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Using of spouted bed spray granulation process for fabricating of metal/ceramic-polymer composites

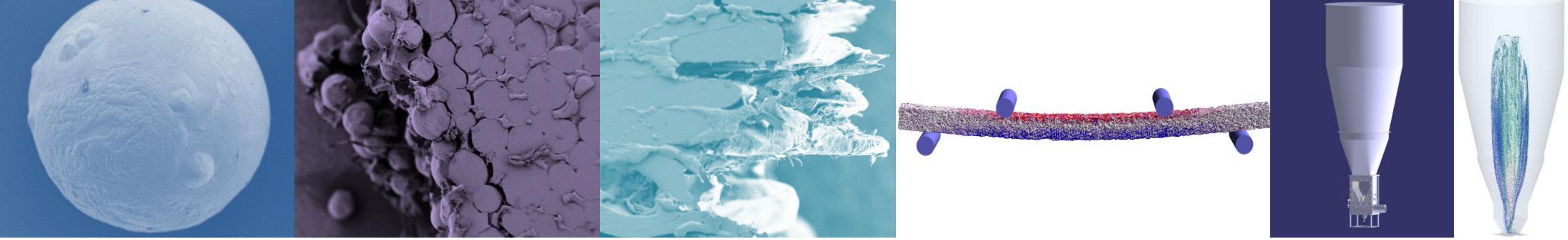
Eduard Eichner
Hamburg University of Technology, Institute of Solids Process Engineering and Particle Technology , Germany, eduard.eichner@tuhh.de

V. Salikov
Hamburg University of Technology, Institute of Solids Process Engineering and Particle Technology , Germany

M. Dosta
Hamburg University of Technology, Institute of Solids Process Engineering and Particle Technology , Germany

S. Heinrich
Hamburg University of Technology, Institute of Solids Process Engineering and Particle Technology , Germany

G.A. Schneider
Hamburg University of Technology, Institute of Advanced Ceramics, Germany



Using dilute spouting for fabricating of highly filled metal-polymer composite materials

Eduard Eichner[1], Vitalij Salikov[1], Maksym Dosta[1], Stefan Heinrich[1], Gerold A. Schneider[2]

[1] Institute of Solids Process Engineering and Particle Technology
[2] Institute of Advanced Ceramics, Hamburg University of Technology

Introduction
Artificial vs. biological structural materials

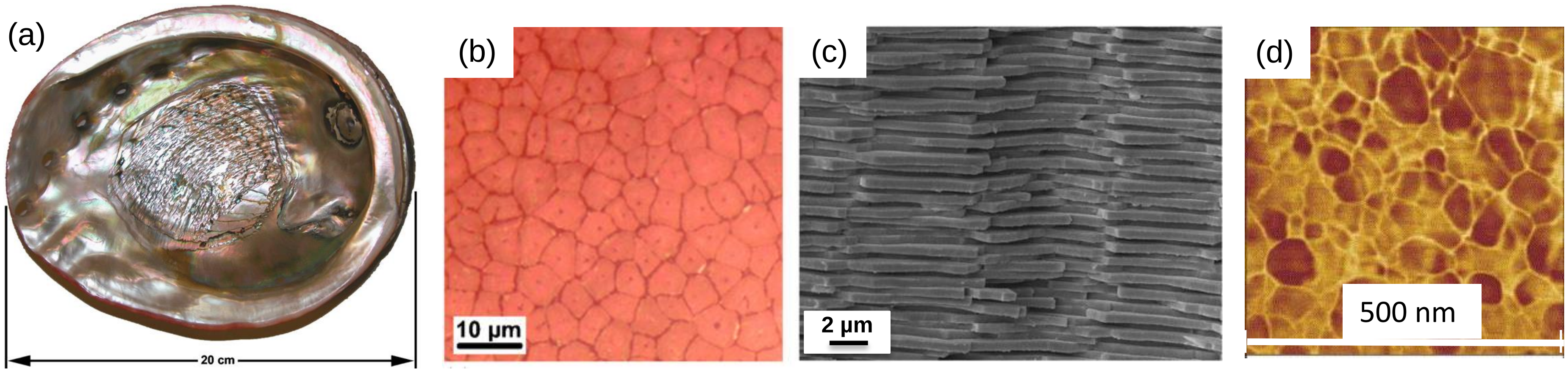
metals/alloys:
- great mechanical properties
- energy-intensive production
- often high density
- electrically conducting

ceramics:
- hard, strong
- difficult to process
- brittle and sensitive to structural defects

polymers:
- ductile
- easy to process
- soft

Biomaterials are well designed

Nacre



- **Highly filled** 95 vol.-% mineral (ceramic)
- 5 vol.-% proteins (polymer)
- Platelets (**high aspect ratio**)
- **Hierarchical structure**

