3D Numerical Simulation of Resistance Sintering Process for Electrical Contact Applications for Breakers.

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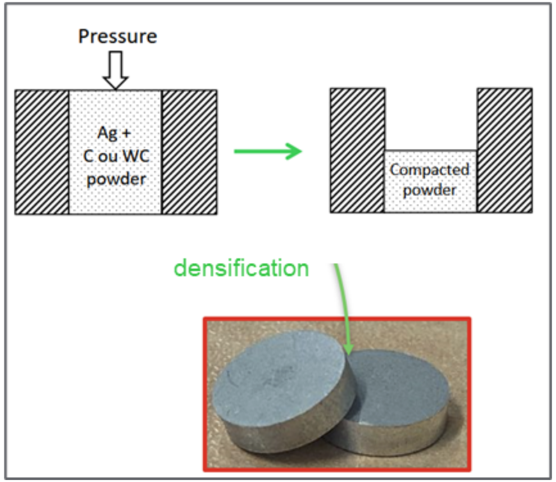
Introduction

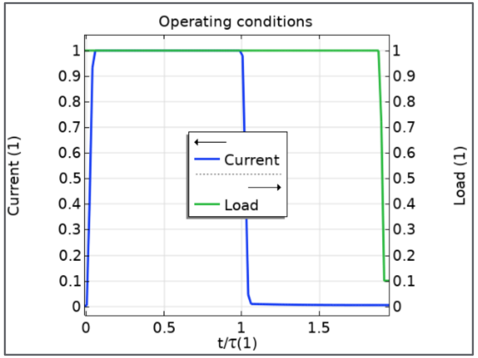
Resistance Sintering (RS) process of contact materials

Switches device

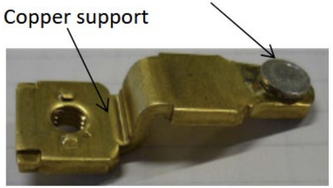


Cold compacted tip

RS device



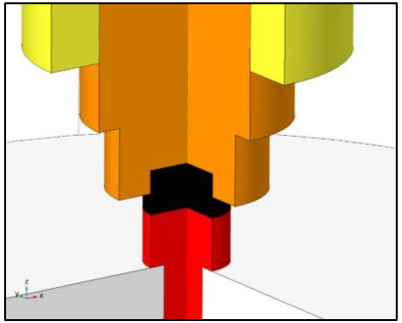
- Power heating (Joule's effect)
- Tip densification
- Deformation of the tip
- Welding to copper contact



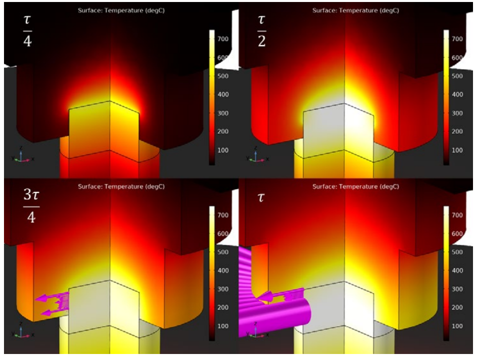
Contact Mechanism

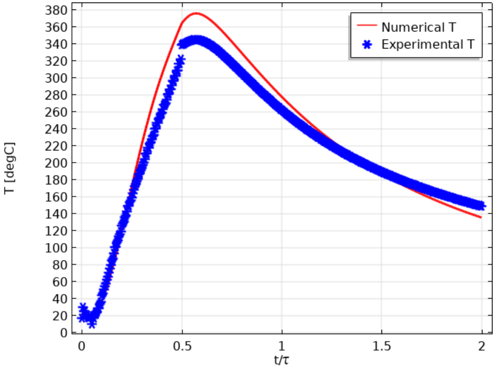
Introduction

Previous works



➔2D axi symmetrical modeling
[COMSOL Conference, 2020]

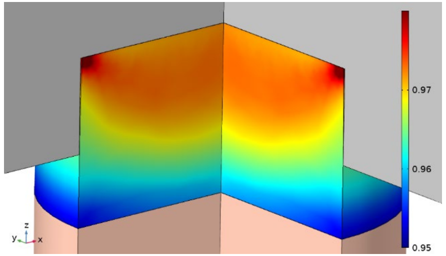




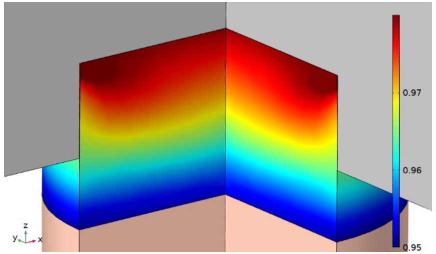
Temperature of a point located in the electrode

