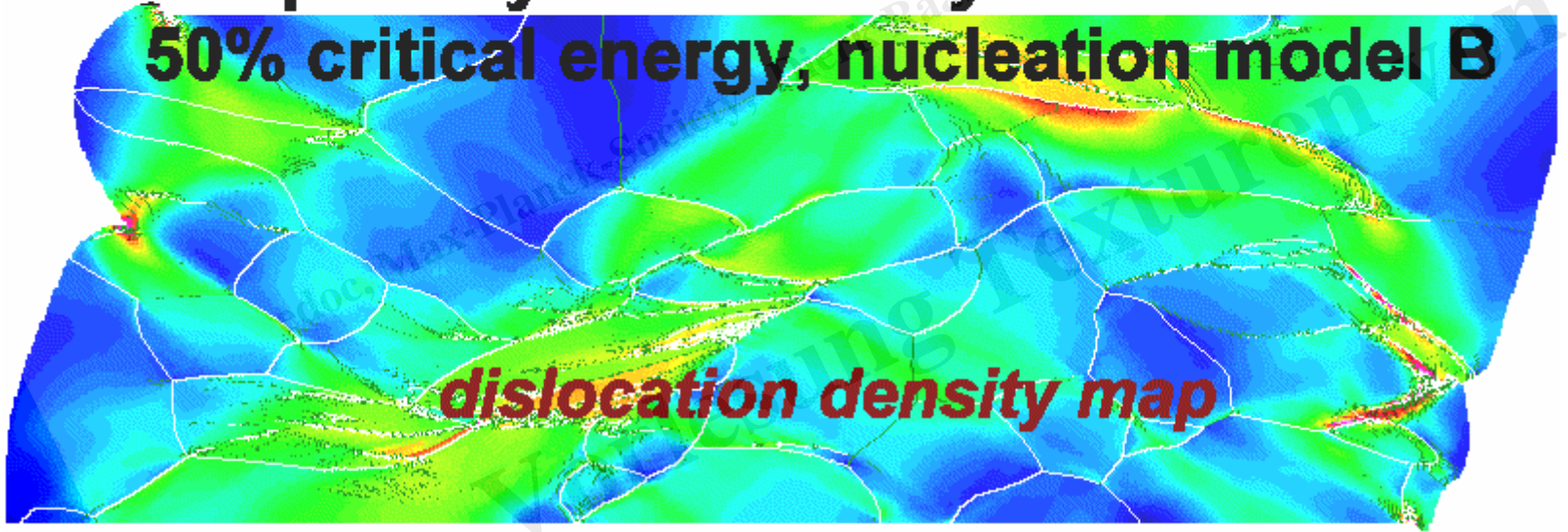
Direction	Min	Max	Total Fraction	Partition Fraction
$\langle 110 \rangle$ [100]	0°	10°	0.306	0.335
$\langle 111 \rangle$ [001]	0°	10°	0.074	0.081

