Ternary high-strength Cu-based in-situ metal matrix composites

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References for this lecture

F. Heringhaus, U. Hangen, D. Raabe, G. Gottstein: Materials Science Forum 157–162 (1994) 709–714.
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„Experimental investigation and simulation of the normal conducting properties of a heavily cold rolled Cu-20mass% Nb in situ composite“

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„Observation of amorphous areas in a heavily cold rolled Cu-20wt.% Nb composite“

F. Heringhaus, D. Raabe, G. Gottstein: Acta Metall. 43 (1995) 1467–1476
„On the correlation of microstructure and electromagnetic properties of heavily cold worked Cu-20 wt.% Nb wires“

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„Investigation of a Cu-20mass%Nb in situ Composite
Part I: Fabrication, Microstructure and Mechanical Properties
Part II: Electromagnetic Properties and Application“

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„Simulation of the yield strength of wire drawn Cu-based in situ composites“

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„On the anisotropy of the superconducting properties of a heavily cold rolled Cu-20 mass% Nb in situ composite“

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„Experimental investigation and modeling of the influence of microstructure on the resistive conductivity of a Cu–Ag–Nb in situ composite“

K. Miyake, N. Hanzawa, H. Takahara, S. Kobayashi, D. Raabe: Japanese Jornal of Applied Physics 39 (2000) 119-121
„Application of In Situ-Formed Metallic-Fiber-Reinforced Copper Matrix Composites to Cables Used for Robots “

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„Processing, microstructure, and properties of ternary high–strength Cu–Cr–Ag in situ composites“

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„Microstructure and mechanical properties of a cast and wire drawn ternary Cu-Ag-Nb in situ composite“

D. Raabe, D. Mattissen: Acta Materialia 47 (1999) 769–777
„Experimental investigation and Ginzburg–Landau modeling of the microstructure dependence of superconductivity in Cu–Ag–Nb wires“

Topics

Introduction

In-situ MMC's Cu-Nb

In-situ MMC's Cu-4%Nb-8.2%Ag

Processing

Practical outline

Results

Discussion

Summary

Introduction

Matrix: Cu

- **Second phase:** high melting bcc element

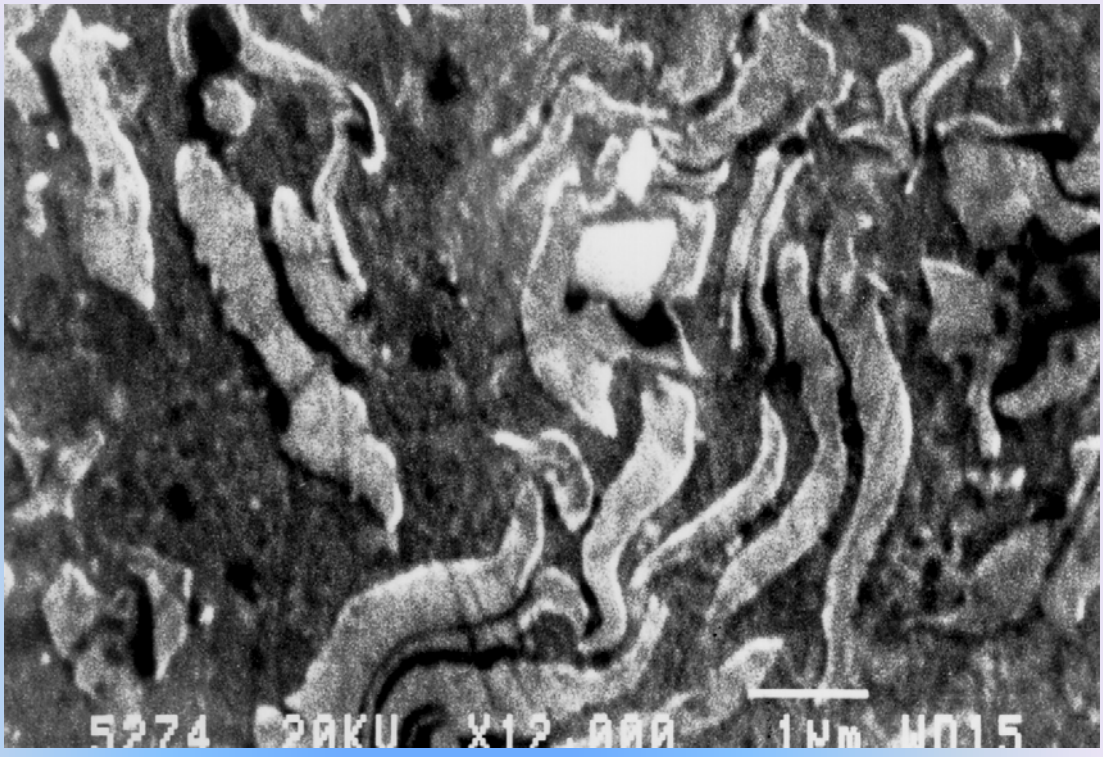
Nb, Cr, Ta, Fe

- Separate phases were formed during the solidification plus deformation processing

properties:

High strength
+ High conductivity

Introduction Cu-20%Nb



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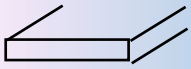

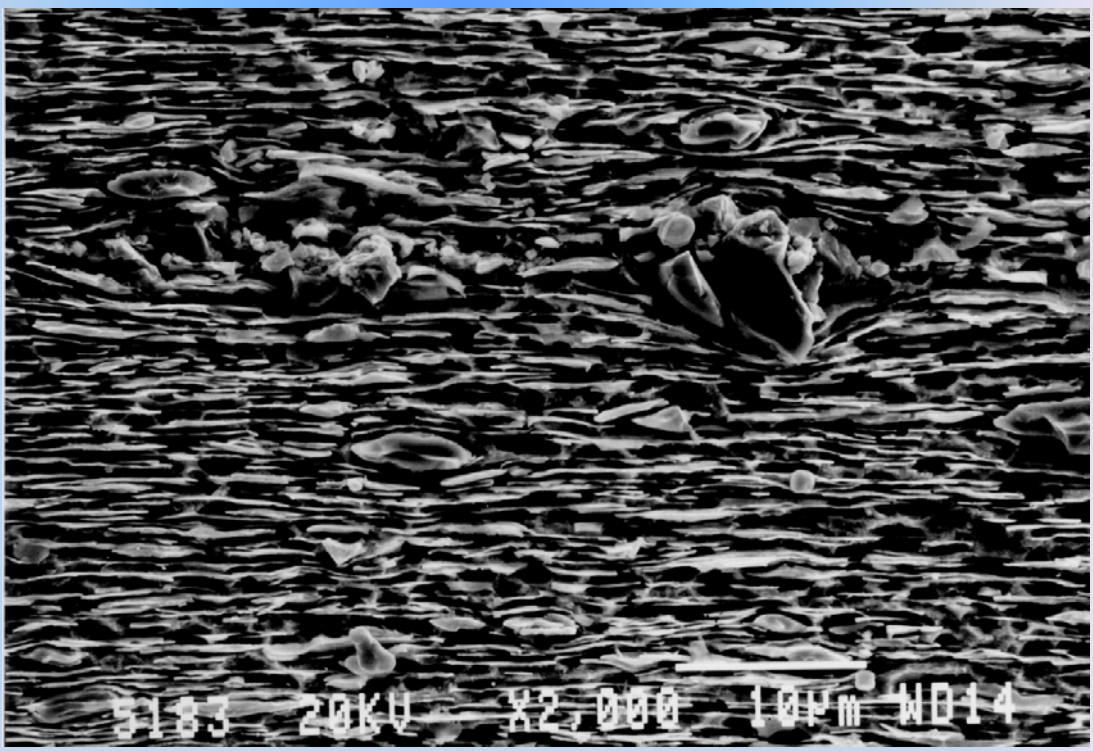

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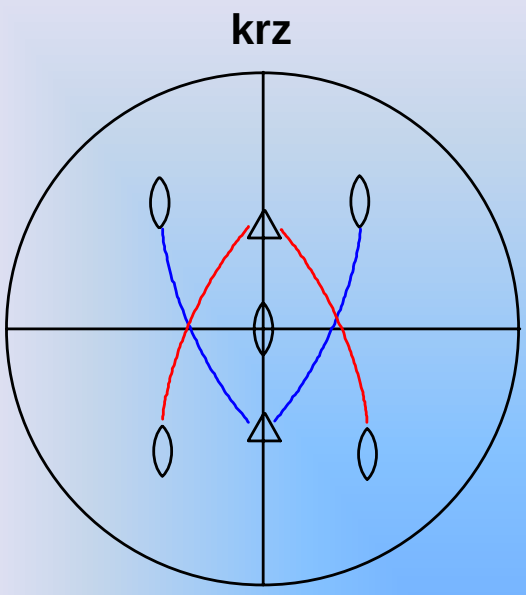
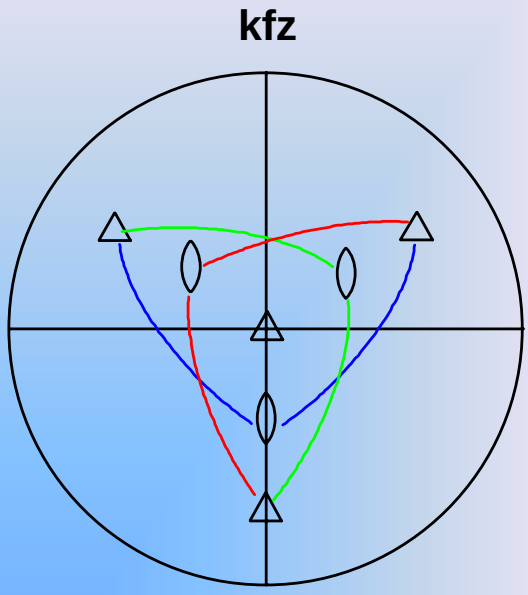
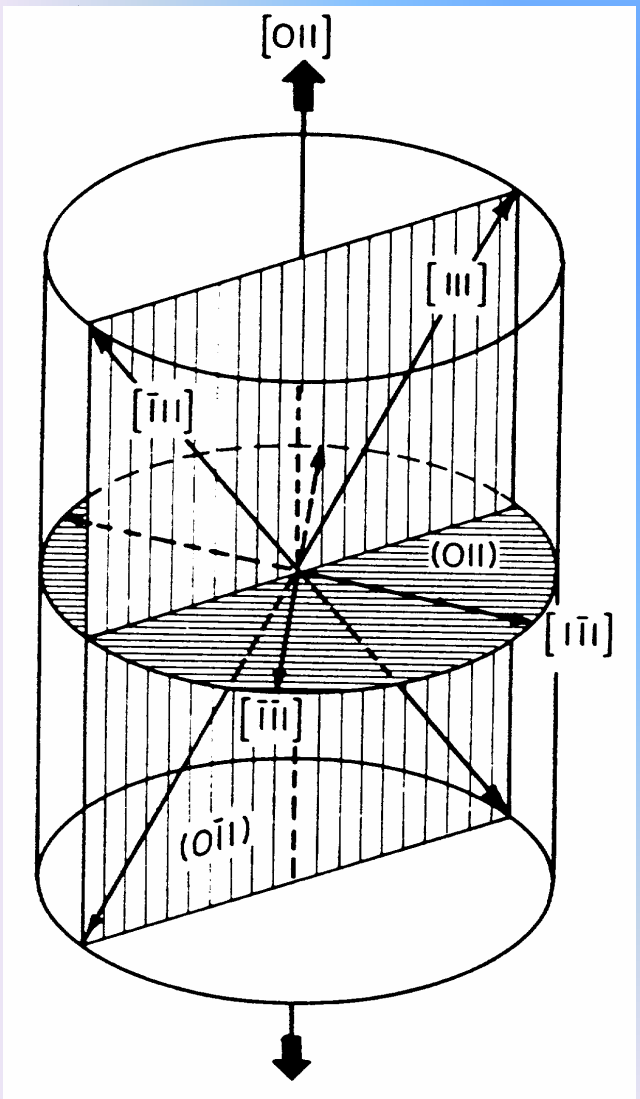
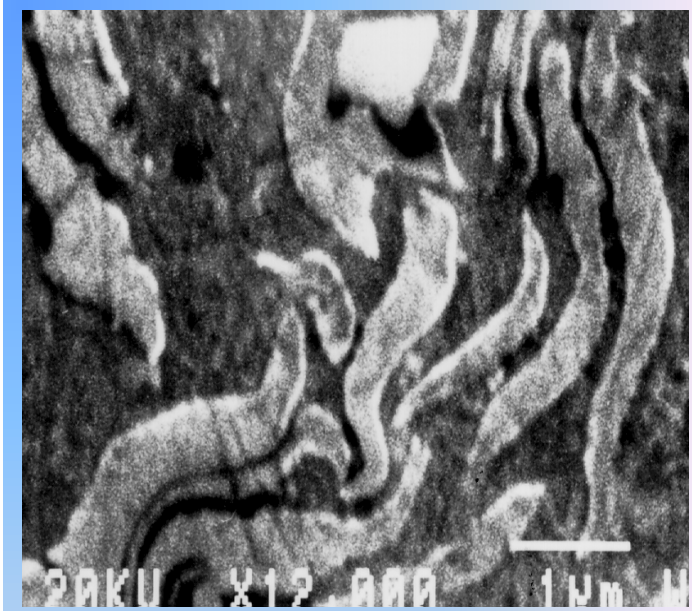
Cu-20%Nb