➔Influence of Contact Resistance (CR) models: dependance on the contact pressure.
[International Multidisciplinary Modeling & Simulation Multiconference, 2022]

Tip's density with TCR(p) and ECR(p)

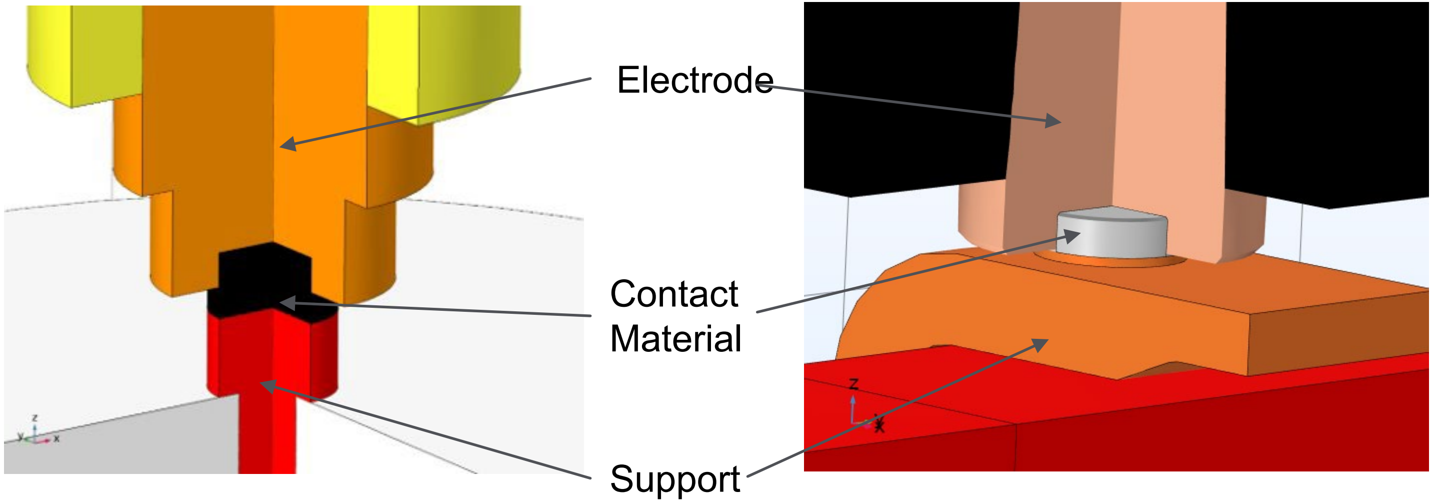


Tip's density without TCR(p) and ECR(p)



Introduction

Goal and Approach



Previous works

➔ 2D axi symmetrical modeling
➔Influence of Contact Resistance (CR) model

3D modeling (for industrial contacts*)

➔ Fully representative model of the industrial process.

**non contractual geometry.*

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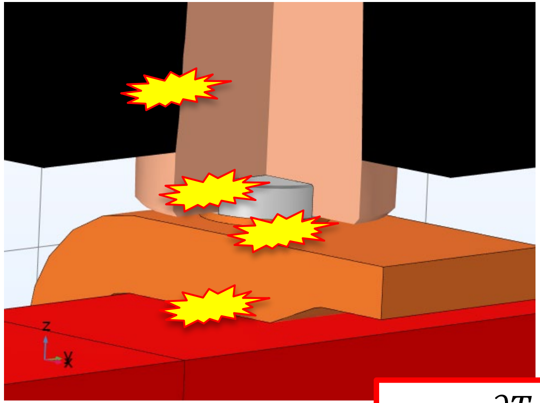
Modeling

Equations

I (A) ↓ ↓ F (N)