→

High fracture toughness
Strength: up to 120 MPa
Elastic modulus: 40-70 GPa

(a, b, c) Barthelat, F.; Tang, H.; Zavattieri, P.D.; Li, C.-M.; Espinosa, H.D.: *On the mechanics of mother-of-pearl: A key feature in the material hierarchical structure*. J. Mech. Ph. Solids 55 (2007) 306-337

(d) Rousseau, M.; Lopez, E.; Stempflé, P.; Brendlé, M.; Franke, L.; Guette, A.; Naslain, R.; Bourrat, X.: *Multiscale structure of sheet nacre*. Biomaterials 26 (2005) 6254-6262

Aim: fabrication of bulk hierarchical materials

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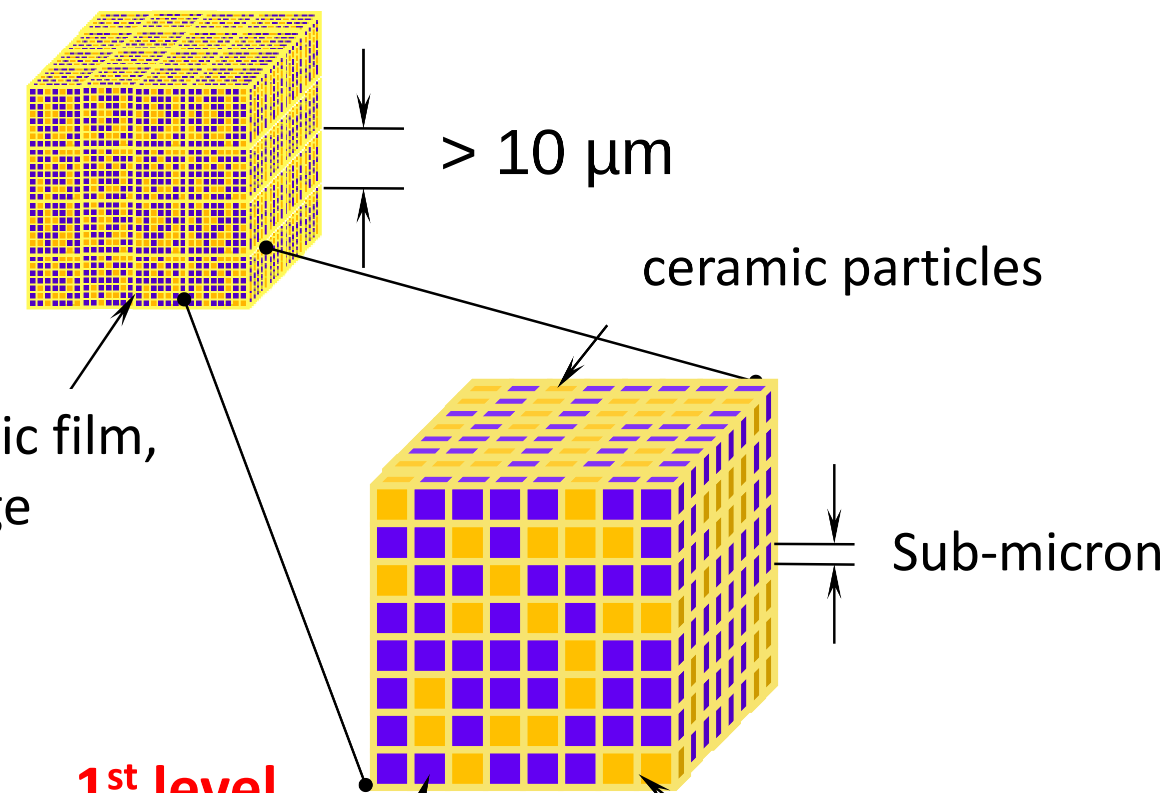
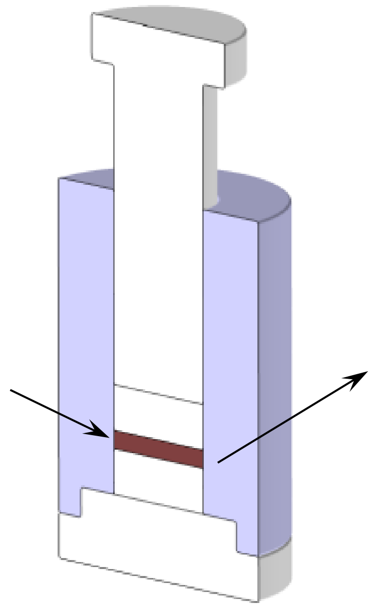


