Thermal and Flow Modelling of Friction Stir Welding using Comsol

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European COMSOL Conference
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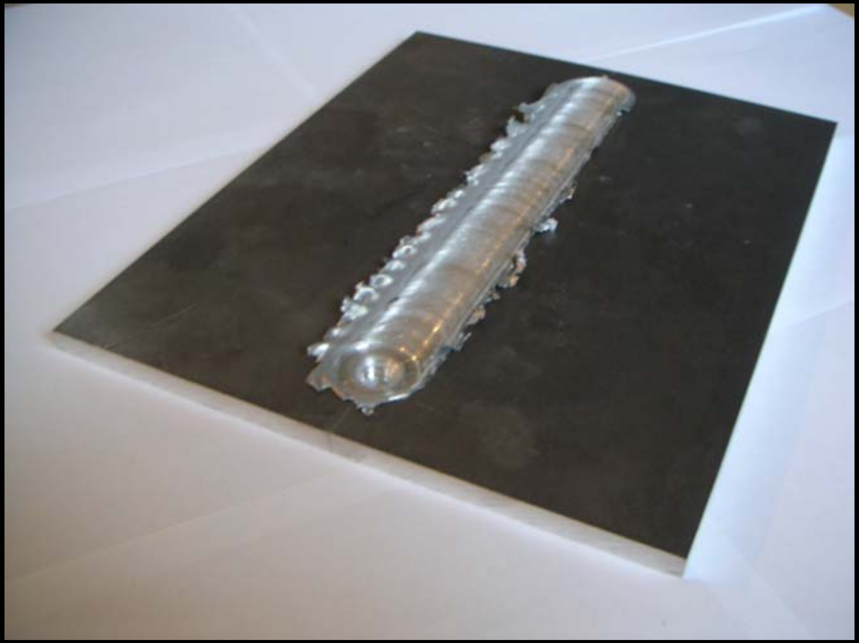
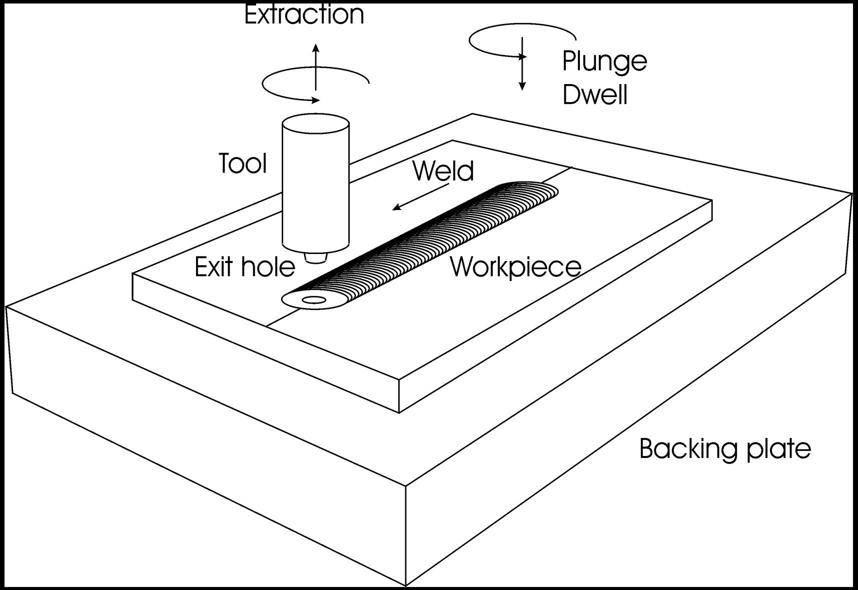
Agenda

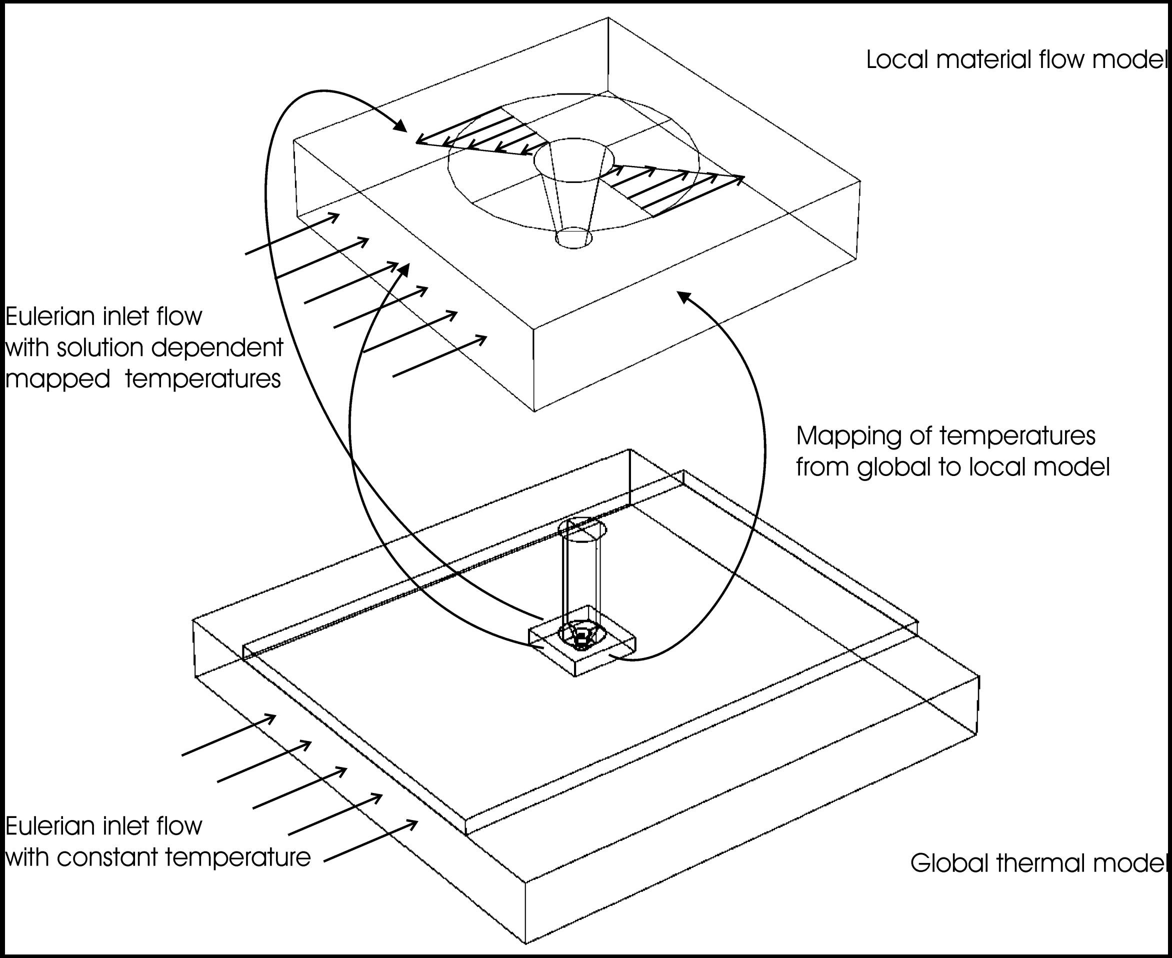
- Short introduction to Friction Stir Welding
- Local – Global modelling
  - Thermal-pseudo-mechanical model
  - Pseudo-Frictional flow model
- Closure

What is Friction Stir Welding?





