COMSOL CONFERENCE BOSTON 2012

Thermal Model for Single Discharge EDM process

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Outline

Thermal (Anode – Cathode Model)

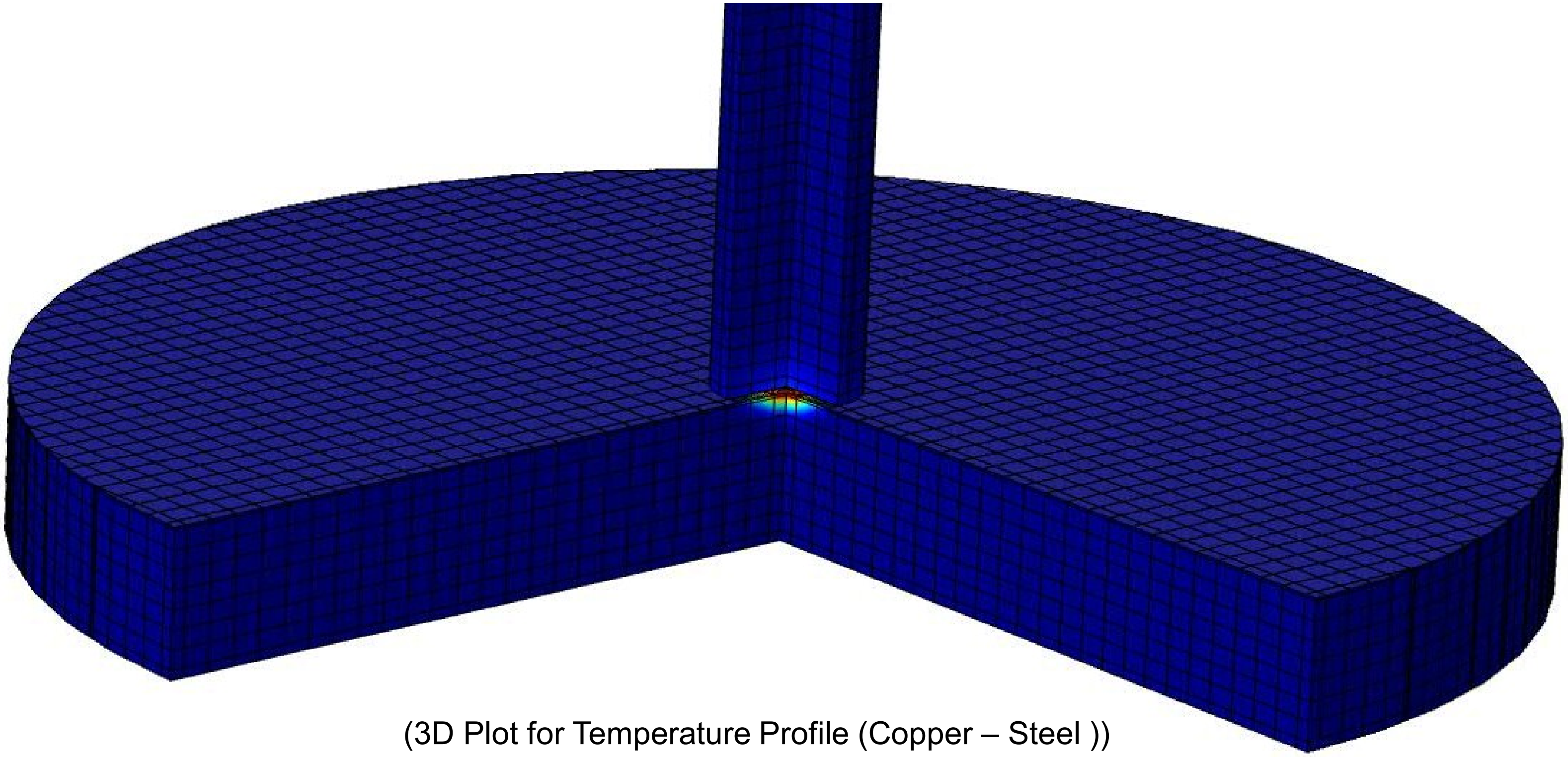
- Single Discharge: Heat Conduction and Joule Heating
- GUI (Comsol – Matlab)
- Residual Thermal Stress

Physical Model

Heat Conduction

Joule Heating

Input Parameters



(3D Plot for Temperature Profile (Copper – Steel))

Heat Conduction

- Governing Equation:
  - Heat Equation: $(\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u}.\nabla T = \mathbf{\nabla}.(k\nabla T) + Q)$
- Boundary Conditions:
  - Initial Values
  - General Inward Heat Flux $(-\mathbf{n}.(-k\nabla T) = q_o)$
  - Thermal Insulation $(-\mathbf{n}.(-k\nabla T) = 0\ )$

Joule Heating

- Governing Equations:
  - $\mathbf{J} = \left(\sigma + \epsilon_0 \epsilon_r \frac{\partial}{\partial t}\right) \mathbf{E} + \mathbf{J_e}$
  - $\nabla . \mathbf{J} = \mathbf{Q_j}$
  - $\mathbf{E} = -\nabla \mathbf{V}$

- Boundary Conditions:
  - Initial Values
  - Normal Current Density $(-\mathbf{n}.\mathbf{J} = \mathrm{J}_n)$
  - Electrical Insulation $(-\mathbf{n}.\mathbf{J} = 0\ )$

Input Parameters

- Plasma Channel Expansion:
  - Empirical
  - Constant Cathode Boiling Temperature
  - Eubank Physical Model
- Flux Profile:
  - Equilibrium
  - Gaussian
  - Parabolic
- Energy Balance:
  - Constant
  - Eubank Physical Model
  - User Defined