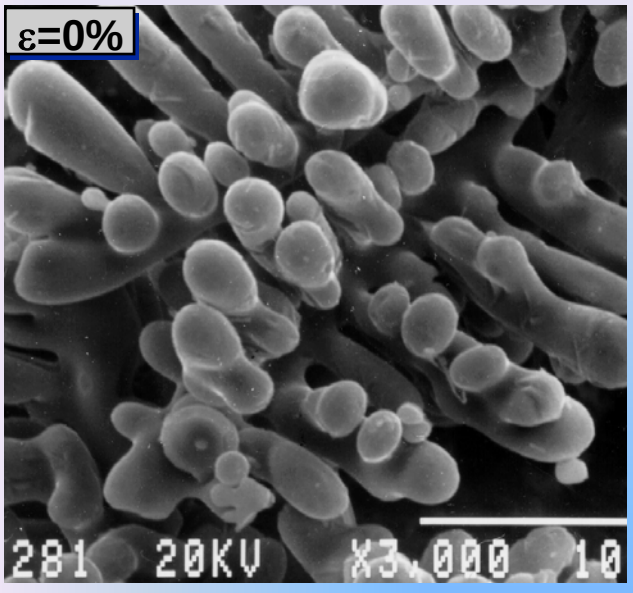


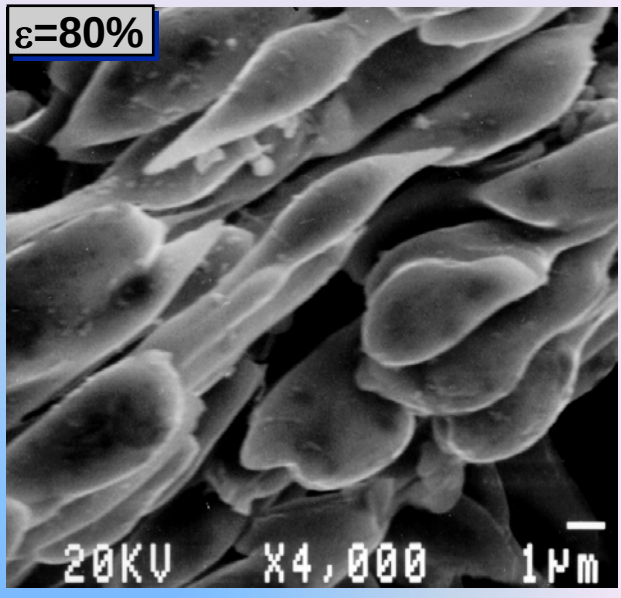


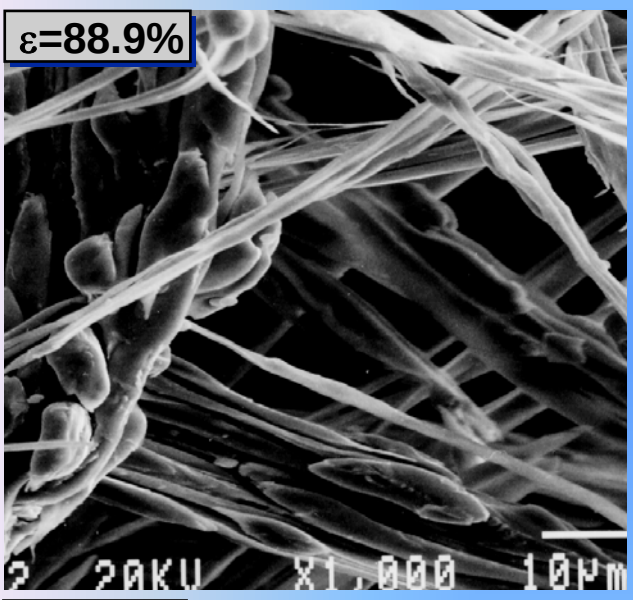


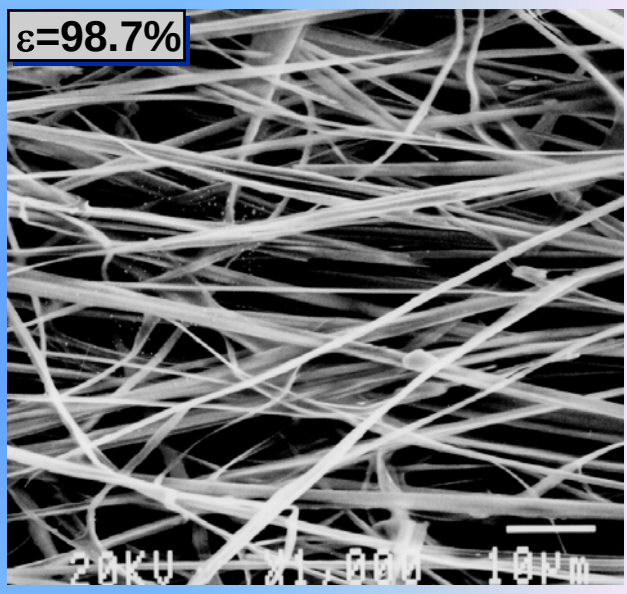


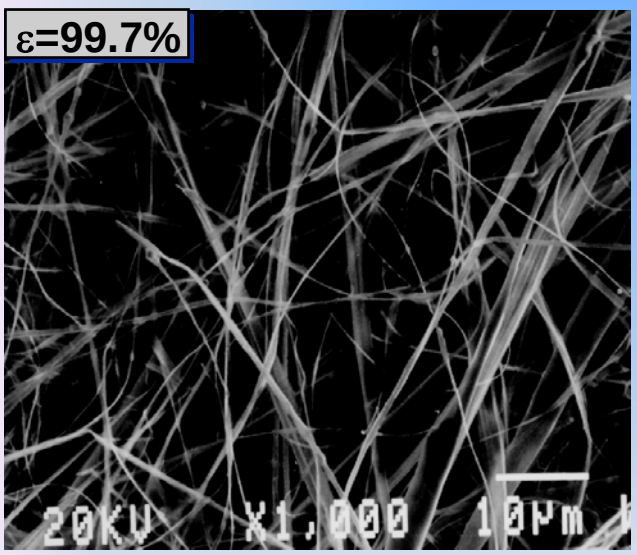
Cu-20%Nb

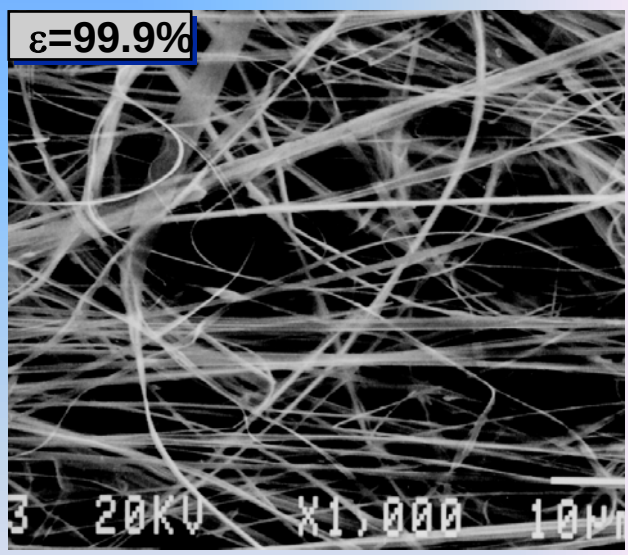












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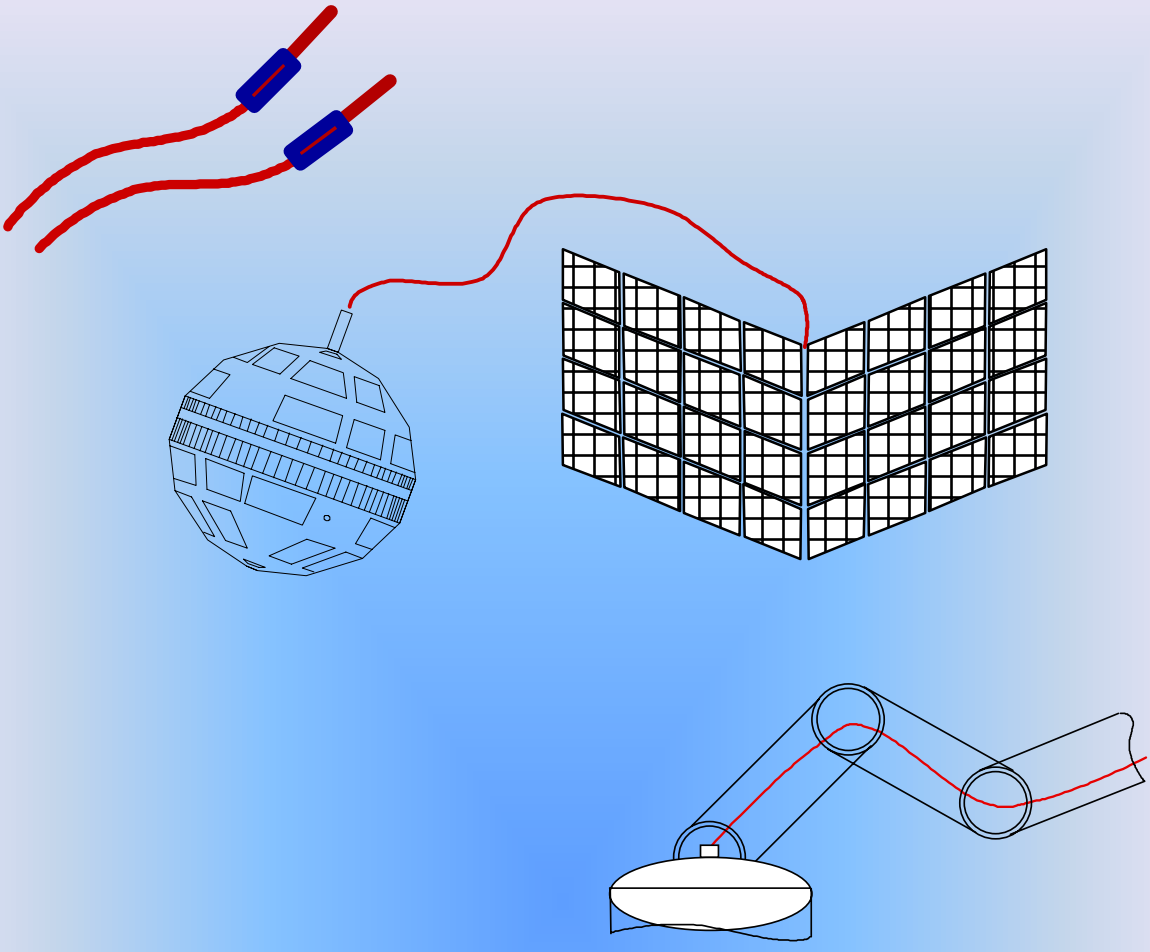
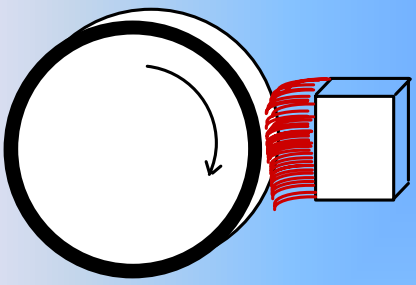
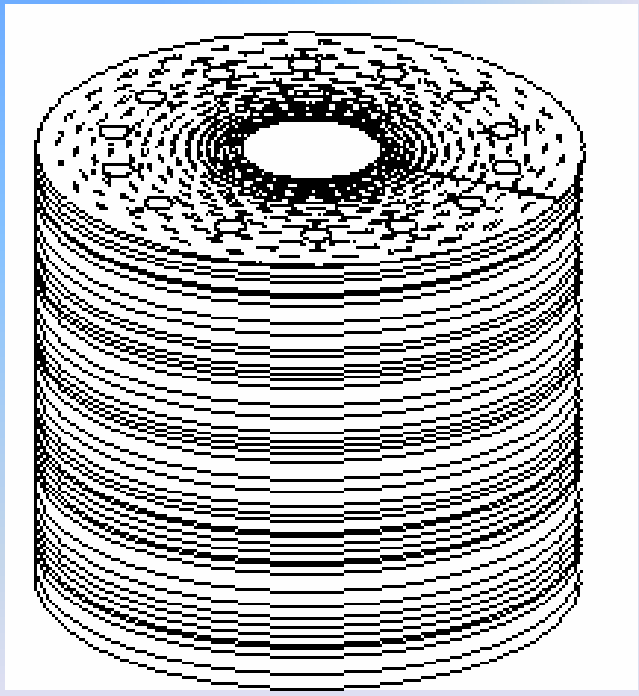
Applications







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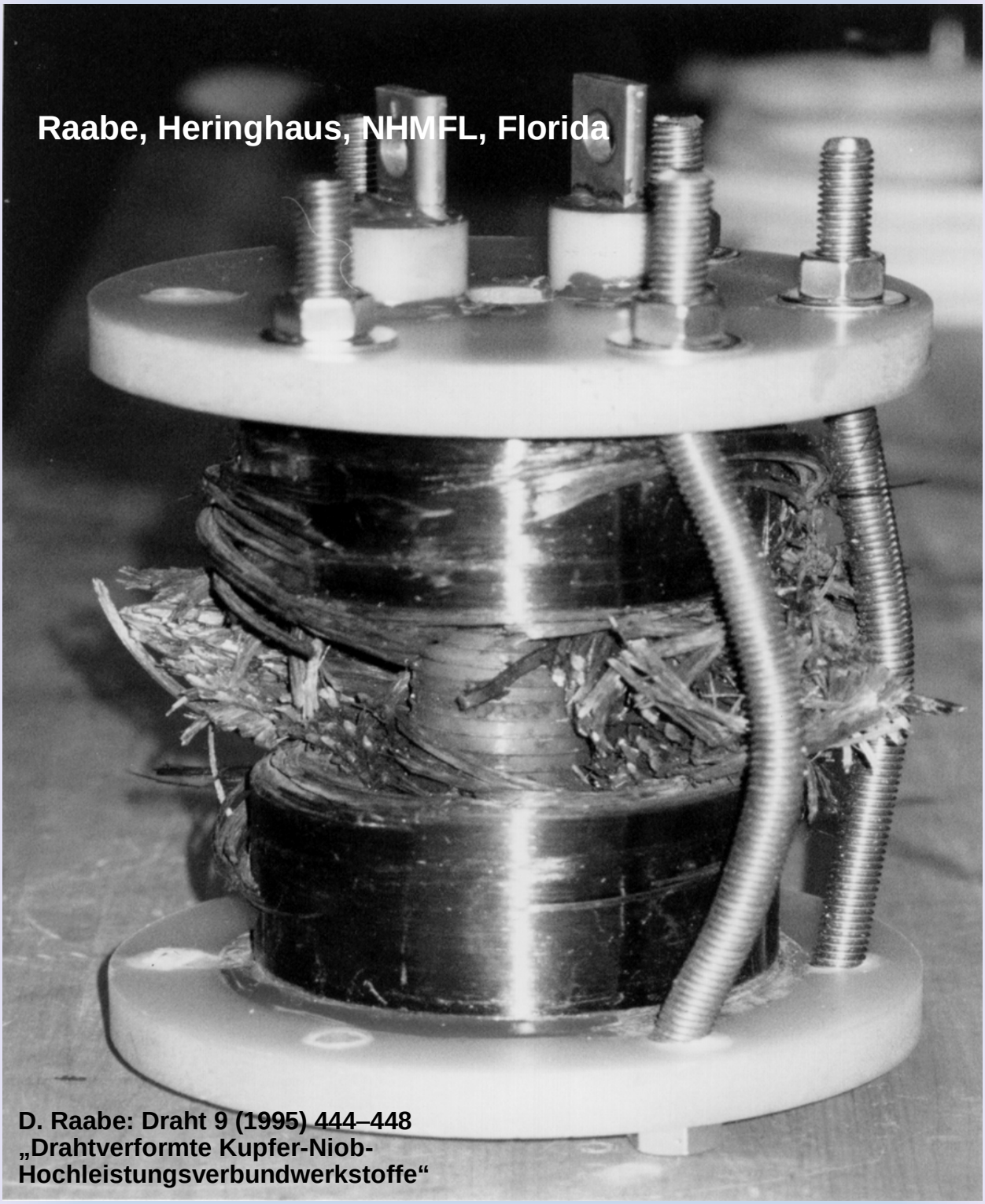

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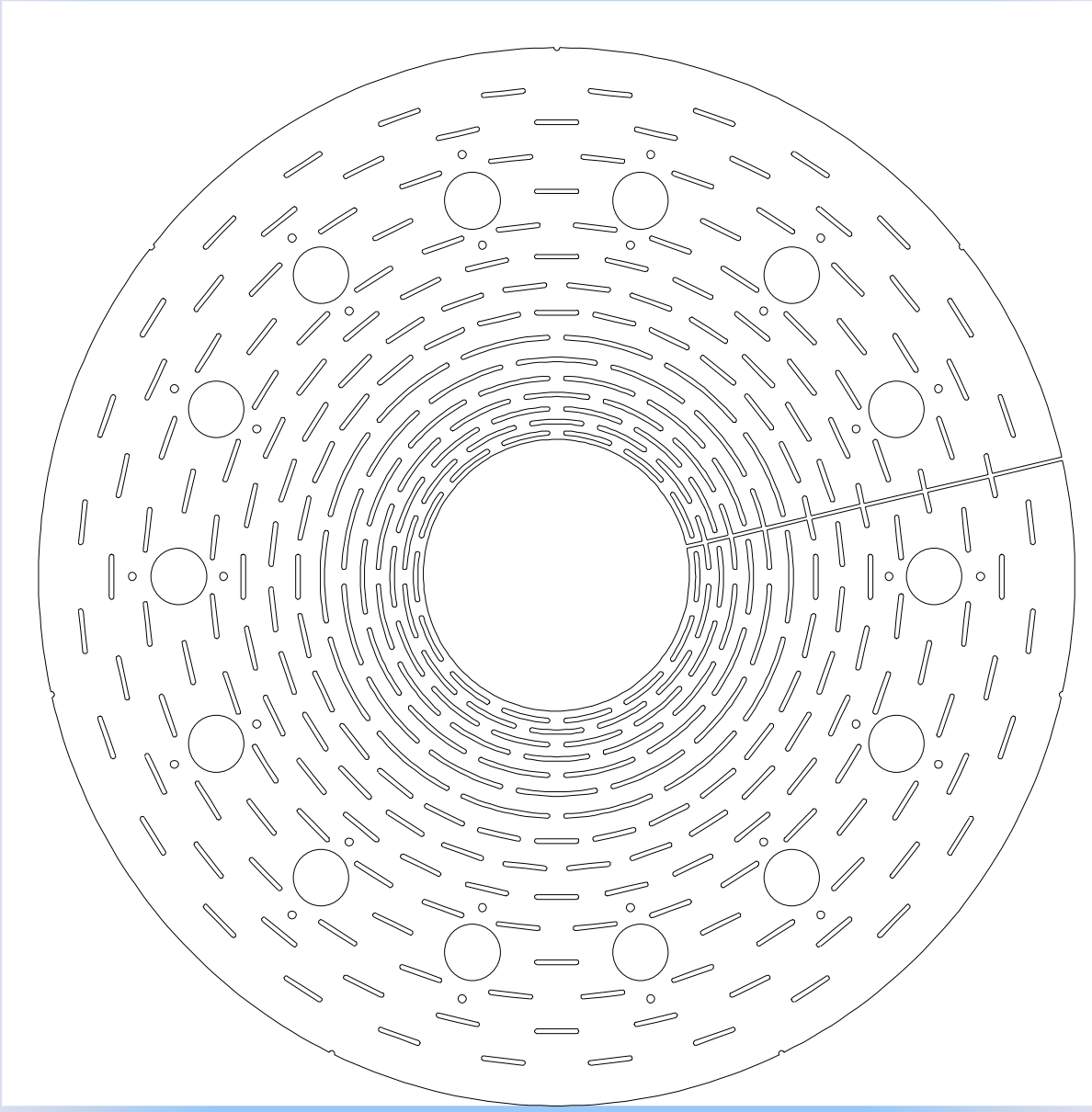

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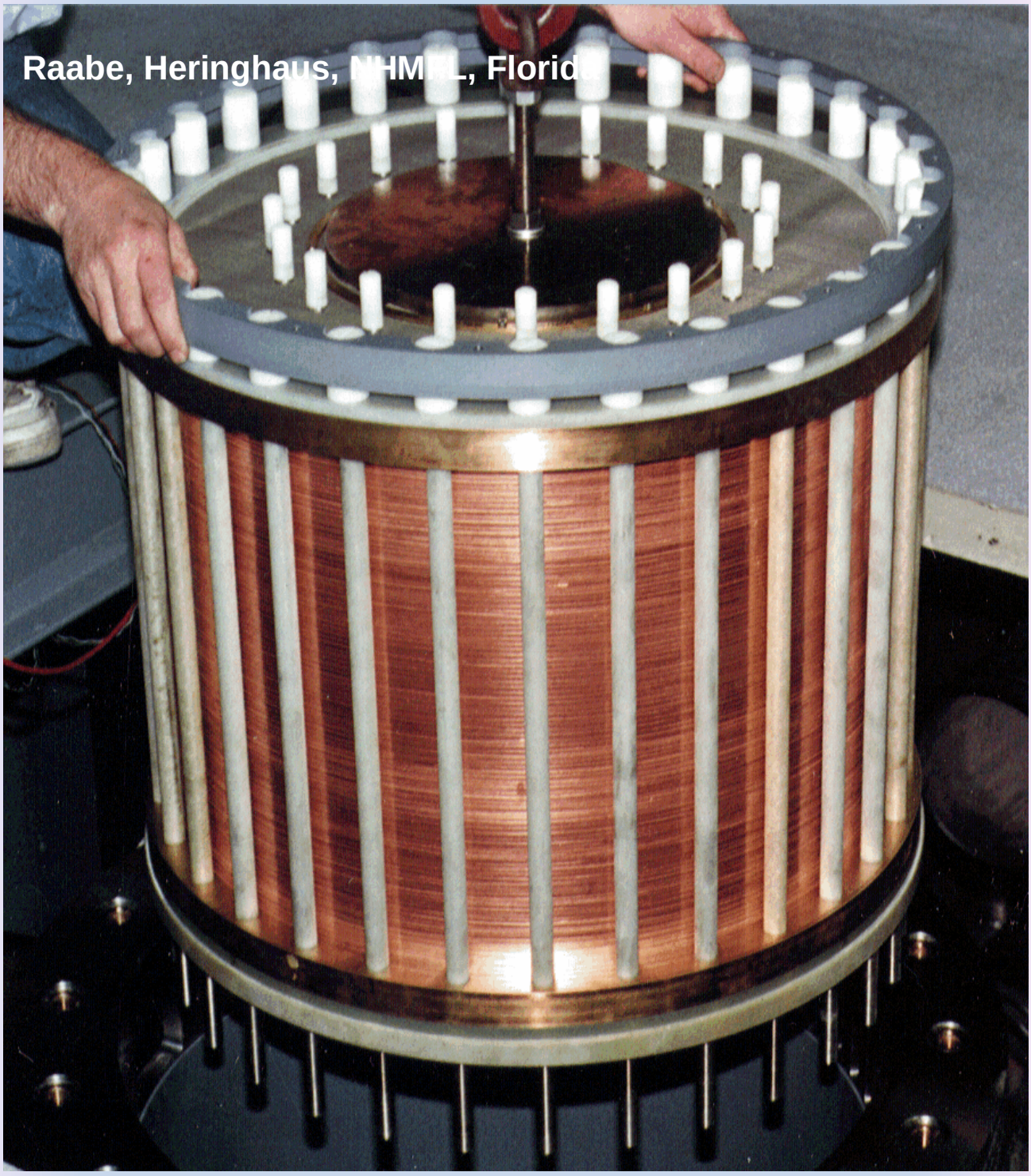

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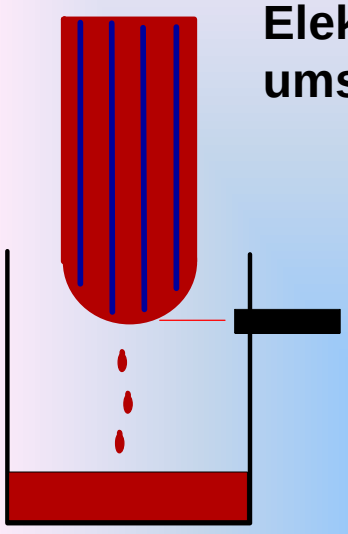
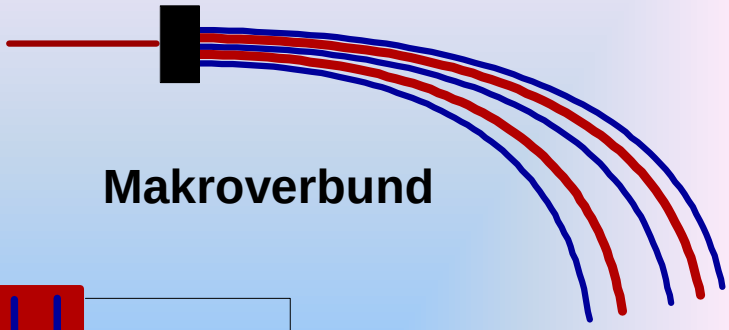
Applications