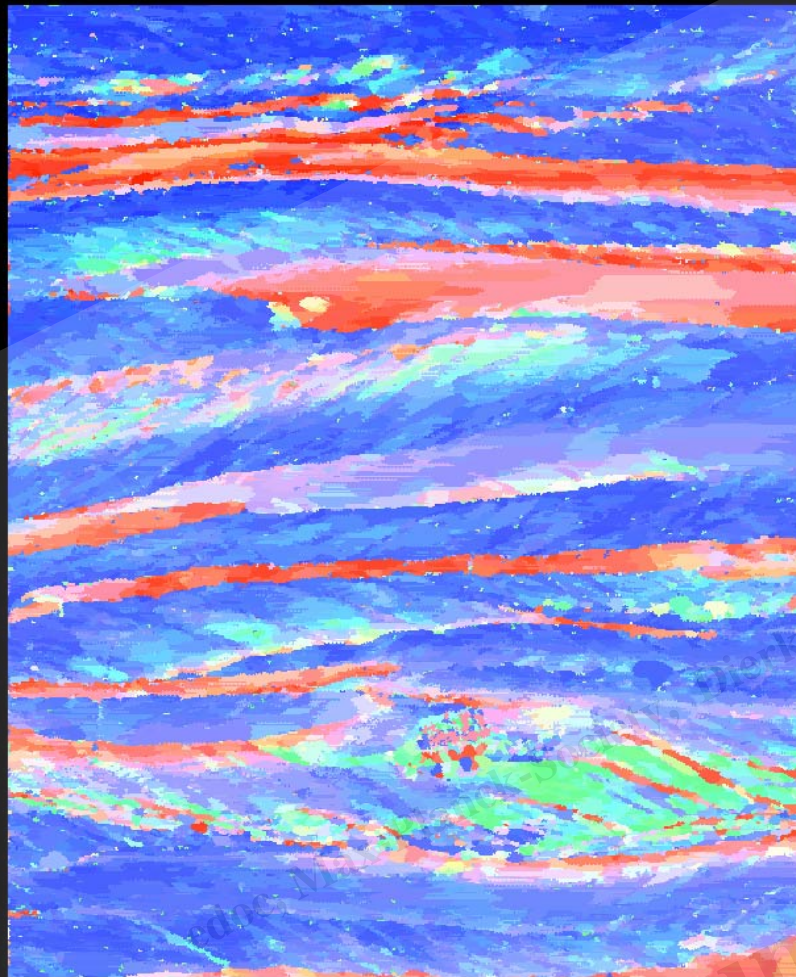




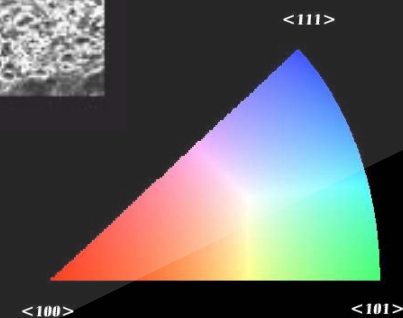
primary statics recrystallization

50% critical energy, nucleation model B

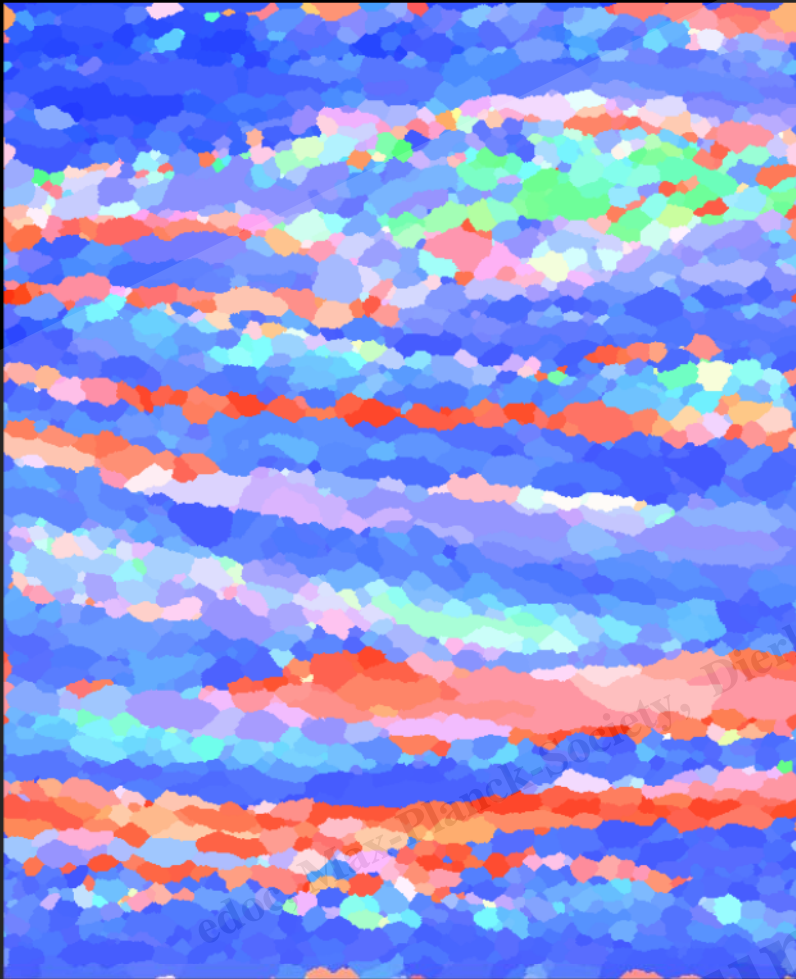




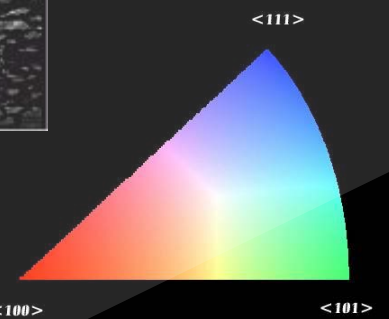
20 μm



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20 μm



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Grundbegriffe

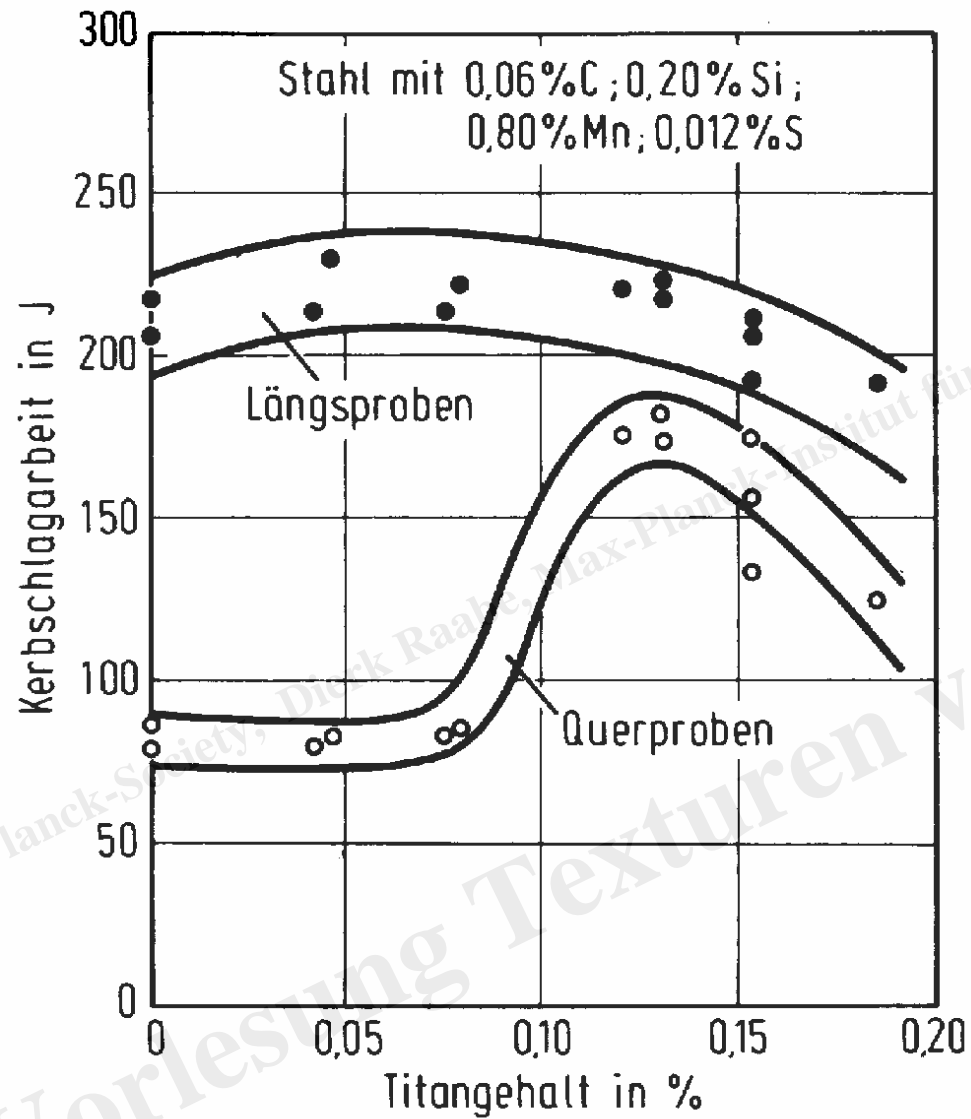
Kristallographie

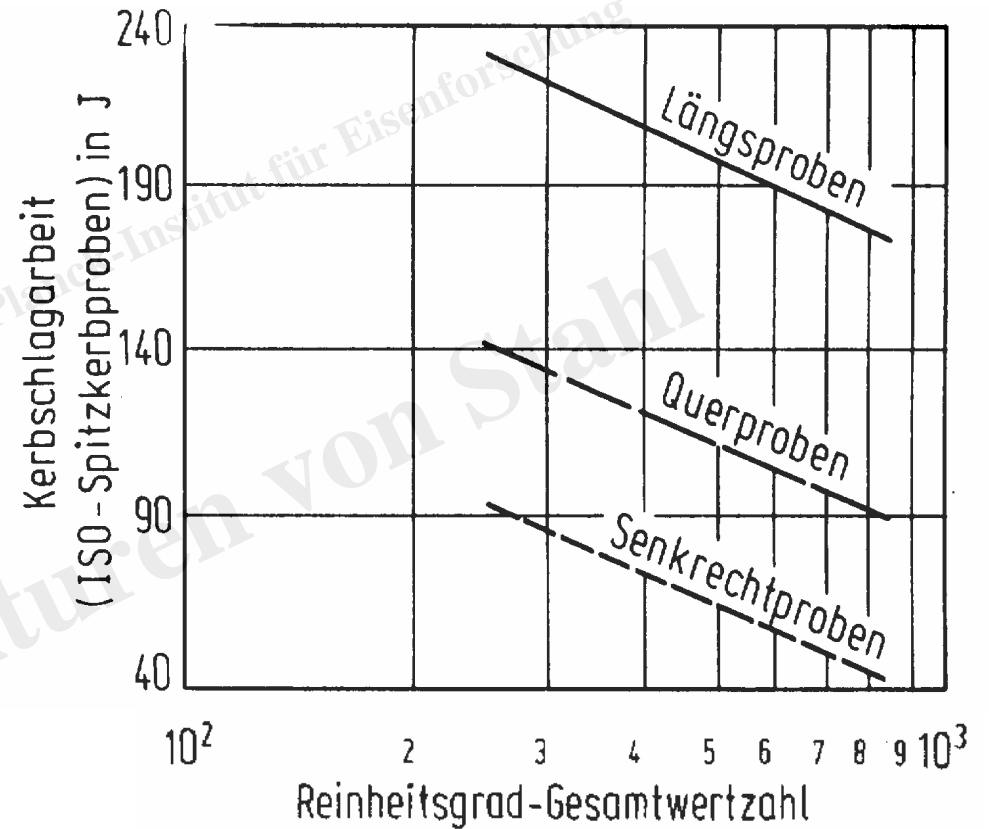
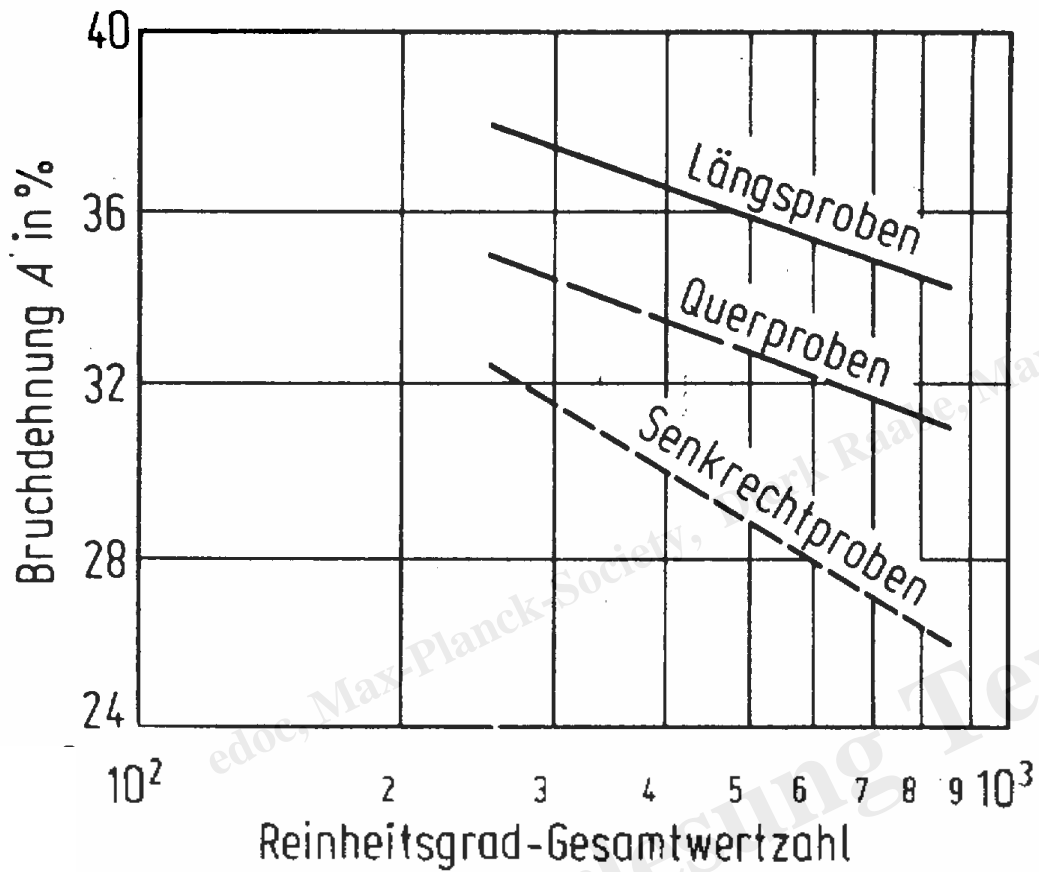
Metallkundliche Grundlagen

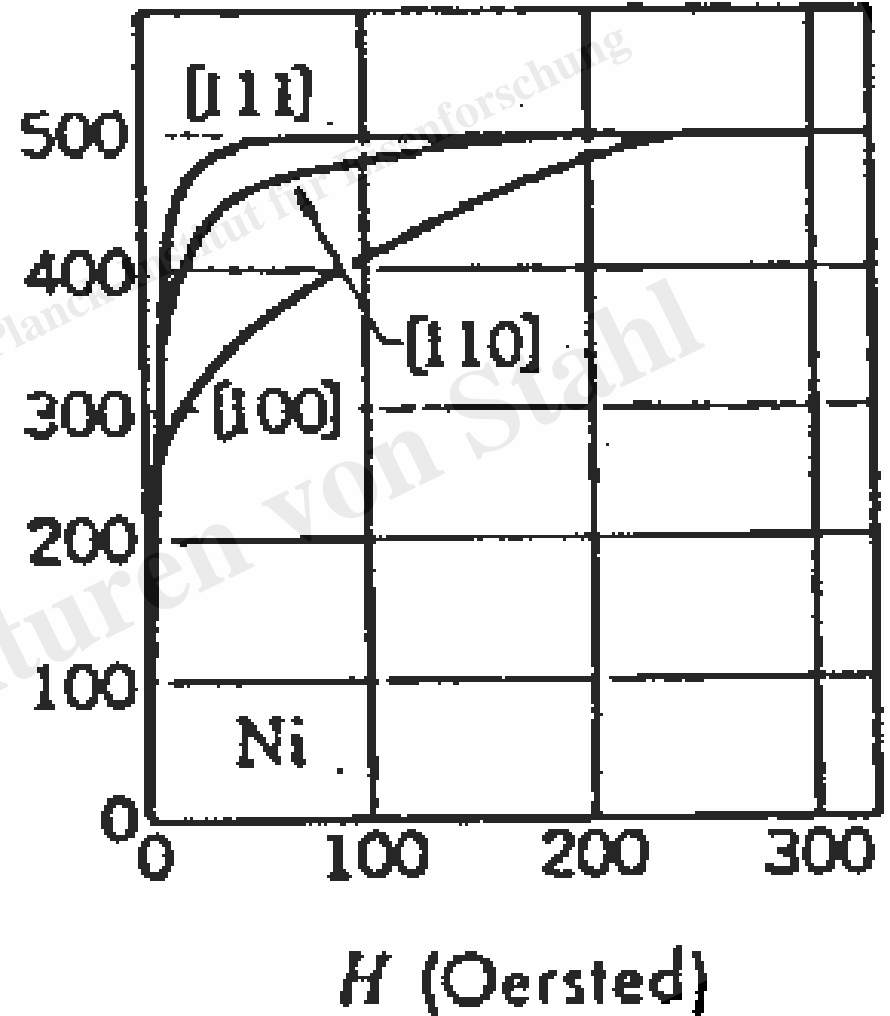
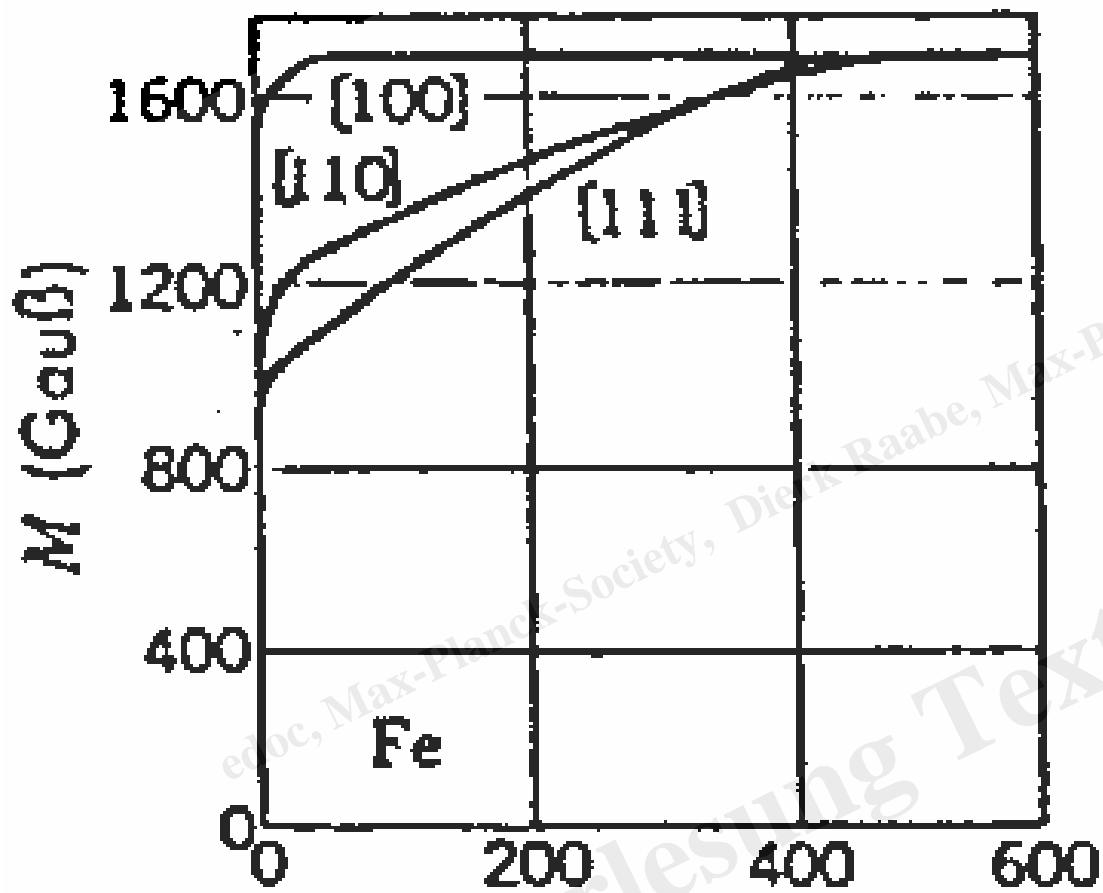
Kristallographische Textur