Input Parameters: Plasma Channel Expansion

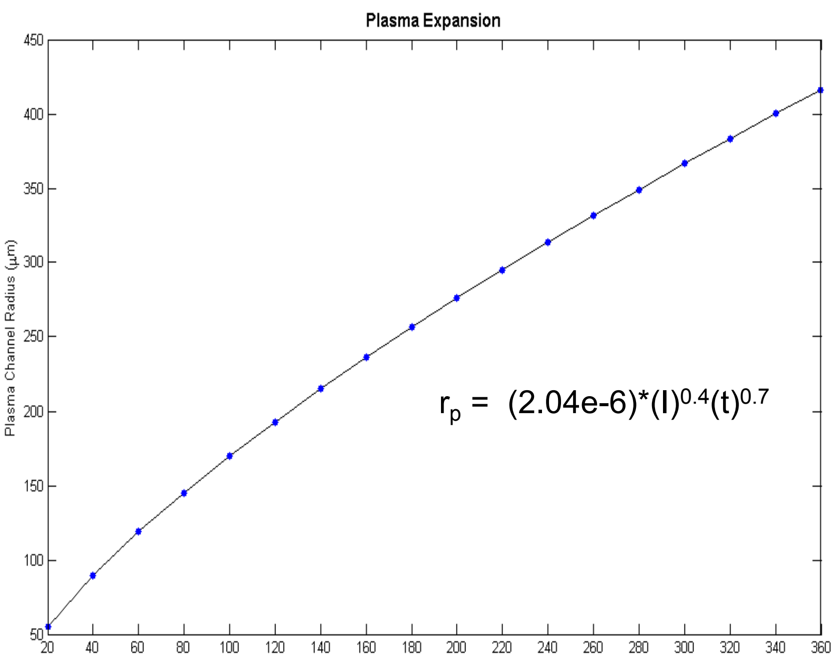
Empirical equation

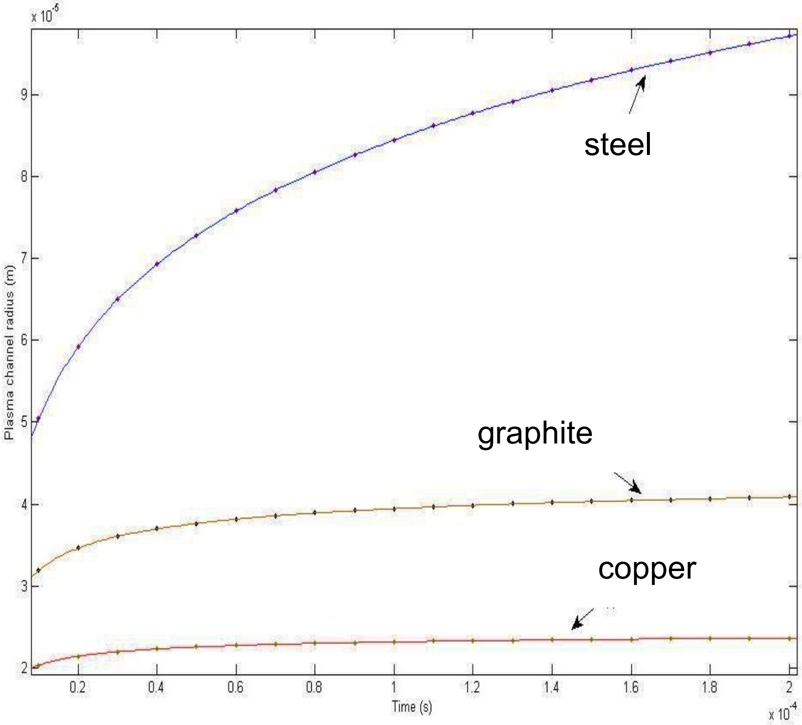
$$r_0 + C * (t)^n = r_p$$

$$r_0 + C * (I)^m * (t)^n = r_p$$

Constant Cathode boiling temp.

$$T_b = \frac{E_0 . r_p}{K . \sqrt{\pi}} \tan^{-1}[\frac{4at}{{r_p}^2}]$$

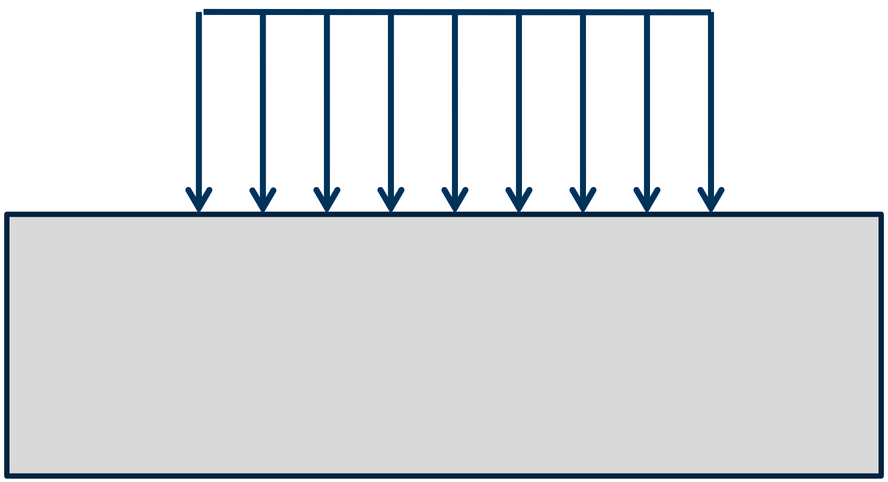




Input Parameters: Flux Profile

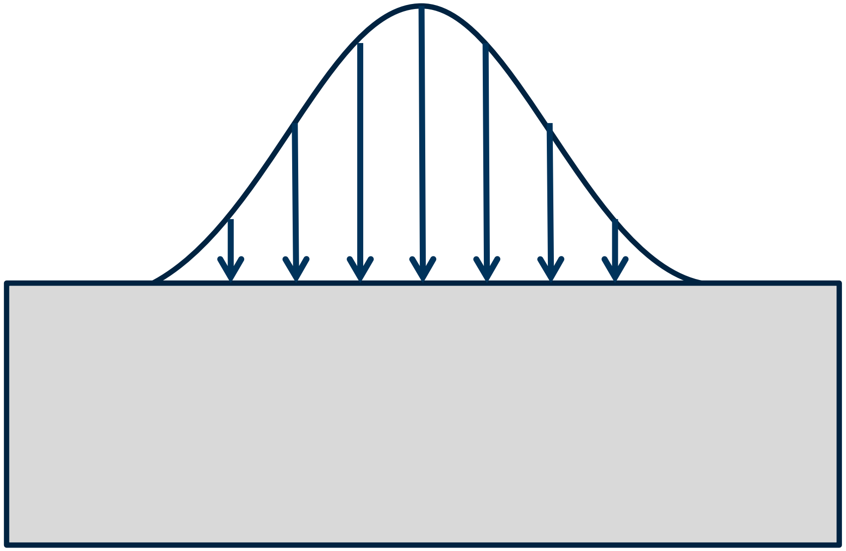
Equilibrium:

$$q_0 = \frac{power}{\pi \cdot r^2}$$



Gaussian:

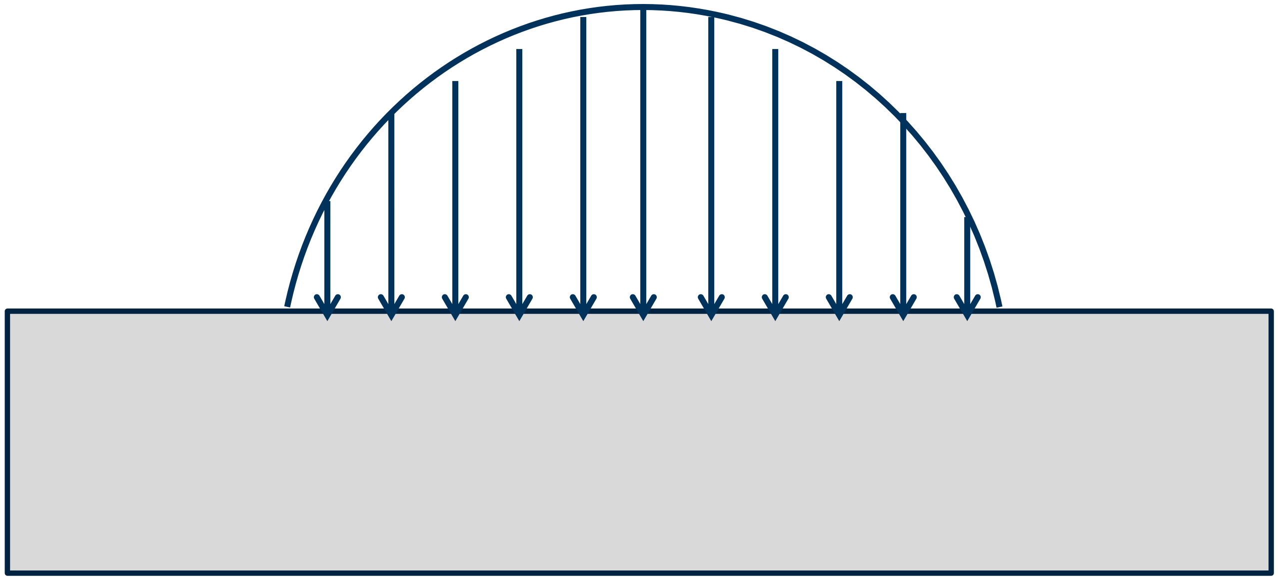
$$q_0 = \left(\frac{power}{\pi \cdot r^2}\right) * \exp\left(-4.5 * \left(\frac{r^2}{R^2}\right)\right)$$



Input Parameters: Flux Profile

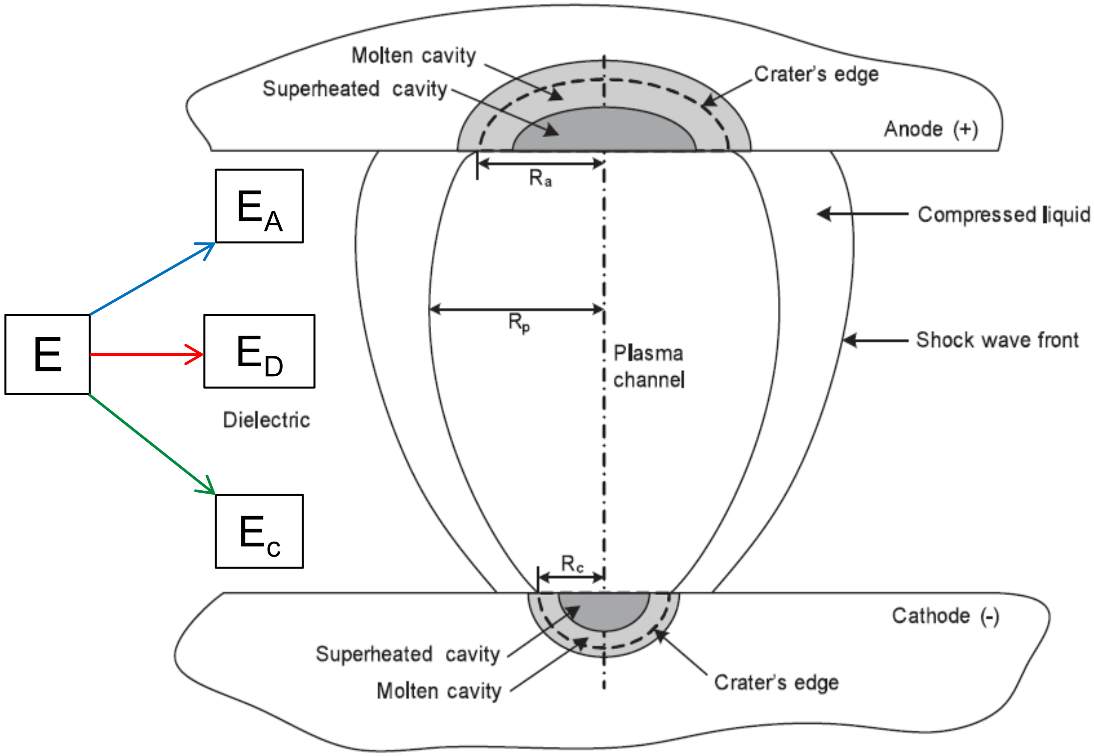
Parabolic:

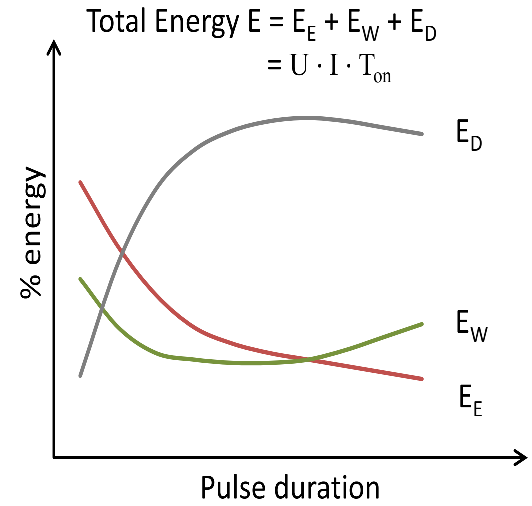
$$q_0 = \left(\frac{power}{\pi \cdot r^2}\right) * \left(1.0002 - \frac{r^2}{R^2}\right)$$



Input Parameters: Energy Balance

- Single discharge: Plasma-material interaction
  - Total power E = voltage (U) • current (I) • pulse duration (t)

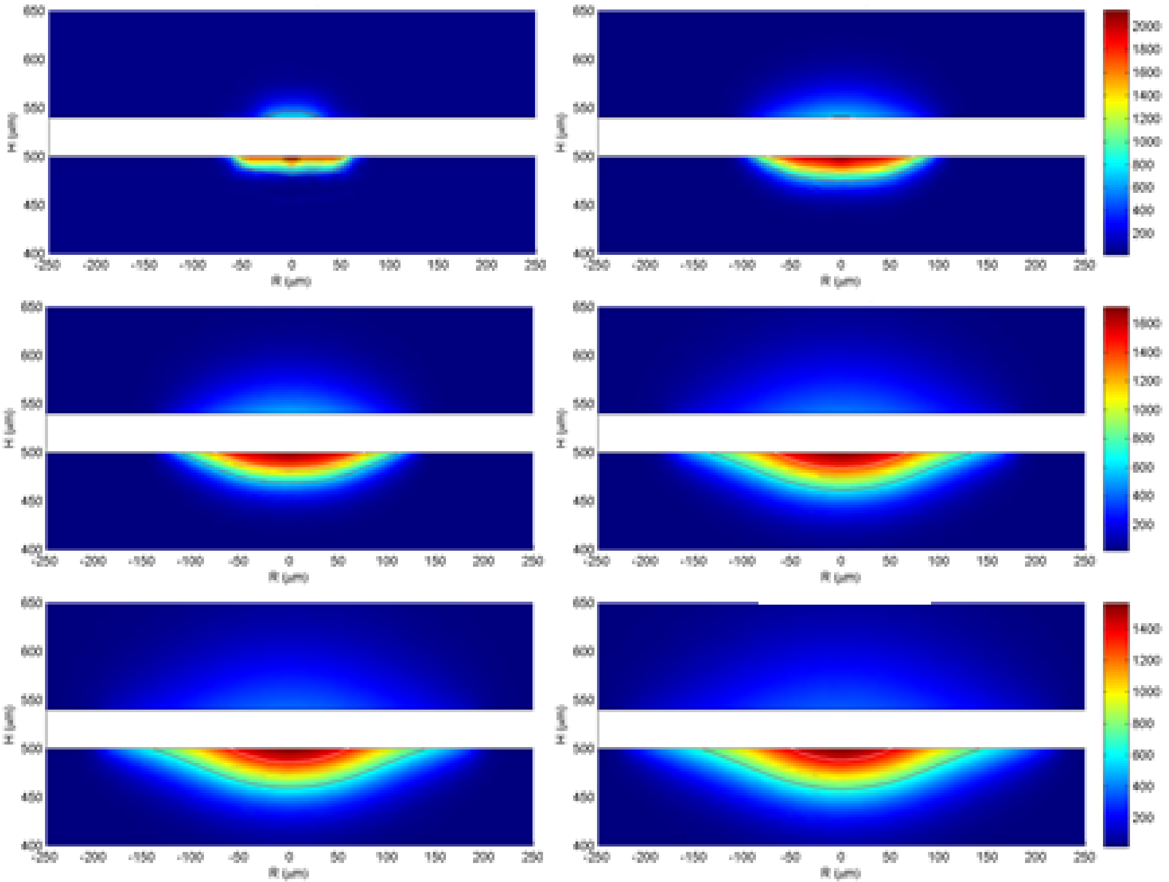




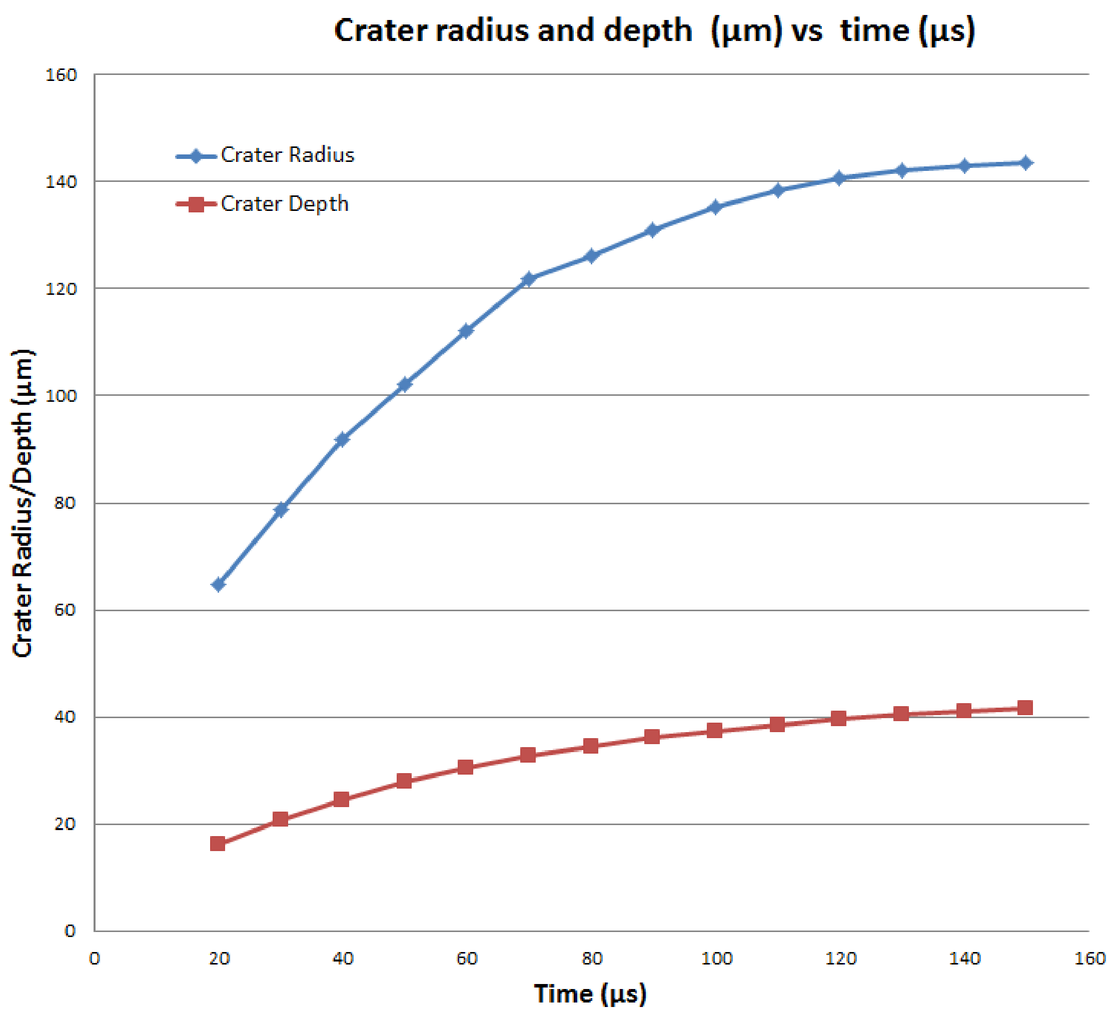
- E_A, E_C : Constant , User Defined or from Eubank's Model

