2nd SCIENTIFIC WORKSHOP May 20-23,2013

ADVANCED TECHNOLOGIES OF ELECTROMAGNETIC FIELD ASSISTED CONSOLIDATION OF MATERIALS

Key Laboratory for Electromagnetic Field Assisted Processing of Novel Materials

Multiscale modeling of Spark Plasma Sintering via COMSOL™ Multiphysics

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Outline

1. The scheme of the SPS multiscale modeling approach
2. Micro scale temperature distribution in the powder particle
3. Modeling SPS as a hot-pressing
4. Free sintering by COMSOL™
5. Future development

Multiscale modeling of SPS

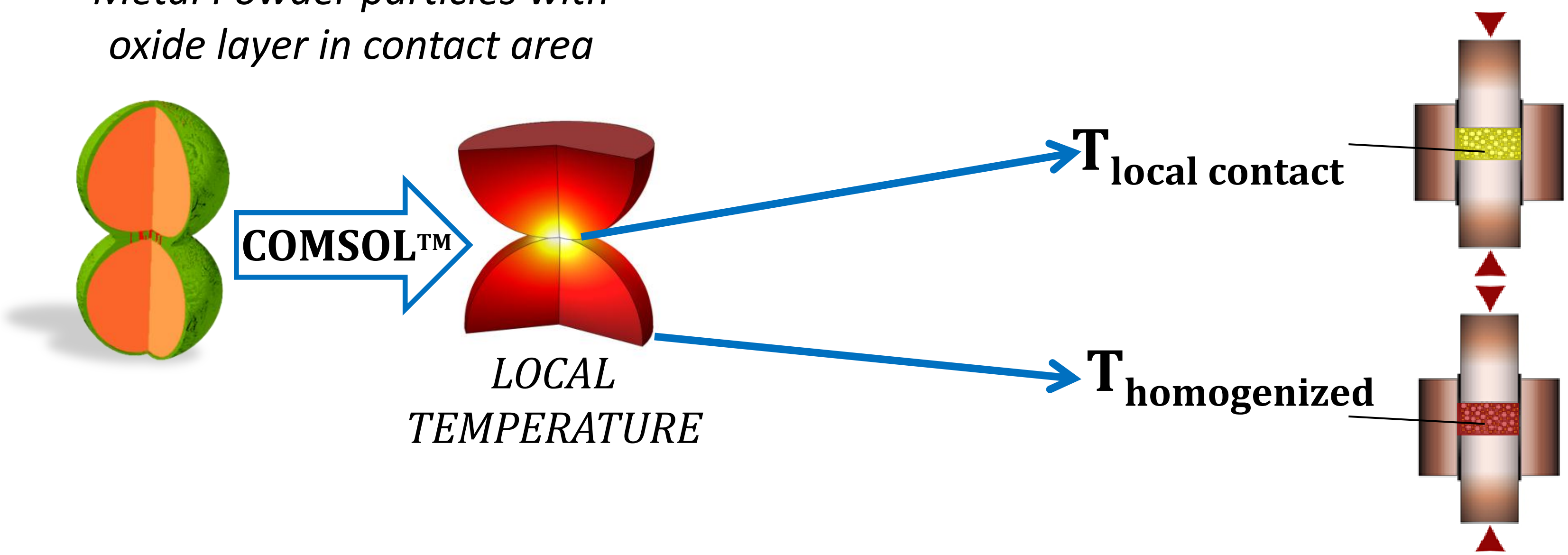
Inter contact softening hypothesis.

Problem 1
Estimation of the micro inhomogeneity of the temperature distribution

Stationary Temperature Field →

Problem 2
Macroscopic modeling of the specimen shrinkage kinetics during SPS

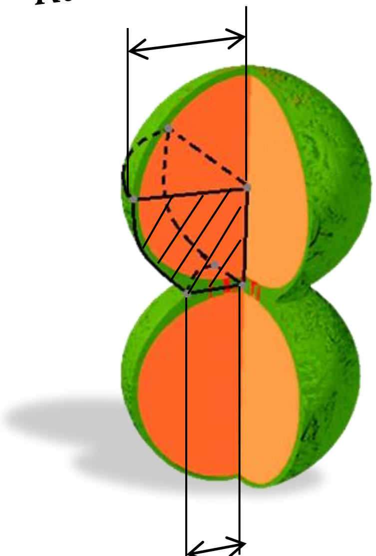
Metal Powder particles with oxide layer in contact area



Estimation of the micro inhomogeneity of the temperature distribution

CONTACT of the COPPER PARTICLES
With OXIDE layer

Radius=2÷200 μm



Contact Area Radius =Radius/5

Equations:

- **Heat Transfer equation**
- **Electric Field equation**

COMSOL MULTIPHYSICS® *Capture the Concept™*

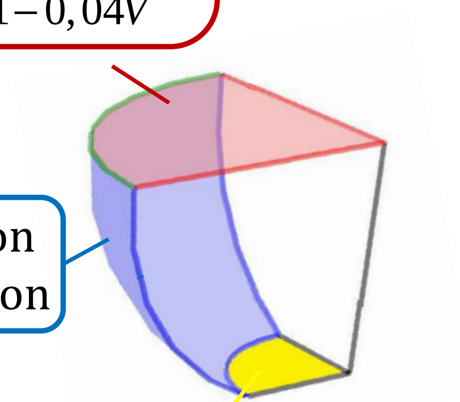
Boundary conditions:

$$T_0 = 1000\,\mathrm{K}$$

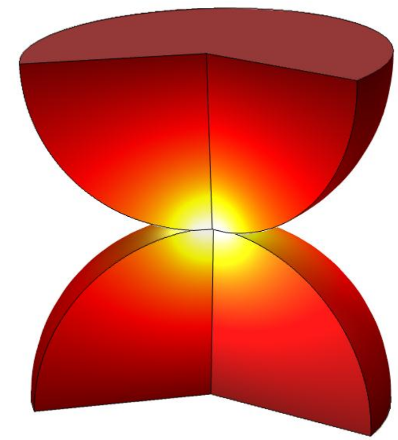
$$\vec{n}\Delta\vec{J}_{oxide-metal} = \frac{\sigma_{oxide}}{d_{oxide}}\Delta U_{oxide-metal}$$