Anisotropie

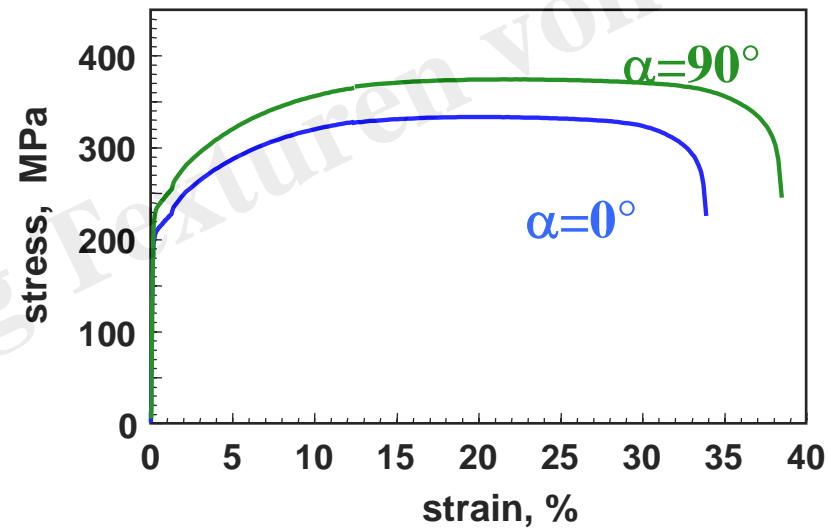
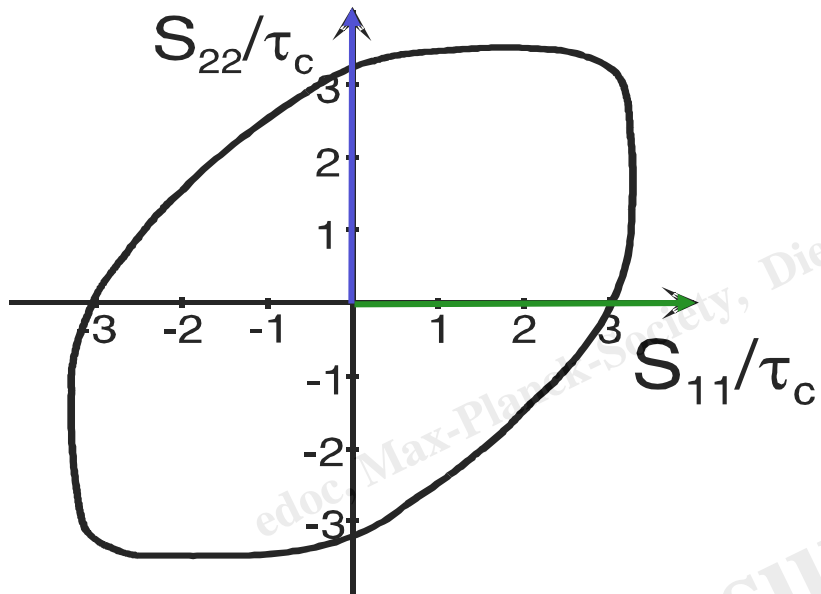
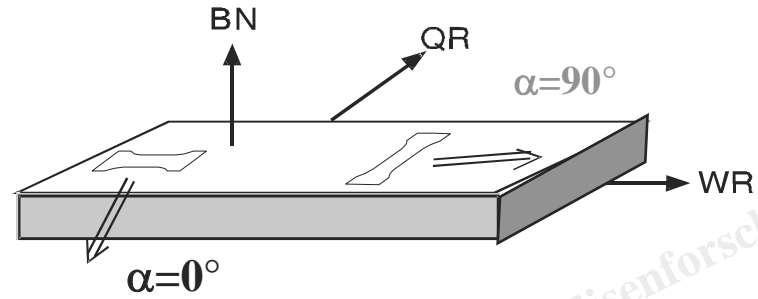
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Forschung und Entwicklung von Stahl

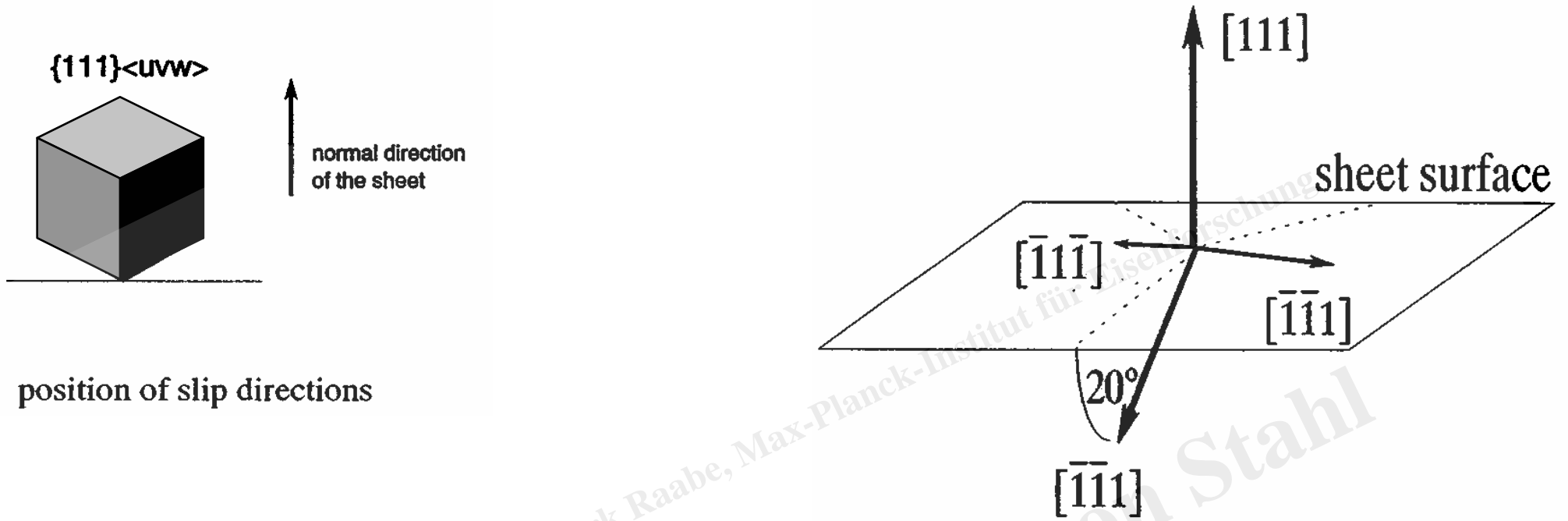




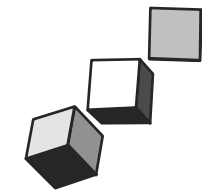
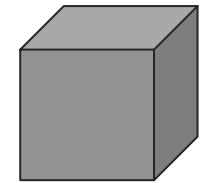
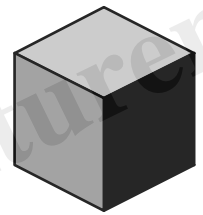
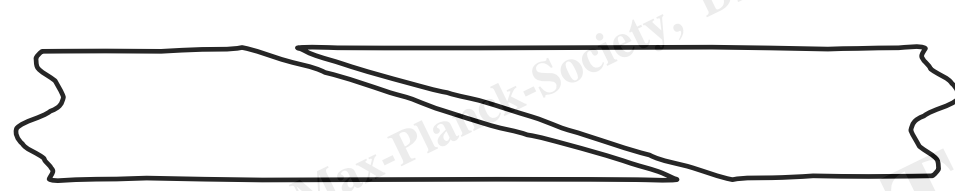