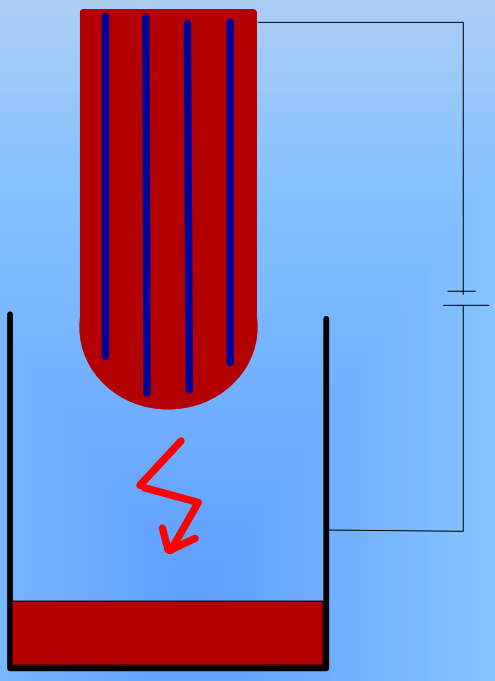
Processing



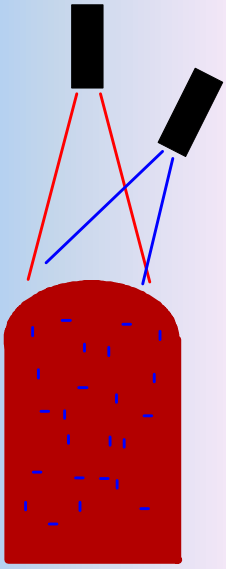
Elektronenstrahl-
umschmelzen



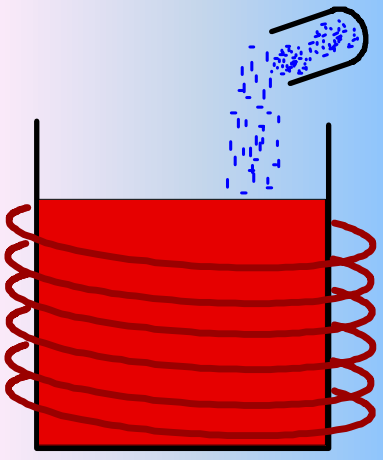
Makroverbund



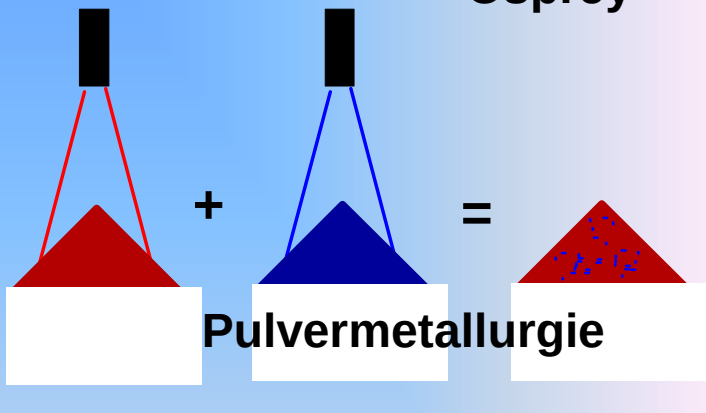
Selbstverzehrende
Elektrode

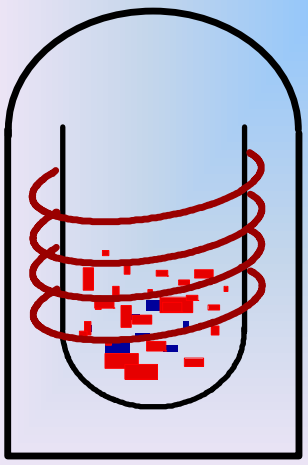


Osprey



Pulver-
Flüssig-
metallurgie





Induktive Schmelzmetallurgie

Rundhämmern
(Strangpressen, "Scherpressen")
Drahtziehen / Kaltwalzen / Wärmebehandlung

Processing

New generation of composites:

ternary Cu- based

in-situ metal matrix composites

Cu-Nb-Ag

- **Combine both strengthening mechanisms**
- **Reduce material cost**
- **Simplify processing**

Cu-Cr-Ag

- **Additional temperature reduction**

Production of cast Cu-Nb-Ag ingots:

Medium frequency induction furnace

- Characteristics: frequency 10kHz
  max. generator power 50KHz
  max. coil voltage 250V
- Complete aggregate was encapsulated
- The Cu and Ag melt was prepared under a vacuum of 10^{-4} mbar
- The aggregate was cleaned and filled with argon
- Temperature was increased up to ca. 1850°C
  => Nb was melted

Mixing of the melt:

Convection currents produced by the electromagnetic stirring effect

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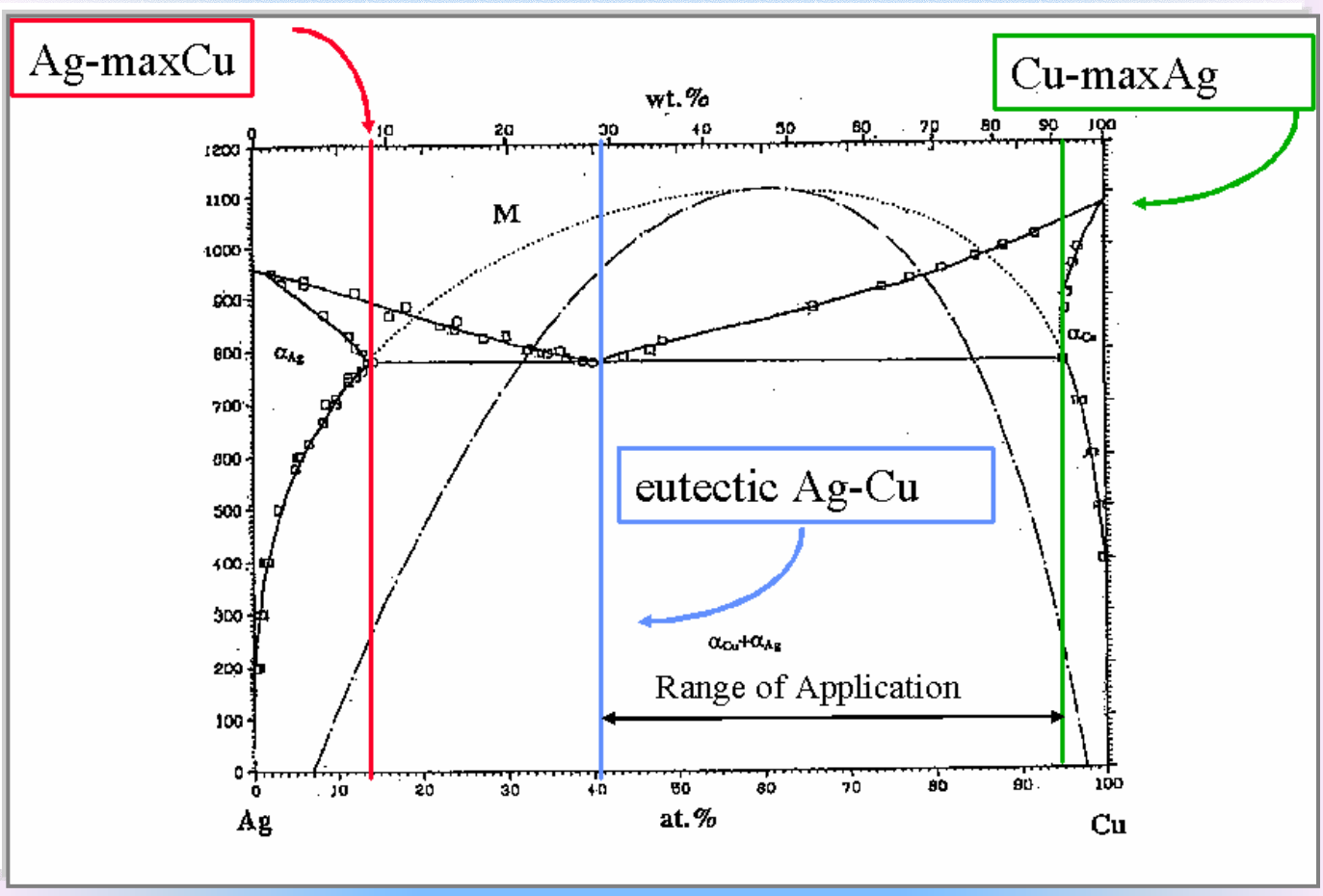
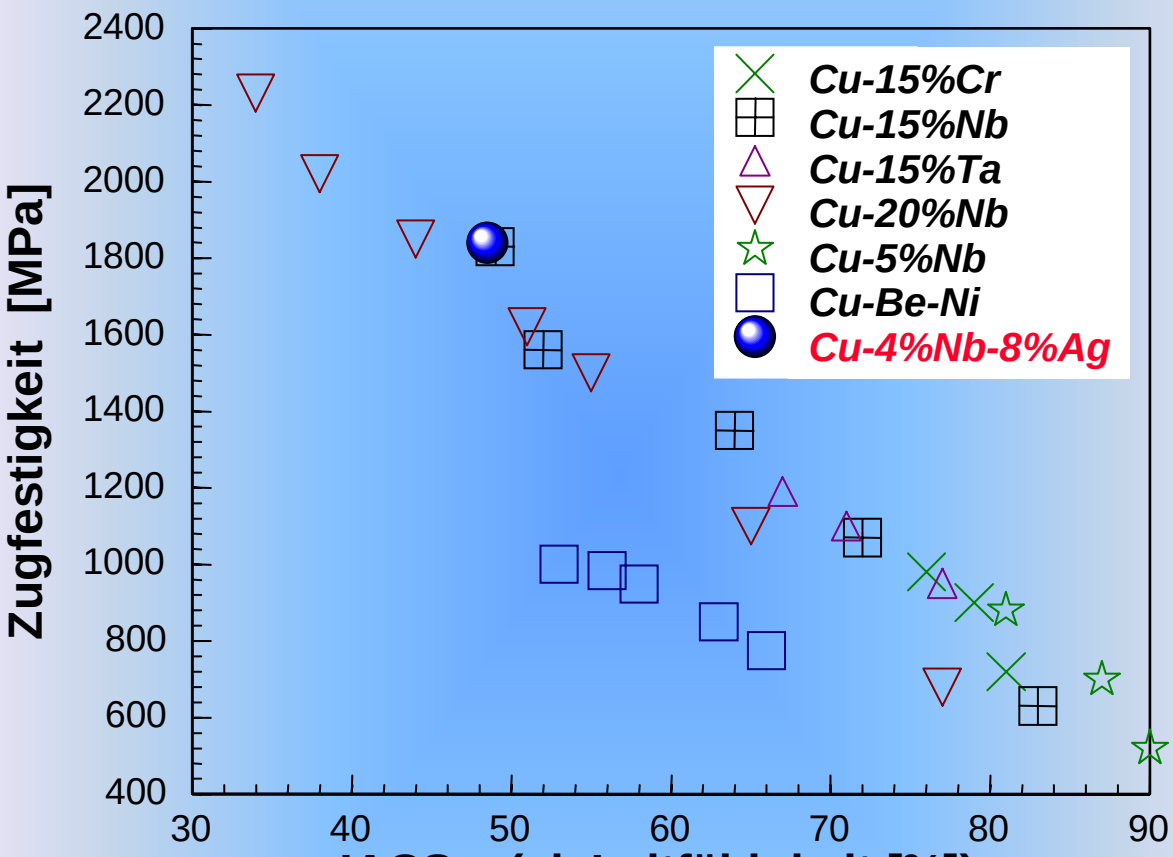

Ag-maxCu
Cu-maxAg
wt.%
M
eutectic Ag-Cu
Range of Application
at.%
Ag
Cu

Conductivity

D. Mattissen, D. Raabe, F. Heringhaus: Acta Materialia 47 (1999) 1627–1634 „Experimental investigation and modeling of the influence of microstructure on the resistive conductivity of a Cu–Ag–Nb in situ composite“



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Conductivity

Cu-2.5%Fe- 2.5%Cr	**32% IACS**
Cu-5%Fe- 0.05%P	**36% IACS**
Cu-4%Nb- 8%Ag	**78% IACS**
Cu-10%Cr (pulv.)	**40% IACS**
Cu-10%Cr (in-situ)	**50-83% IACS**

Conductivity

Cu-20%Nb (in-situ)

Cu-10%Cr (powder metall.)

Cu-4%Nb-8.2% Ag (in-situ)

Cu-Ag, Ag-Cu, eutetectic (in-situ)

Cu-2,5%Fe-2.5%Cr (in-situ)

Cu-10%Cr-1%Ag (in-situ)

Cu-10%Cr-3%Ag (in-situ)

Cu-10%Cr-5%Ag (in-situ)

Cu-10%Cr-7%Ag (in-situ)

Cu-2.5%Fe-2.5%Cr 32% IACS

Cu-5%Fe-0.05%P 36% IACS

Cu-4%Nb-8.2%Ag 78% IACS !

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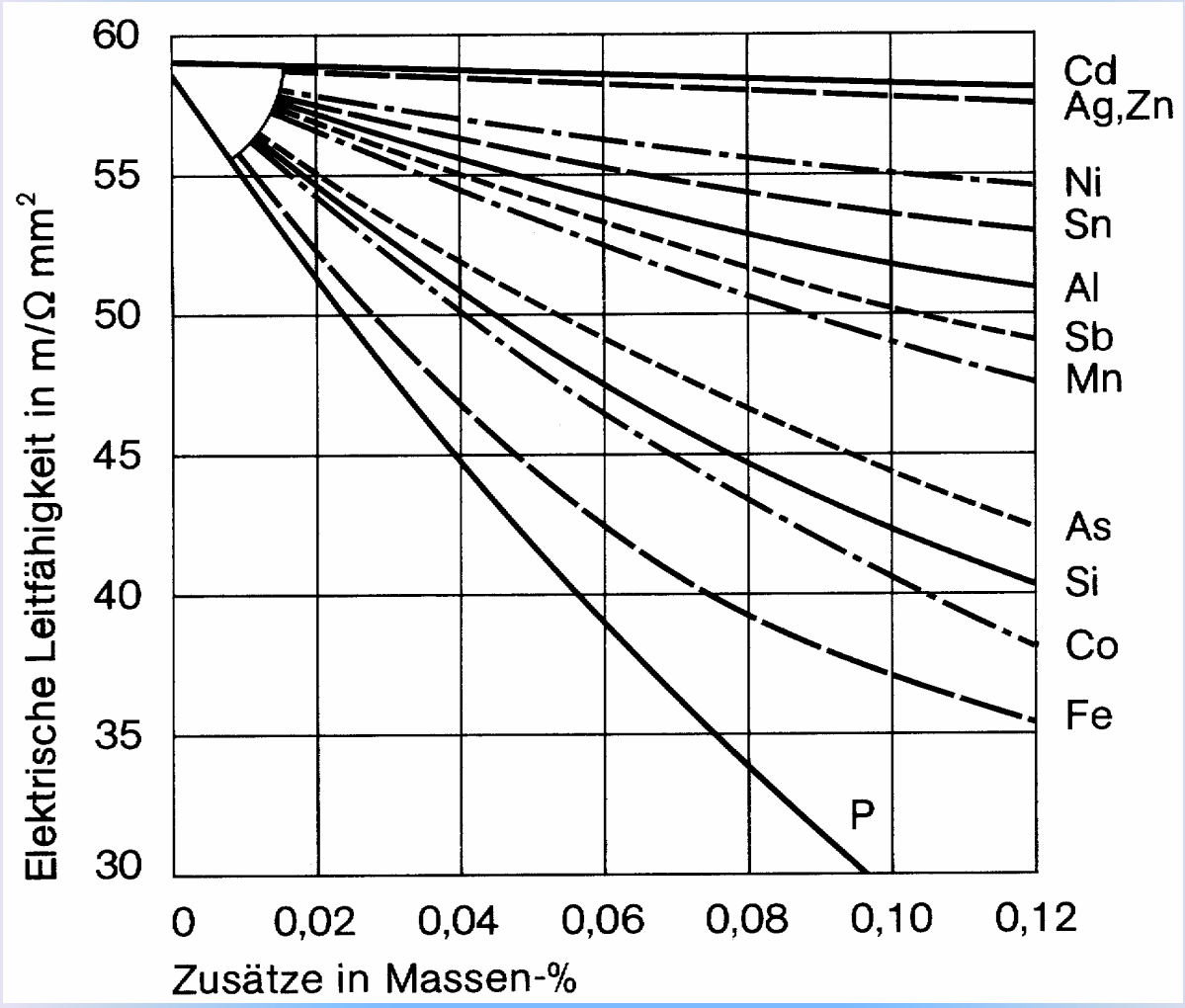
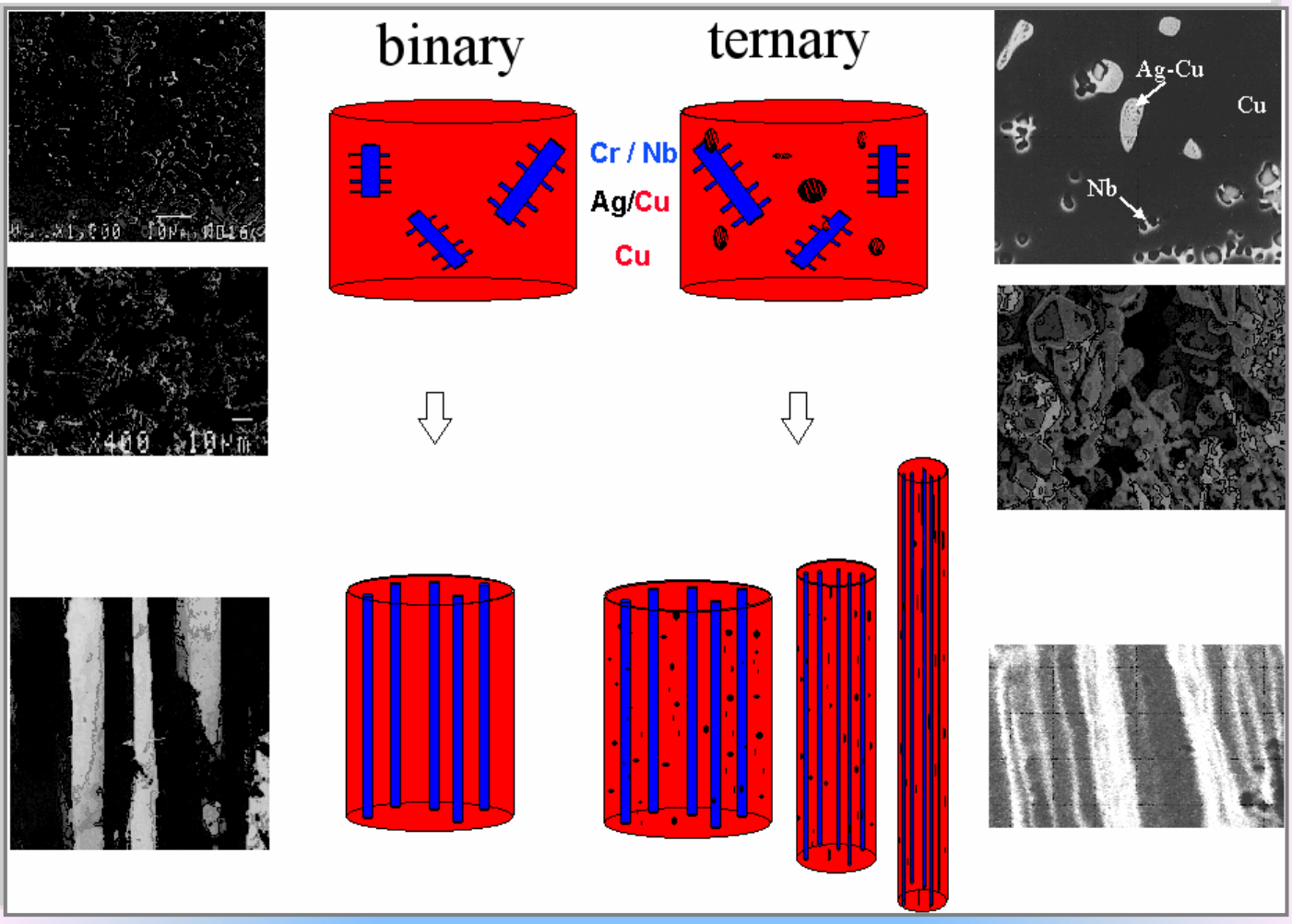