warm compaction at T = 160 °C > T_g
and high pressure 500, 750 MPa

copper powder
d_p≈30µm

spouted bed coating

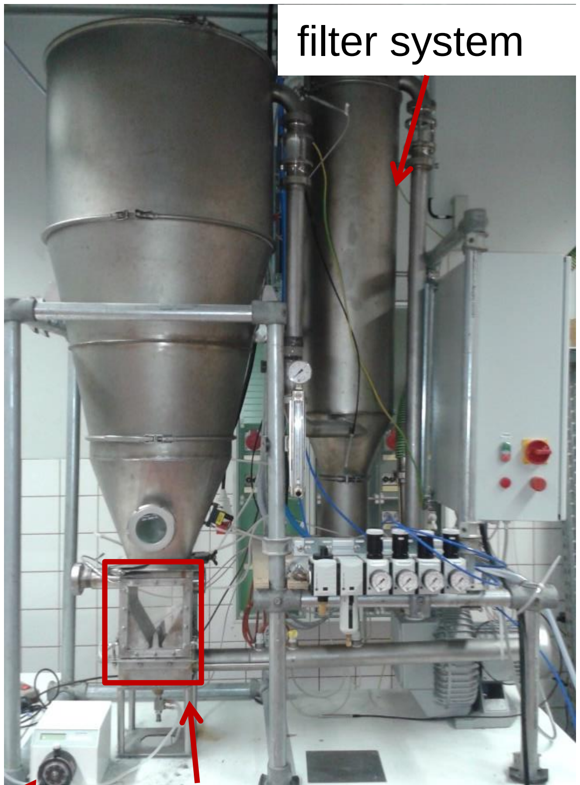
copper-polymer
granules



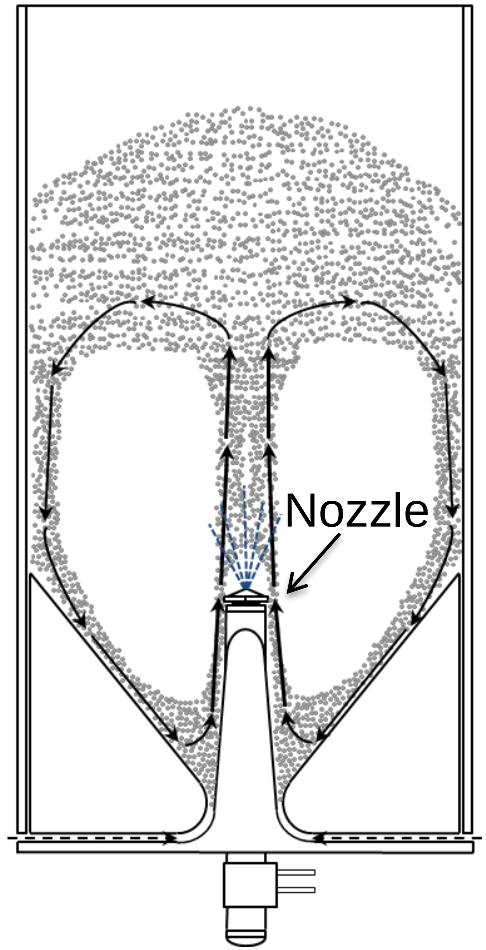
metal-polymer
composite

(bending bars)