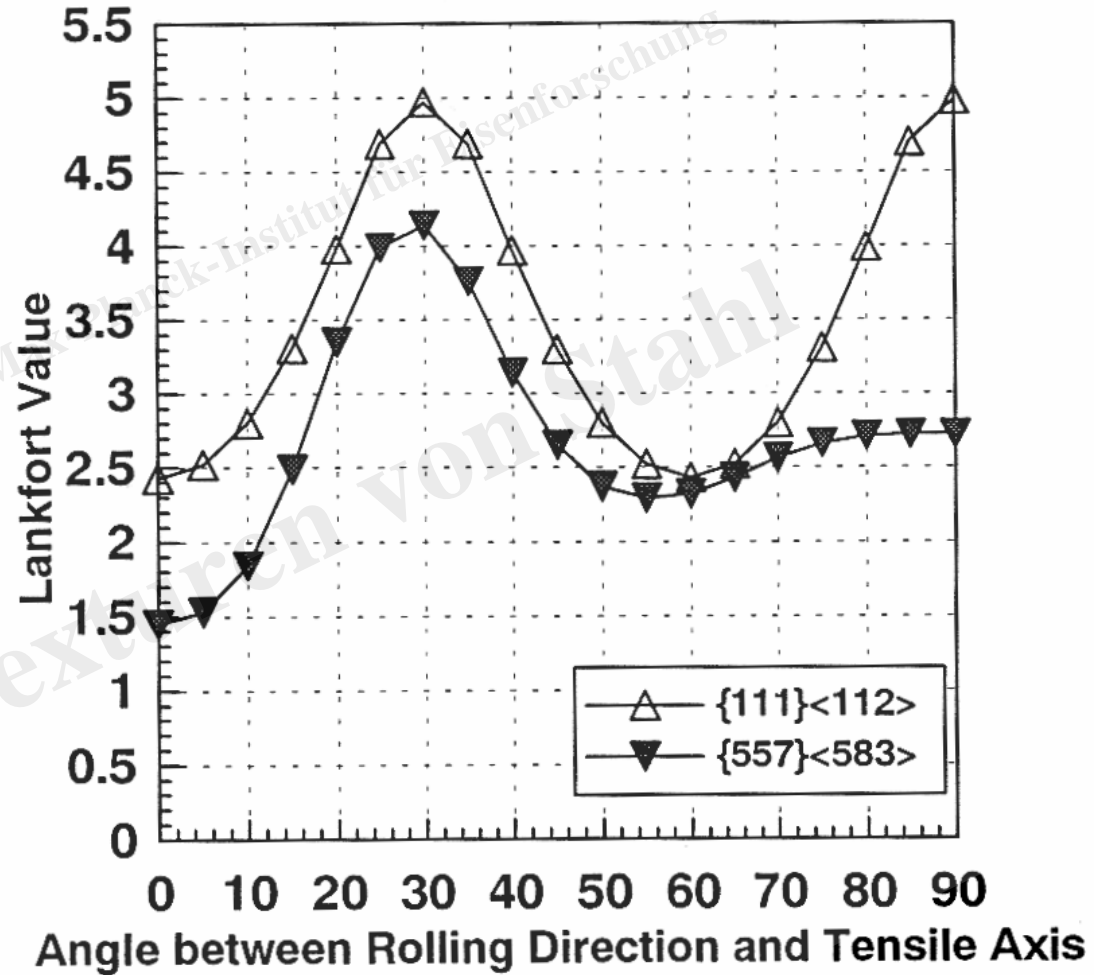
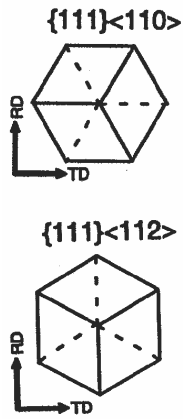
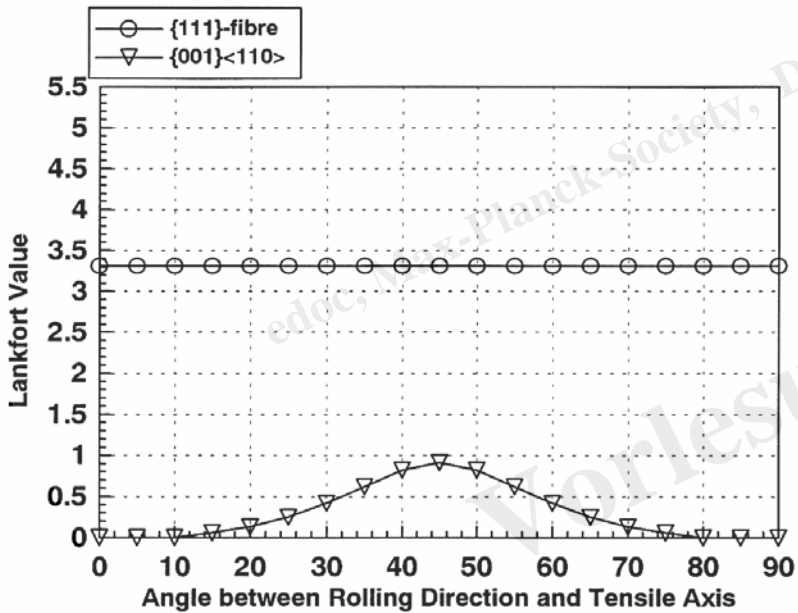
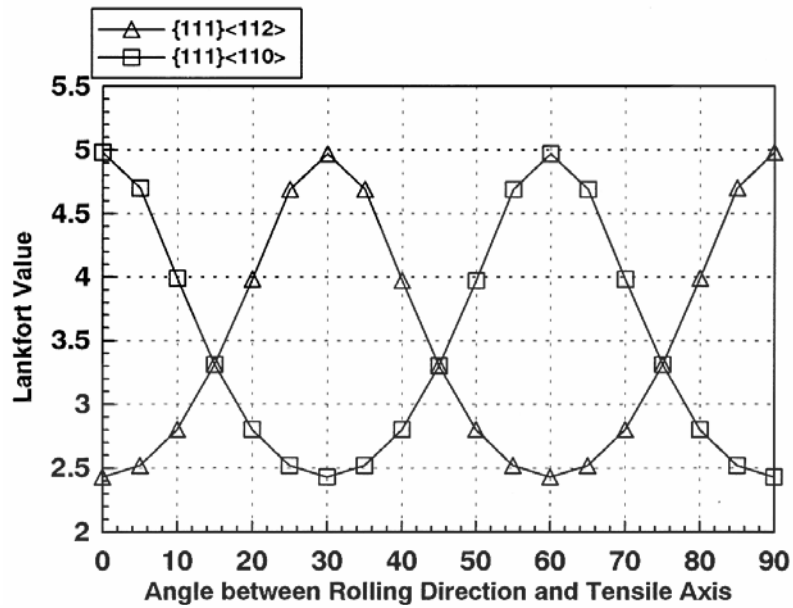
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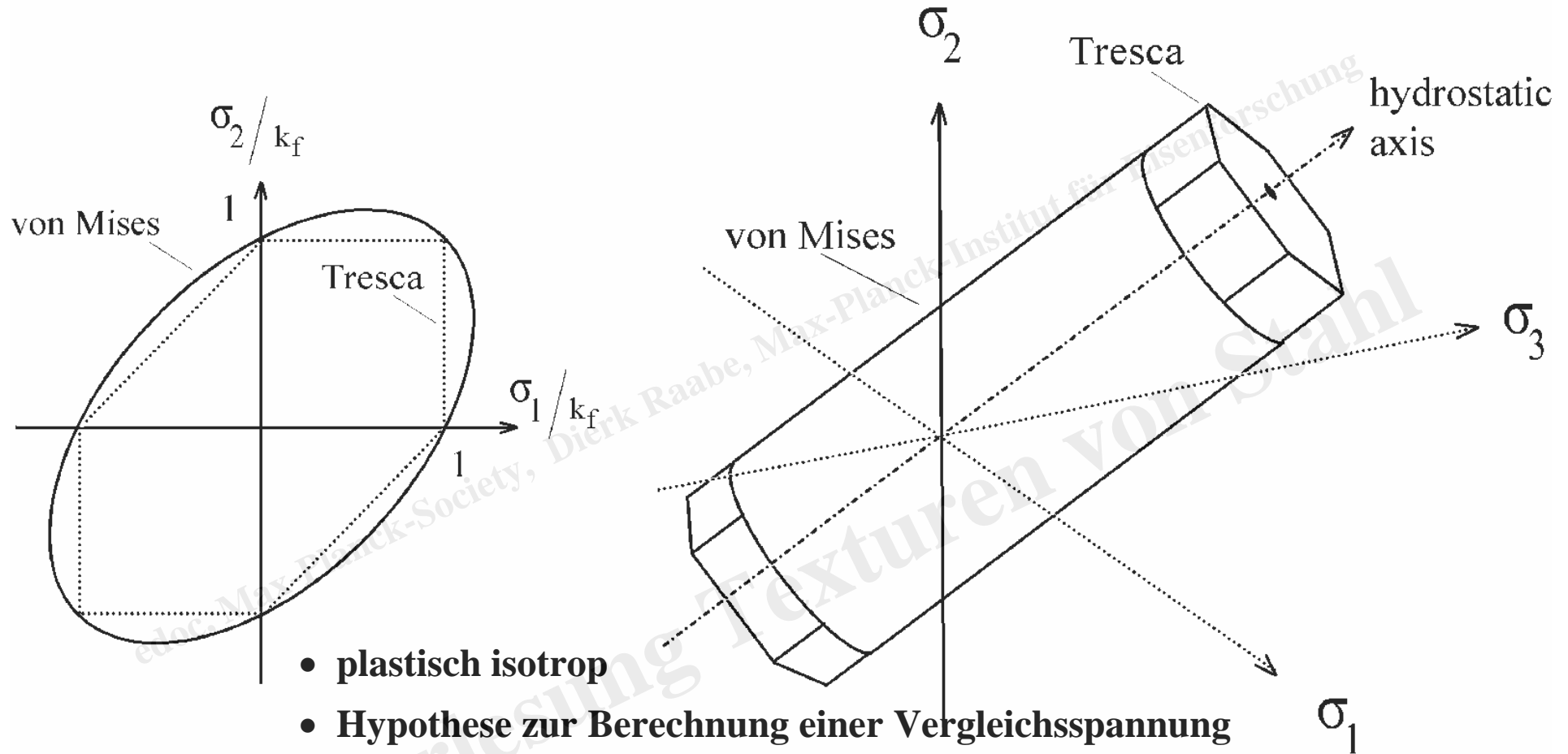


position of slip directions



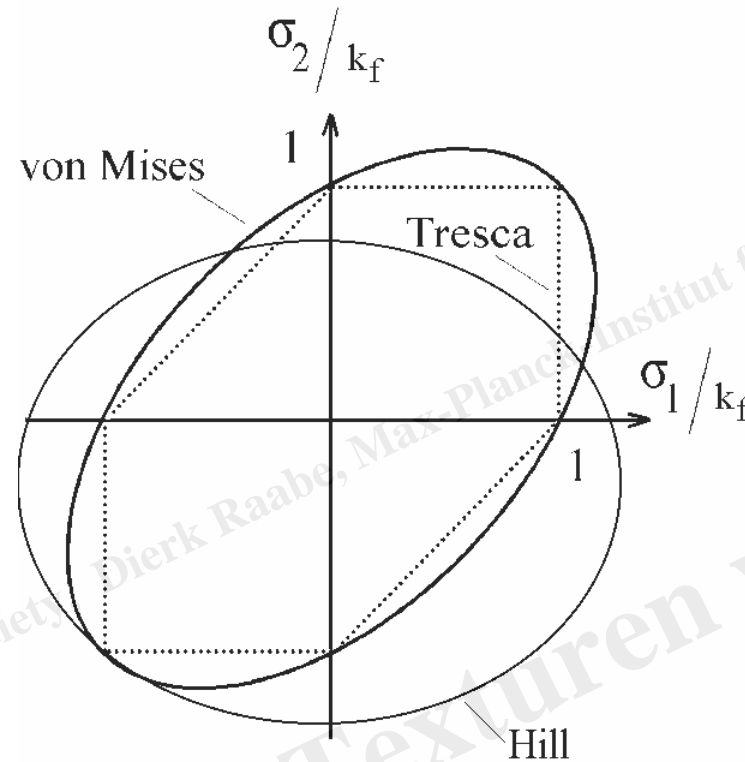


$$\frac{1}{2} \left[(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2 + 6\sigma_{23}^2 + 6\sigma_{13}^2 + 6\sigma_{12}^2 \right] = \sigma_{vM}^2 = k_f^2$$



- **plastisch isotrop**
- **Hypothese zur Berechnung einer Vergleichsspannung**
- **Reduzierung eines Tensors auf einen Skalar**
- **k_f aus 1-achsigem Versuch**

$$\frac{1}{2} \left[H(\sigma_{11} - \sigma_{22})^2 + F(\sigma_{22} - \sigma_{33})^2 + G(\sigma_{33} - \sigma_{11})^2 + 2L\sigma_{23}^2 + 2M\sigma_{13}^2 + 2N\sigma_{12}^2 \right] = \sigma_H^2 = k_f^2$$



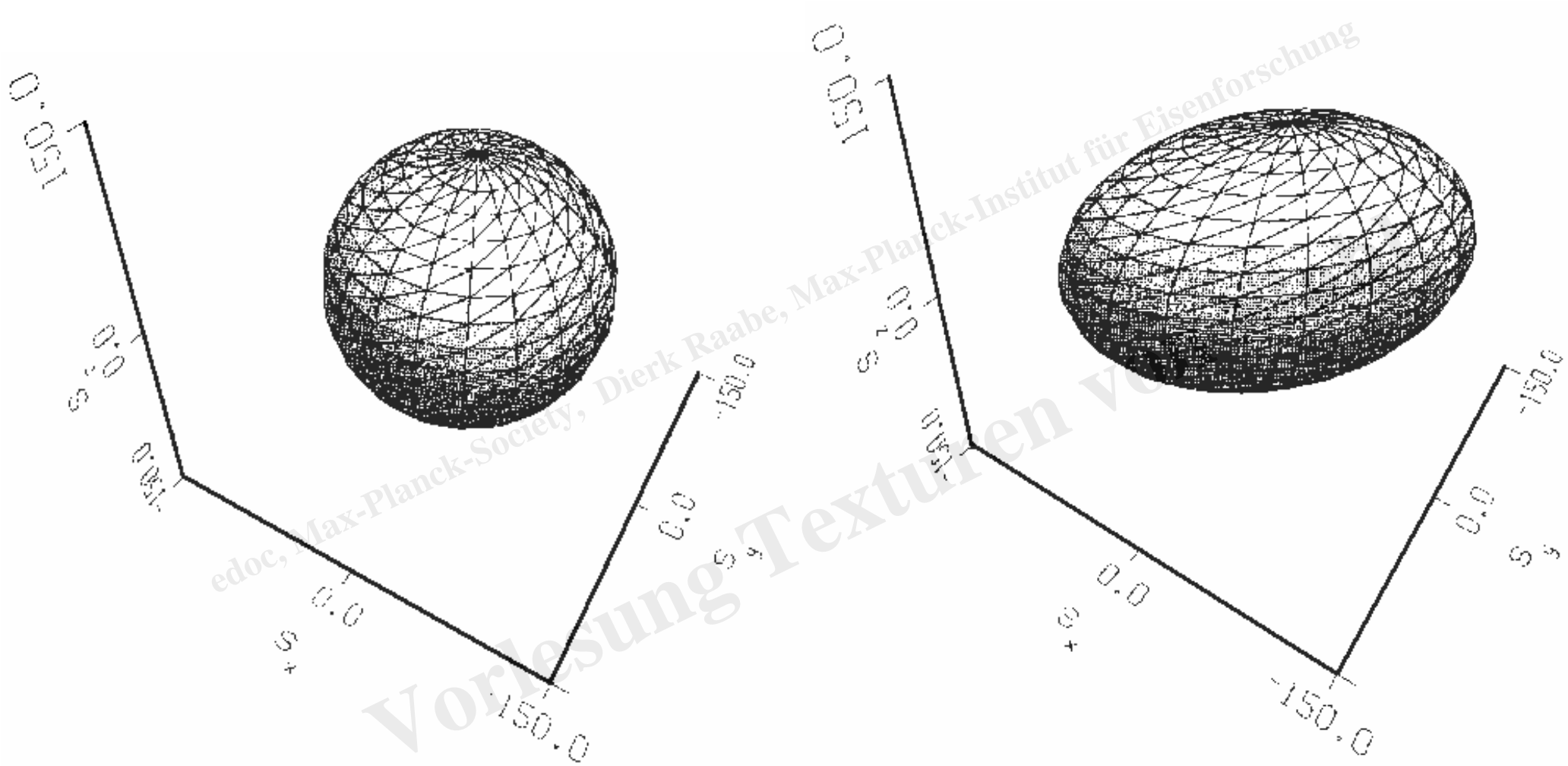
- analytisch-empirische Hypothese zur Berechnung einer Vergleichsspannung
- plastisch anisotrop
- Reduzierung eines Tensors auf einen richtungsabhängigen Skalar
- bei Anisotropie eine Funktion aller Spannungs- (bzw. Deviator-)komponenten