Strategy



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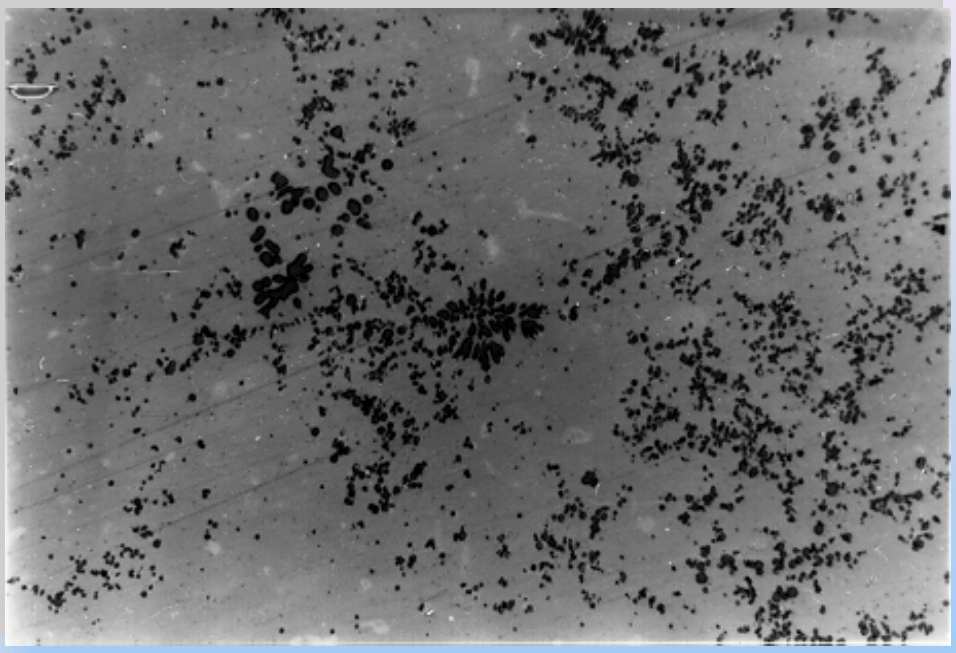
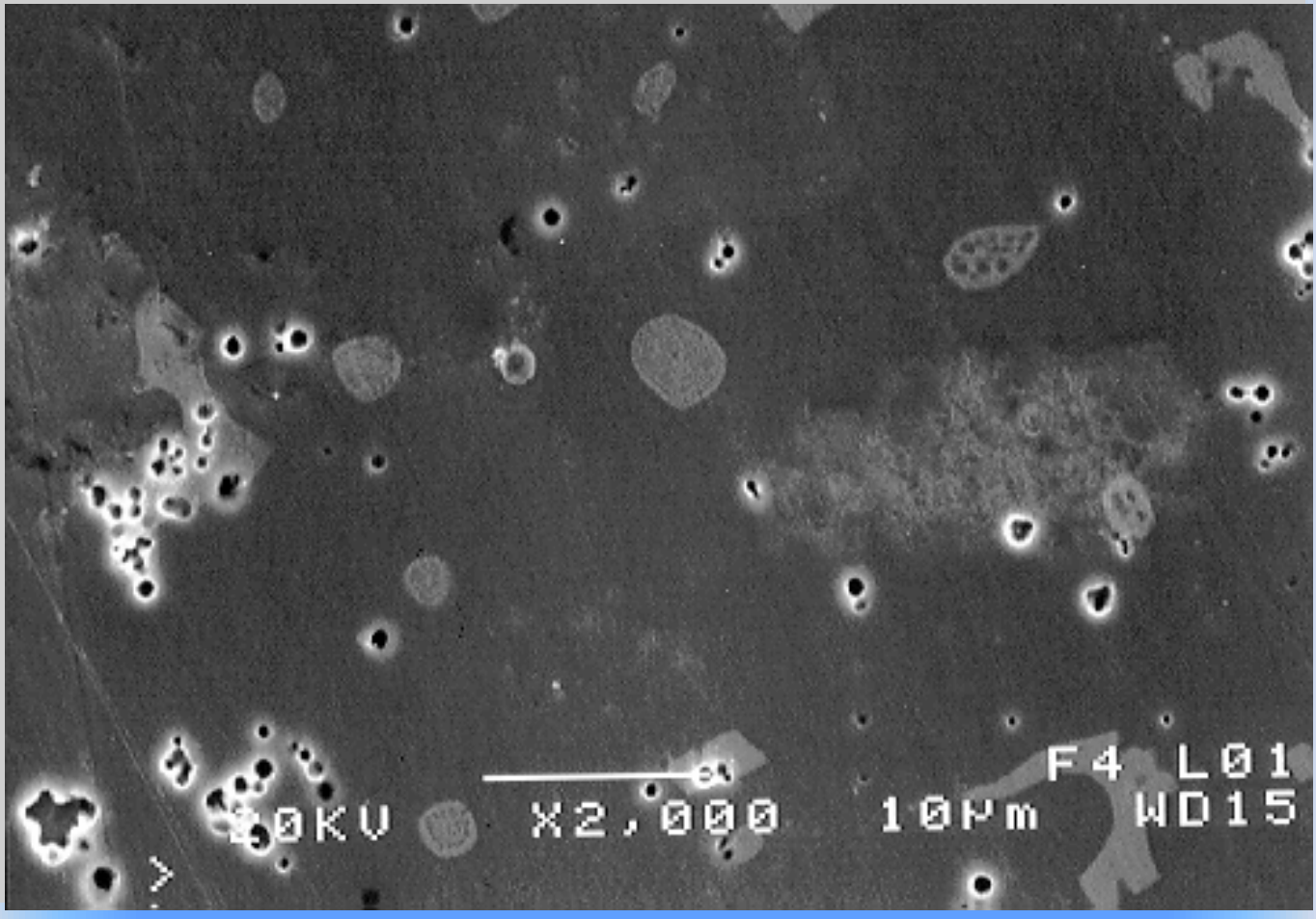
Cu-4%Nb-8.2% Ag



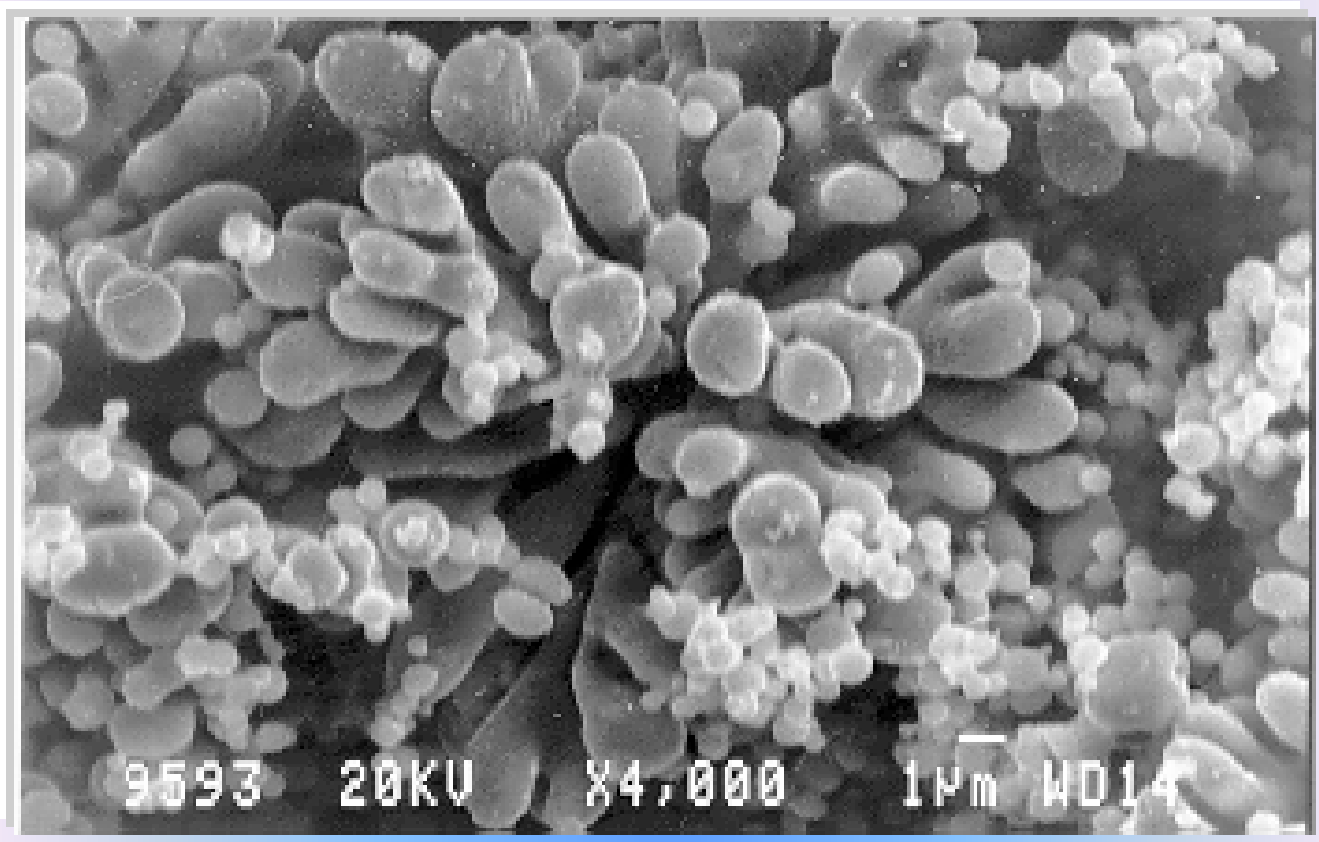
casting diameter
d = 18mm

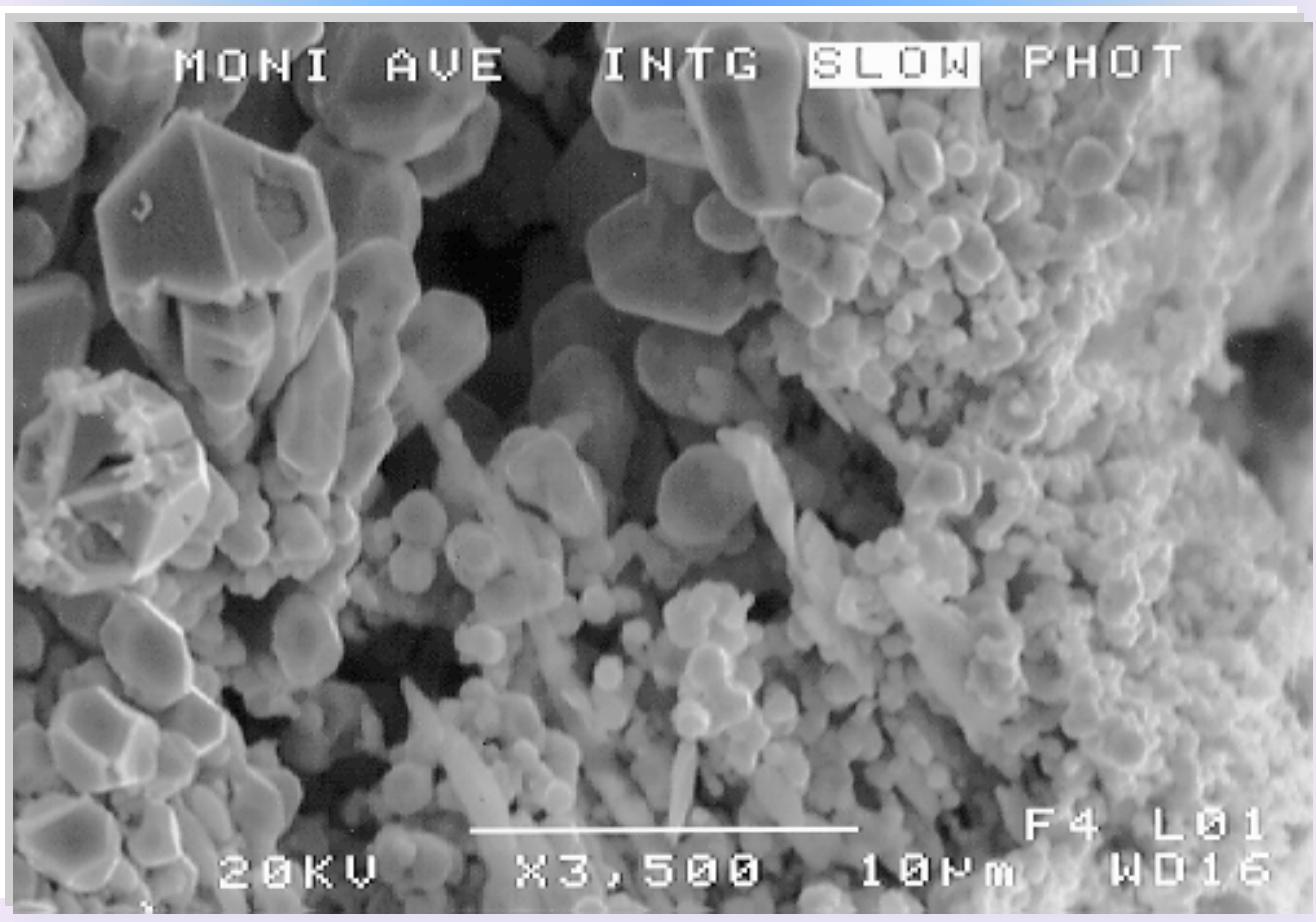
20µm



results casting

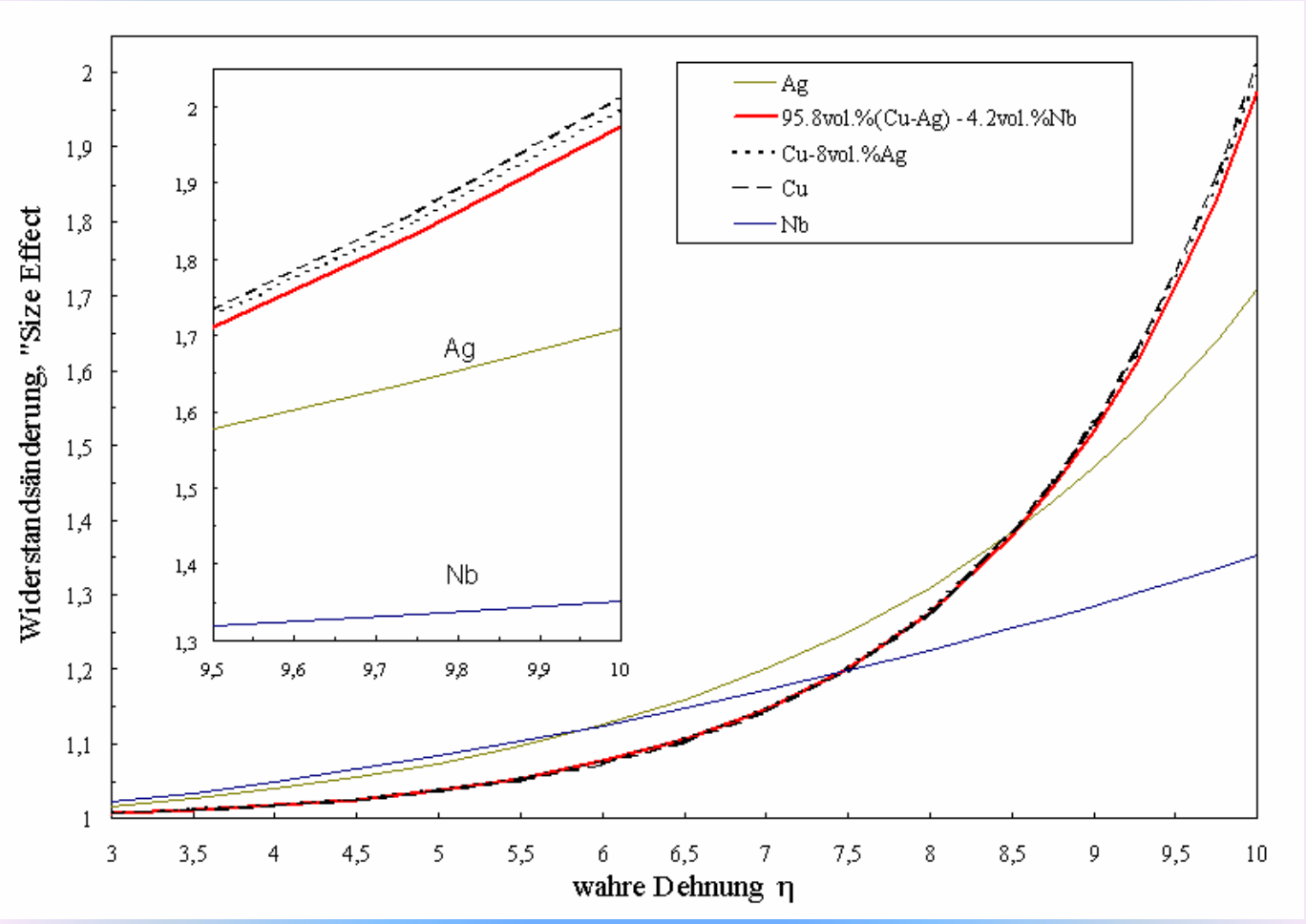
Cu-4%Nb-8.2% Ag


9593 20KV X4,000 1µm WD14


MONI AVE INTG SLOW PHOT
F4 L01
20KV X3,500 10µm WD16

Conductivity

Cu-4%Nb-8%Ag, 77 K



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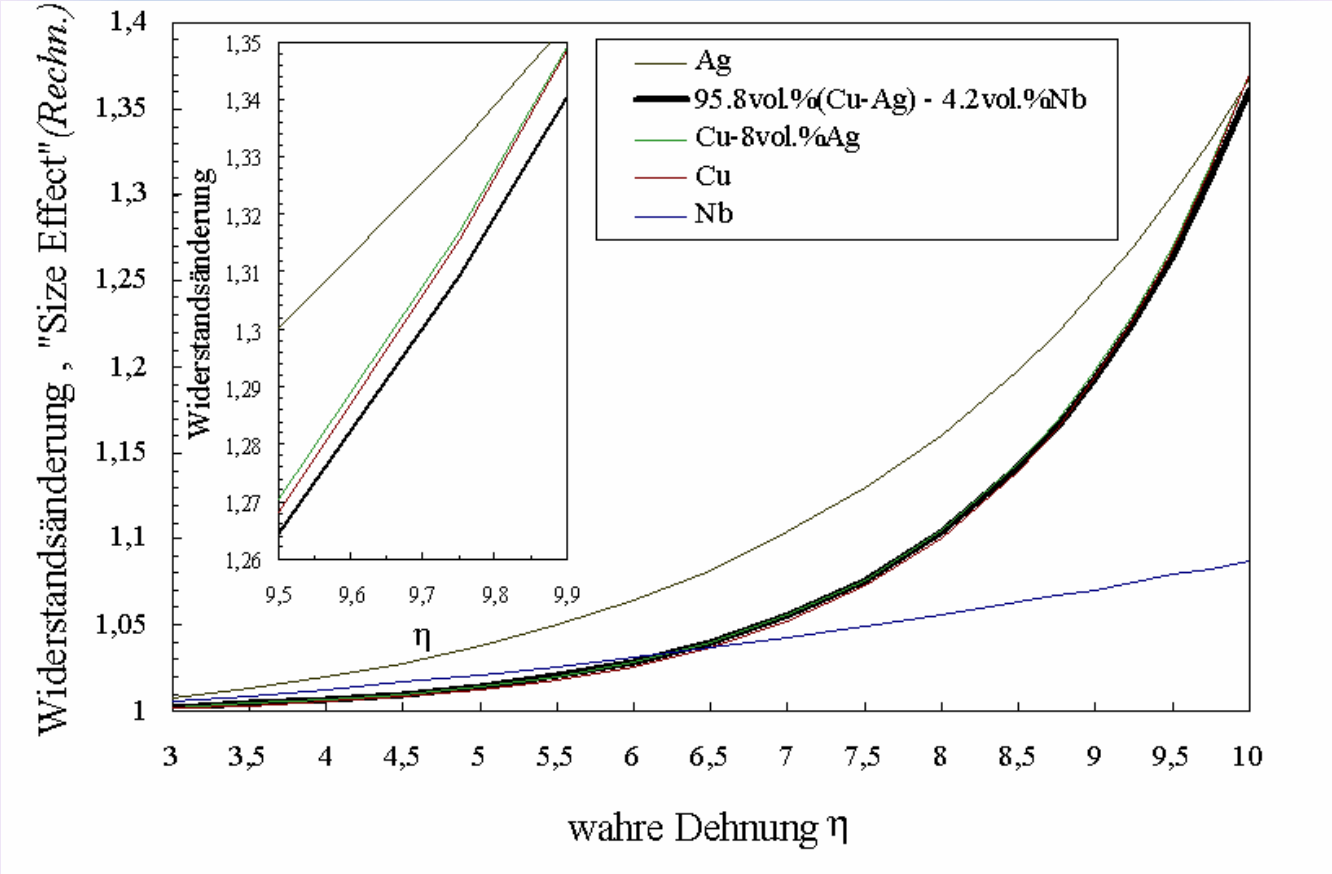
Conductivity