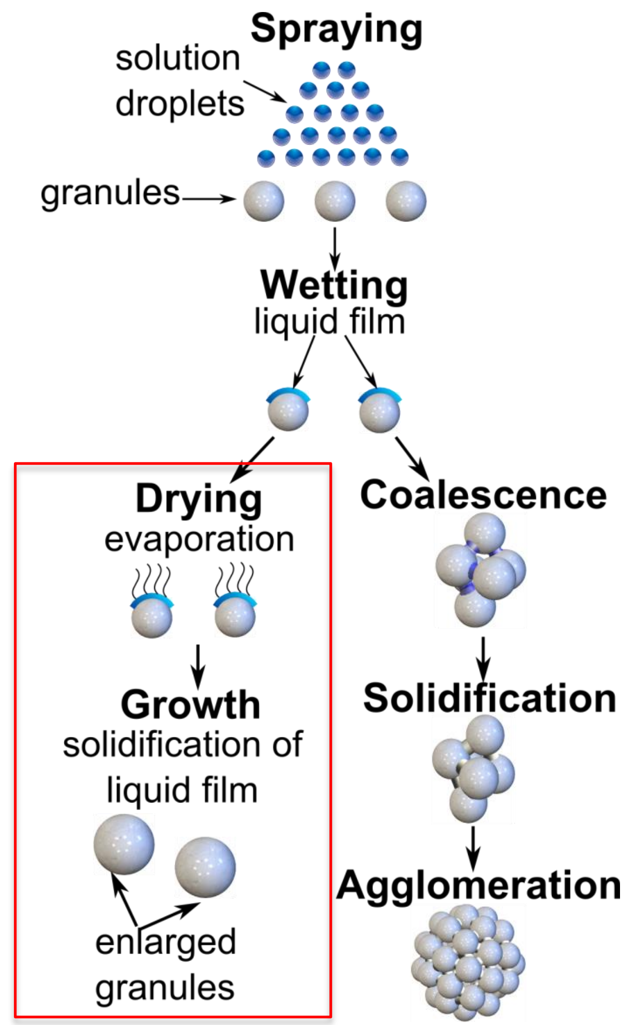
Coating of ceramic-polymer composites
Spouted bed granulation



spouted bed apparatus optimized for fine particles



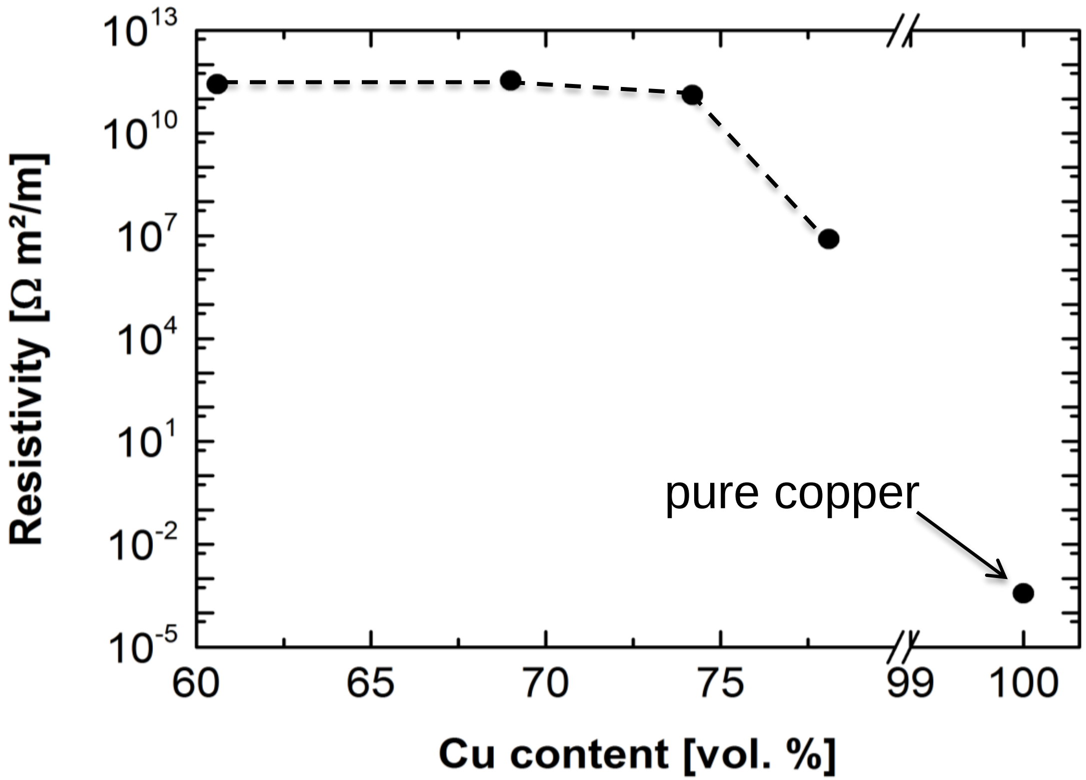
particle movement in the process chamber