Mechanical

$$\nabla \cdot \sigma = \rho \frac{\partial^2 u}{\partial t^2}$$

$$\frac{1}{d}\frac{\partial}{\partial t}(d) = -tr(\dot{\epsilon})$$

$$\overline{\dot{\varepsilon_{vp}}} = \frac{1}{K^n}\frac{(\sigma_{eq}-\sigma_{yy})^n}{\sigma_{eq}} * \left(\frac{3}{2}c\bar{s} + f I_1 \bar{I}\right)$$

$$\sigma_{eq} = \sqrt{\underline{f\, I_1^2} + \underline{3\, c\, J_2}}$$

Mechanical → Electrical: $d, S_{contact}$

Thermal → Mechanical: d, T

Electrical

$$\nabla \cdot (\sigma_{elec} \nabla V) = 0$$

$$\sigma_{élec}(T) = \underline{\sigma_0(T)} * \underline{(F_1(d) + F_2(d, T, T_{max}))}$$

Thermal

$$\rho\, Cp \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + P$$

$$\mathrm{k}(T) = \underline{k_0(T)} * \underline{(F_1(d) + F_2(d, T, T_{max}))}$$

Electrical ⇄ Thermal: *Joule heating*

$$P = \sigma_{élec}\,(\nabla V^2)$$

Variables

$\{\boldsymbol{u}\}$

V

T

Dense material (red underline) — Consideration of densification (blue underline)

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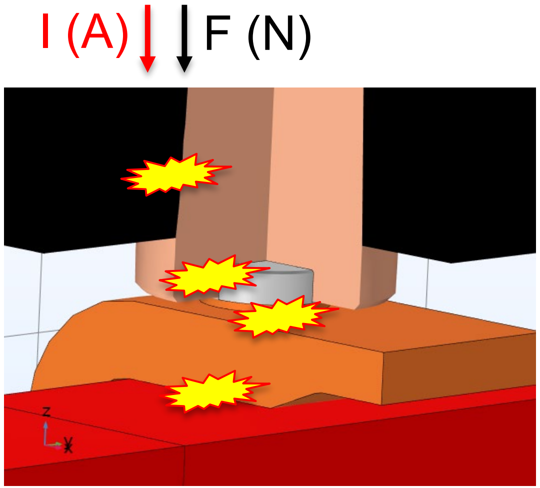
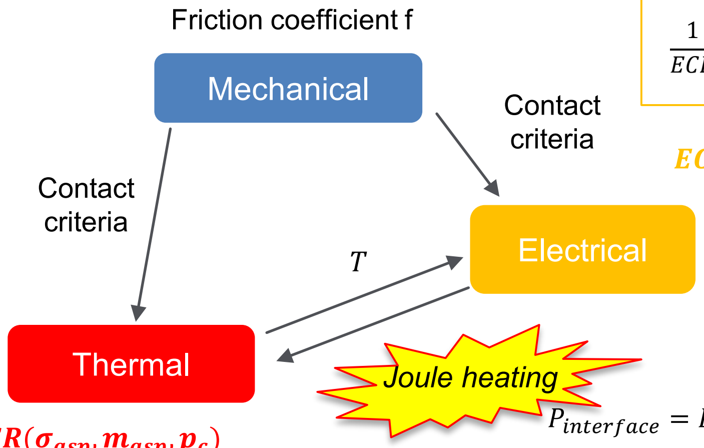
Modeling

Contact resistances ➔ Mikic model





$$\frac{1}{ECR} = 1.54 \cdot \sigma_c \frac{m_{asp}}{\sigma_{asp}} \left(\frac{p_c \sqrt{2}}{m_{asp} E_c} \right)^{0.94}$$

$ECR(\sigma_{asp}, m_{asp}, p_c)$

$$\boldsymbol{n} \cdot \boldsymbol{j_1} = \frac{1}{ECR}(V_2 - V_1)$$

$$\boldsymbol{n} \cdot \boldsymbol{j_2} = \frac{1}{ECR}(V_1 - V_2)$$

$$P_{interface} = ECR \cdot (\Delta j)^2$$

$TCR(\sigma_{asp}, m_{asp}, p_c)$

$$\boldsymbol{n} \cdot \boldsymbol{q}_1 = \frac{1}{TCR}(T_2 - T_1) + \alpha . P_{interface}$$

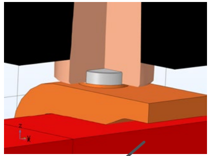
$$\boldsymbol{n} \cdot \boldsymbol{q}_2 = \frac{1}{TCR}(T_1 - T_2) + (1 - \alpha) . P_{interface}$$