Cu-4%Nb-8%Ag, 298 K



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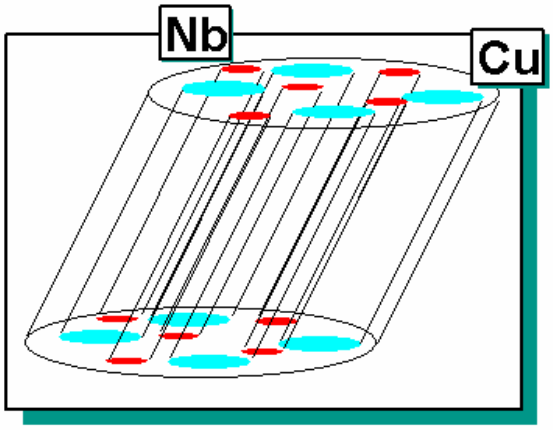
Conductivity

1 Analytical Model
2 Rule of Mixture
3 Size / Morphology / Topology
4 Mean Free Electron Path
5 Dislocations

1 ⇨ $\rho(d) = \rho_0 (1 + \frac{3}{4} \cdot \frac{l_0}{d})$



2 ⇨ $\frac{1}{\rho} = \frac{0.8}{\rho_{Cu}} + \frac{0.2}{\rho_{Nb}}$

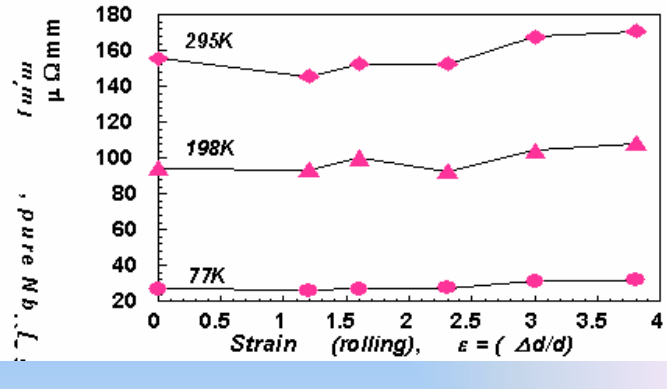
3 ⇨ *Exp.*

⇧ *diameter as function of strain*

⇧ *Curling*

4 ⇨ *Exp., Theor.*

5 ⇨ *Exp.* ⇨ ⇨



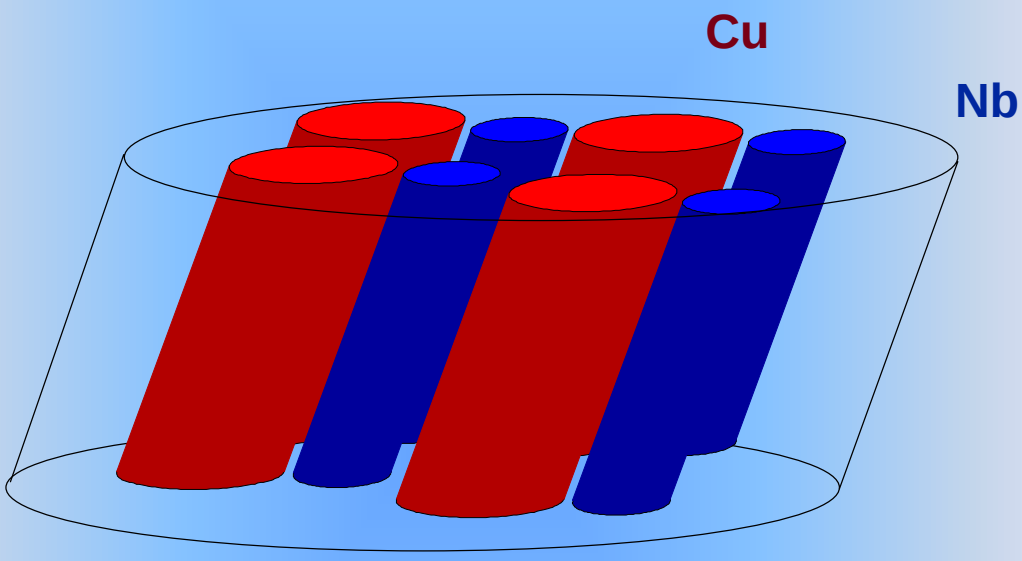
D. Raabe, F. Heringhaus, U. Hangen, G. Gottstein: Zeitschrift für Metallkunde 86 (1995) 405–422
„Investigation of a Cu-20mass%Nb in situ Composite
Part I: Fabrication, Microstructure and Mechanical Properties
Part II: Electromagnetic Properties and Application“

D. Raabe, U. Hangen: Computational Materials Science 5 (1996) 195–202
„Simulation of the yield strength of wire drawn Cu-based in situ composites“

Conductivity

Mischungsregel

$$\frac{1}{\rho} = \frac{0.8}{\rho_{Cu}} + \frac{0.2}{\rho_{Nb}}$$

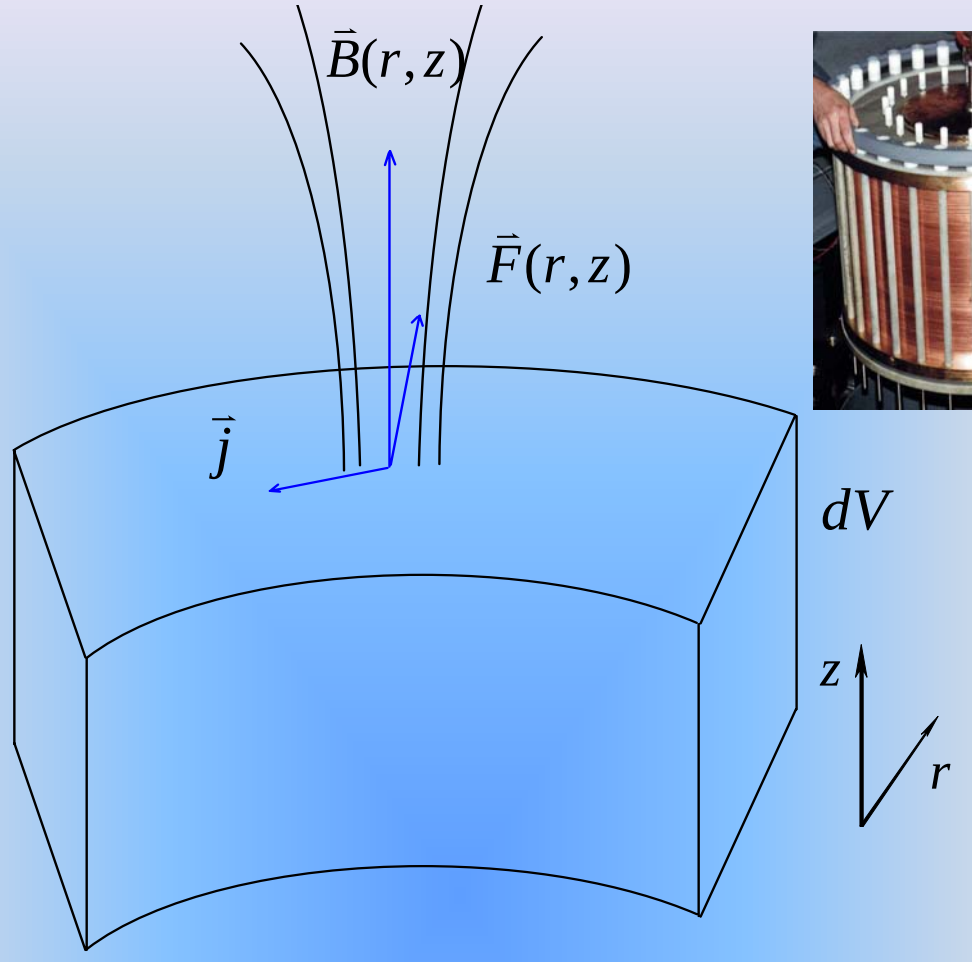


D. Raabe, U. Hangen: Computational Materials Science 5 (1996) 195–202
„Simulation of the yield strength of wire drawn Cu-based in situ composites“

Für jede Phase: Streuung an Phasengrenzen

$$\rho(d,T) = \rho_0(T)\,(1+\frac{3}{4}\cdot\frac{l_0}{d})$$

Conductivity



Lorentz Kraft $d\vec{F}(r,z) = \vec{j} \times \vec{B}(r,z)\, dV$

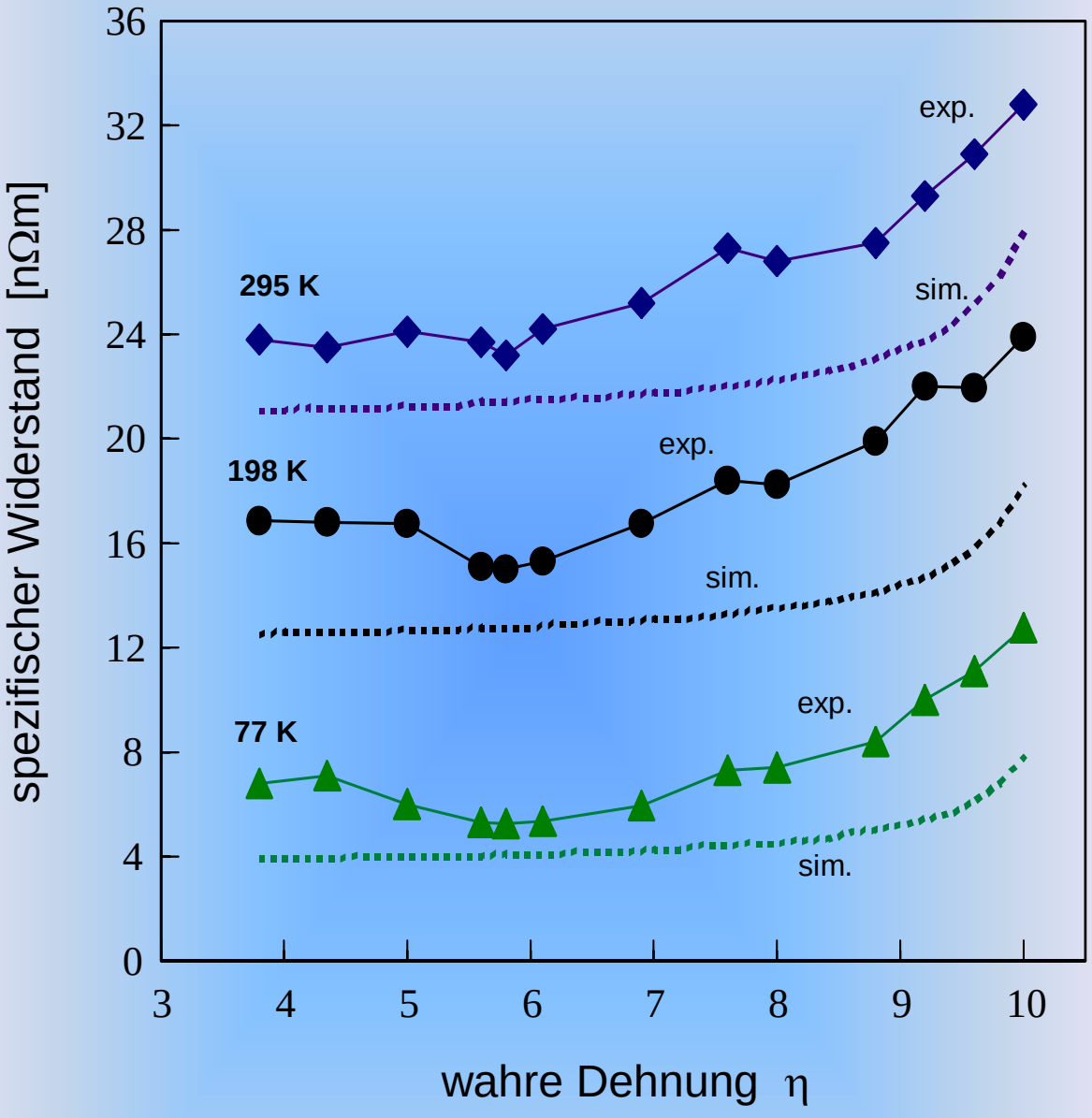
Radialspannung $\sigma(r,z) = j_r \; B_z(r,z)$

Fabry Gleichung $B_{\max} \propto \sqrt{\sigma_{\max}}$

B_{max} [Tesla]	σ_{max} [MPa]
50	600
75	1300
100	2300

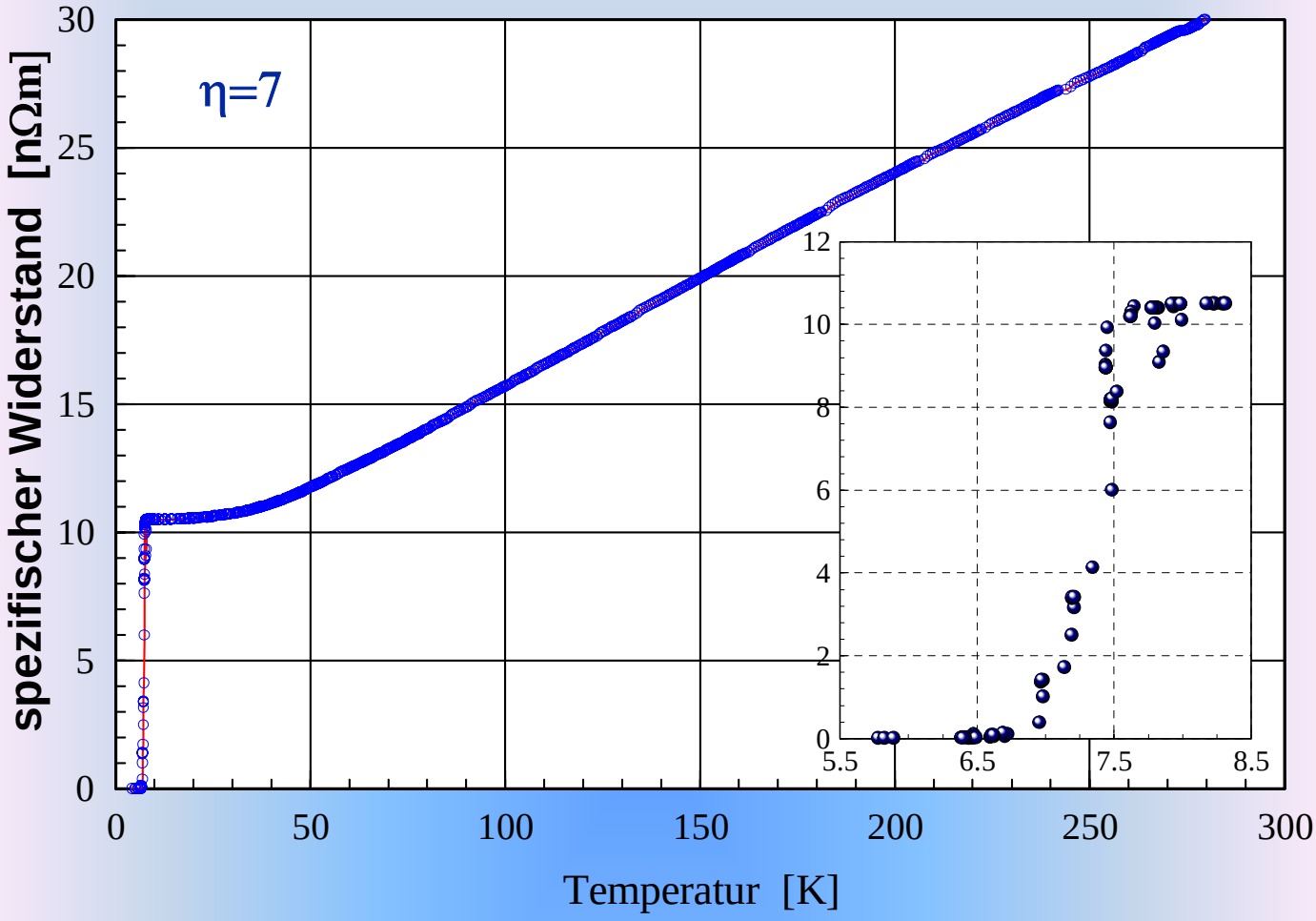
Conductivity

D. Raabe, U. Hangen: Computational Materials Science 5 (1996) 195–202
„Simulation of the yield strength of wire drawn Cu-based in situ composites“



Cu-20%Nb

Conductivity

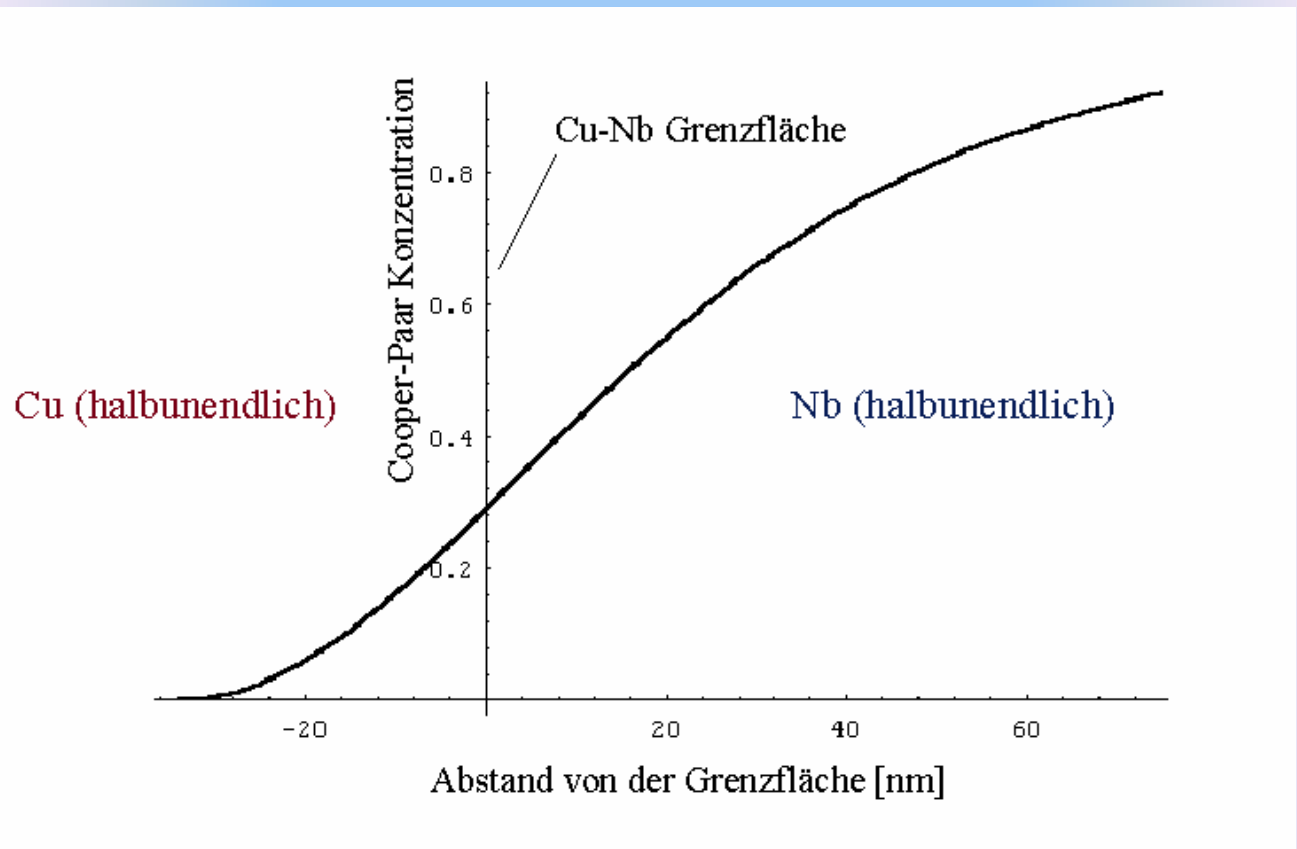


Cu-4%Nb-8%Ag, Supraleitung

D. Raabe, D. Mattissen: Acta Materialia 47 (1999) 769–777
„Experimental investigation and Ginzburg–Landau modeling of the microstructure dependence of superconductivity in Cu–Ag–Nb wires“