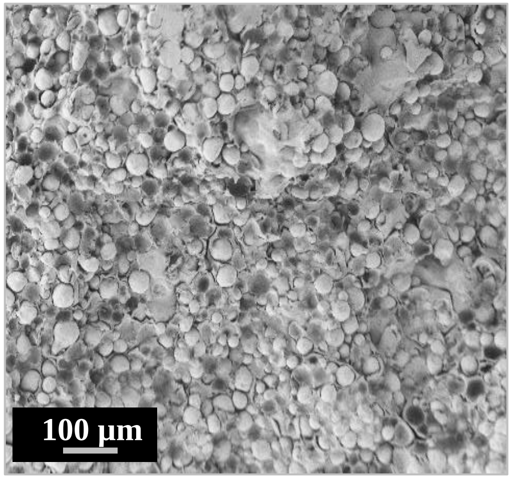
particle formulation process

Electrical properties of copper-polymer composites
Resistivity

- Good insulator properties of metal polymer composites
- These results reveal that particles are uniformly coated (separated from each other by polymer and screened)
- In spite of 78 vol.% of copper composites are insulator (10^5 Ωm)



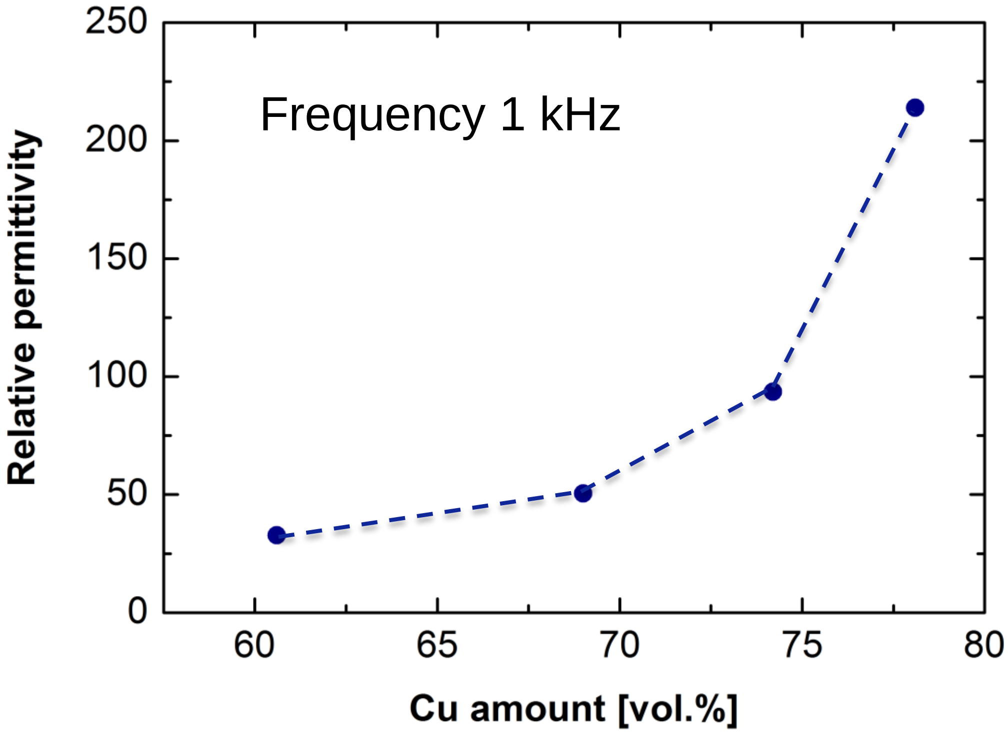
Bulk material (Cu 60 vol.%)