Schematic of local-global model



Thermal-pseudo-mechanical model

- Heat generation is output (like in a thermomechanical/CFD model)
- Heat source distribution is part of the solution
- Temperature dependent yield stress is the driver for the heat generation
- Prescribed shear layer – convective heat flow
  - Realizing that it is NOT the correct flow
- Computational less complex than traditional CSM/CFD models (100 simulations in 30 min)

Thermal-pseudo-mechanical model

$$q_{plastic} = \delta \omega r \tau_{yield}$$

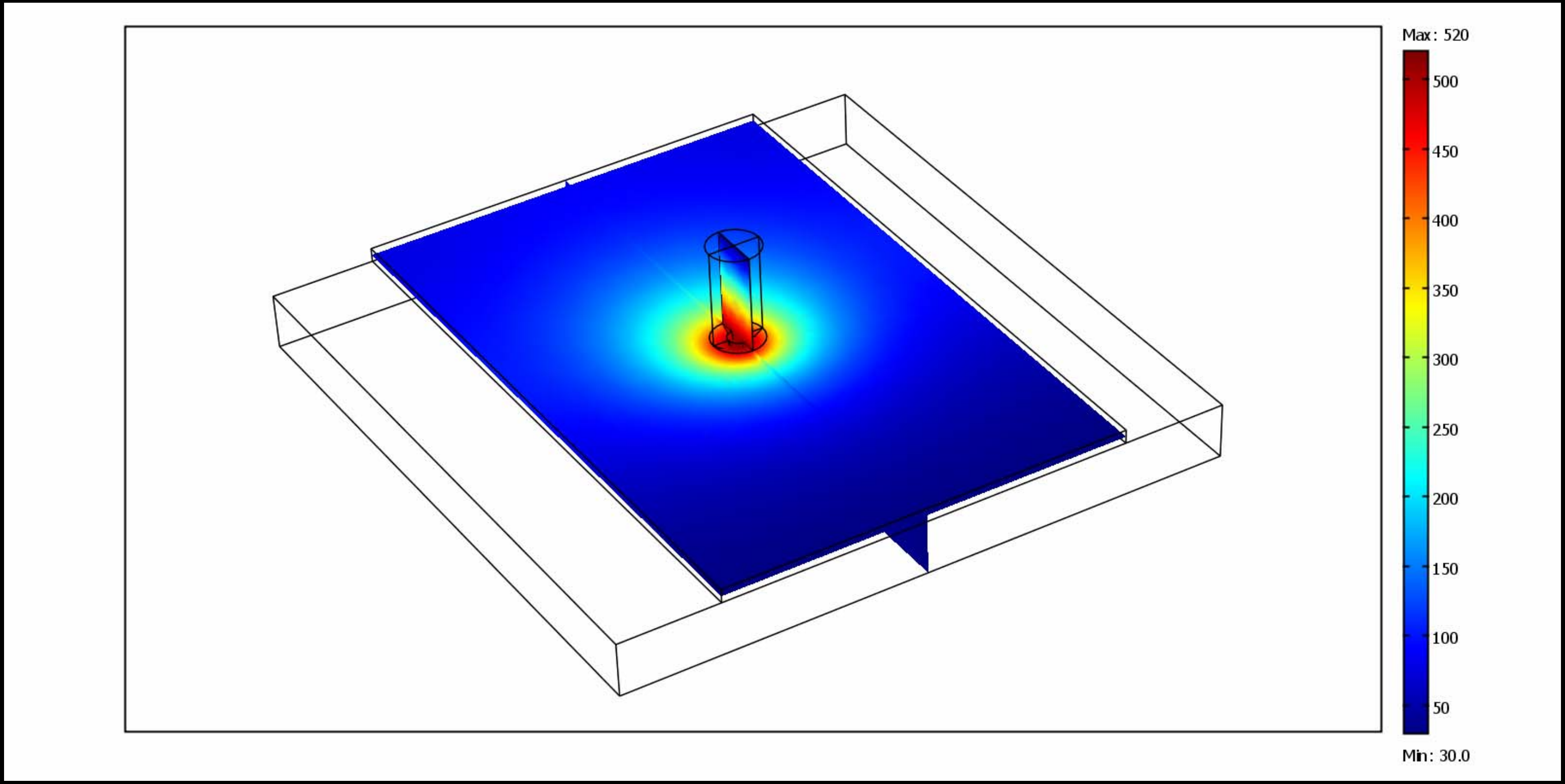
$$q_{fric} = \left(1 - \delta\right) \omega r \tau_{fric}$$

$$\tau_{friction} = \tau_{plastic} = \frac{\sigma_{yield}}{\sqrt{3}}$$

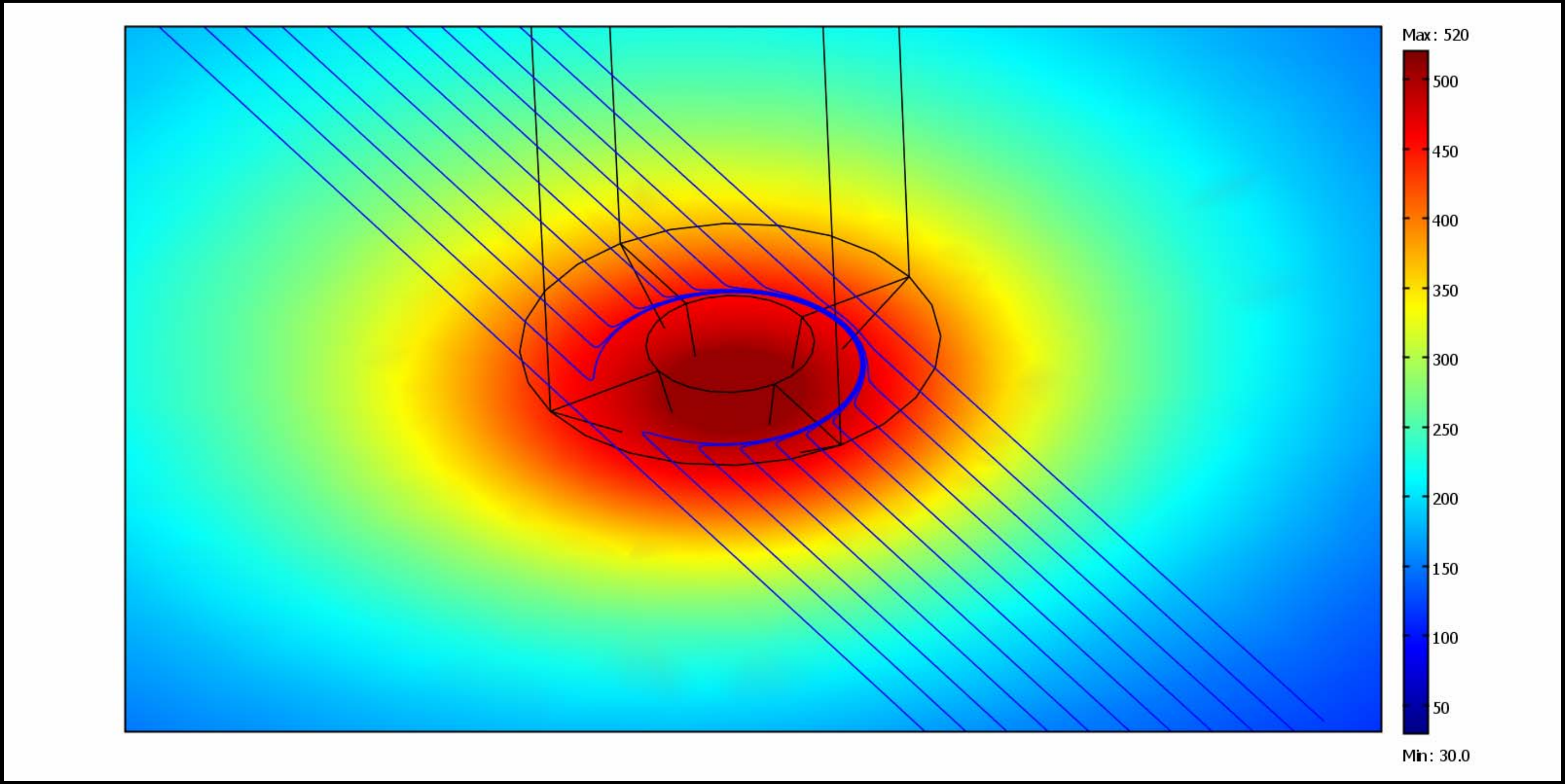
$$\begin{aligned} q_{total} &= q_{friction} + q_{plastic} \\ &= \left(1 - \delta\right) \omega r \tau_{friction} + \delta \omega r \tau_{yield} \\ &= \omega r \tau_{yield} \end{aligned}$$

Thermal modelling of Friction Stir Welding, VP set on FSP, Scripta Materialia, 2008
A thermal-pseudo-mechanical model for the heat generation in Friction Stir welding, TWI, 2008