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von Mises

Hill



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Gleitsystem s:

$$\mathbf{n}_i^s, \mathbf{b}_i^s$$

Orientierungsfaktor für s (Gleitsystem → Kristall):

$$m_{ij}^s = n_i^s b_j^s$$

symmetrischer Anteil:
$$m_{ij}^{\text{sym},s} = \frac{1}{2} (\mathbf{n}_i^s \mathbf{b}_j^s + \mathbf{n}_j^s \mathbf{b}_i^s)$$

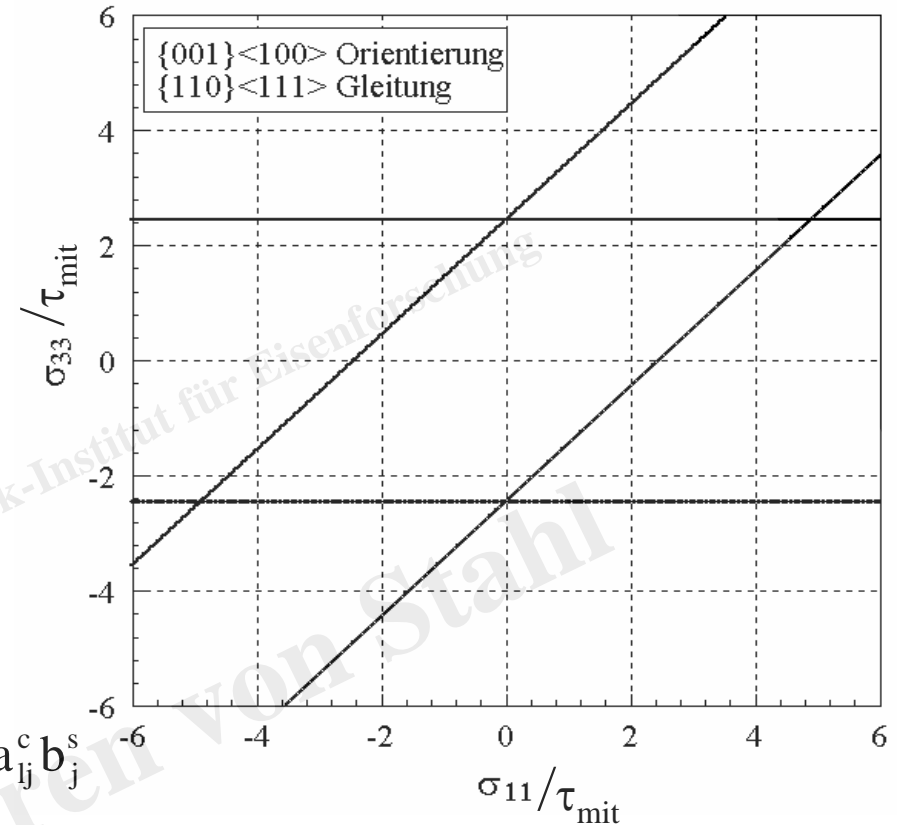
Orientierungsfaktor für s (Kristall → Probe):
$$m_{kl}^s = a_{ki}^c n_i^s a_{lj}^c b_j^s$$

symmetrischer Anteil:
$$m_{kl}^{\text{sym},s} = \frac{1}{2} (a_{ki}^c n_i^s a_{lj}^c b_j^s + a_{lj}^c n_j^s a_{ki}^c b_i^s)$$

Fließort der aktiven Systeme:
$$m_{kl}^{\text{sym},s=\text{aktiv}} \sigma_{kl} = \sigma_{\text{aufg}}^s = \tau_{\text{krit},(+)}^{s=\text{aktiv}}$$

$$m_{kl}^{\text{sym},s=\text{aktiv}} \sigma_{kl} = \sigma_{\text{aufg}}^s = \tau_{\text{krit},(-)}^{s=\text{aktiv}}$$

Nicht-aktive Systeme:
$$m_{kl}^{\text{sym},s=\text{inaktiv}} \sigma_{kl} = \sigma_{\text{aufg}}^s < \tau_{\text{krit},(\pm)}^{s=\text{inaktiv}}$$

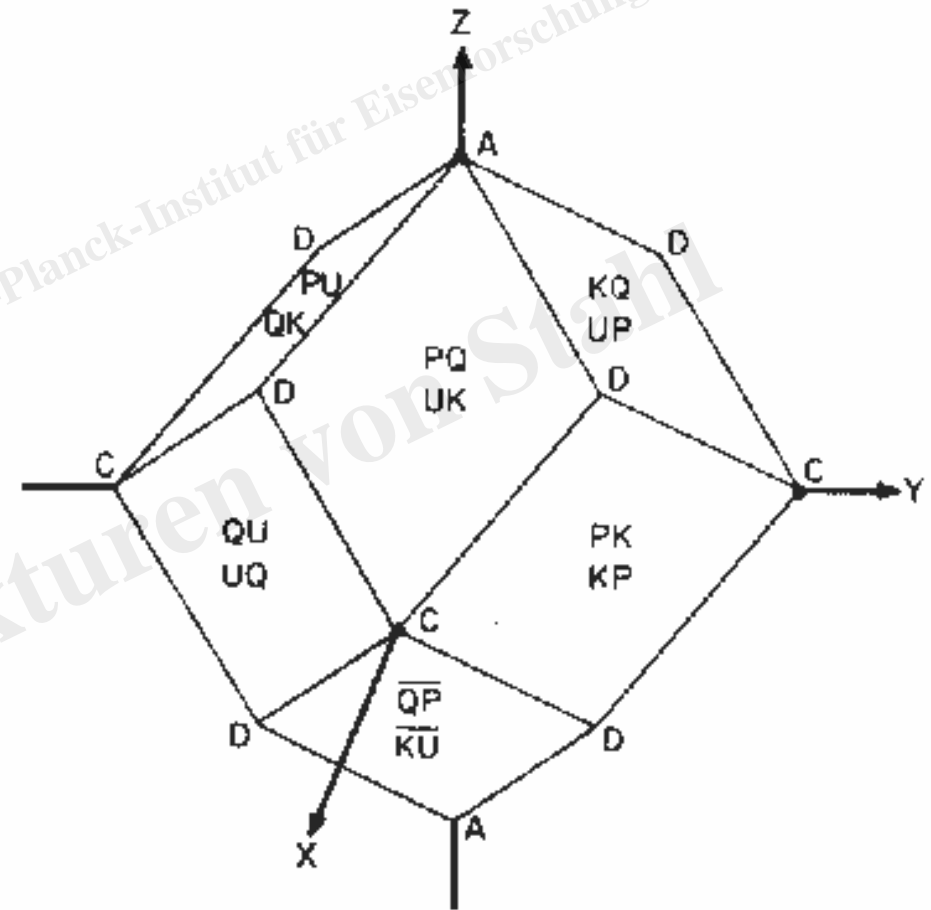
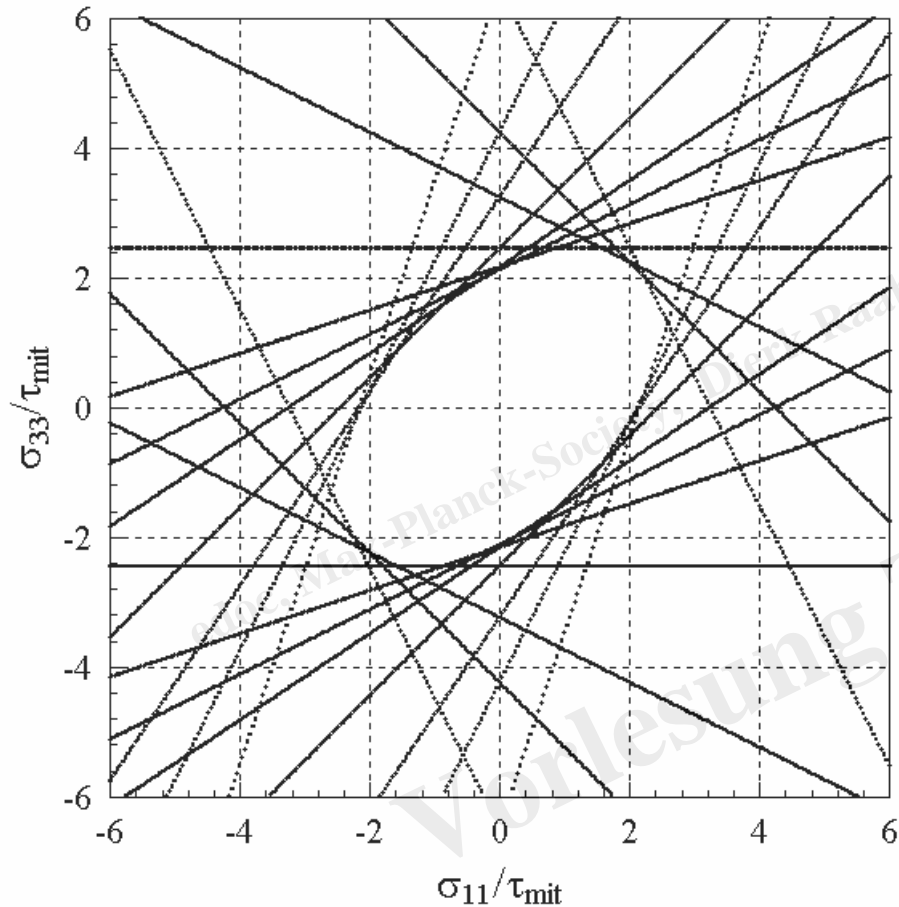


krz, 48 Systeme,
Schnitt

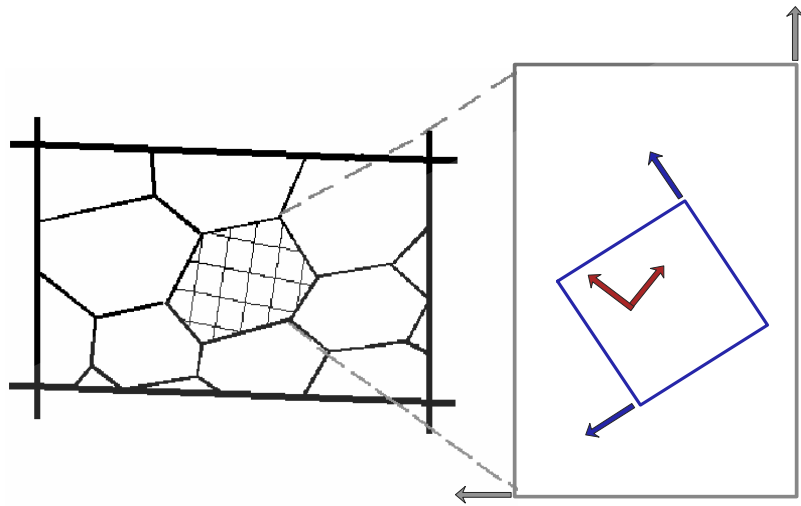
$$\begin{aligned}\tau_{\text{krit}}(110) &= \tau_{\text{krit}}(112) \\ &= \tau_{\text{krit}}(123)\end{aligned}$$

$$\bar{\tau}_{\text{krit}} = \frac{\sum_{s=1}^N \tau_{\text{krit}}^s \dot{\gamma}^s}{\dot{\Gamma}}$$

$$\tau_{\text{mit}} = \sum \tau_{\text{krit}}(i)/N$$



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slip systems
 $\bar{n} \bar{b}$

crystal (k,l)
 $m_{kl} = n_k b_l$

sample (i,j)
 $m_{ij} = a_{ik} n_k a_{jl} b_l$

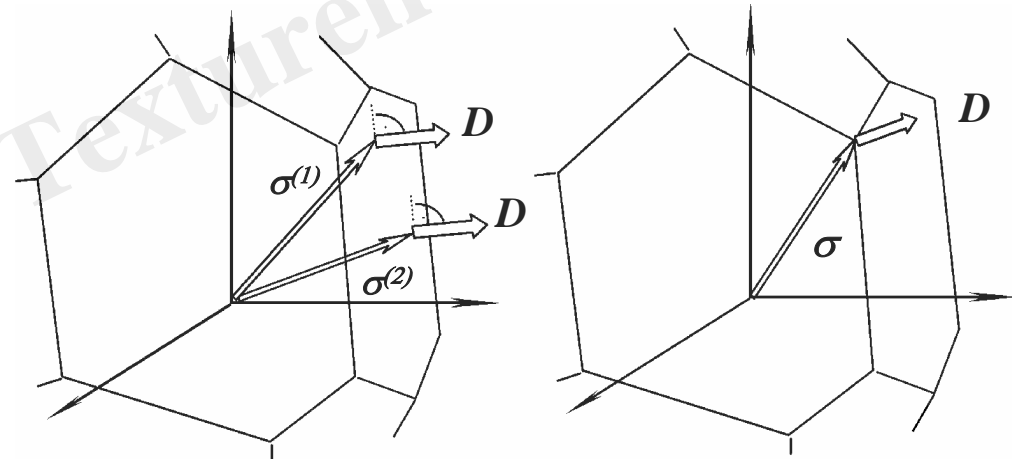
Ein Korn, ein System:

Kinematik Kinetik

$$\boxed{a_{ik} n_k a_{jl} b_l \sigma_{ij}} = \boxed{\tau^{crit}}$$



Ein Korn, viele Systeme:



Fließort:

auf FO: elastisches und plastisches Fließen

unterhalb FO: elastisches Fließen

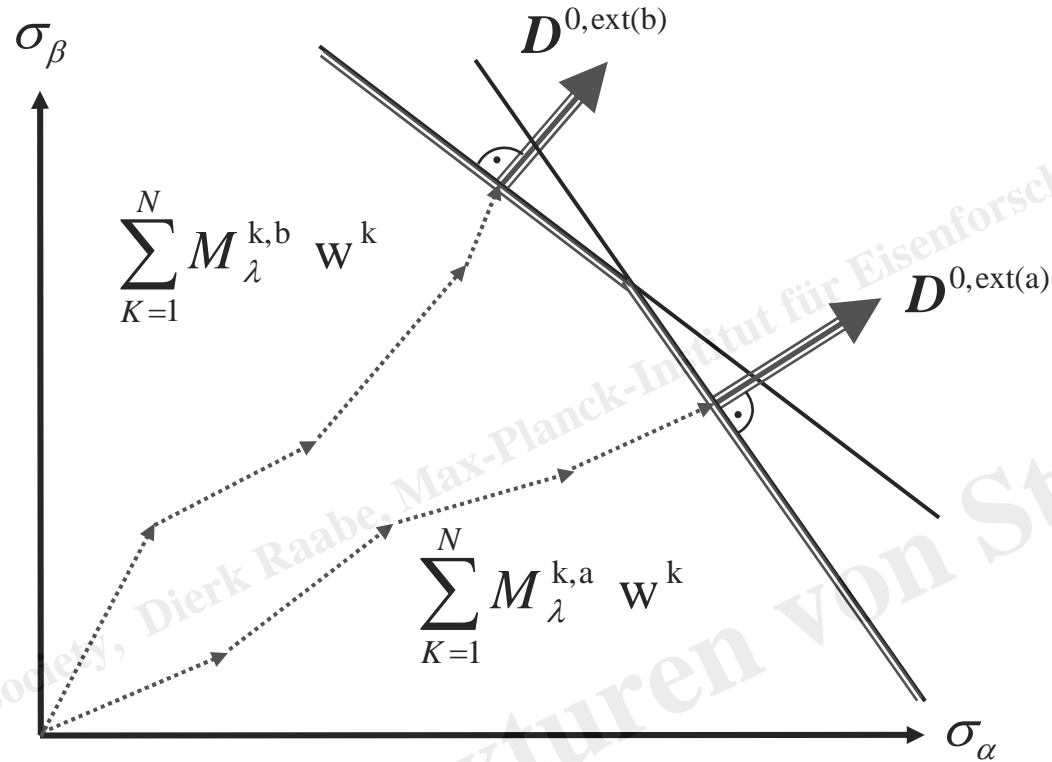
oberhalb FO: existiert nicht

Größe:

M: 2.1 - 4.5



Viele Körner, viele Systeme:

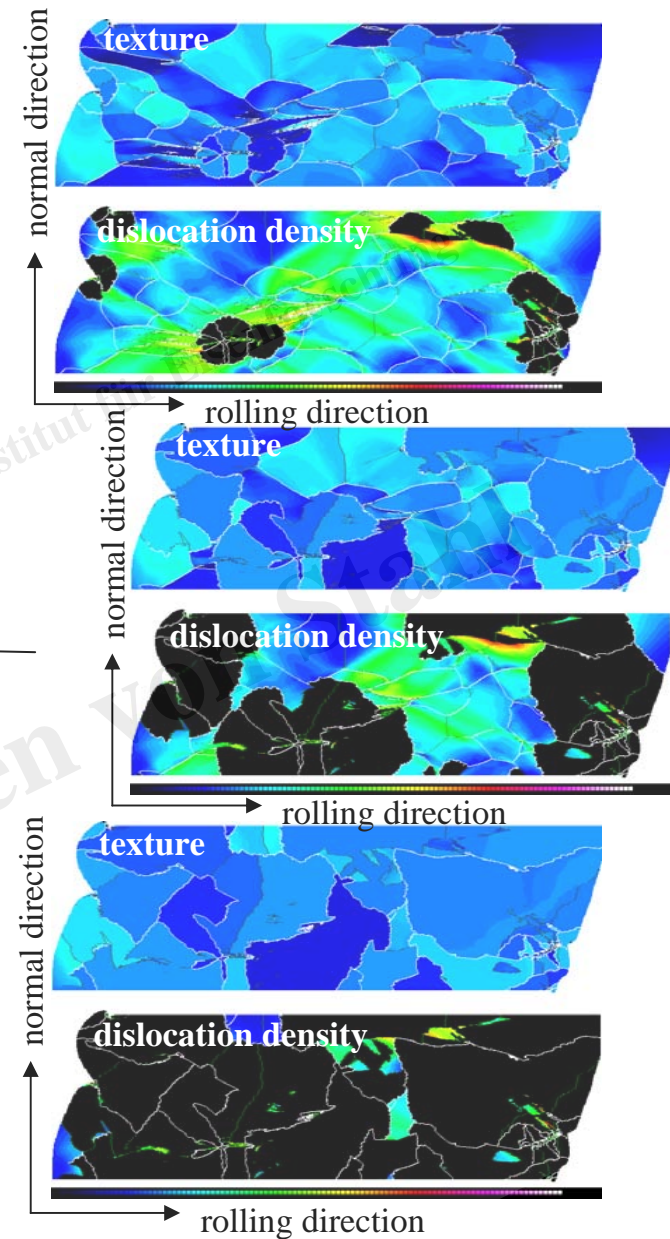
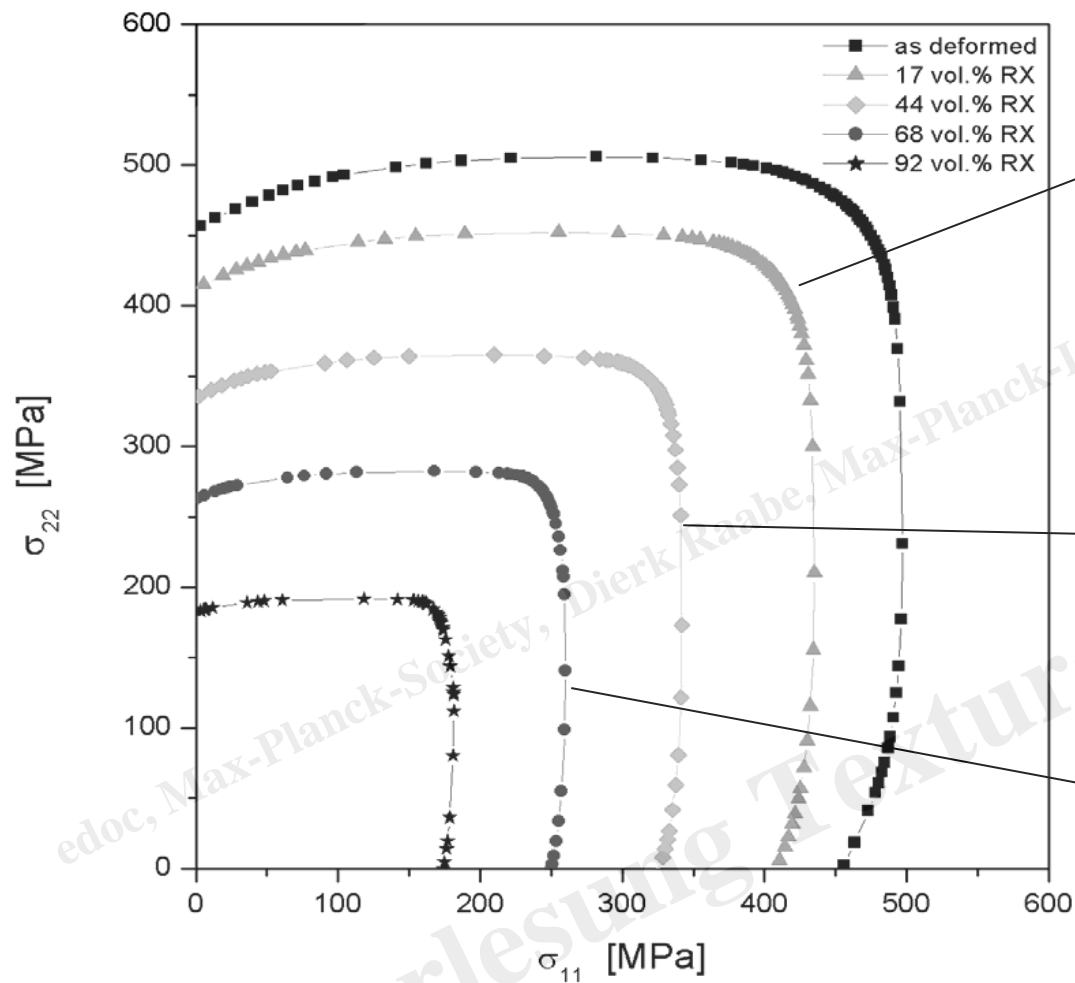


$$R_{ij}^P = \frac{1}{V} \int_V \underbrace{M_{ij}^{\text{hom}}(\mathbf{g}, D_{ij})}_{\text{Kinematik}} \underbrace{\tau_{\text{crit}}(s^1, \dots, s^m, s_{ij}^1, \dots, s_{ij}^n, T, D_{ij}^{\text{Kon}}, \mathbf{g})}_{\text{Kinetik}} dV \approx \sum_{k=1}^N M_{ij}^{\text{hom},k} \tau_{\text{crit}}^k w^k$$