Results

- Graphite,150 (µs) (Empirical Equation)



Results

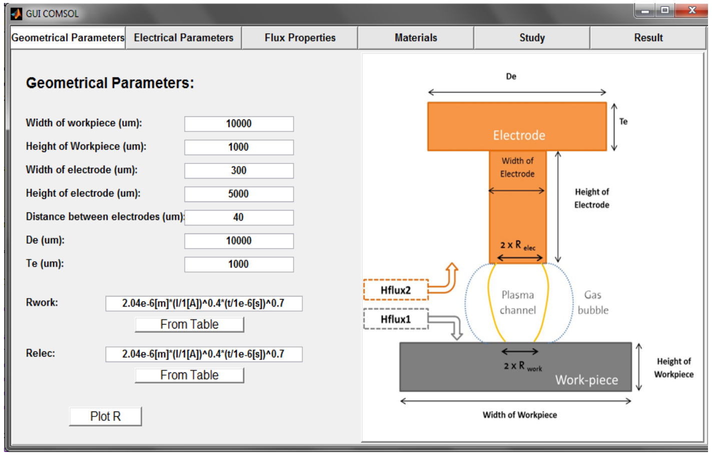

Crater radius and depth (µm) vs time (µs)
Crater Radius
Crater Depth
Crater Radius/Depth (µm)
Time (µs)
0
20
40
60
80
100
120
140
160

GUI (Comsol – Matlab)

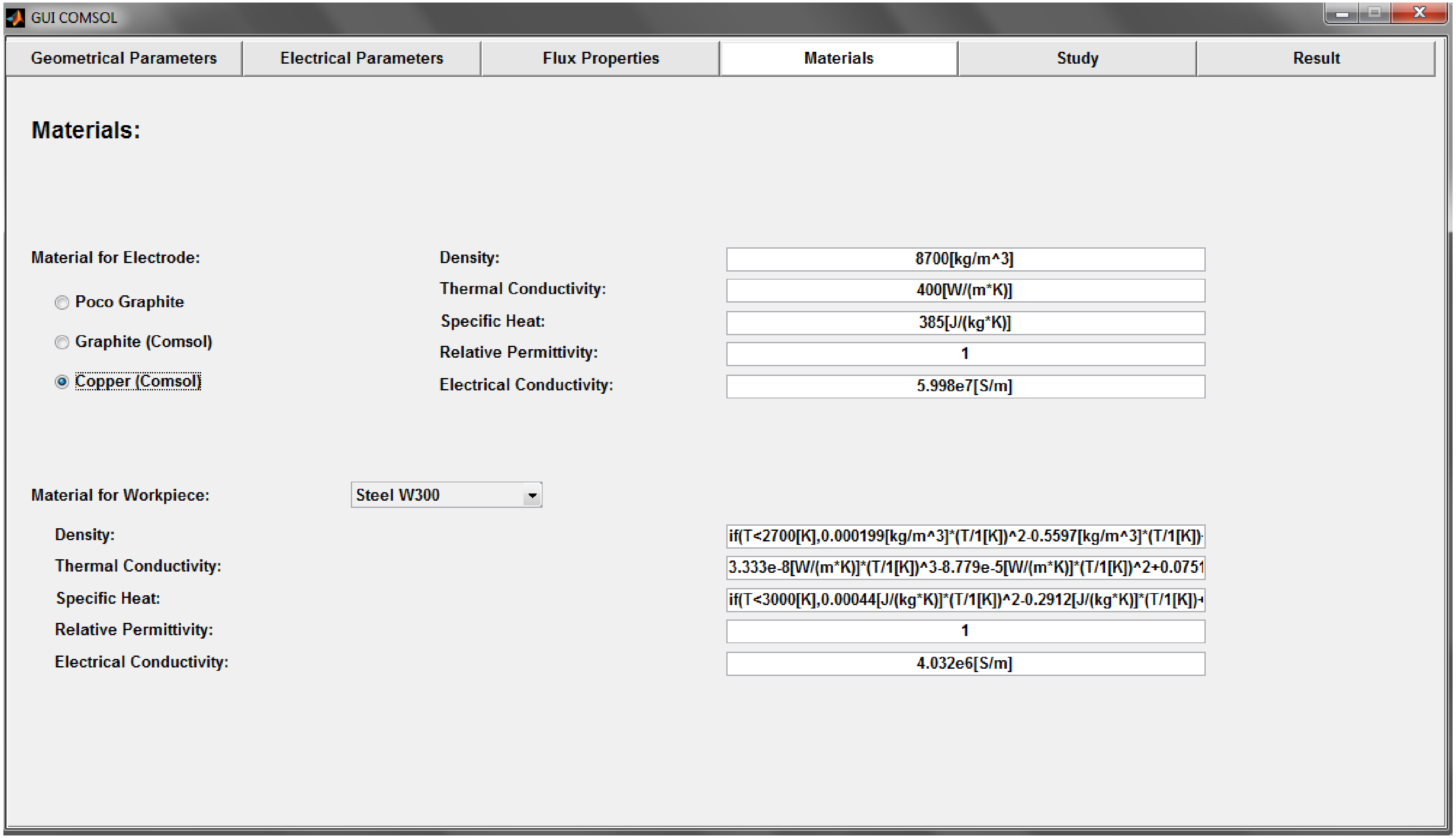
Need for GUI ?