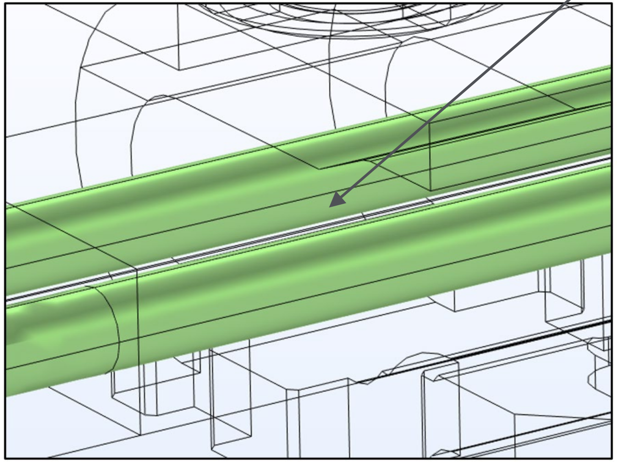
$$\frac{1}{TCR} = 1.54 \cdot k_c \frac{m_{asp}}{\sigma_{asp}} \left(\frac{p_c \sqrt{2}}{m_{asp} E_c} \right)^{0.94}$$

- p_c: Effective contact pressure
- Roughness profile (m_{asp}, σ_{asp}),
  - ✓ m_{asp} average slope of asperities
  - ✓ σ_{asp} average height of asperities
- $(E, \nu, \lambda, \sigma_{elec})$ Properties of the materials in contact.

Modeling

Cooling





Cooling bar

Internal forced convective heat flux computed at cooling surfaces

$$\Phi_{th} = h \times (T - T_{ext}) \cdot S$$
$$h = \frac{\lambda}{D} f(Re, \mathrm{Pr}) = \frac{\lambda}{D} Nu$$

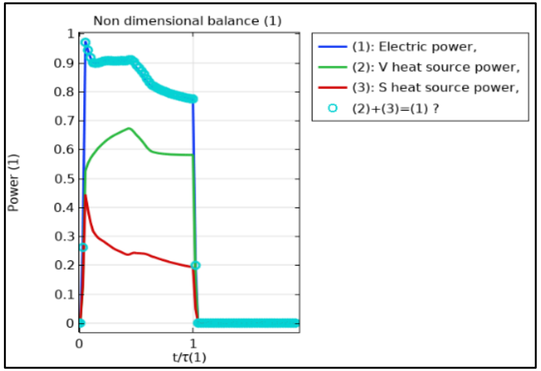
ϕ_{th}: *Thermal heat flux [W]*
h: *Thermal heat exchange coefficient* $[W/(m^2K)]$
Re: *Reynolds number*
Pr: *Prandtl number*
$Nu = h \cdot \frac{D}{\lambda}$: *Nusselt number*
λ: *Thermal conductivity*

Numerical strategy and validation

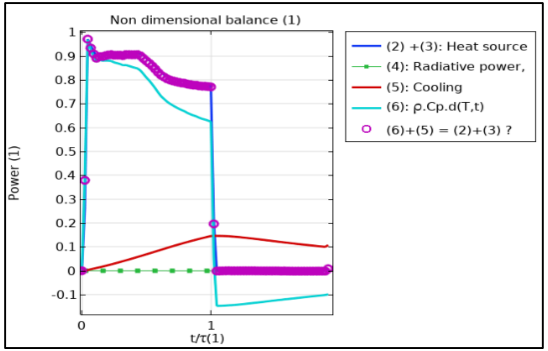
Numerical strategy

- Penalty algorithm used for tip contacts
  - ✓ sensitivity study
  - ✓ comparison to Augmented Lagrangian algorithm
  - ✓ Ensure non-dependency with an acceptable CPU time.
- Refined mesh around tip's contacts
- BDF algorithm (solver)
- Adjusted time step
- Segregated approach (solver)