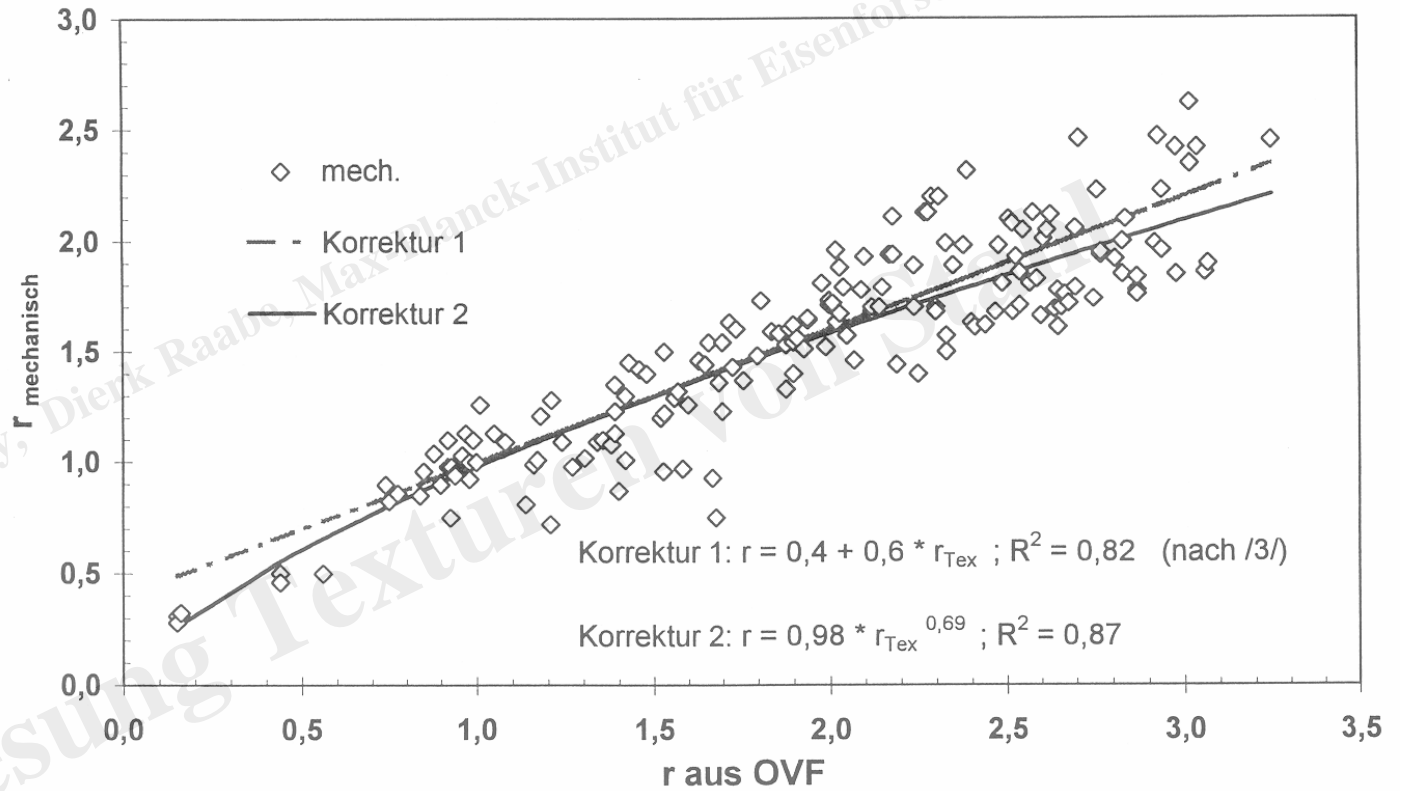
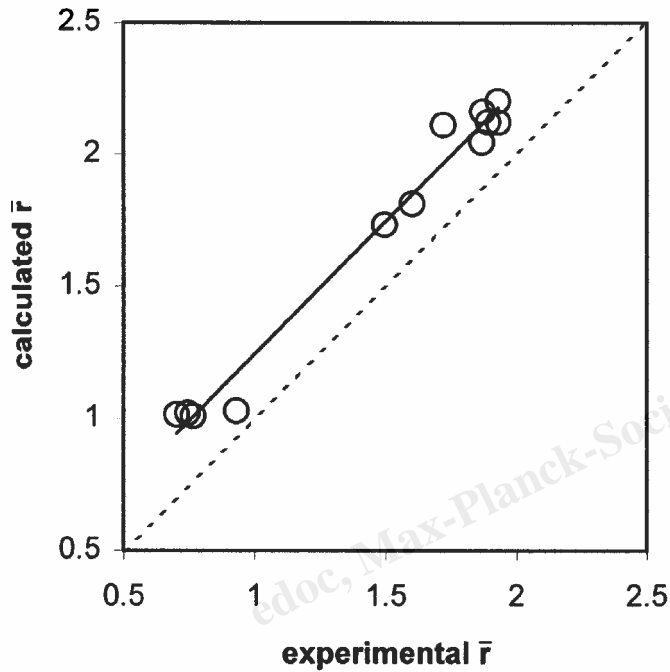
Kinematik

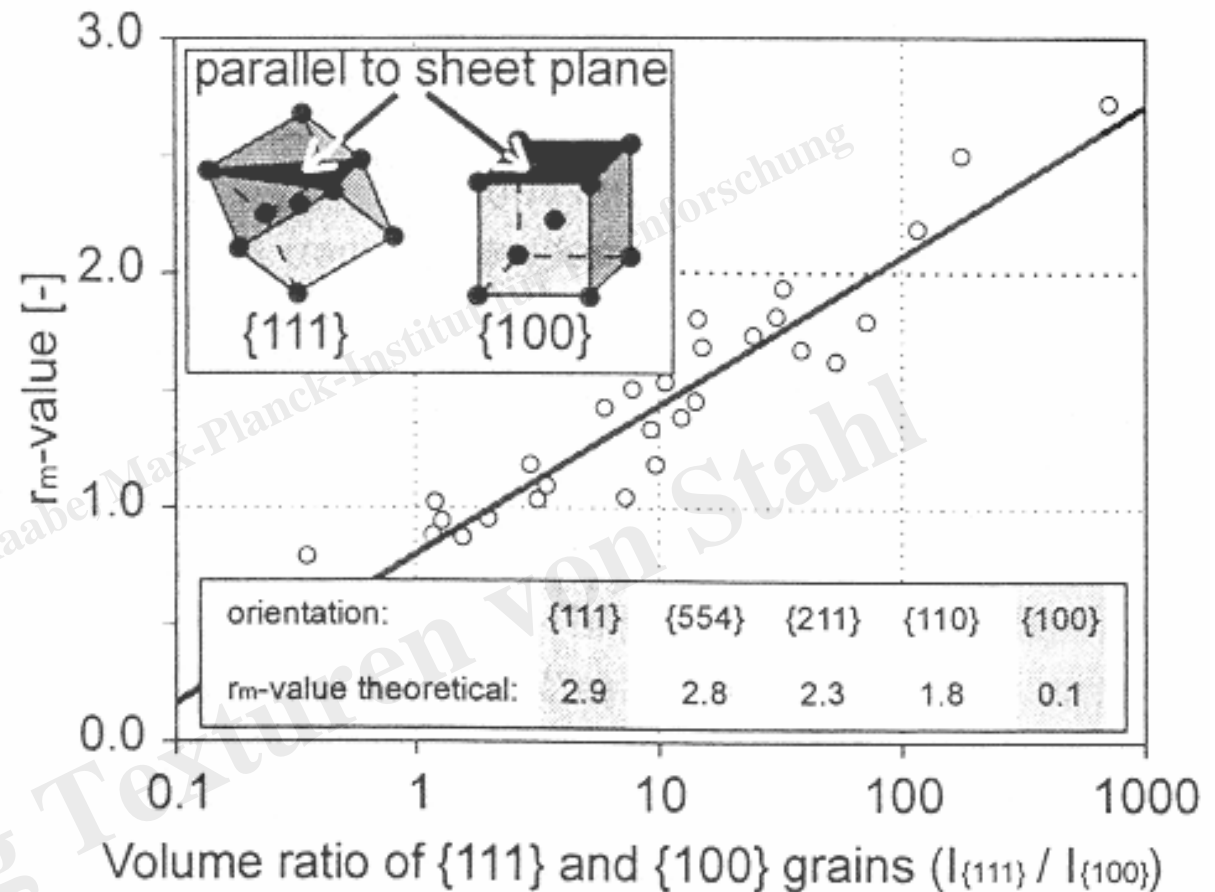
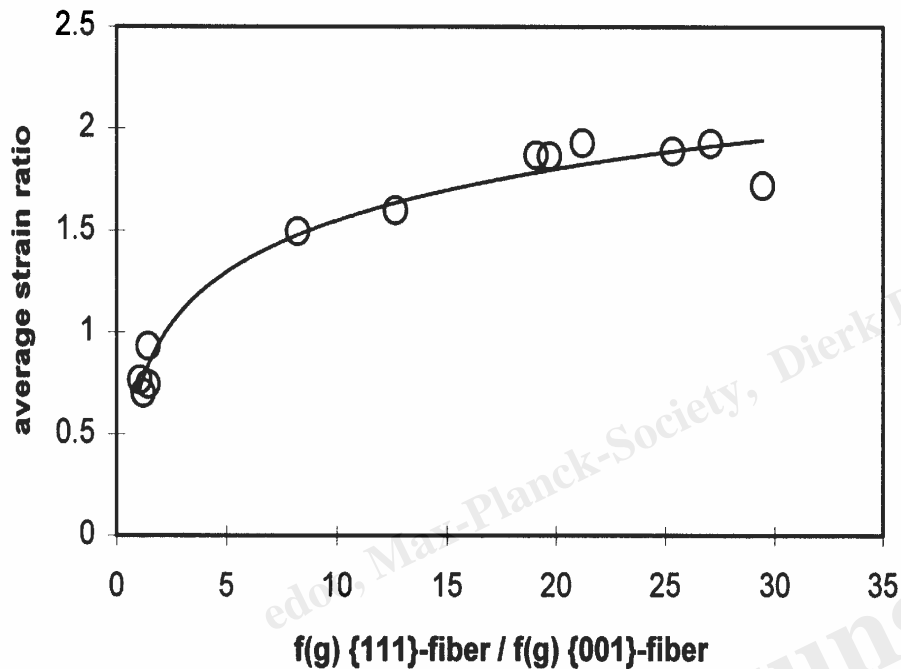
Kinetik



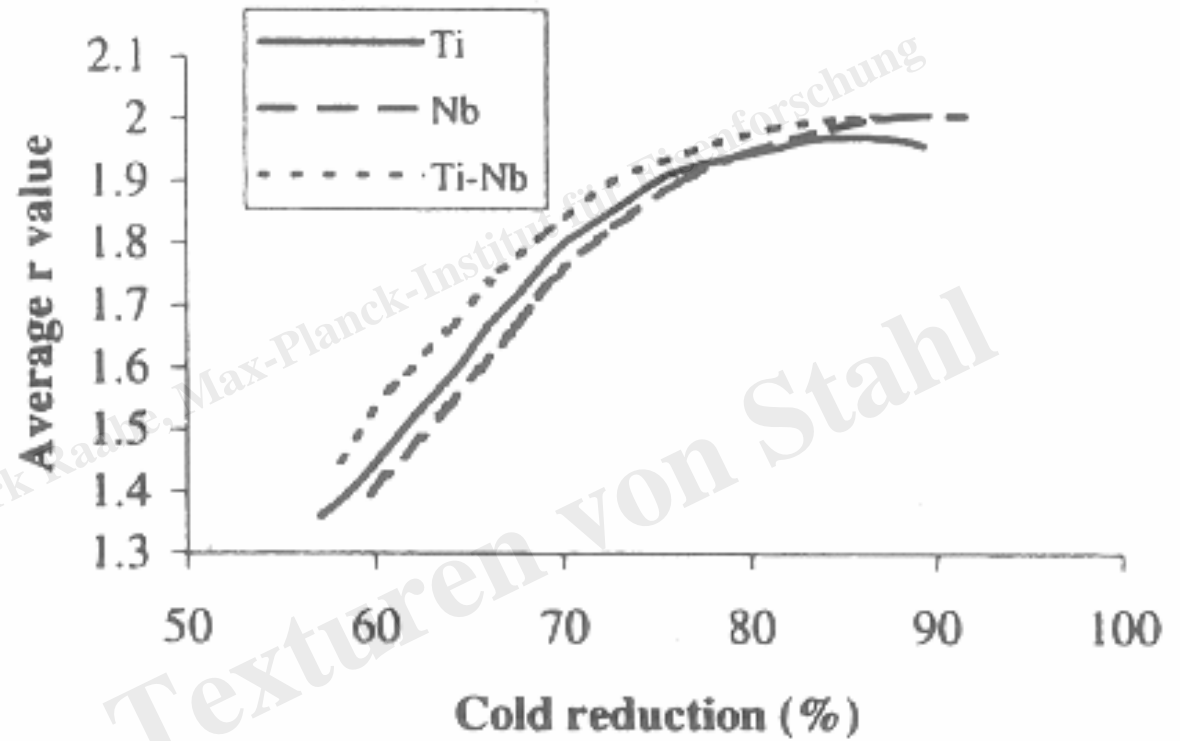
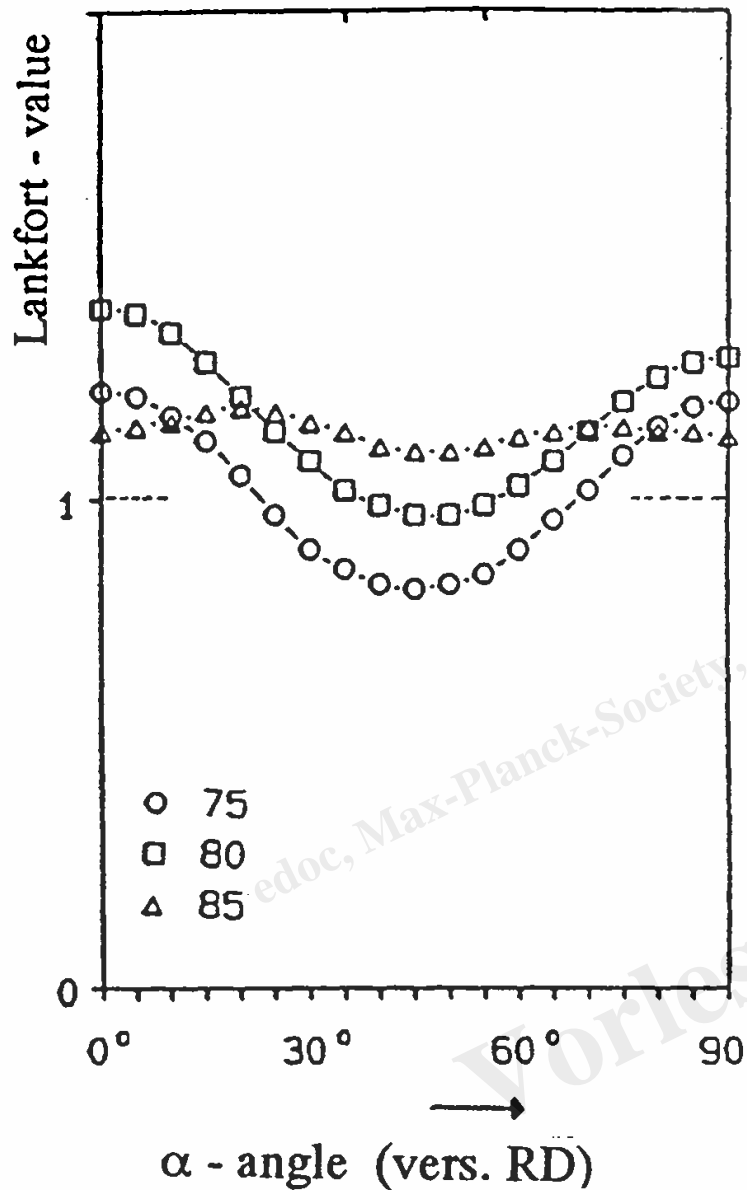