- Main use of GUI was to get isotherm plots in matlab figure window for easy editing of plots, obtaining curves for crater radius and crater depth based on results obtained from Comsol.

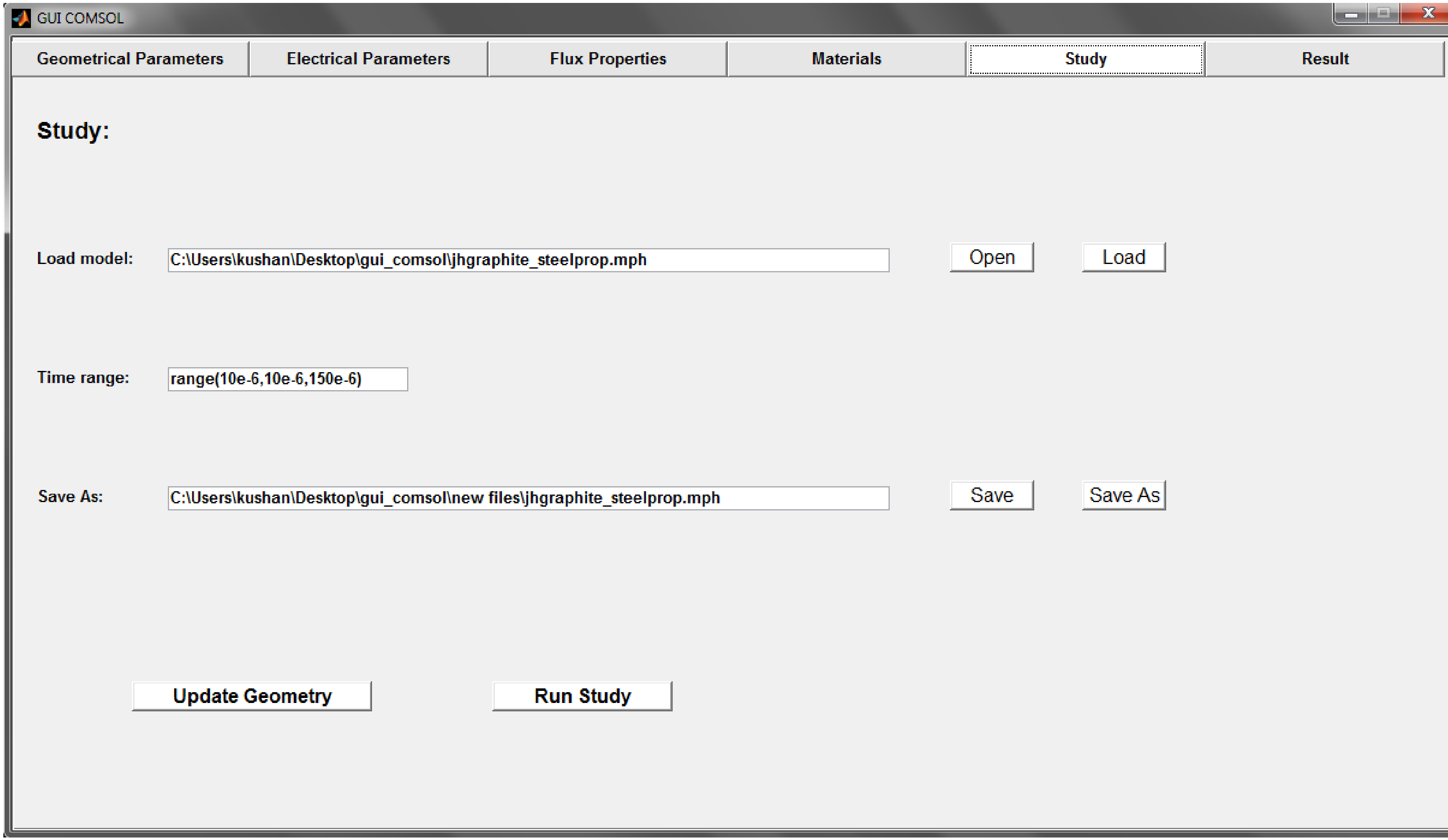
- Other than that it could update geometrical parameters, change materials and their properties, add time dependent equation for current or time energy balance based on interpolation of values, run the study and get results in Matlab variables by using GUI.