Thermal-pseudo-mechanical model

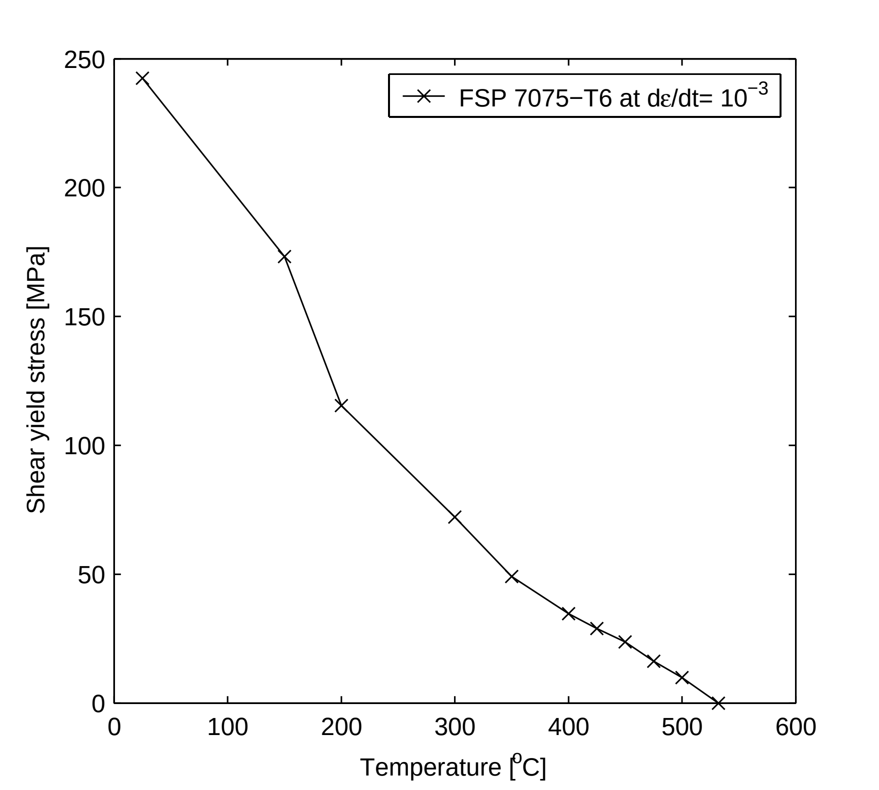


Thermal-pseudo-mechanical model

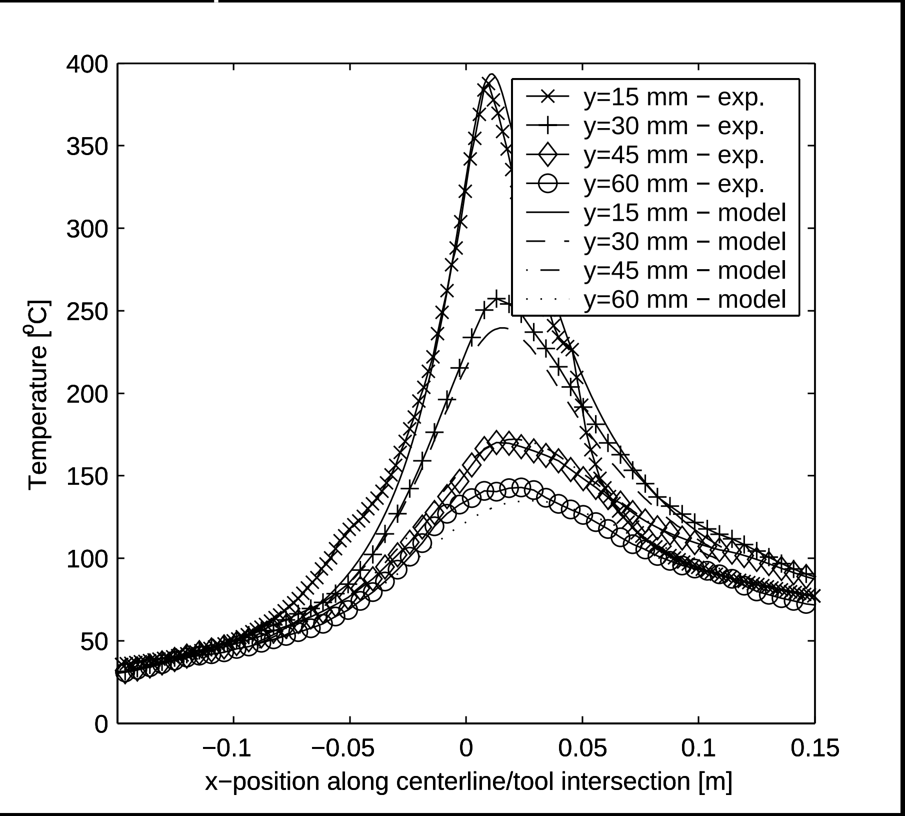


TPM-model Characteristics

Temperature dependent maximum yield shear stress

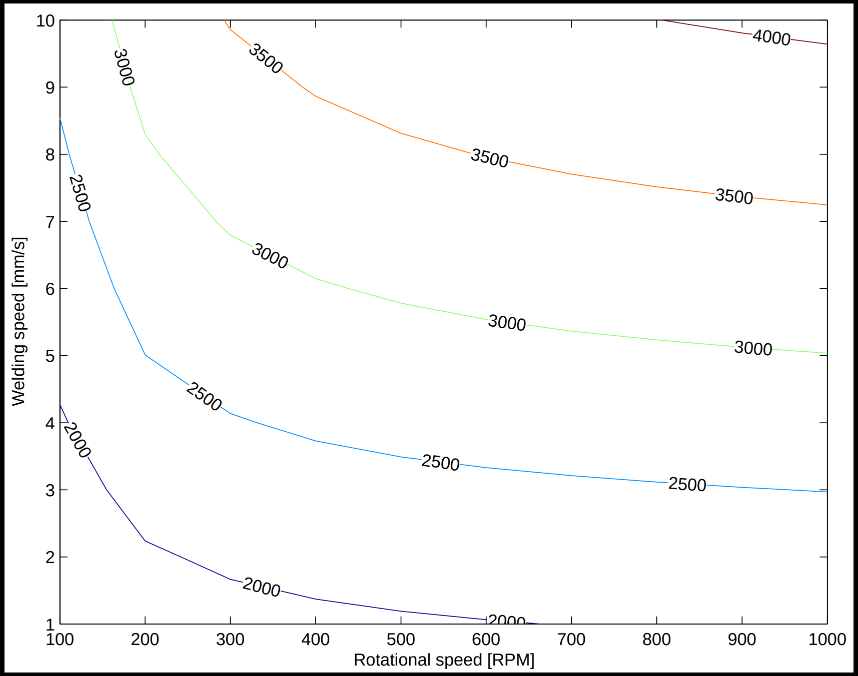


Comparison between experimental and numerical temperatures

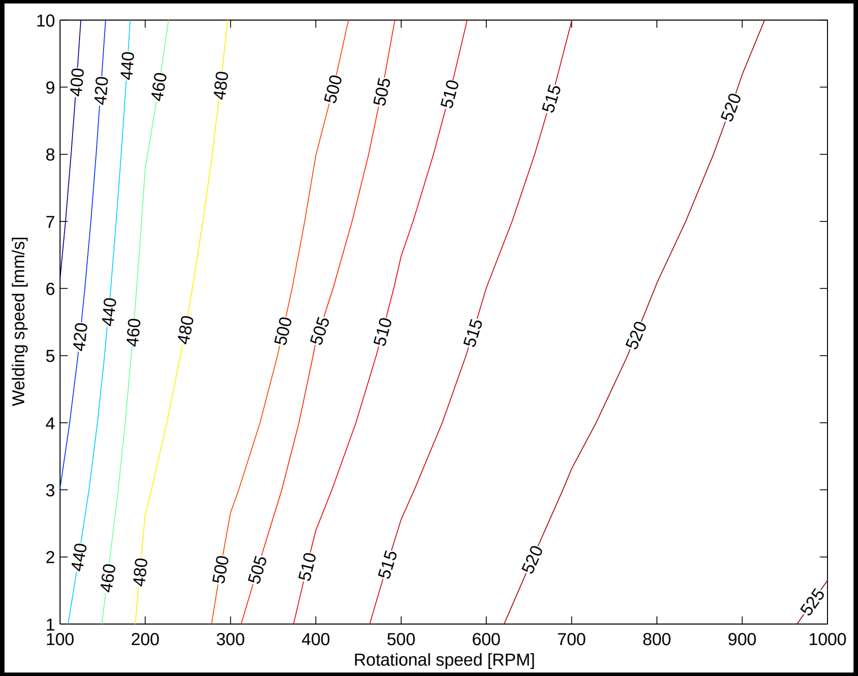


Parameter study using TPM-model

Total heat generation



Maximum temperature



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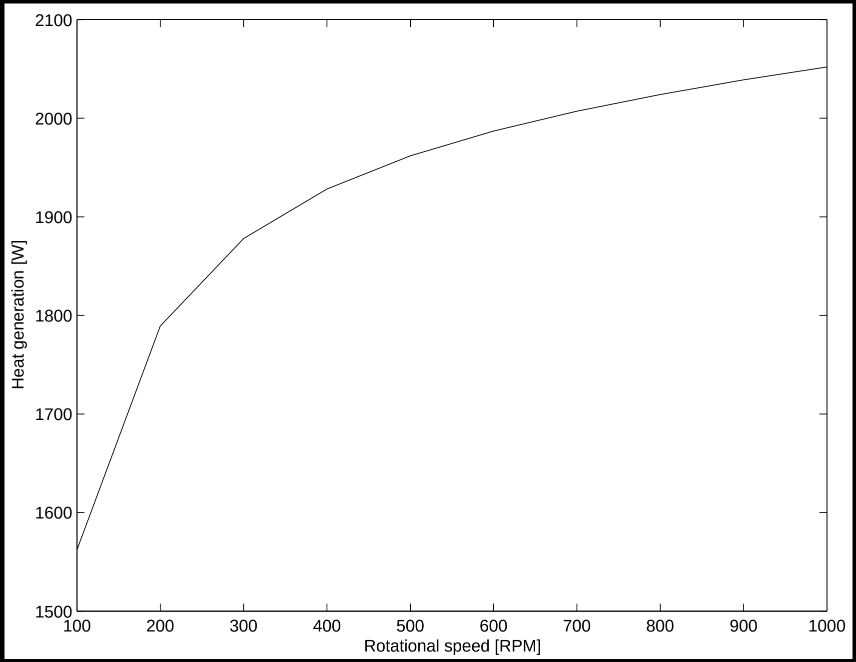
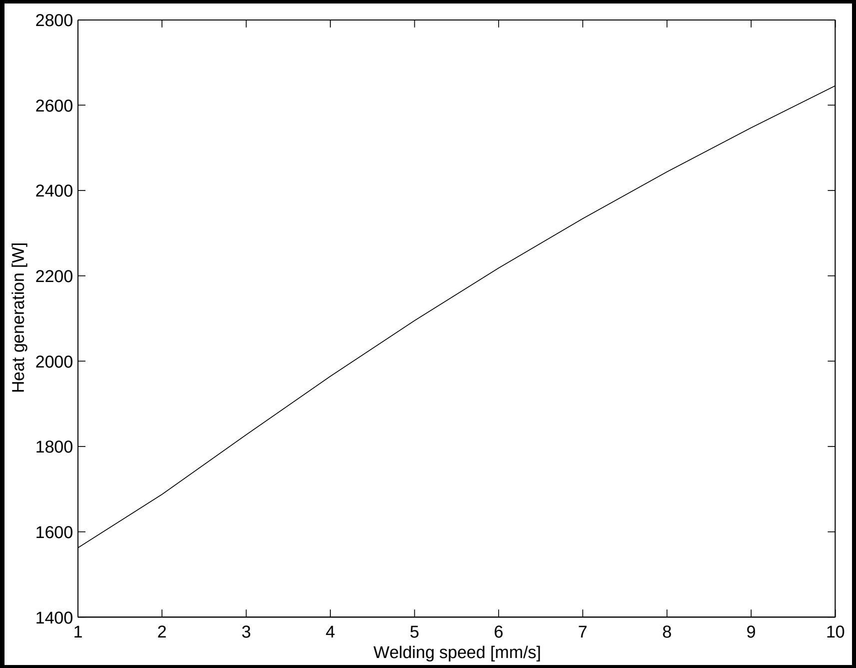