$$\Delta U_{oxide-metal} = 0,001 - 0,04V$$

- Current Insulation
- Thermal Insulation



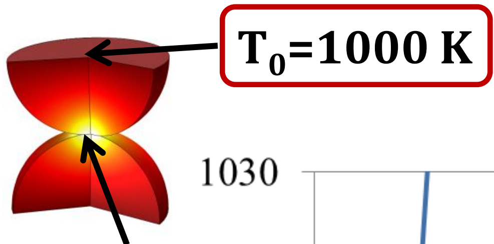
$V = 0\,\mathrm{V}$

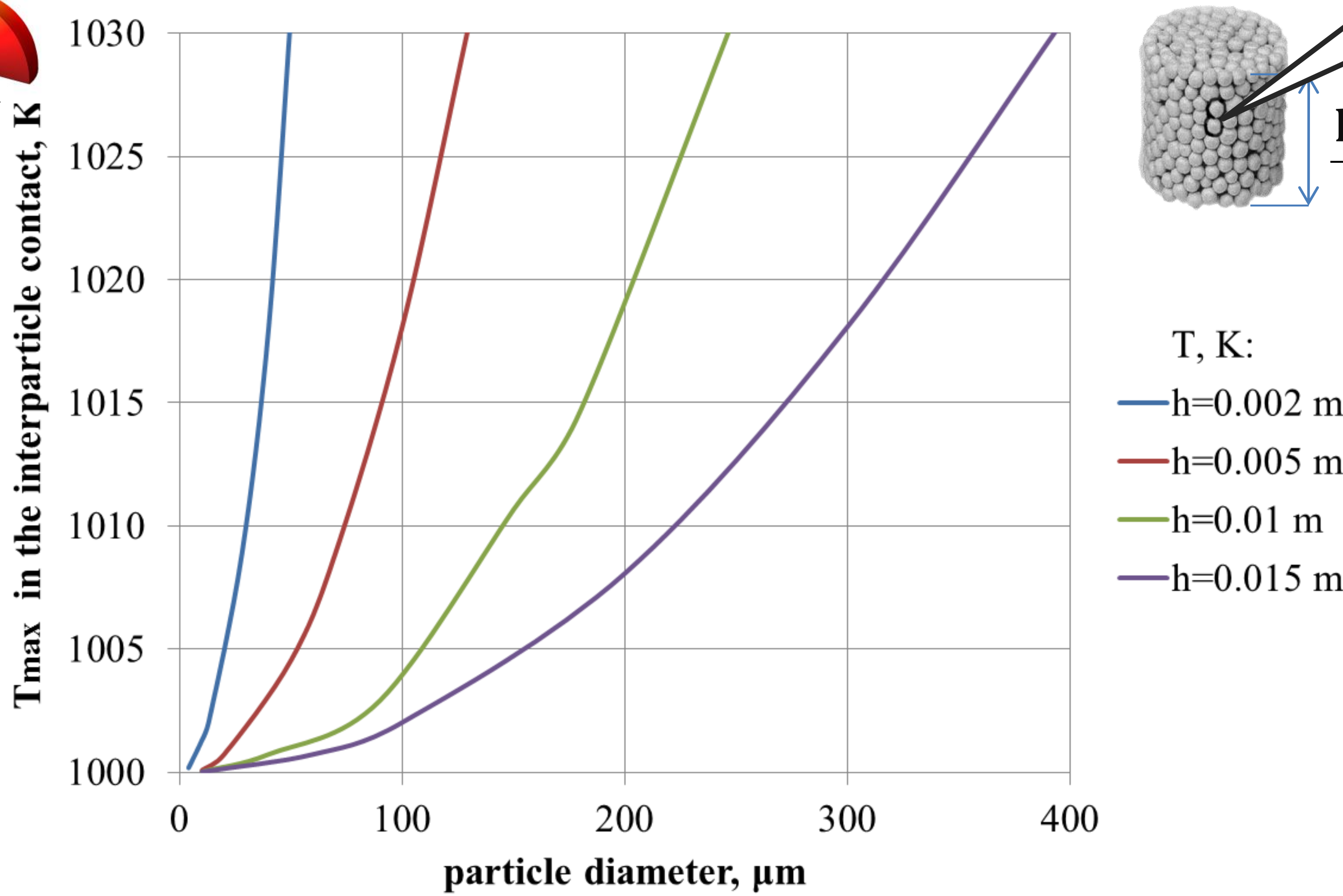


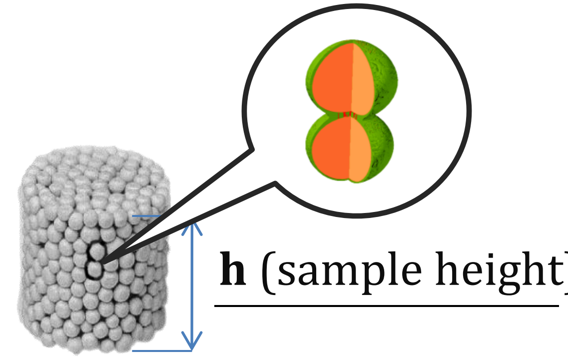
stationary LOCAL TEMPERATURE DISTRIBUTION

[1] Кузьмов А. В., Олевский Е. А., Александрова Е. В., Микронеоднородность нагрева порошка при электроспекании и её влияние на кинетику усадки. *Порошк. метал.*, 11/12, 50-60 (2012)

Micro-Scale Modeling results: Maximum temperature in contact area with presence of an oxide layer







Modeling SPS as a hot-pressing (based on microscopic temperature distribution)

$$\sigma_{ij} = W^{m-1}(\theta) \cdot A_1 \cdot \left(\exp\left(-{Q_c}/{RT} \right) \right)^{-m} \left[\varphi(\theta)\dot{\varepsilon}_{ij} + \left(\psi(\theta) - \frac{1}{3}\varphi(\theta) \right) \dot{e}\delta_{ij} \right]$$

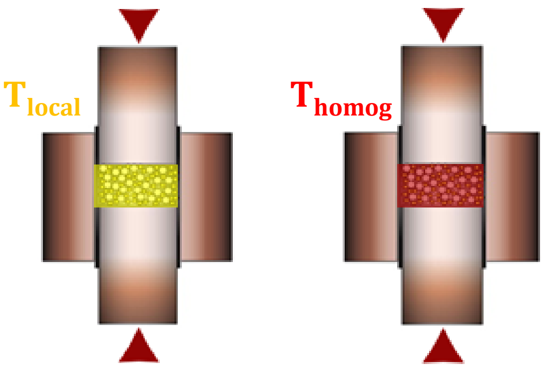
[1] E.A. Olevsky, M. Sci. En., 1998

Copper particle diameter:

$d = 100\ \mu m$

Applied Stress:

$\sigma_z = 30MPa$

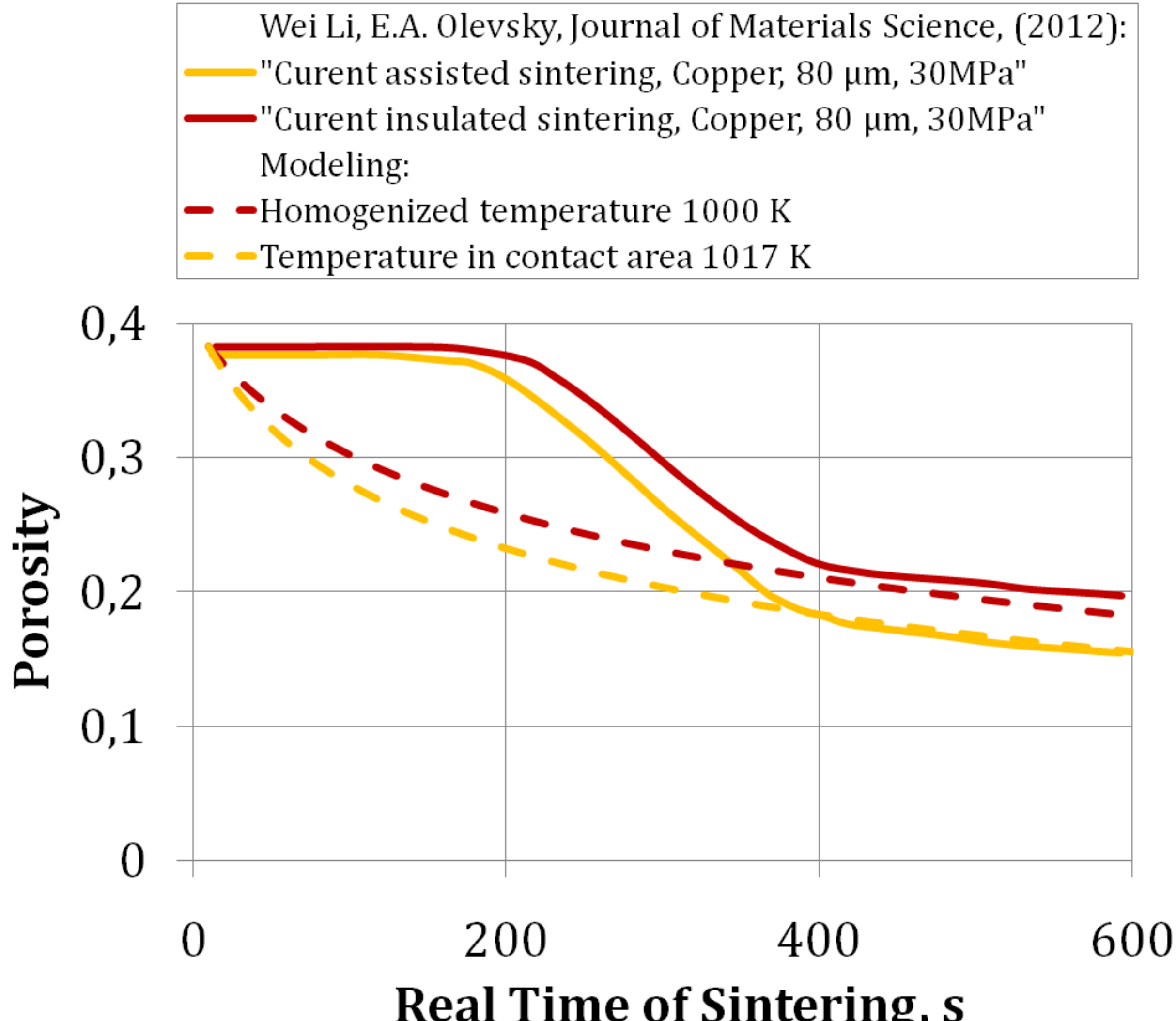


Power-law parameters:

$$A_1 = 1{,}19 \times 10^6 \left[\frac{kg \times s^{m-2}}{m^{m+1}} \right]$$

$m = 0{,}34$

$Q_c = 197 kJ / mole$



Free Sintering in COMSOL™

- Continuum Theory of Sintering

$$2\eta_0\left[\varphi\dot{\varepsilon}_{ij}+\left(\psi-\frac{1}{3}\varphi\right)\dot{e}\delta_{ij}\right]+P_L\delta_{ij}=0$$