Empirischer Abgleich mechanisch und aus Texturen (OVF) ermittelter r-Werte

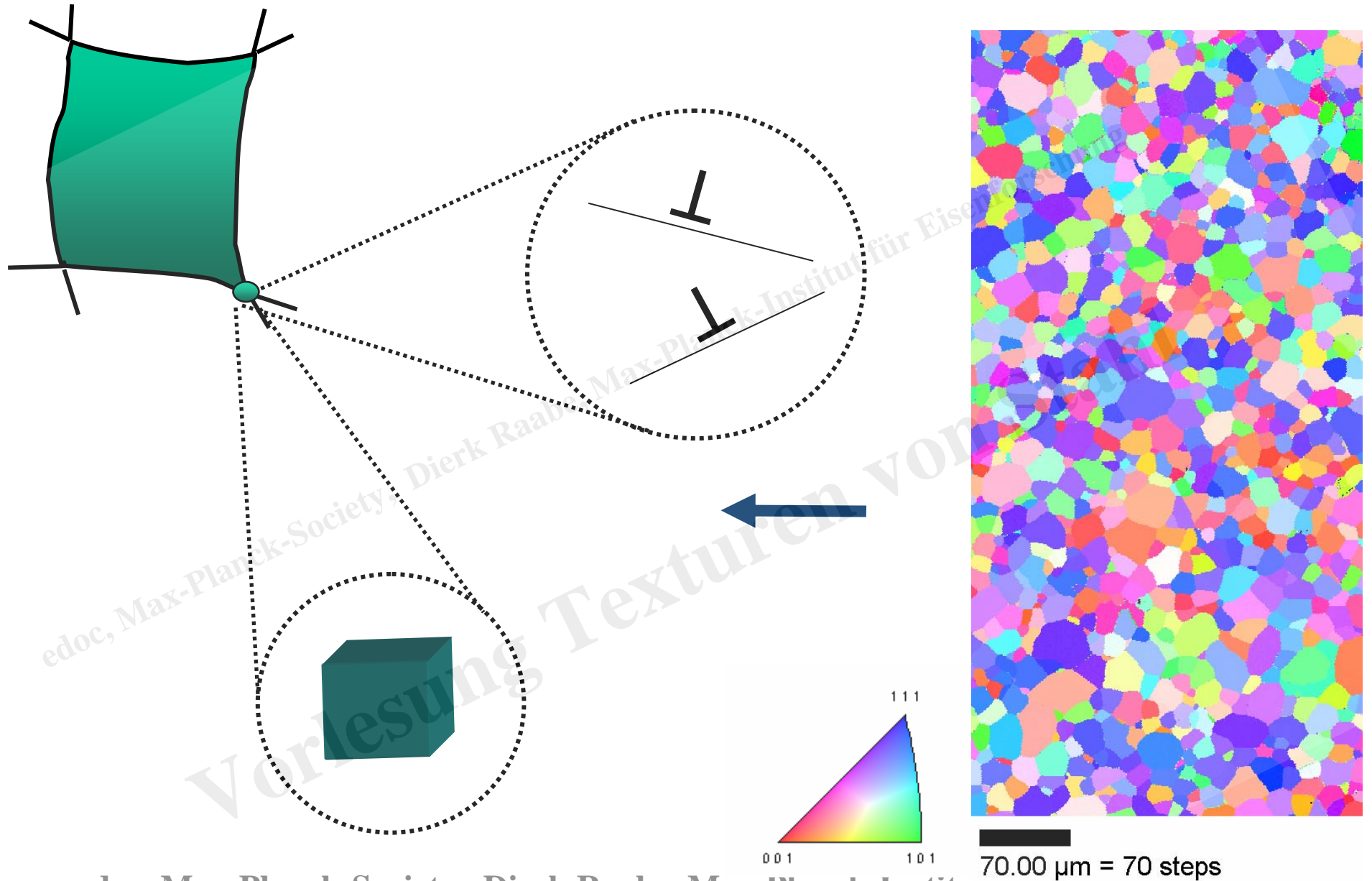




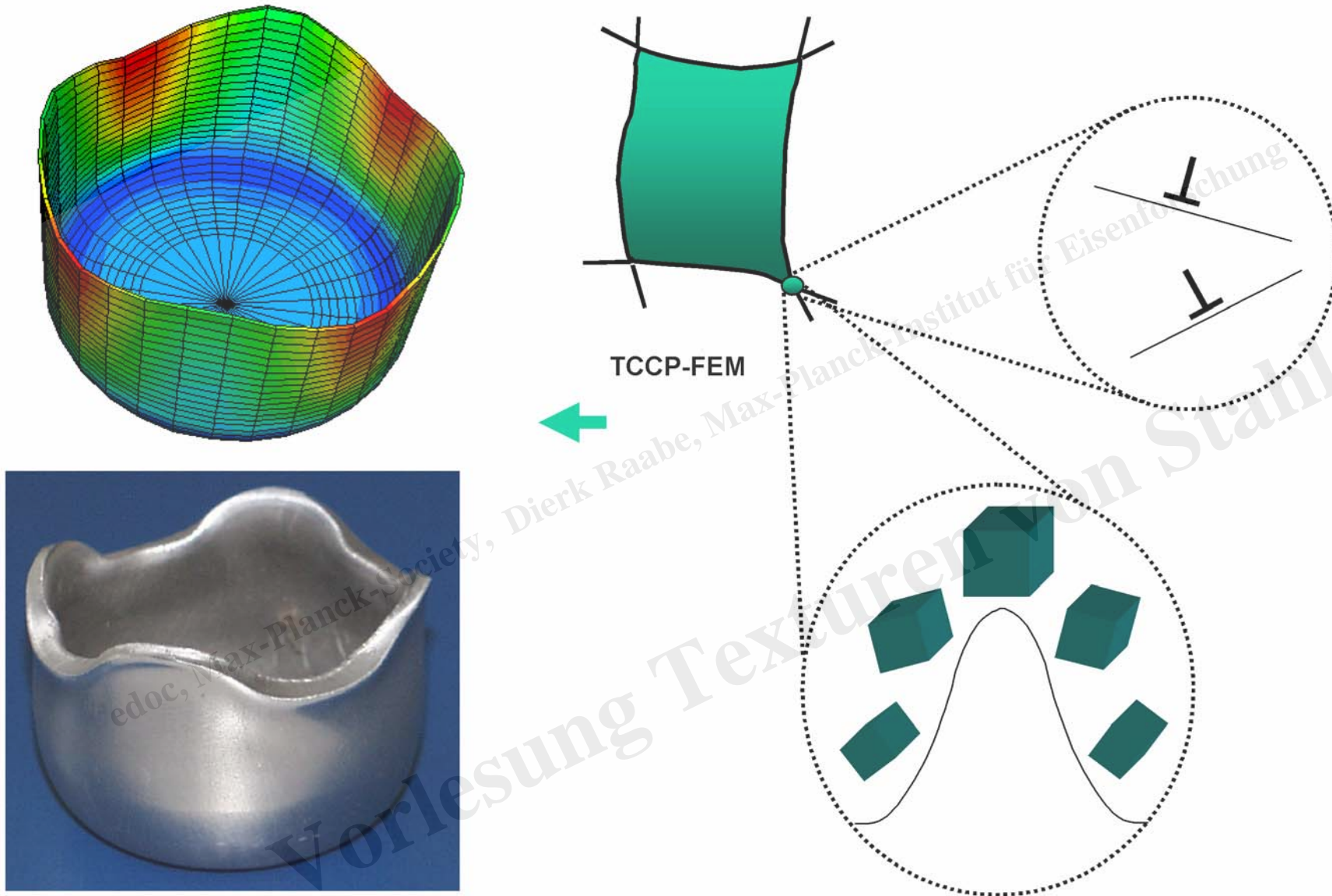
Effect of texture on the mean r -value r_m . $I_{\{111\}}$ and $I_{\{100\}}$ are the texture intensities of the corresponding orientations.³⁾



Effect of cold reduction on \bar{r} value of Ti, Ti-Nb, and Nb IF steels: after Ref. 22



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- D. Raabe: *Acta metall.* 43 (1995) 1023–1028 „Texture simulation for hot rolling of aluminium by use of a Taylor model considering grain interactions“
- D. Raabe: *Textures and Microstructures* 23 (1995) 115–129 „Examination of the iterative series-expansion method for quantitative texture analysis“
- D. Raabe: *Metallurgical and Materials Transactions A* 26A April (1995) 991–998 „Microstructure and crystallographic texture of strip cast and hot rolled austenitic stainless steel“
- D. Raabe: *Steel Research* 66 (1995) 222–229 „Investigation of the orientation dependence of recovery in low-carbon steel by use of single orientation determination“
- D. Raabe: *physica status solidi (a)* 149 (1995) 575–581 „Contribution of {123}<111> slip systems to deformation of bcc metals“
- D. Raabe: *Materials Science and Engineering A* 197 (1995) 31–37 „Simulation of rolling textures of bcc metals under consideration of grain interactions and {110}, {112} and {123} slip planes“



- D. Raabe: *Materials Science and Technology* 11 (1995) 461–468 „Textures of strip cast and hot rolled ferritic and austenitic stainless steel“
- D. Raabe: *Materials Science and Technology* 11 (1995) 455–460 „Investigation of contribution of {123} slip planes to development of rolling textures in bcc metals by use of Taylor models“
- M.-Y. Huh, D. Raabe, O. Engler: *Steel Research* 66 (1995) 353–359 „On the influence of solution treatment on the microstructure and crystallographic texture of cold rolled and recrystallised low carbon steel“
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