Parameter study using TPM-model

Heat generation vs. RPM
for constant welding speed

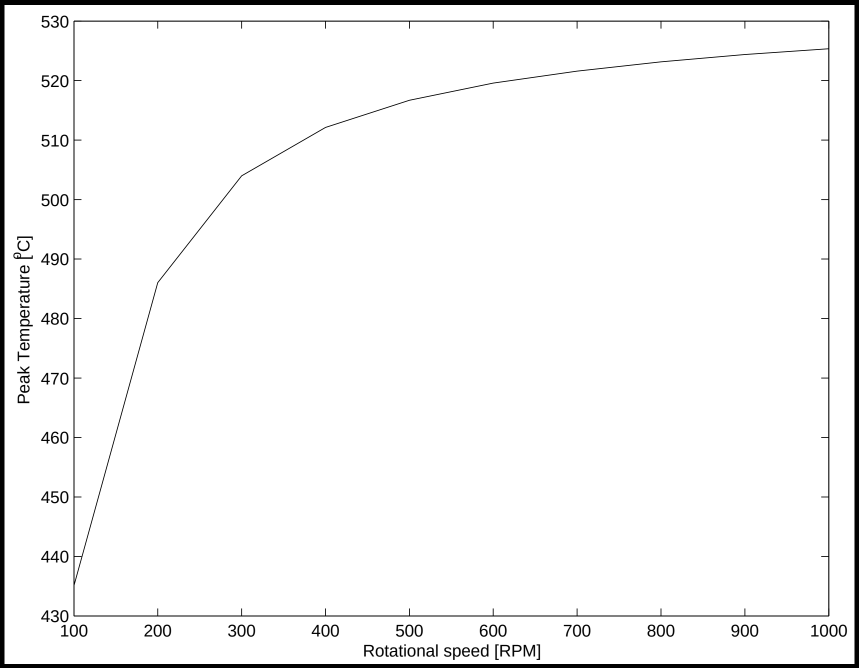


Heat generation vs. Welding Speed
for constant RPM

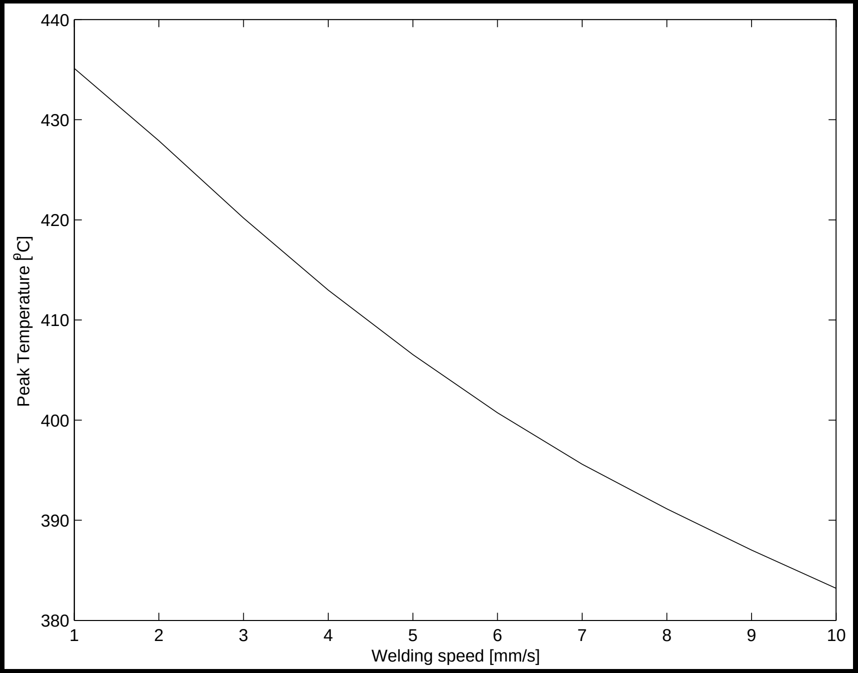


Parameter study using TPM-model

Max. Temp. vs. RPM
for constant welding speed



Max. Temp vs. Welding Speed
for constant RPM



Pseudo-frictional Flow model with frictional dissipation

- Plastic/viscous dissipation
  - Volumetric heat source
- Frictional dissipation
  - Surface heat source
- Valid for all contact conditions, e.g.
- Velocity prescribed at contact interface