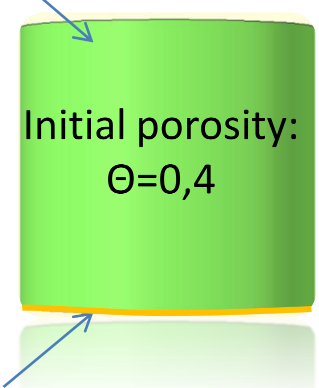
Sintering Stress

- Porosity kinetics

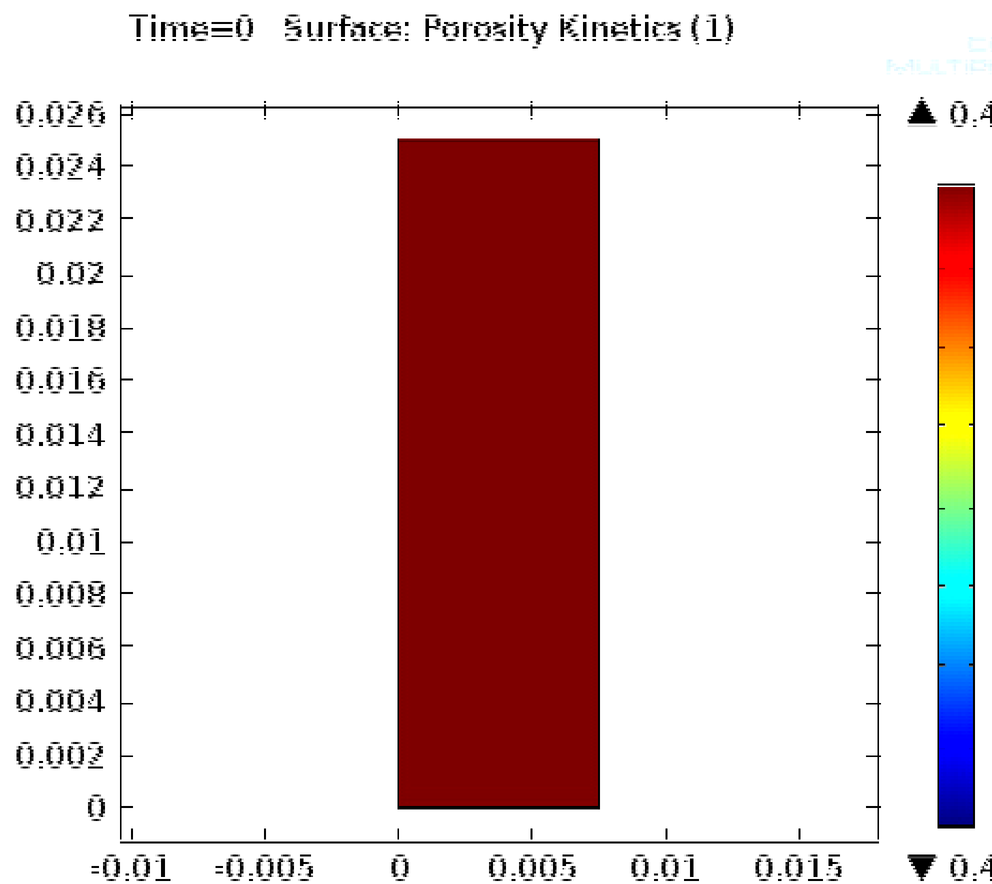
$$\frac{\partial\theta}{\partial t}-\nabla_i[(1-\theta)\dot{u}_i]=0$$

[1] E.A. Olevsky, M. Sci. En., 1998

Body load:
Sintering Stress P_L

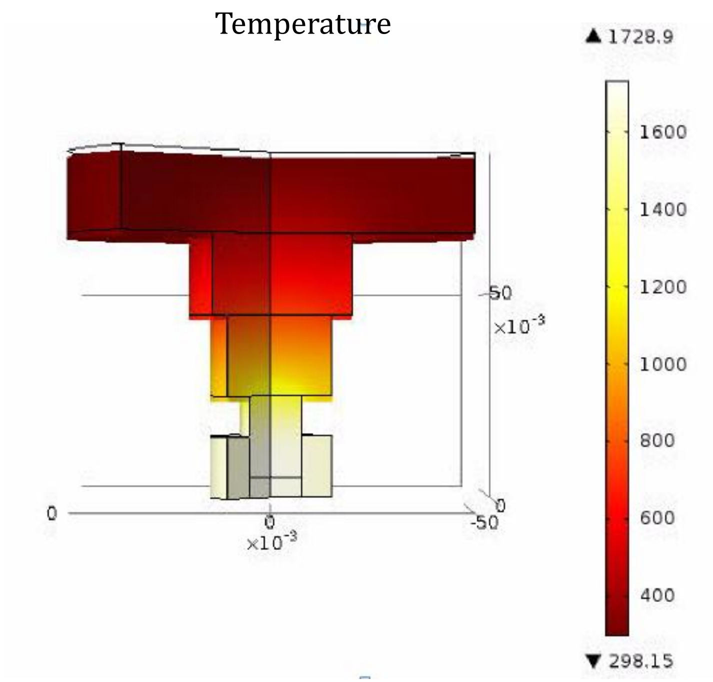


Prescribed displacement:
Uz =0



Future Development

Building of the multiscale **electro-thermo mechanical** model of SPS of the **non-linear viscous** body in COMSOL^{TM} Mutiphysics with full tooling.



Thank you for your attention!