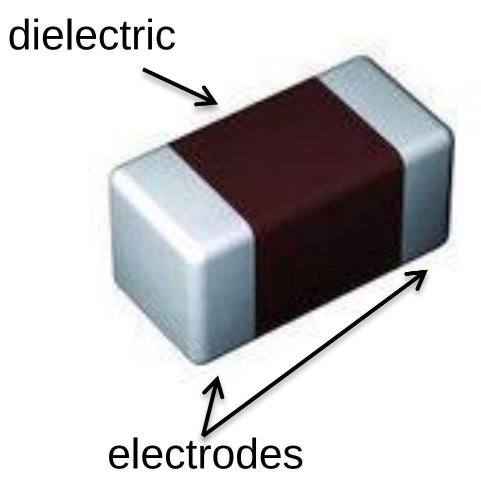
- Good relative permittivity of copper-polymer composites
- The relative permittivity on high metal contents above 200

$$C = \varepsilon_0 \varepsilon_r * \frac{A}{d}$$

C capacitance [F]
ε_r relative permittivity [ ]
d distance between plates [m]
ε_0 electric constant 8.854×10^{-12} F·m^{-1}
A cross section area of electrode plates [m^2]



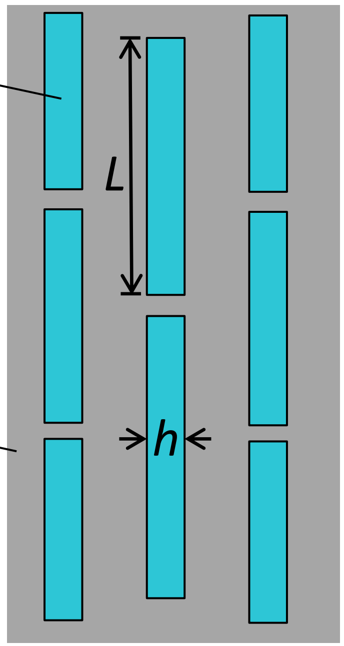
condenser



Design parameter aspect ratio
Current research

Aspect ratio: $\boldsymbol{\rho = L/h}$

$$\frac{1}{E} = \frac{4(1-\Phi)}{G_m \Phi^2 \rho^2} + \frac{1}{\Phi E_p} \rightarrow \boxed{E \propto G_m \rho^2}$$