Conductivity

Cu-4%Nb-8%Ag, Supraleitung



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Conductivity

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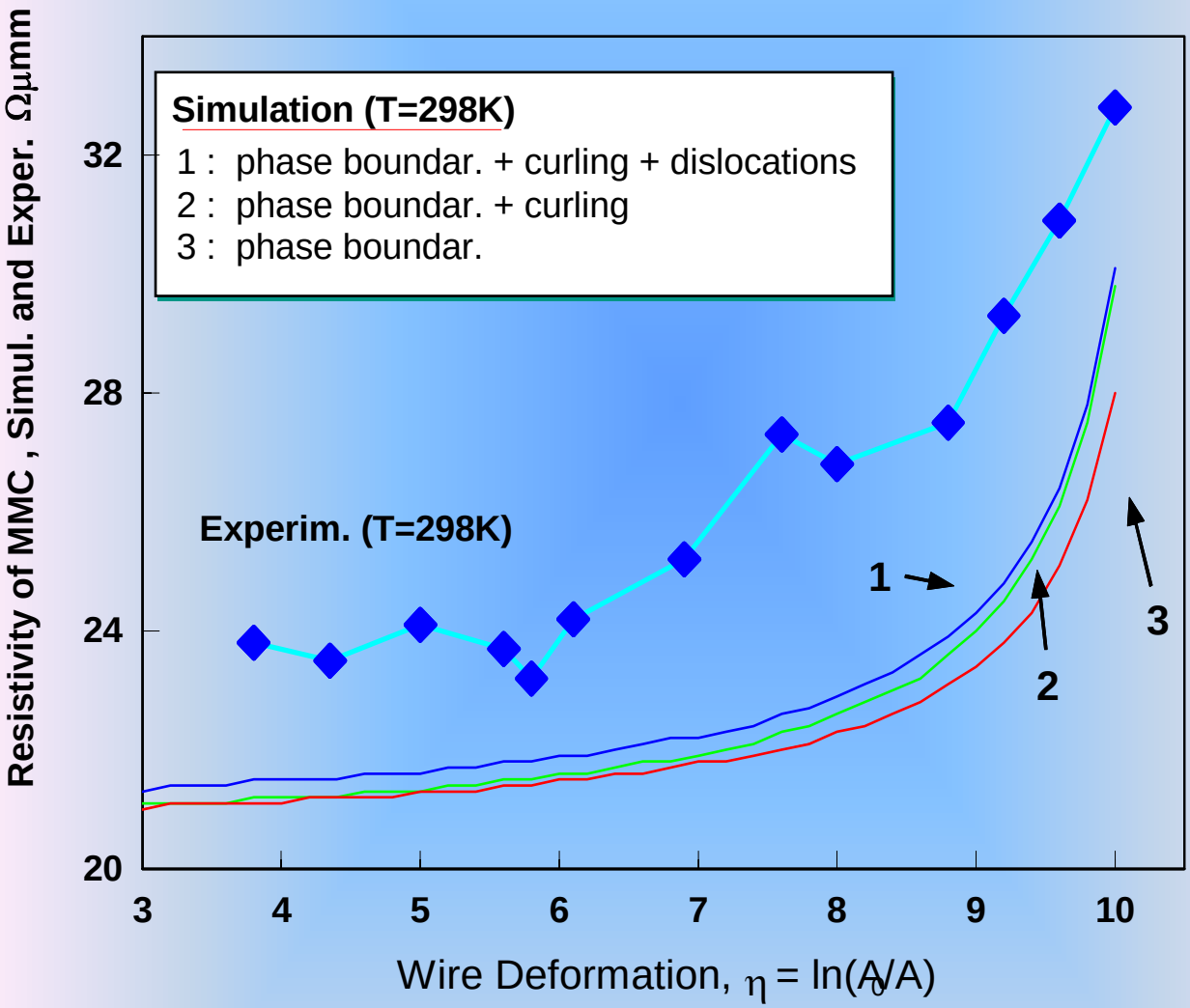
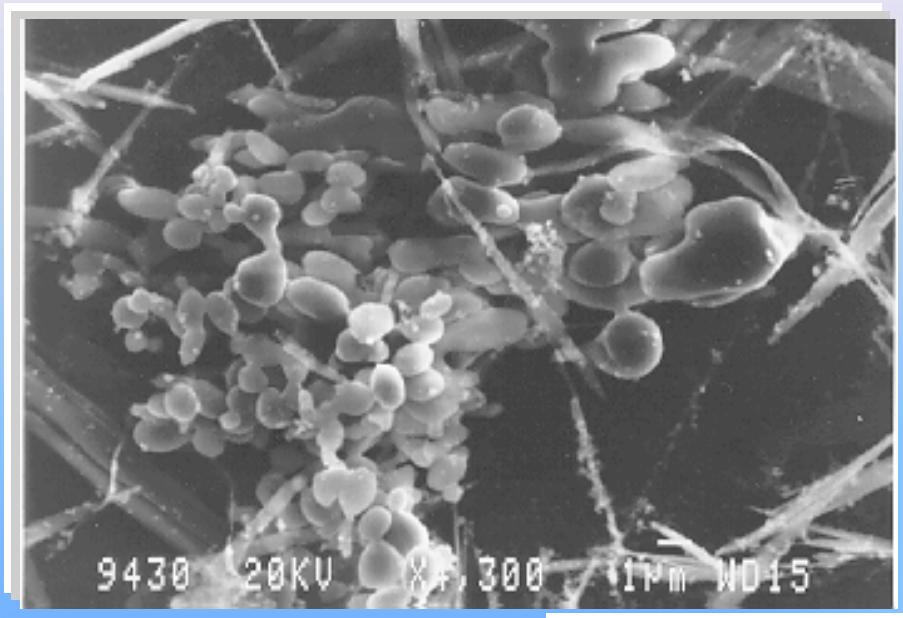
DETAILS:

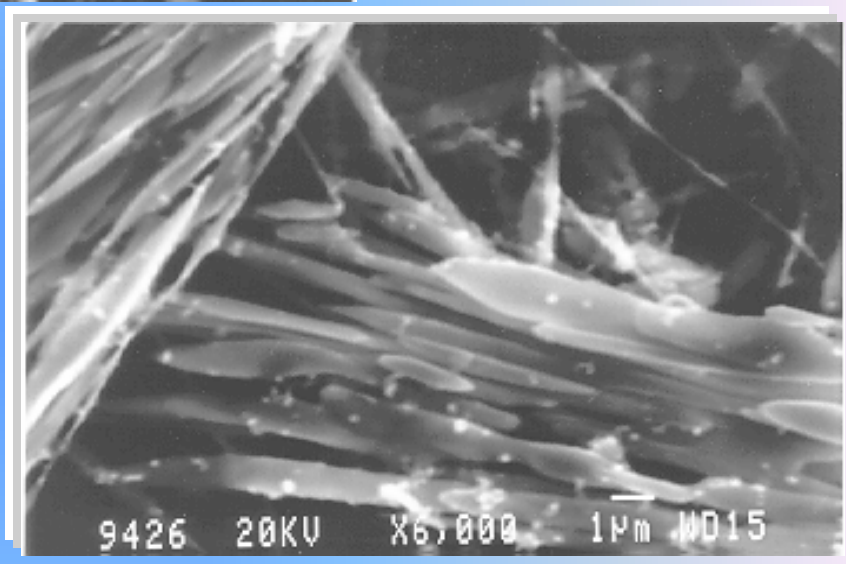


Cu-4%Nb-8.2% Ag

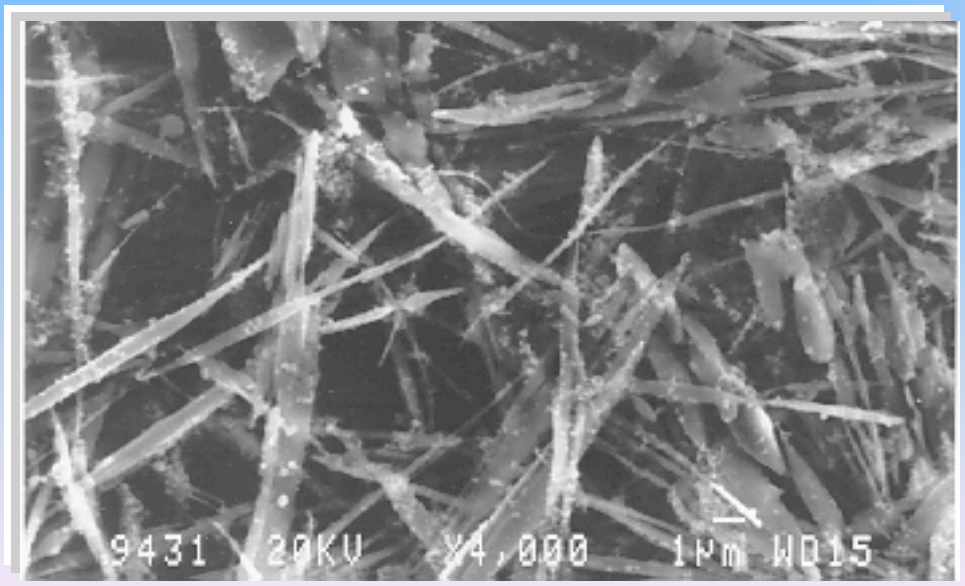


true strain = 2.5

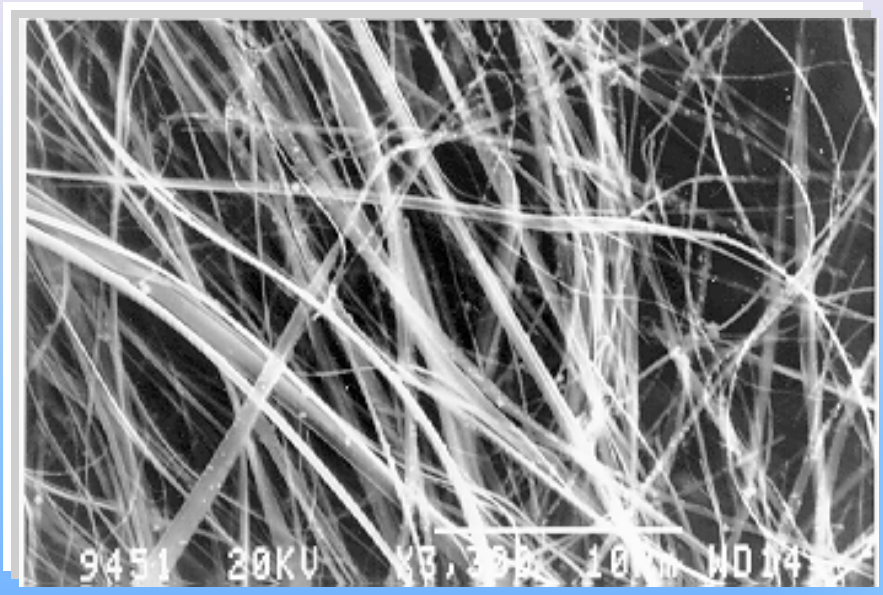
Nb-filaments



D. Raabe, D. Mattissen: Acta Materialia 46 (1998) 5973–5984
„Microstructure and mechanical properties of a cast and wire drawn ternary Cu-Ag-Nb in situ composite“



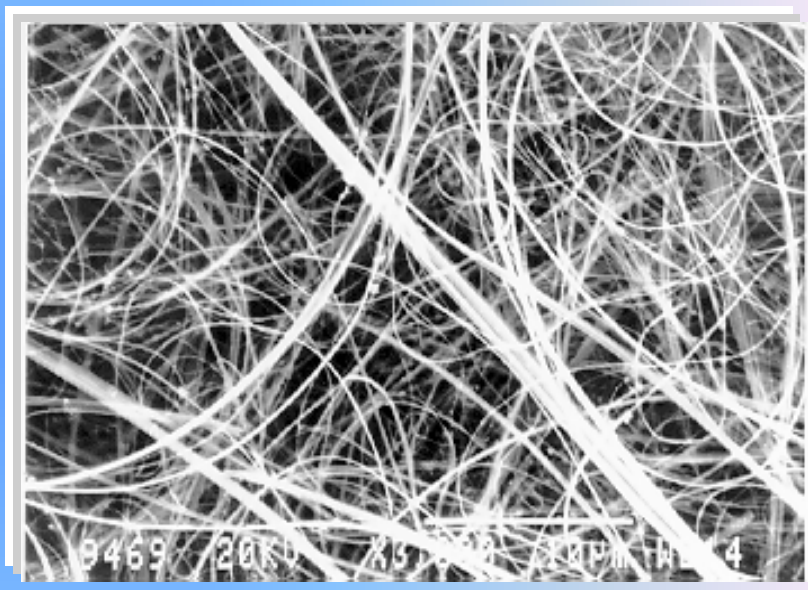
Cu-4%Nb-8.2% Ag



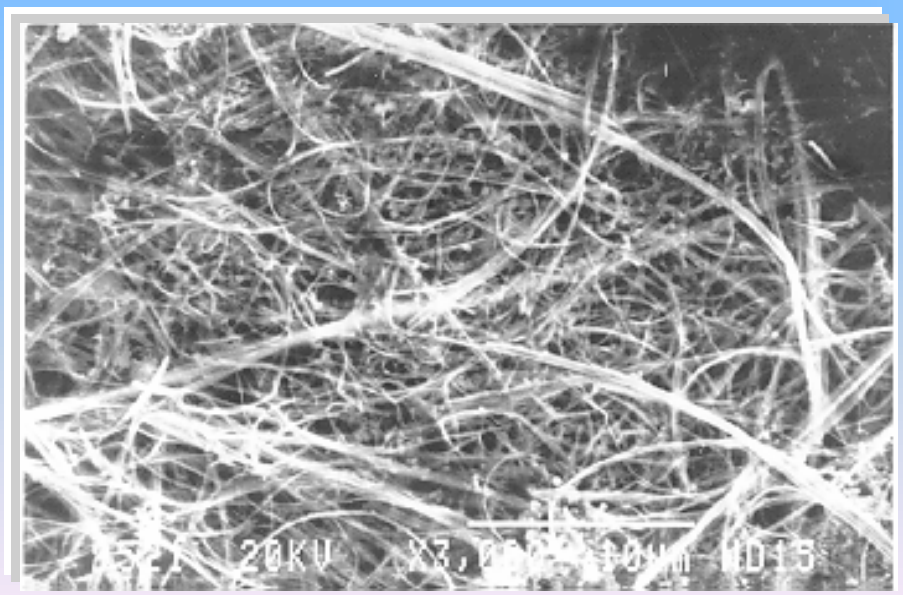
true strain = 4

true strain = 5.9

Nb-filaments

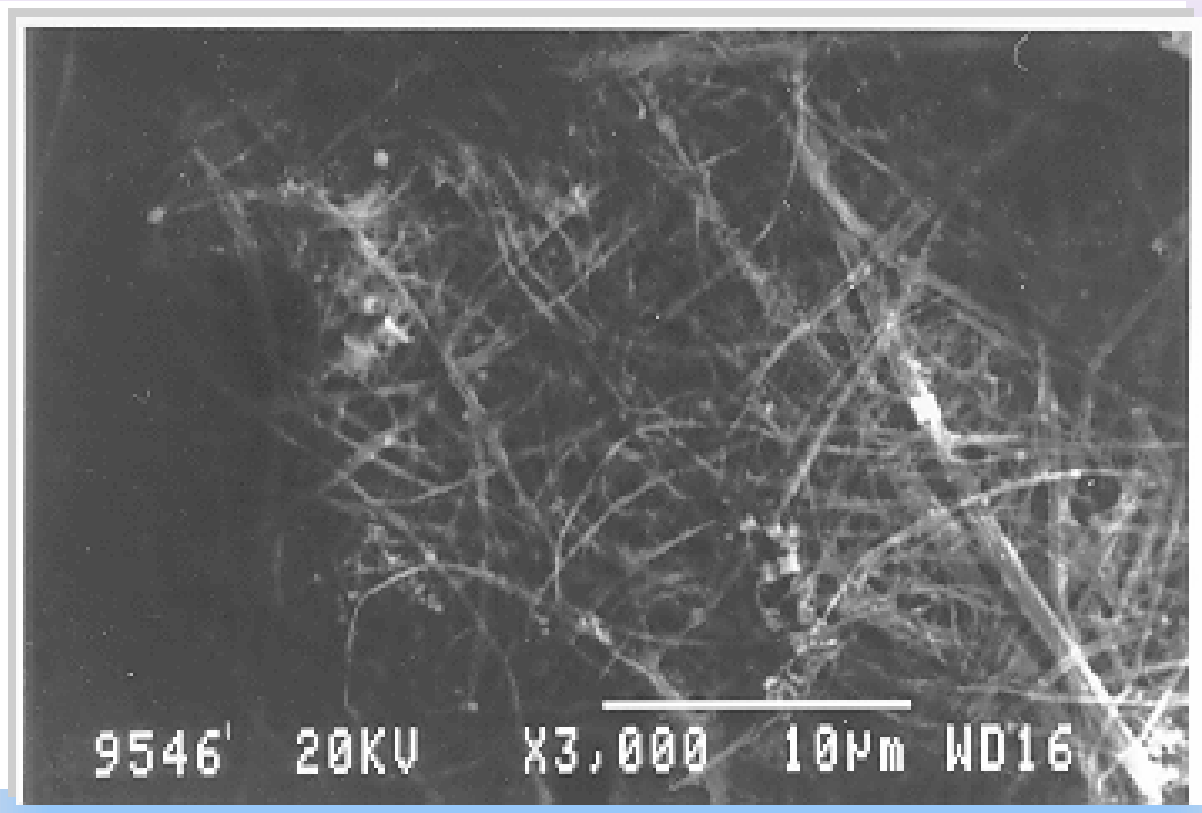


D. Raabe, D. Mattissen: Acta Materialia 46 (1998) 5973–5984
„Microstructure and mechanical properties of a cast and wire drawn ternary Cu-Ag-Nb in situ composite“