$$q_{viscous} = s_{ij}\dot{\varepsilon}_{ij}$$

$$q_{fric} = (1-\delta)\omega r \tau_{fric}$$

$$\tau_{friction} = \tau_{viscous}$$

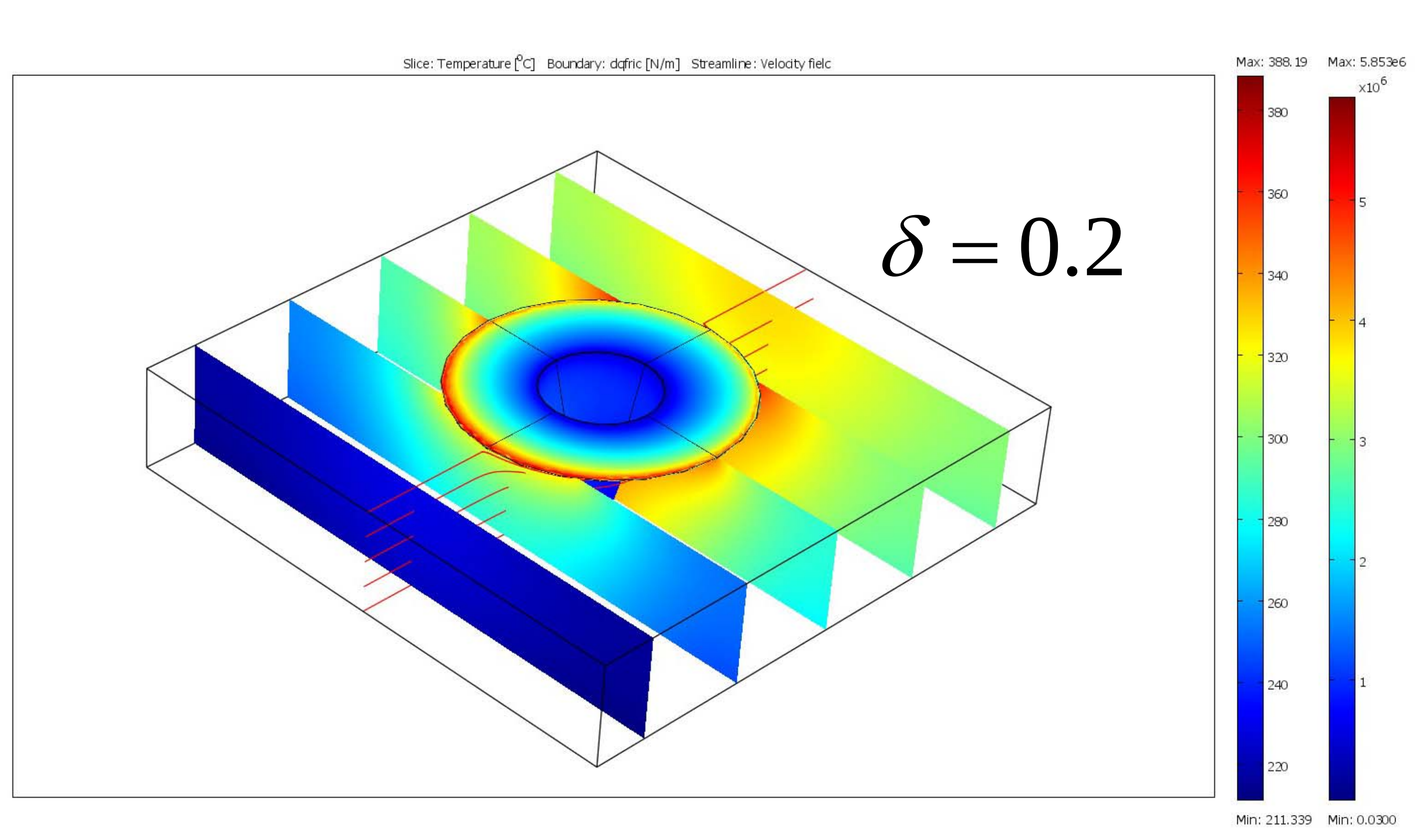
$$\delta = 0.2$$

$$u_\theta = \delta\omega r$$

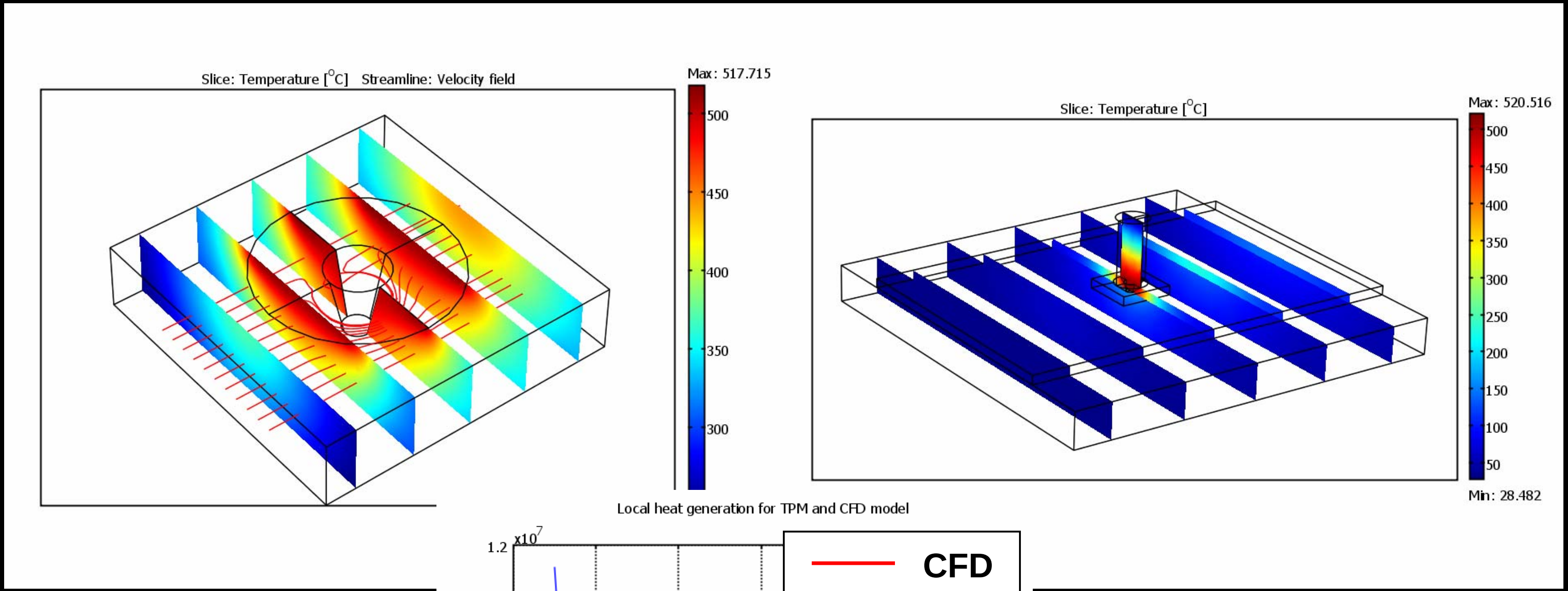
$$\tau = \frac{\tau_{ref}(T)}{\dot{\gamma}_{ref}}\dot{\gamma}^m = \frac{\tau_{ref}(T)}{\sqrt{3}\dot{\varepsilon}_{ref}}\dot{\gamma}^m$$