Large aspect ratio of mineral crystals can compensate softness of matrix

matrix (polymer) particles

$$S = min\left(\frac{\Phi \rho S_m}{2}, \frac{\Phi S_p}{2}\right)$$

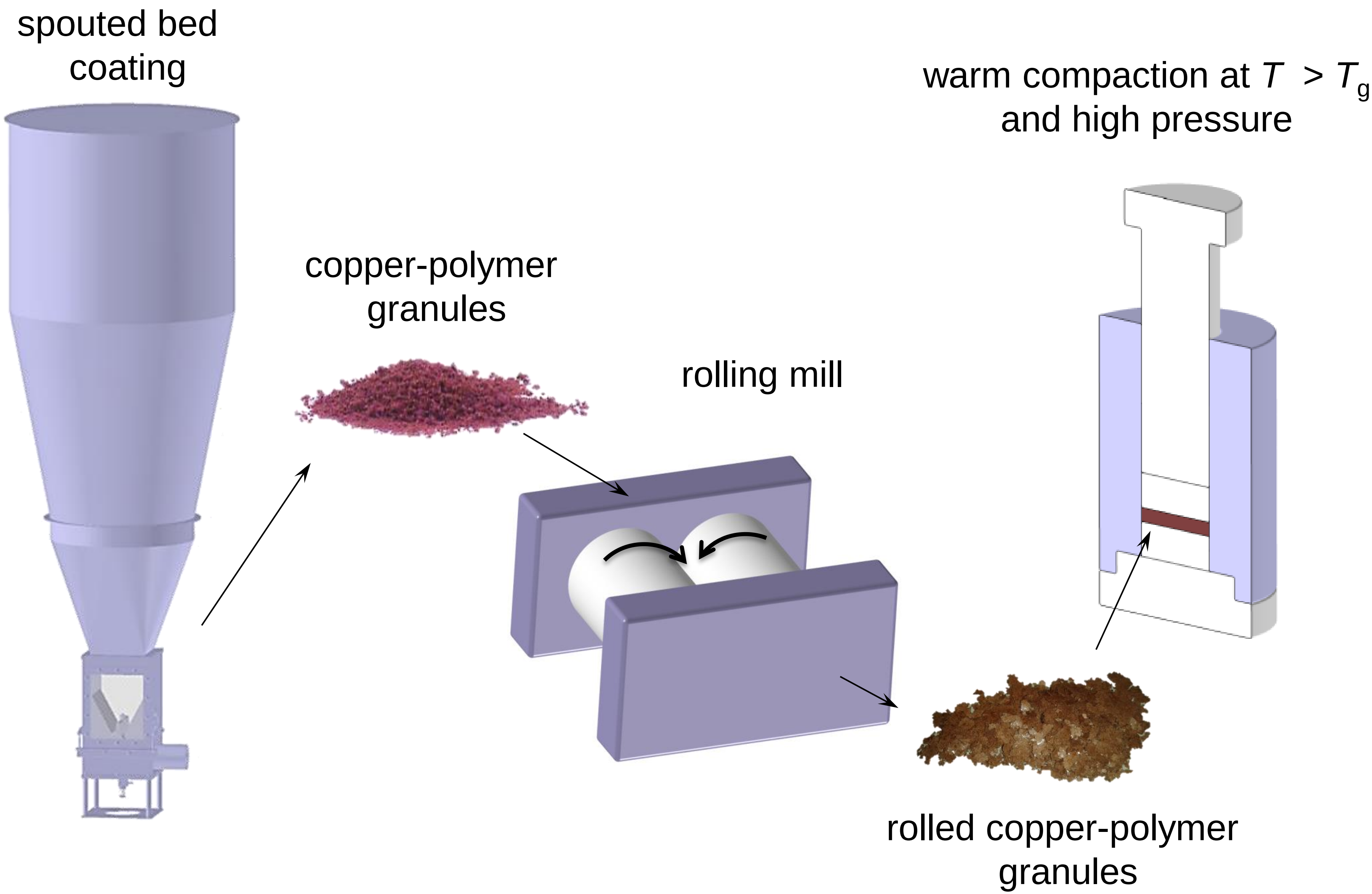
Optimal design of composite materials: $S_p = S_{int} = S_m/\rho$

G_m: shear modulus of matrix
S_m: strength of matrix
Φ: volume fraction of particles
S_p: tensile strength of particles
E: Young's modulus
S_{int}: strength of interface

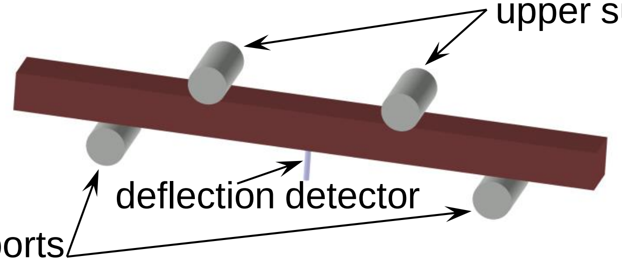
Gao, H.; *Application of fracture mechanics concepts to hierarchical biomechanics of bone and bone-like materials,* International Journal of Fracture 138 (2006) 101-137.