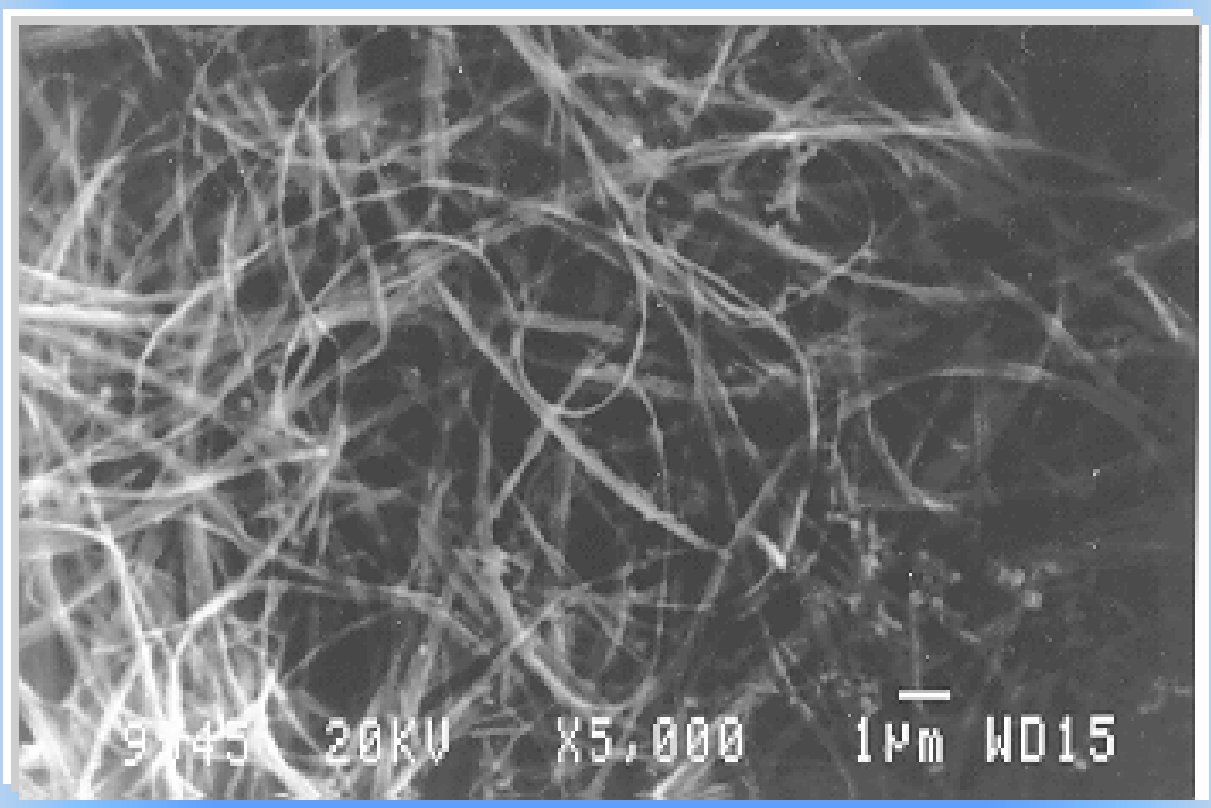


true strain = 8

Cu-4%Nb-8.2% Ag

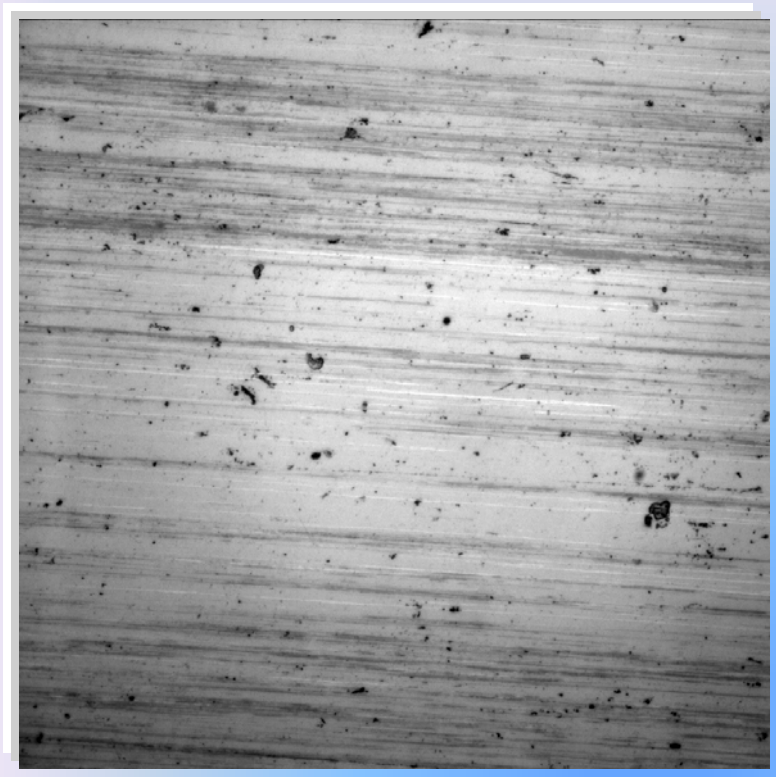


true strain = 10.5



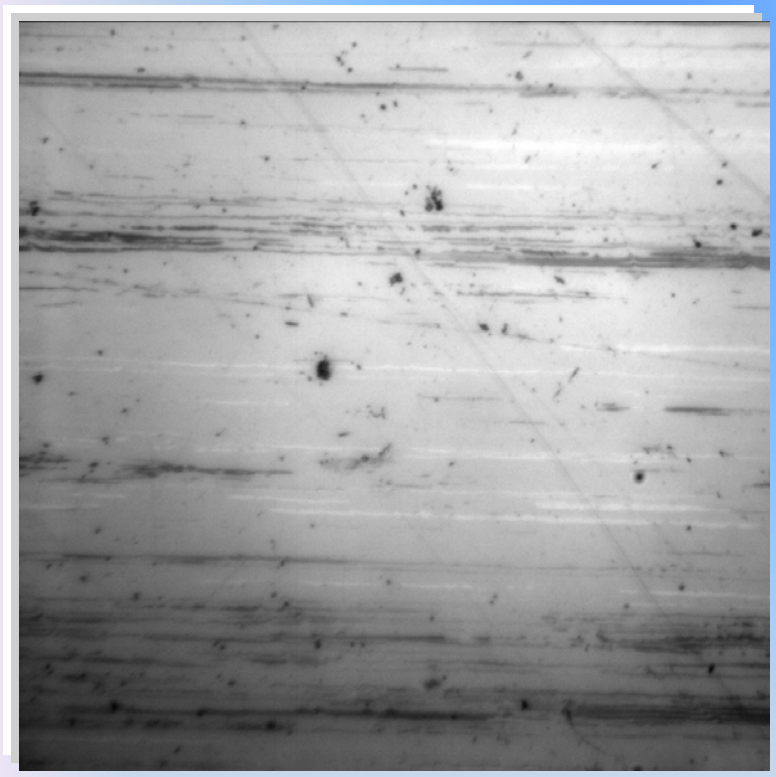
Nb-filaments

Cu-4%Nb-8.2% Ag



true strain = 4.5

20µm

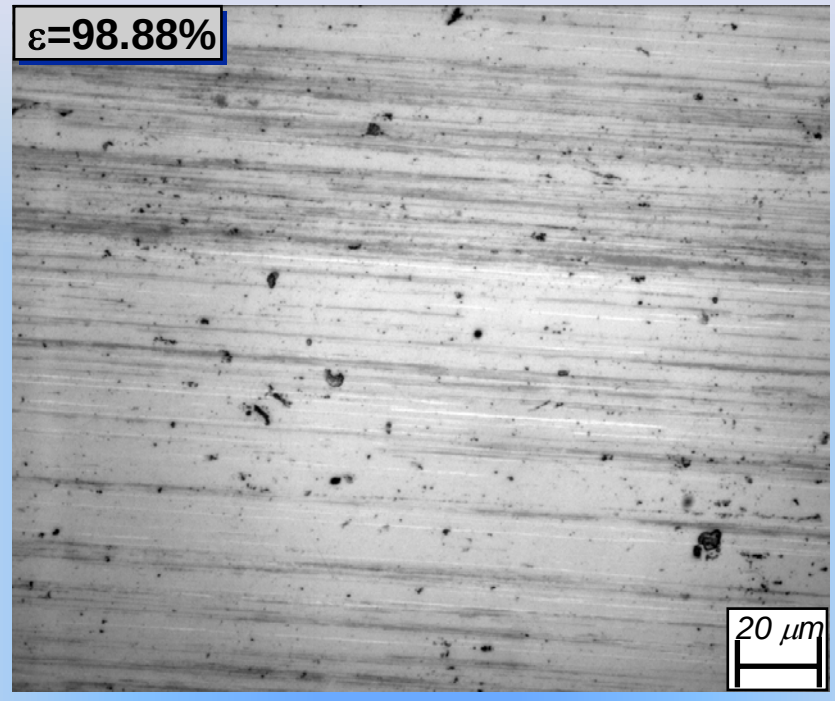


true strain = 4.0

10µm

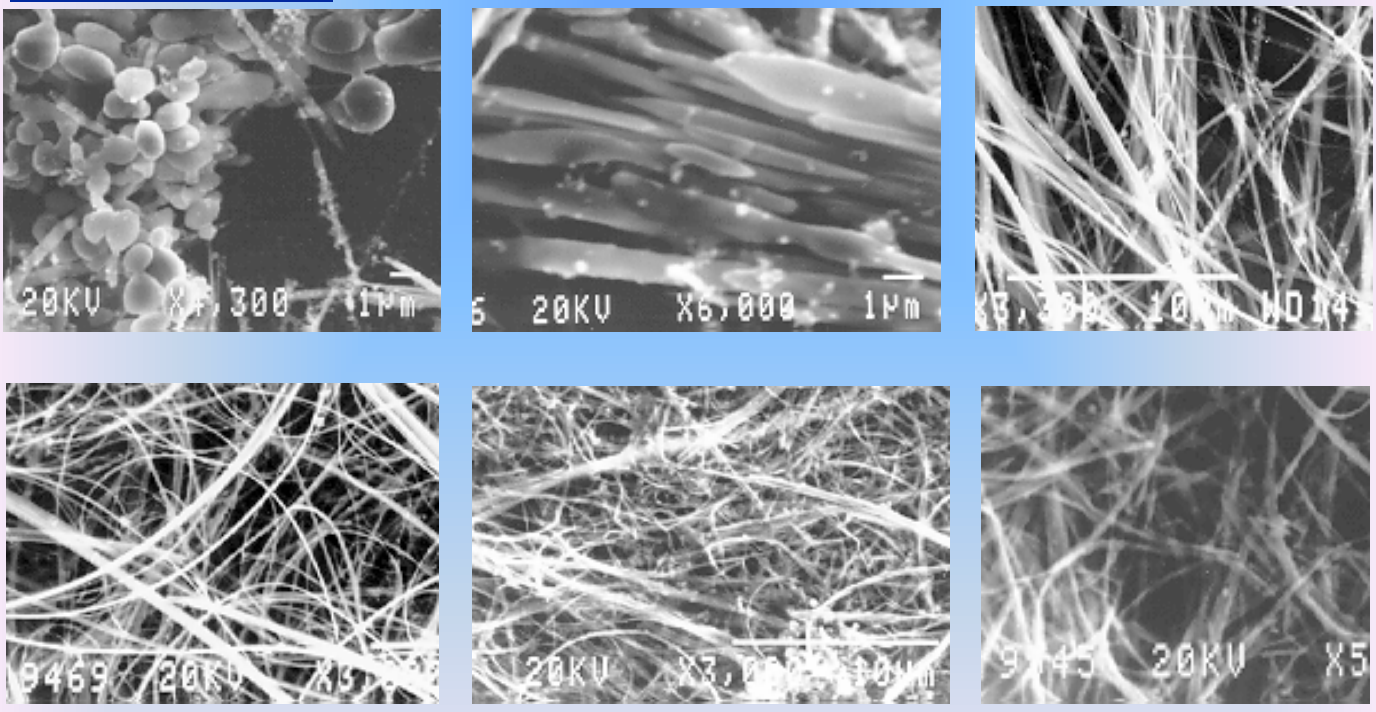
D. Raabe, D. Mattissen: Acta Materialia 46 (1998) 5973–5984
„Microstructure and mechanical properties of a cast and wire drawn ternary Cu-Ag-Nb in situ composite“

Cu-4%Nb-8.2% Ag

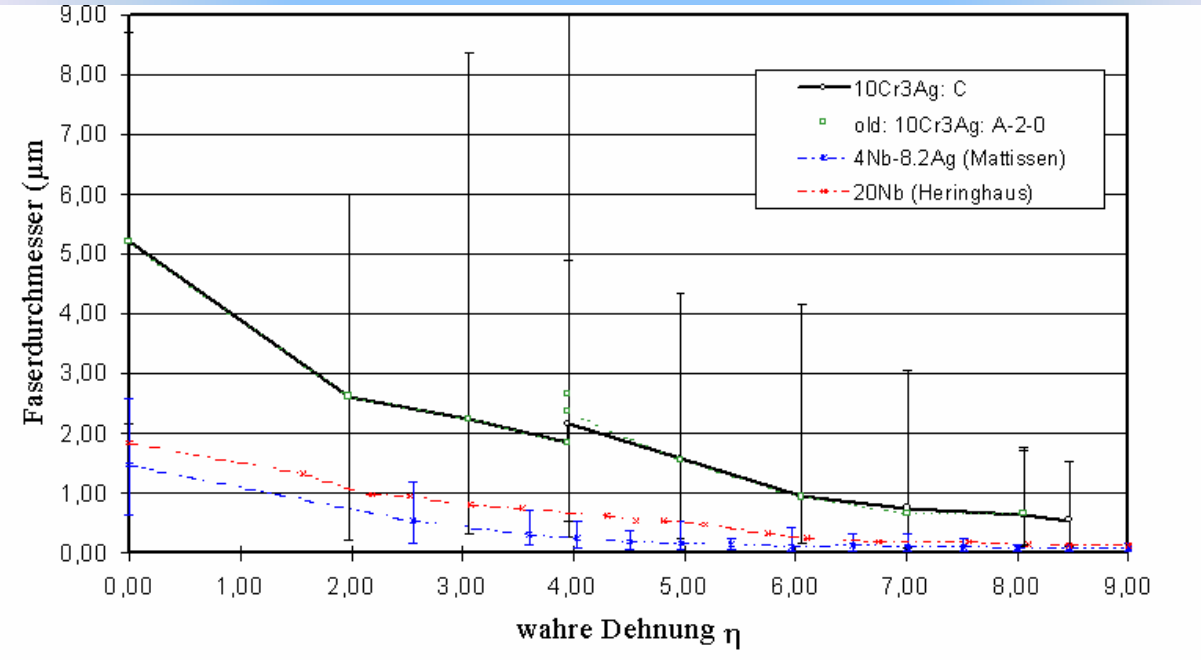


D. Raabe, D. Mattissen: Acta Materialia 46 (1998) 5973–5984
„Microstructure and mechanical properties of a cast and wire drawn ternary Cu-Ag-Nb in situ composite“

ε=90%-99.996%

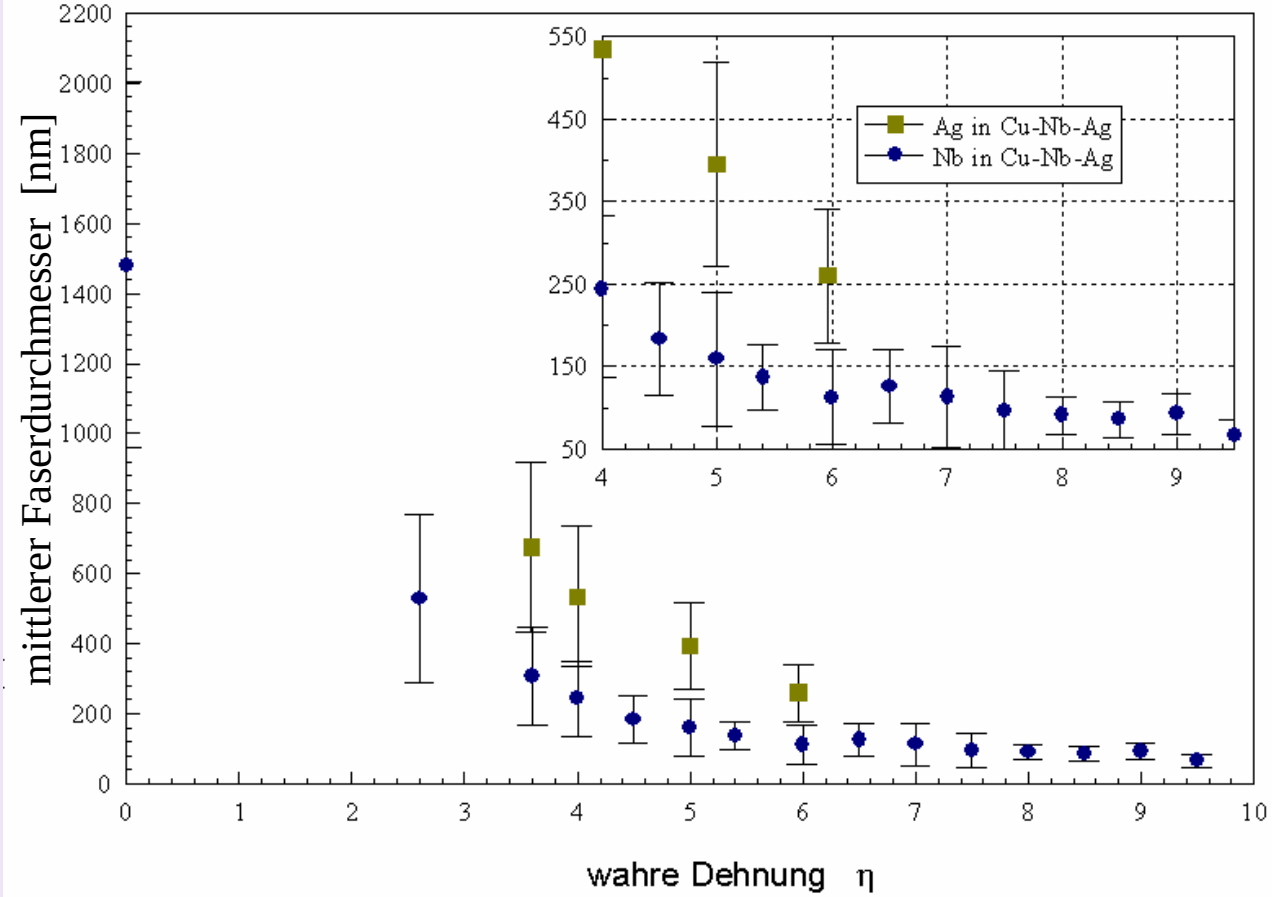


Filaments



D. Raabe, K. Miyake, H. Takahara: Material Science and Engineering, A 291 (2000) 186-197
„Processing, microstructure, and properties of ternary high–strength Cu–Cr–Ag in situ composites“