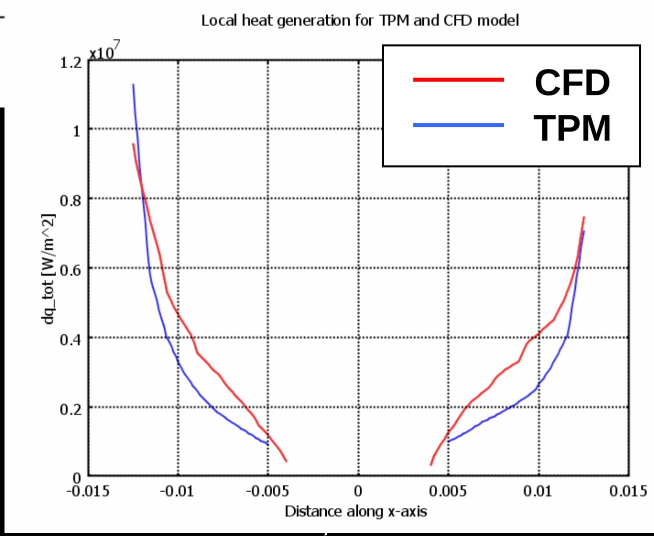
$$m = 0.17 \sim 0.2$$

PFF model
with frictional dissipation



Local CFD and global TPM





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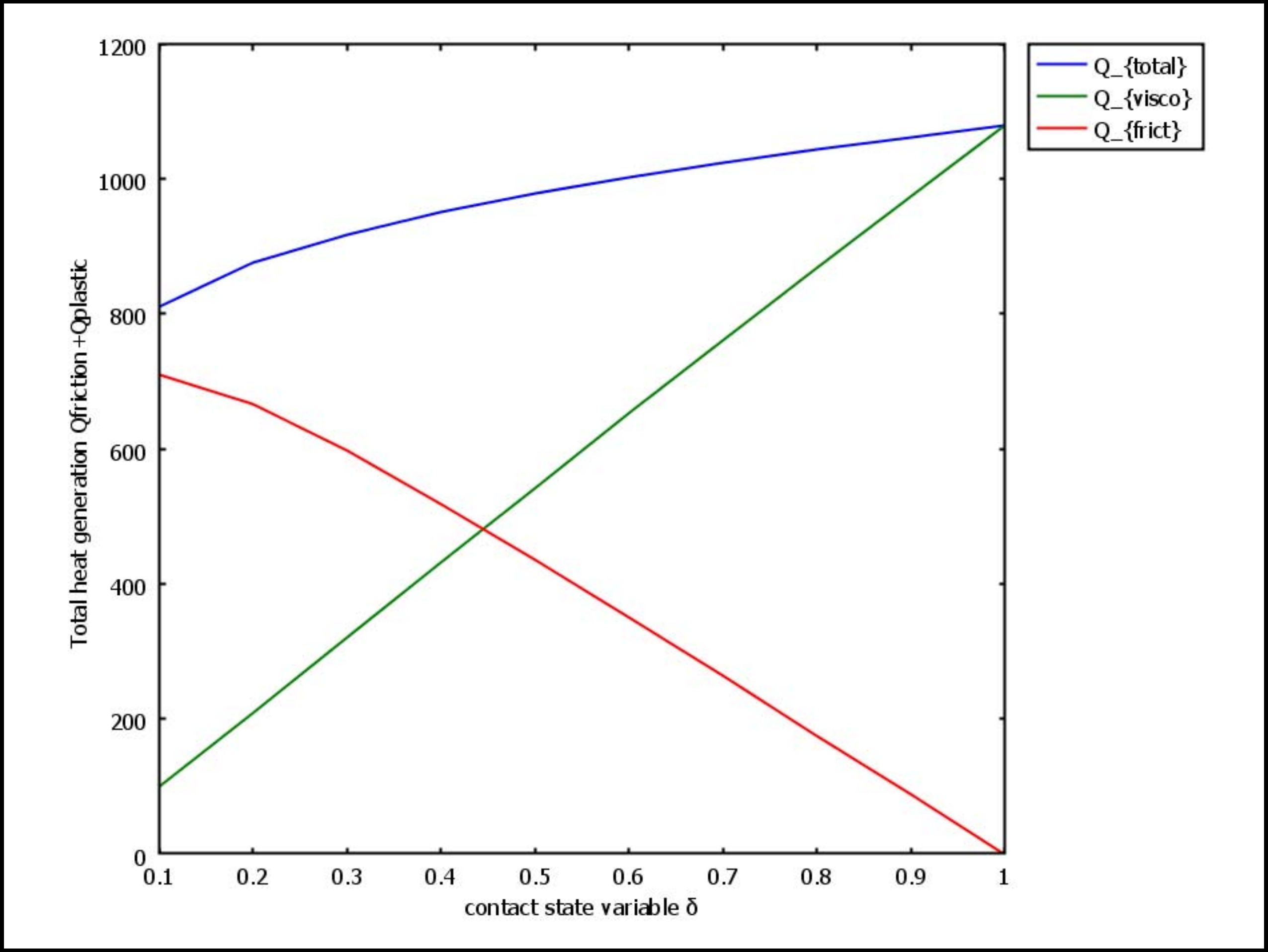
Pseudo-frictional Flow model Heat generation for δ from 0.1 to 1

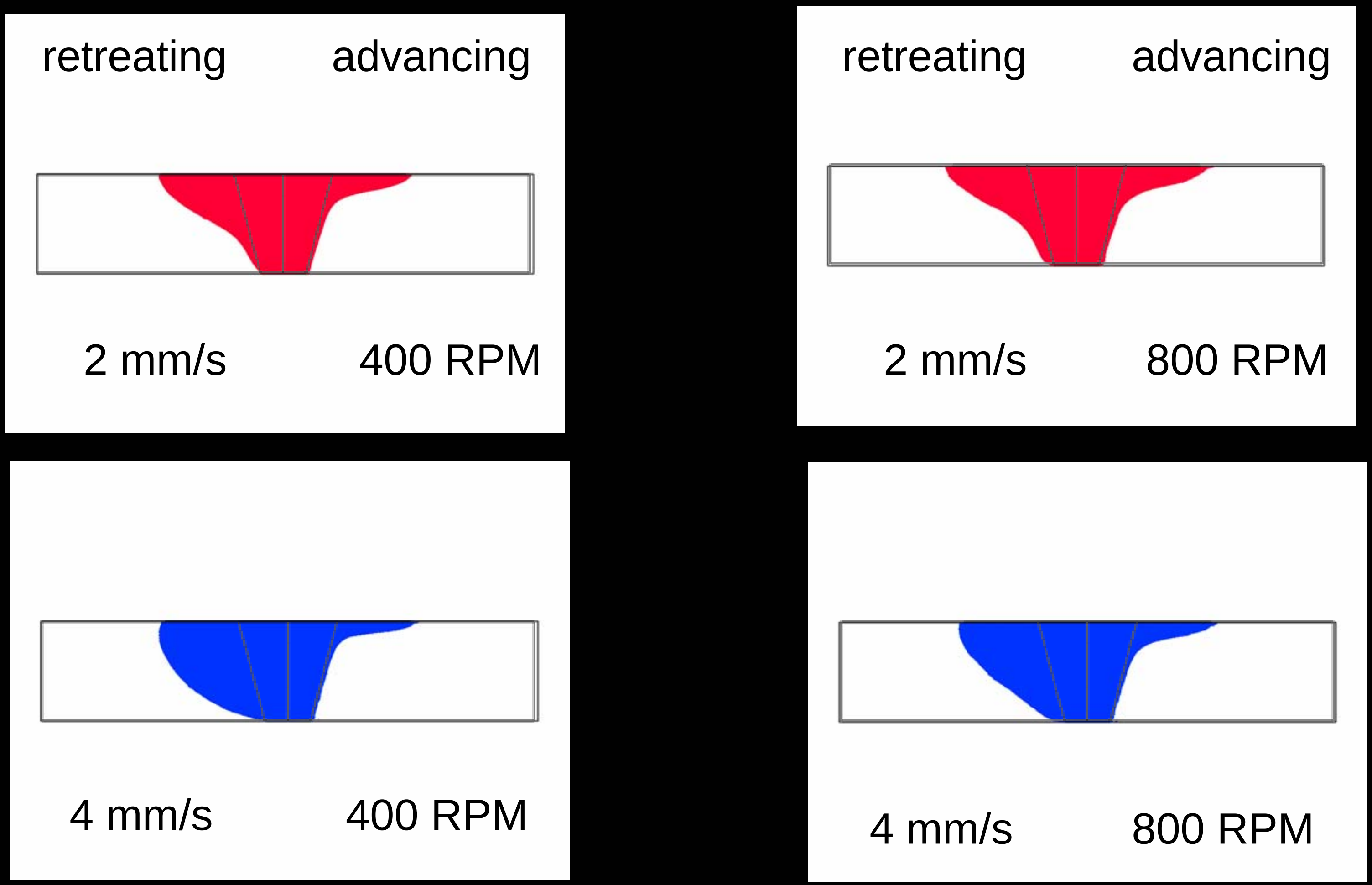


Parameter study using PFF model

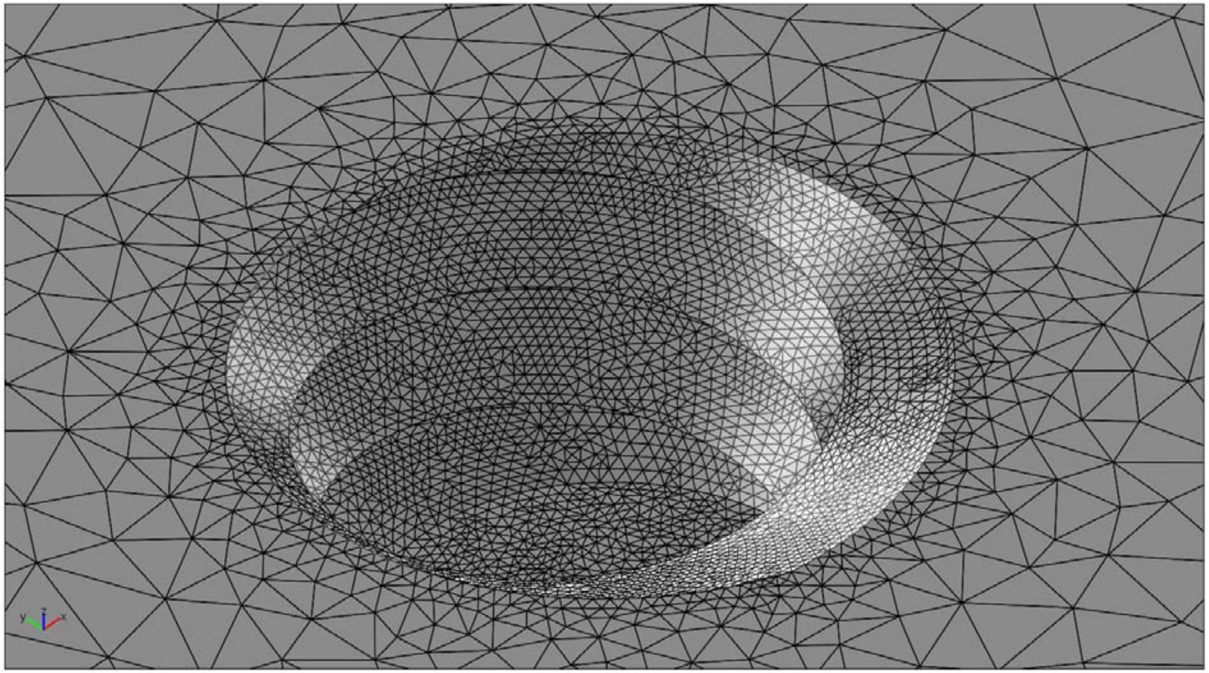
Maximum temperature and total heat generation