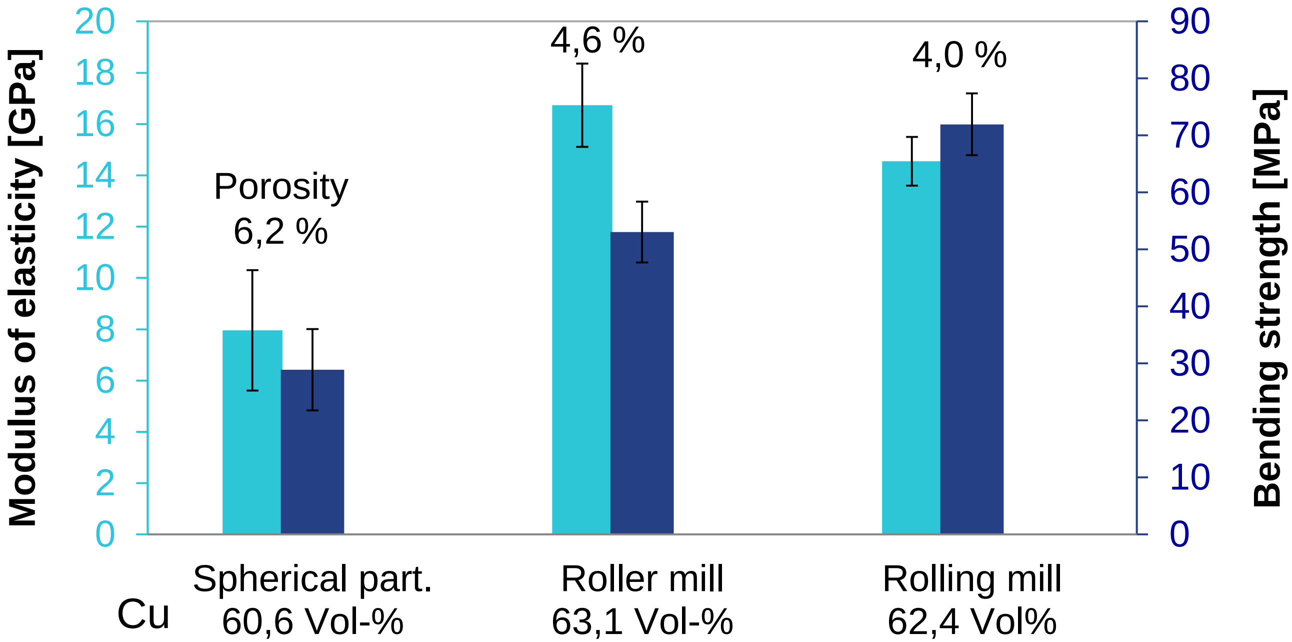
Deformation of copper-polymer agglomerates

Extension of process route by rolling

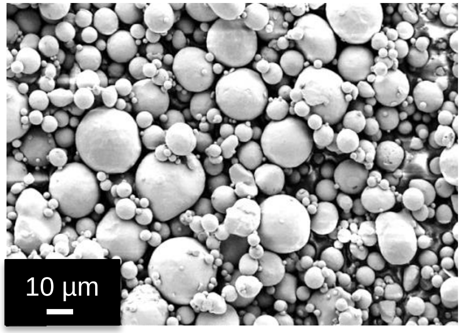


4-point-bending tests for determination of mechanical properties

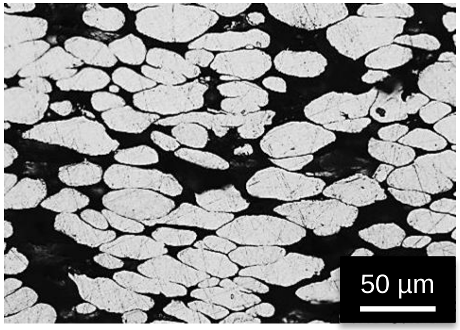




Original copper particles



Rolled copper particles



Enhancement of mechanical properties of copper-polymer composites by increasing of aspect ratio of particles

Summary and outlook

Summary

- fabricating of copper-polymer composites with high resistivity
- high permittivity of copper-polymer composites
- development of new process route for studiyng of aspect ratio
- improvement of mechanical properties by rolling (higher aspect ratios)

Outlook

- use of coarser metal particles for higher aspect ratios
- use high-performance polymers (high shear modulus)
- improvement of particle-polymer interface

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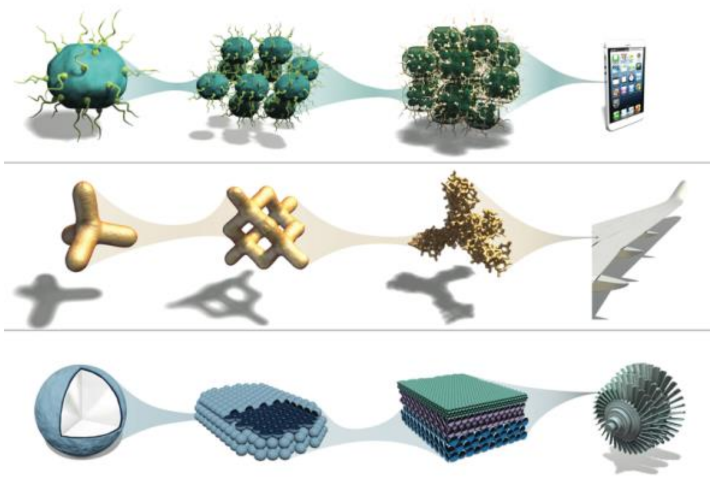

Thank you for attention!

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