Filaments



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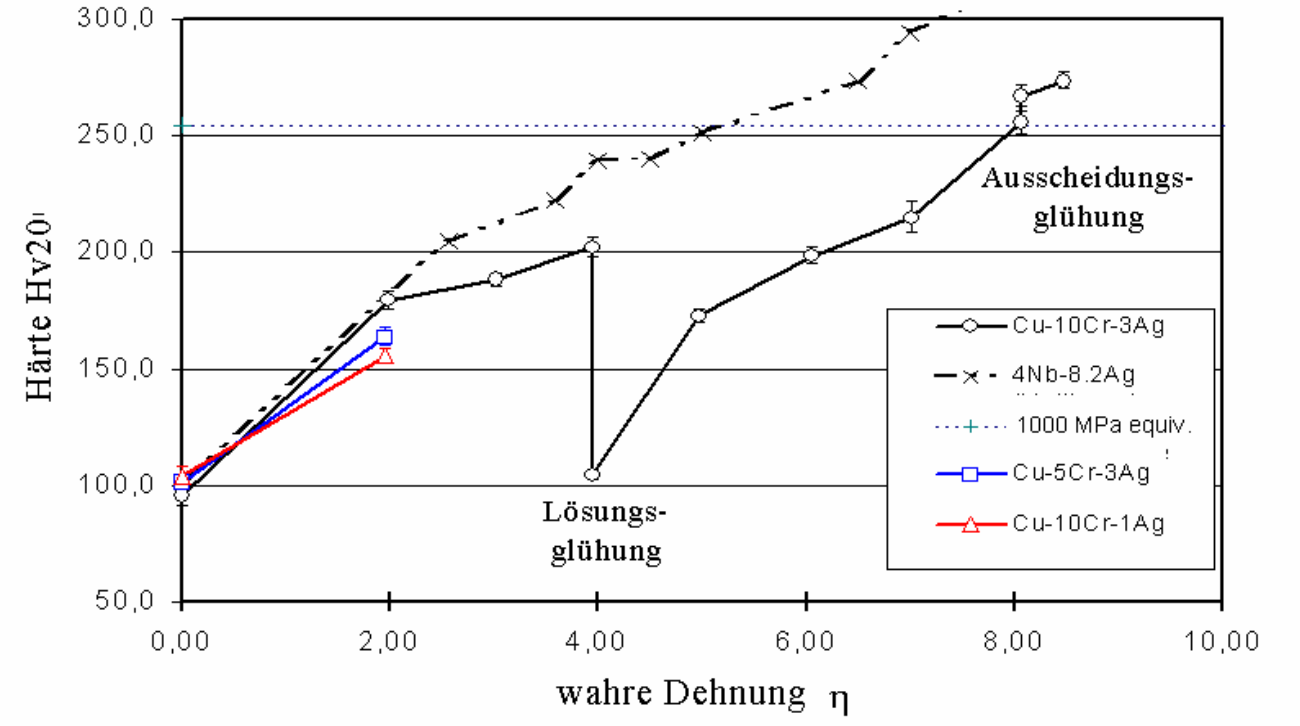

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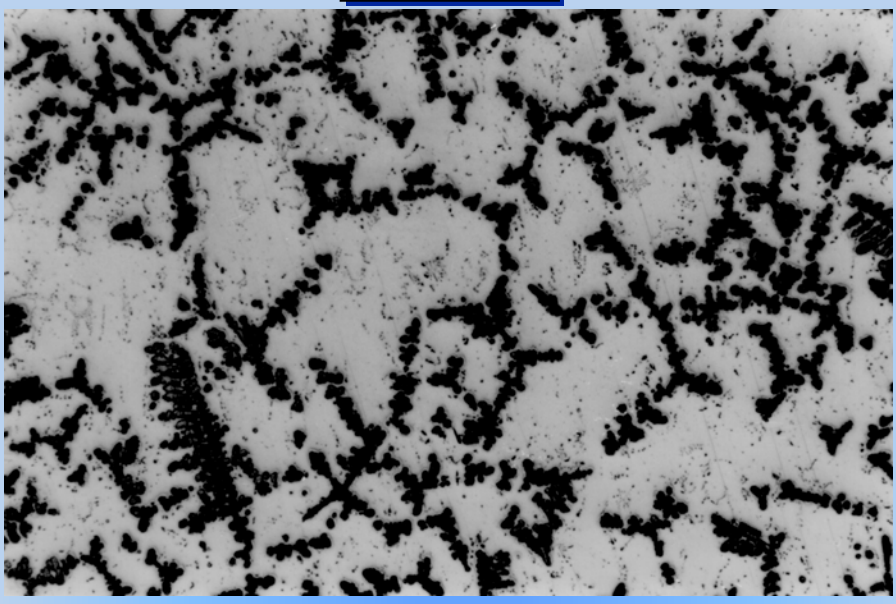
„Processing, microstructure, and properties of ternary high–strength Cu–Cr–Ag in situ composites“

Filaments

Cu-10%Cr-3%Ag

mit Matrix



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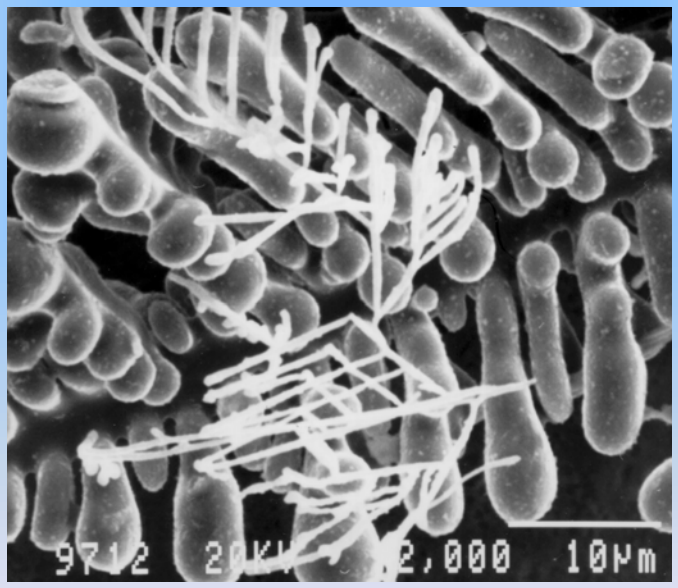
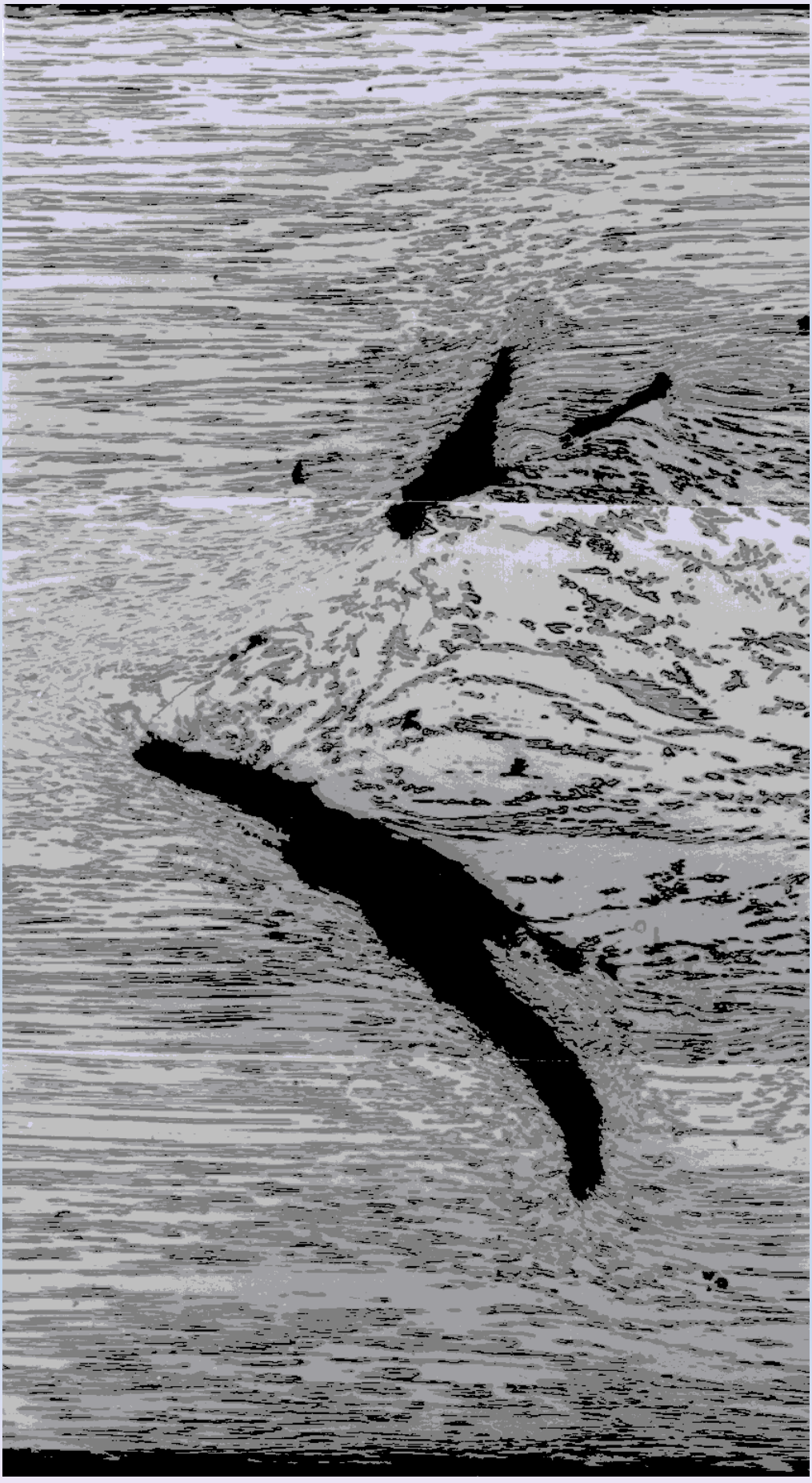
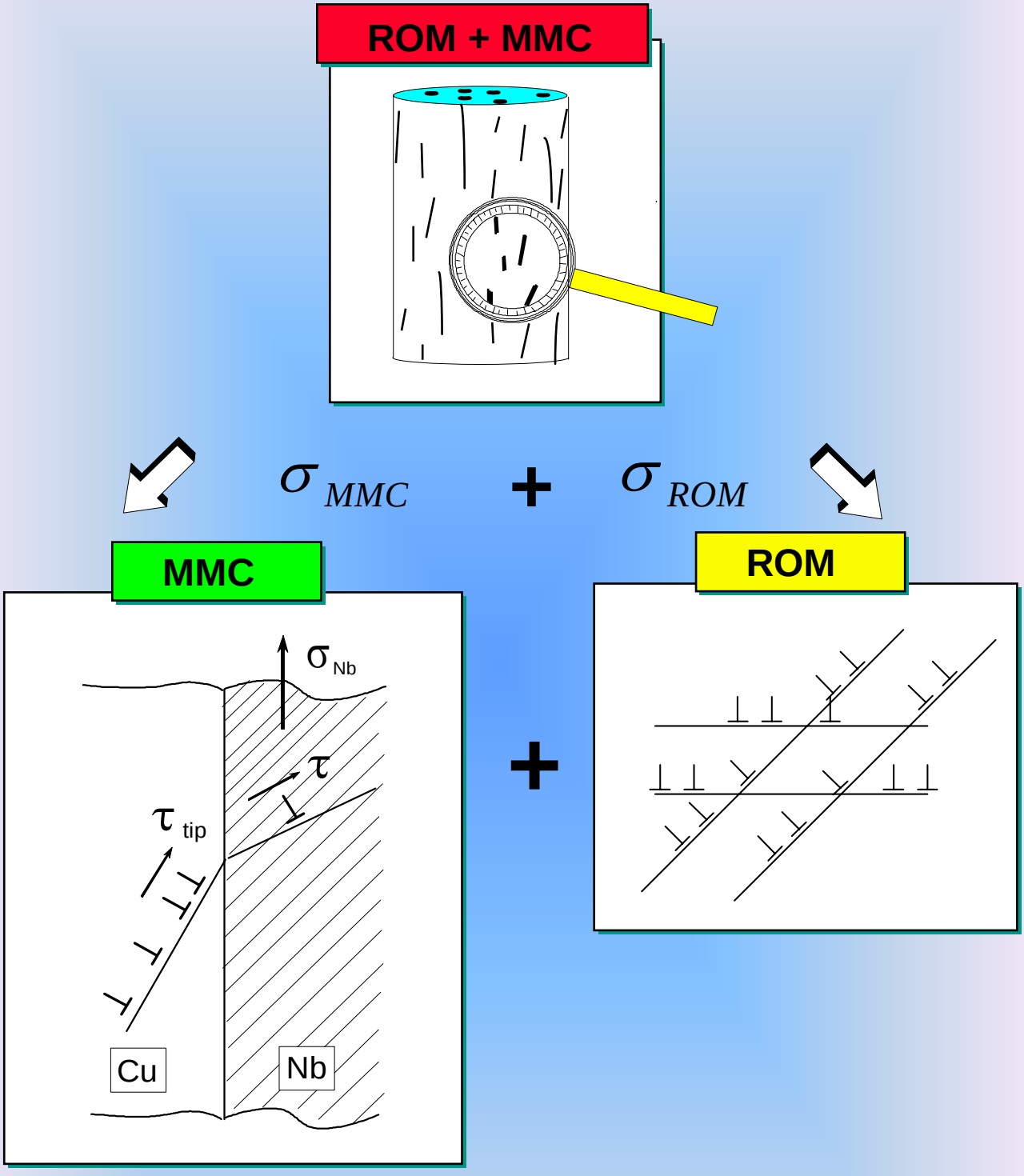
ohne Matrix



Filaments



Strength



U. Hangen, D. Raabe: Acta Metall 43 (1995) 4075–4082
„Modelling of the yield strength of a heavily wire drawn Cu-20%Nb composite by use of a modified linear rule of mixtures“

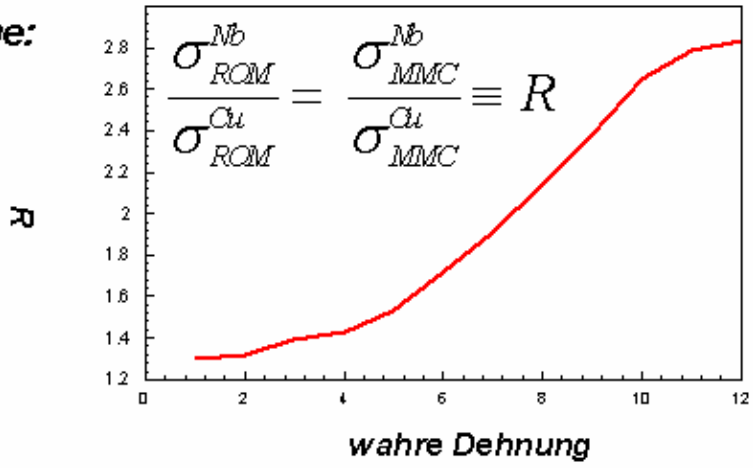
Strength

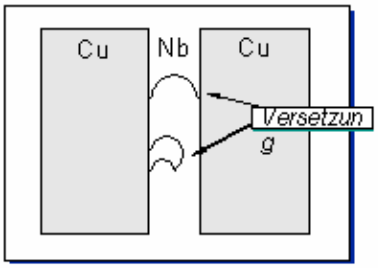
$$\sigma_{P0,2} = \sigma_{ROM} + \sigma_{MMC}$$

$$\sigma_{ROM} = \sigma_{ROM}^{Cu} \cdot V_{Cu} + \sigma_{ROM}^{Nb} \cdot V_{Nb} \qquad \sigma_{MMC} = \sigma_{MMC}^{Cu} \cdot V_{Cu} + \sigma_{MMC}^{Nb} \cdot V_{Nb}$$

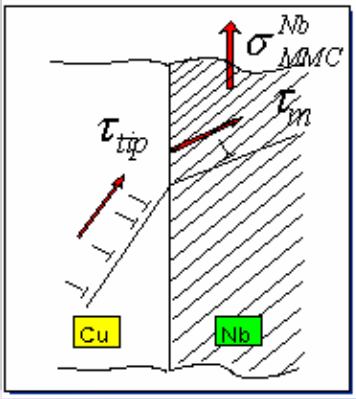
Annahme:

$$\frac{\sigma_{ROM}^{Nb}}{\sigma_{ROM}^{Cu}} = \frac{\sigma_{MMC}^{Nb}}{\sigma_{MMC}^{Cu}} \equiv R$$





$$\tau_m = \frac{A \cdot G \cdot b}{2\pi \cdot S} \cdot \ln\left(\frac{S}{b}\right) \quad ; \quad A \equiv 1.2$$



$$\tau_{tip}^{Cu} = \tau_{plp}^{Cu} \cdot n_{plp} = \frac{1}{m} \cdot \left(\tau_m - \frac{\sigma_{MMC}^{Nb}}{M_{Nb}} \right)$$

$$n_{plp} = \frac{\tau_{plp}^{Cu} \cdot \lambda^{+} \cdot (1 - \nu_{Cu})}{G_{Cu} \cdot b_{Cu}}$$

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„Modelling of the yield strength of a heavily wire drawn Cu-20%Nb composite by use of a modified linear rule of mixtures“

Strength

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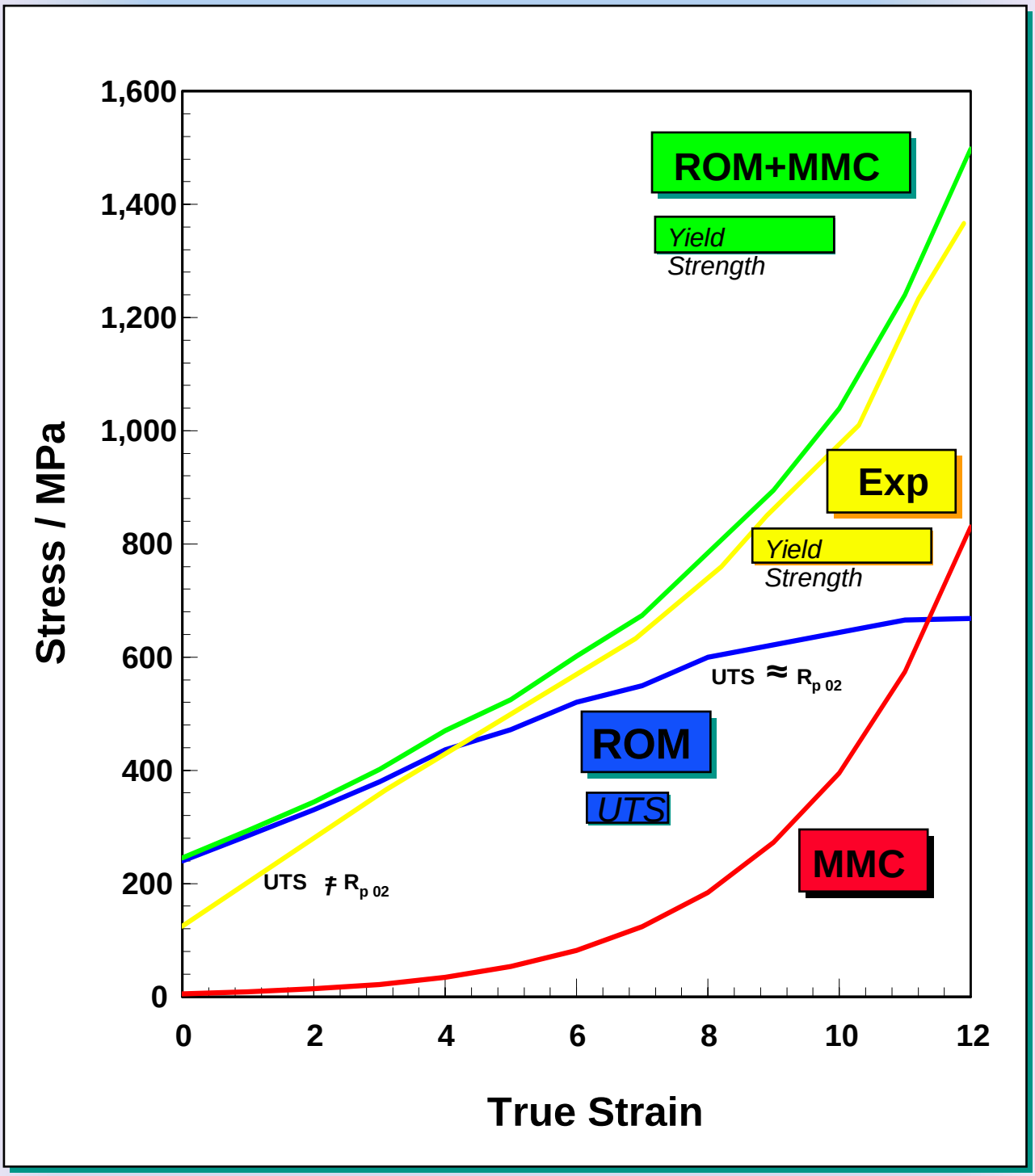

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