Welding speed \ Rotational speed	400 RPM	800 RPM
2 mm/s	388 °C 840 W	448 °C 1080 W
4 mm/s	384 °C 880 W	448 °C 1200 W

Shear layer characteristics



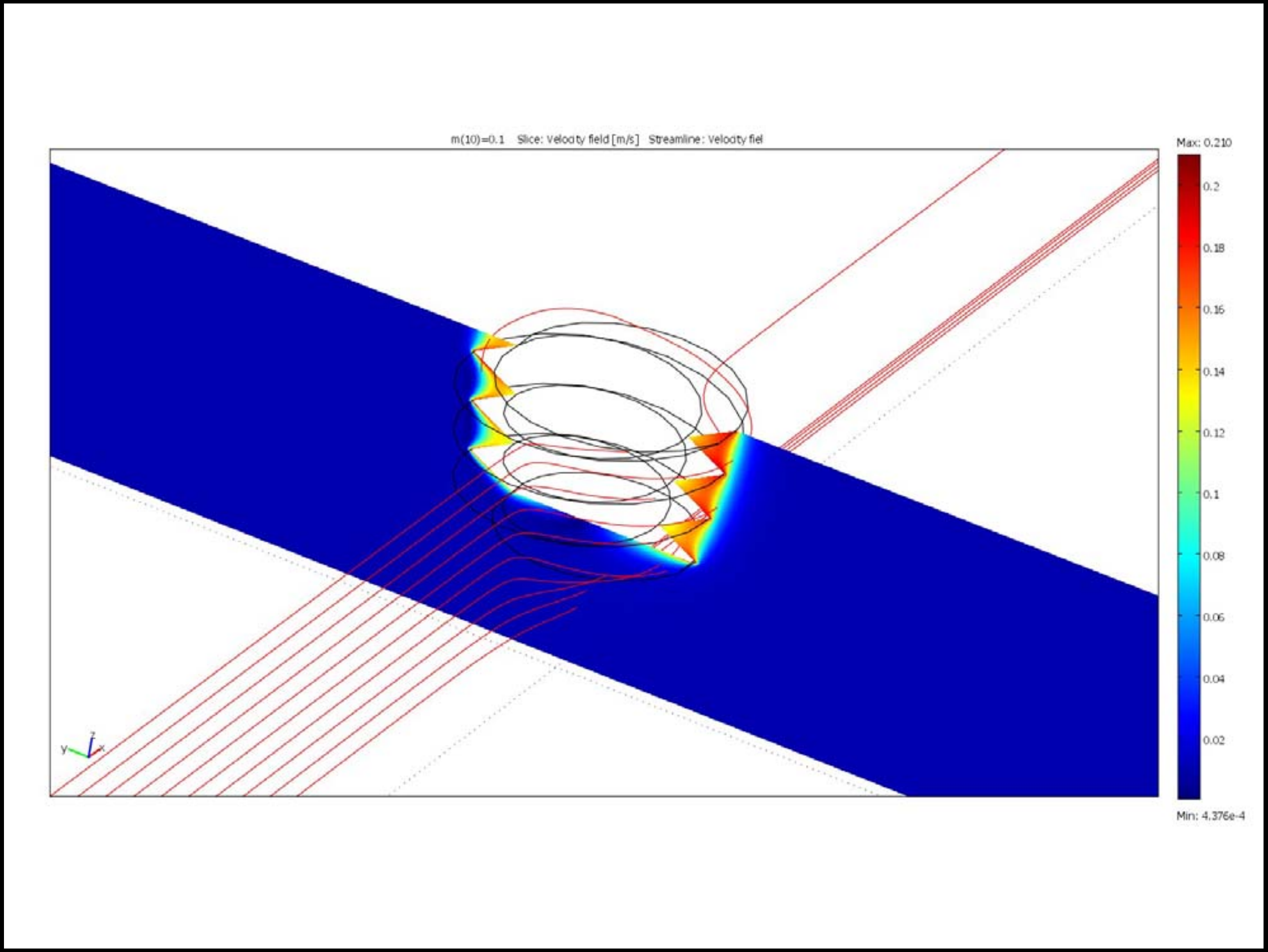
3D CFD – threaded probe



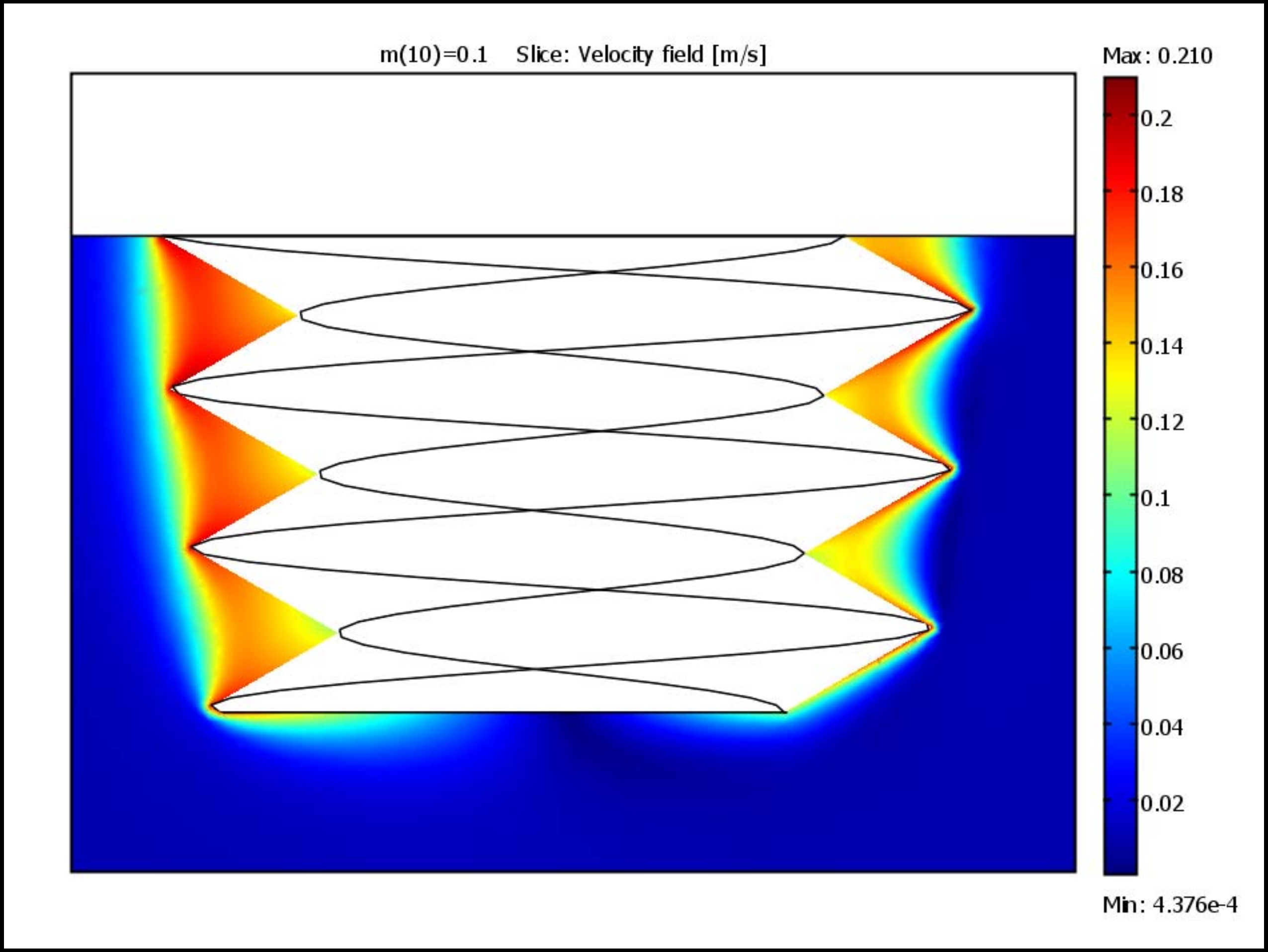
852000 dof

CPU-time: 3 mill sec=34 days

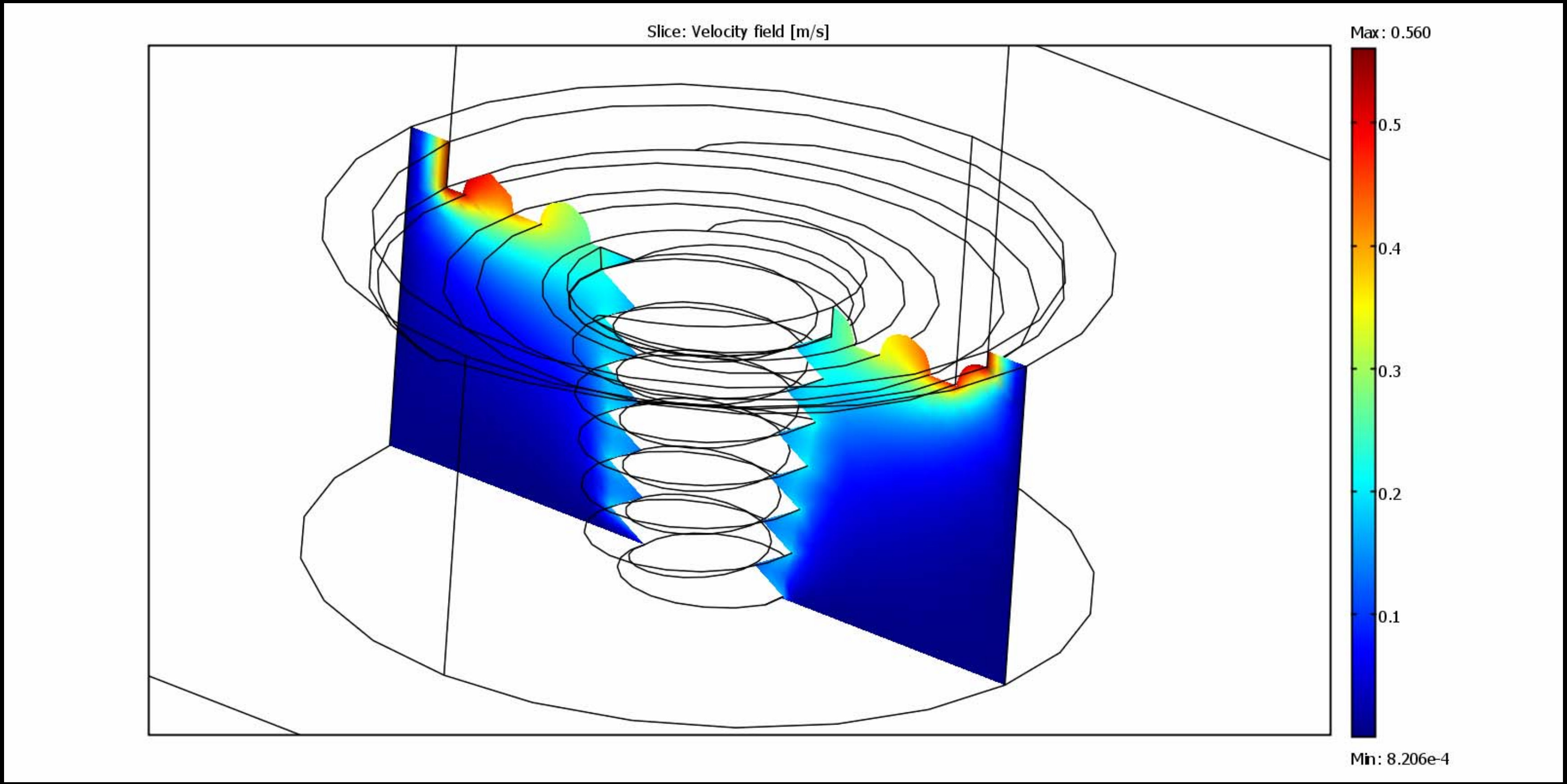
3D CFD – threaded probe
Velocity field with streamlines



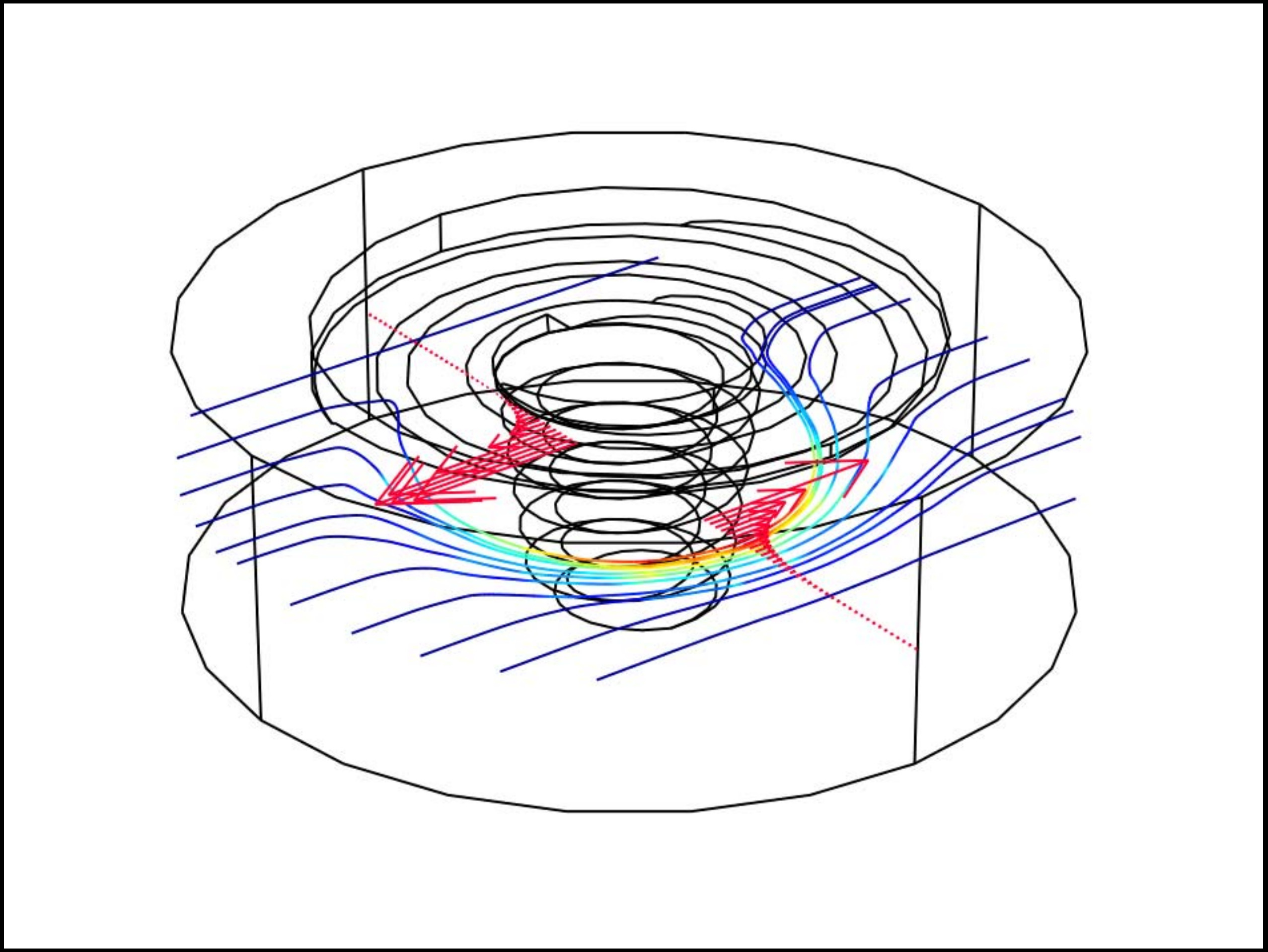
Flow field close to the threads



3D CFD – Scroll shoulder threaded probe Velocity field



Stream lines and flow around the probe



Closure

- Examples on FSW modelling
- Thermal-pseudo-mechanical model
  - Temperature dependent yield stress
  - Equilibrium between friction and flow shear stress
  - Q is output
  - Self-stabilizing heat source
- Pseudo-Frictional Flow model
  - Viscous *AND* frictional heat generation
  - Different degree of contact conditions
- Local-Global coupling
  - TPM and PFF (CFD)
- Preliminary models
  - Influence of threads and scroll