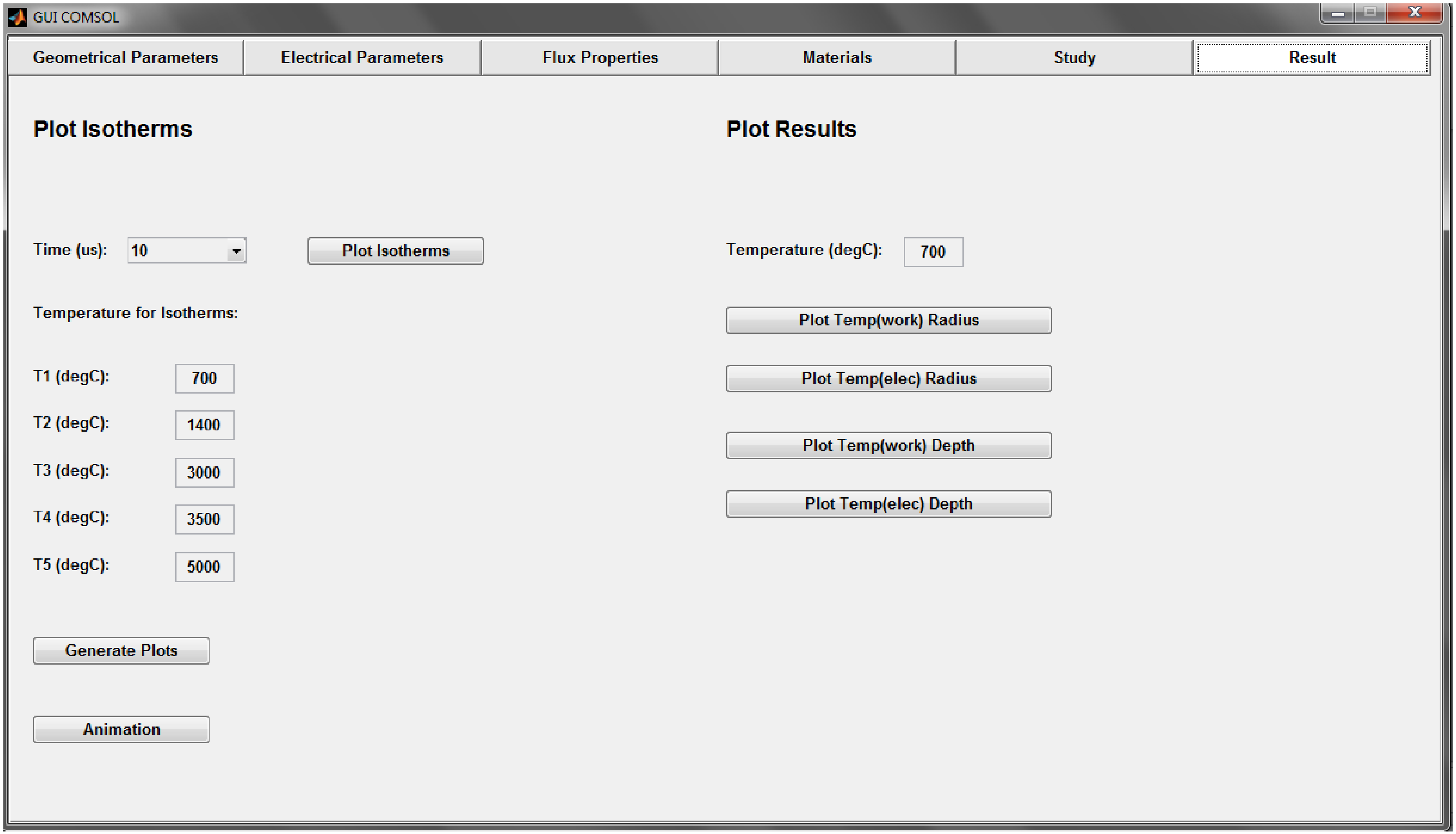
GUI Window: Materials Tab



GUI Window: Study Tab



GUI Window: Results Tab

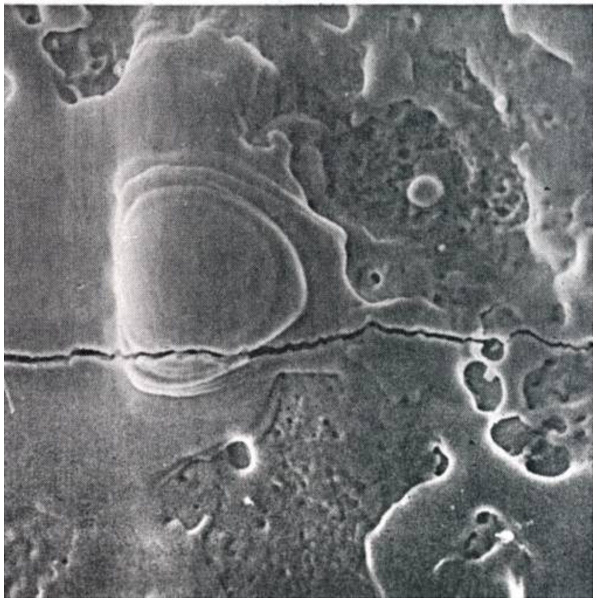


Residual Stress Modeling

(Using Thermal Stress Module)