Generated power vs thermal power

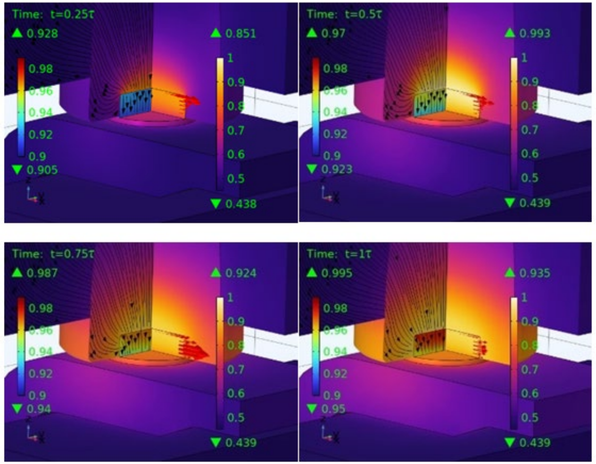


Generated thermal power vs dissipated power

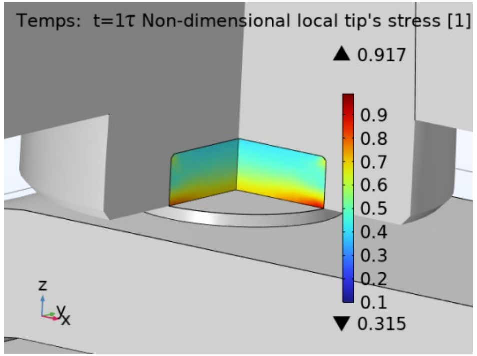


Results

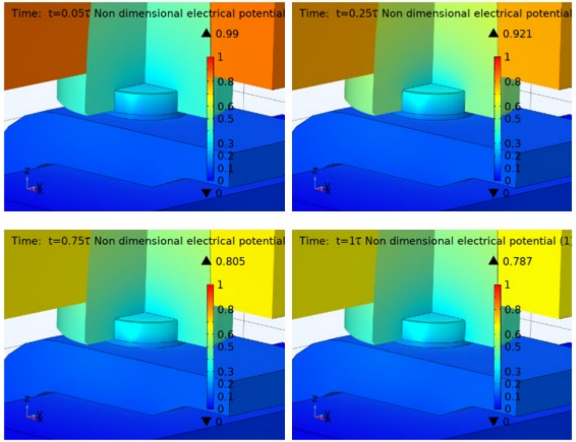
Variables of interest



Temperature and tip's densification evolution.



Tip's local stress.



Electrical potential in different parts.

- The more densified is the tip, the less is the local stress

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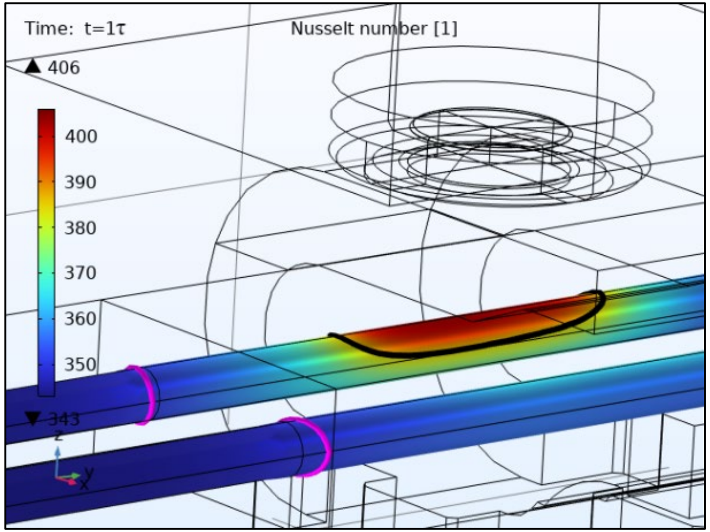
Results

Cooling channel



Nusselt number in the cooling bar. Magenta isovalue: T<T0+5, and black isovalue for: T>2·T0; with T0, the initial temperature

Dittus-Boettler equation:

$$Nu = 0.023 \times Re^{4/5} \times Pr^{0,4}$$

Temperature is non-constant in the cooling channel

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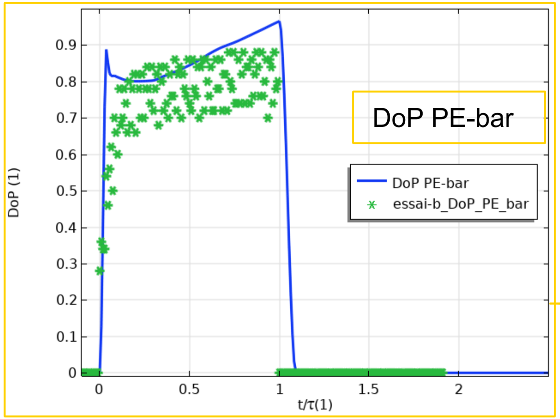
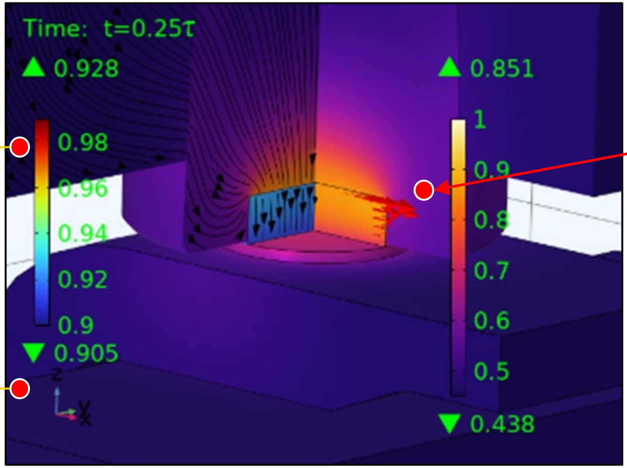
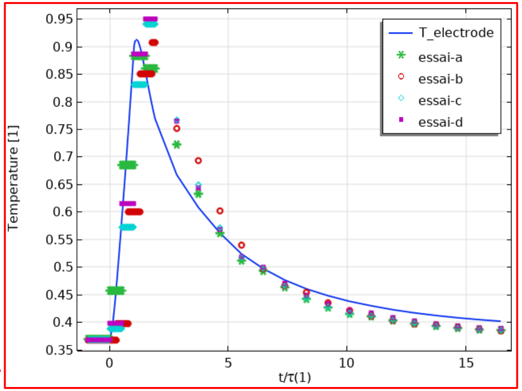
Results

Experimental confrontations



DoP between the electrode holder and the cooling bar





Temperature of a point located in the electrode.

**Comparisons are made with the industrial contact but the geometry shown here is different (for confidentiality reasons).*

- Validation of the model

Results

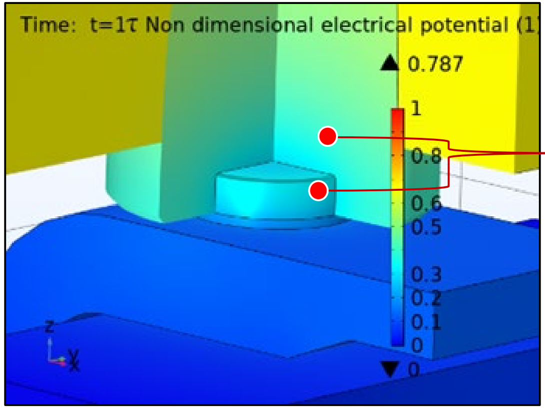
Experimental confrontations

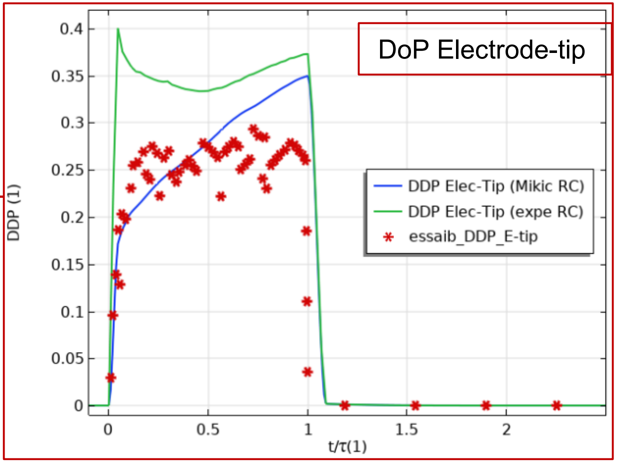
Two different approaches for the ECR and TCR calculation.

- ❑ Experimental Measurements
  without TCR(p) and ECR(p)

- ❑ Mikic model
  with TCR(p) and ECR(p)

B. Mikic, (1974), *Thermal contact resistance; Theoretical considerations,* Department of Mechanical Engineering, Massachusetts Institute of Technology, Int J. Heat Mass Transfer. Vol. 17, pp. 205-214.





DoP between the electrode and the tip.
Red markers : experimental results
Blue: with ECR(p) and TCR(p)
Green: without ECR(p) and TCR(p)

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- Validation of the model

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Conclusions

- Digital twin fully representative of the RS process
- Possibility to make digital Design Of Experiments (DOE) at lower cost
- Improving the process (cooling, geometries,…)

Followings

- Modeling the assembly phenomenon between the tip and the copper substrate
- Design the RS application
  - ✓ To “bring” to welding experts a decision tool
  - ✓ Make DOEs much easier…

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