Residual Stress

1. Physics
   - Governing equations
   - Boundary Conditions



2. Results
   - Residual Stress Isocontours
   - Residual Stress with Depth along central Axis

3. Further work
   - Rapid cooling effect

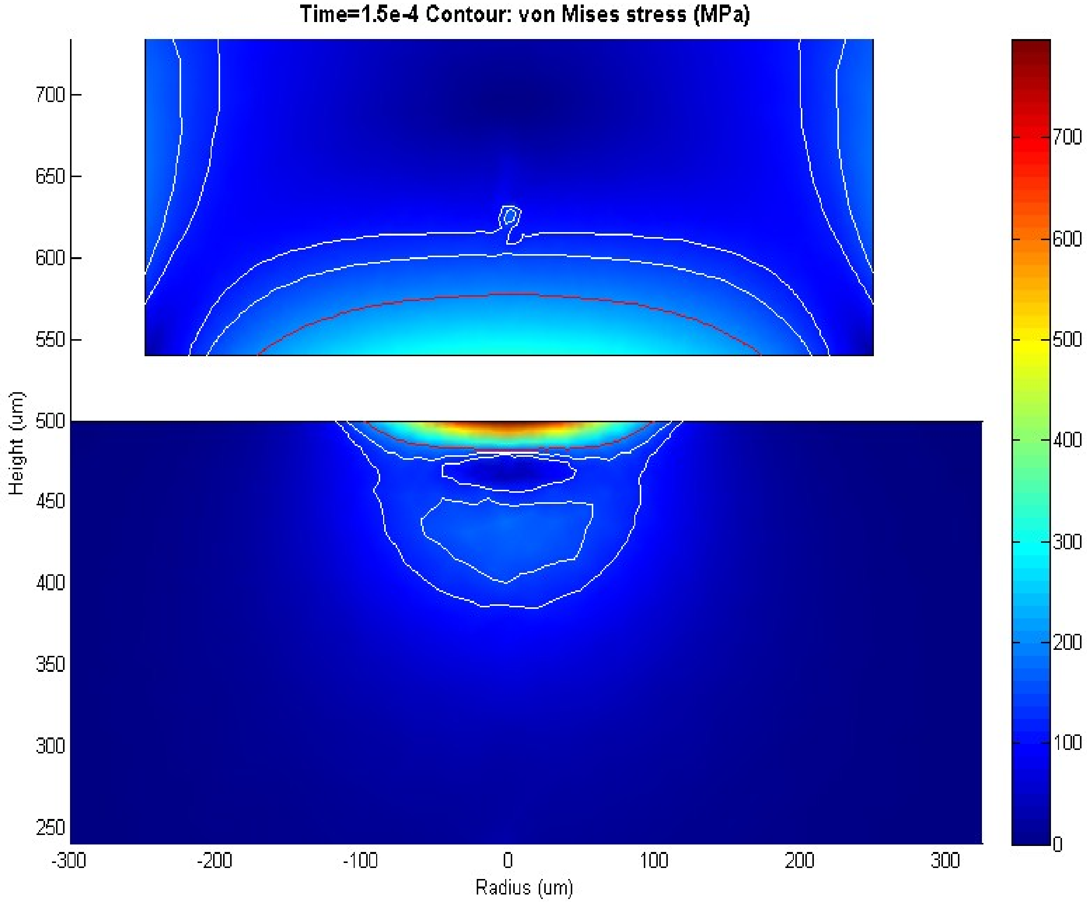
Physics: Governing Equations

- $(-\nabla \cdot \sigma = \mathbf{F}_{\mathrm{V}}),\ (\sigma = \boldsymbol{s})$
- $(\boldsymbol{s} - \boldsymbol{S_o} = \boldsymbol{C}: (\epsilon - \epsilon_o - \epsilon_{inel})),\ (\epsilon_{inel} = \alpha(T - T_{ref}))$
- $\epsilon = \frac{1}{2}((\nabla \mathbf{u})^{\mathrm{T}} + \nabla \mathbf{u})$
- $\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u}.\nabla T = \boldsymbol{\nabla}.(k \nabla T) + Q$

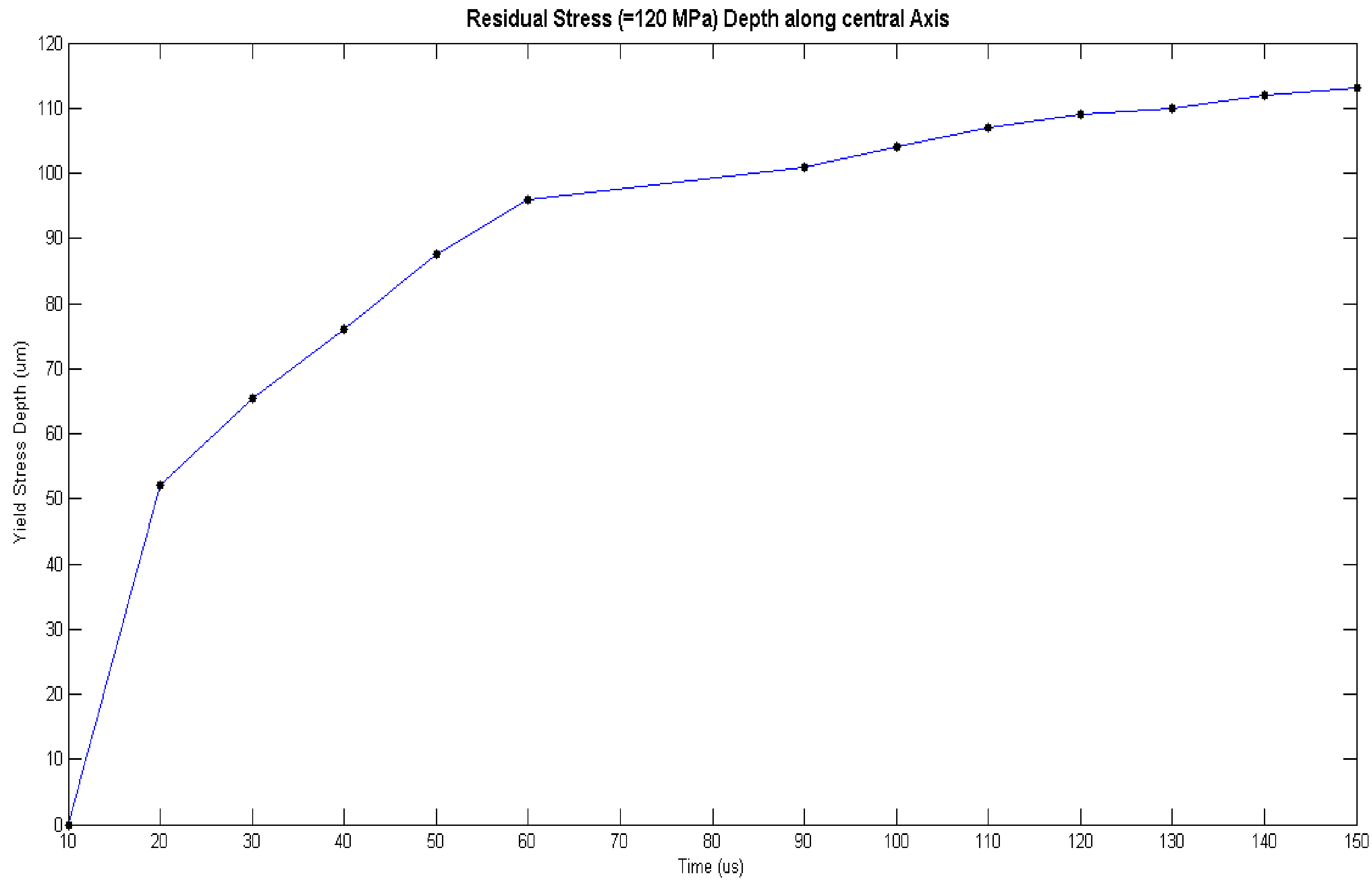
Physics: Boundary Conditions

- Initial Values
- Thermal Insulation $(-\mathbf{n}.(-k\nabla T) = 0\ )$
- Heat Flux $(-\mathbf{n}.(-k\nabla T) = q_o\ )$
- Fixed Constraint $(\mathbf{u} = 0\ )$

Results: Residual Stress Isocontours



Results: Residual Stress with Depth



Thank You for your attention!

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