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Simulating Wear in Disc Brakes

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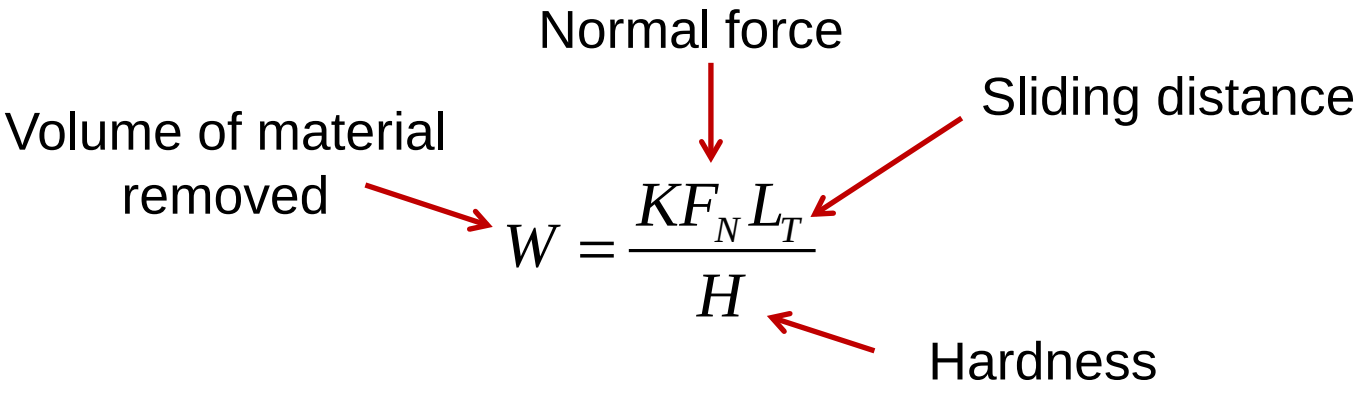
COMSOL CONFERENCE 2014 BOSTON

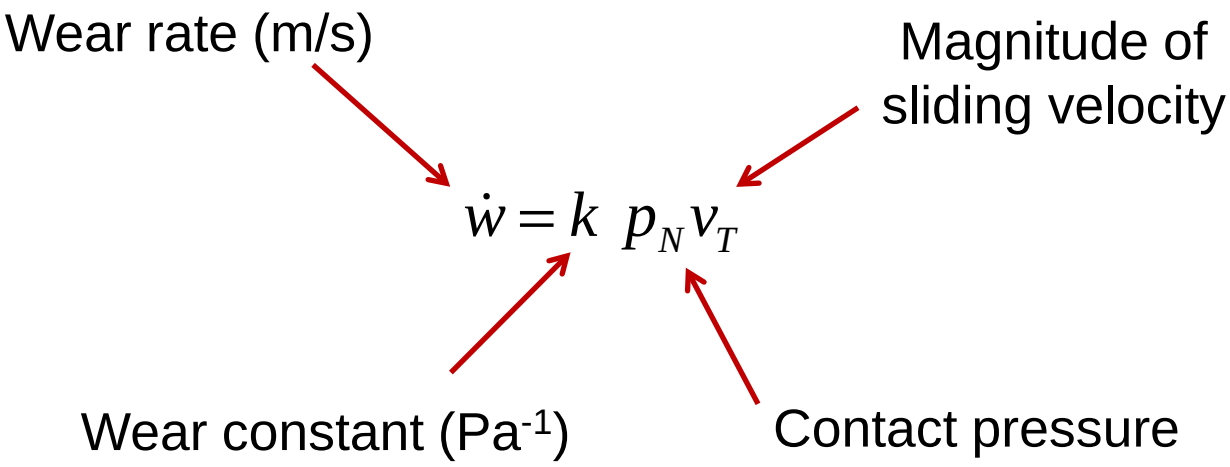
About Wear

- Wear is the process of gradual removal of material from solid surfaces subject to sliding contact
- Rate of wear depends on properties of contacting surfaces and operating conditions
- Archard's equation is simple but widely used



About Wear

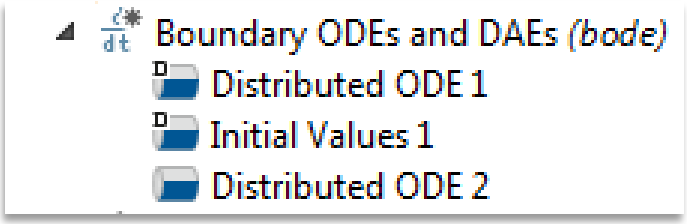
- We used a modified version of Archard's equation



Wear constant *k* can be a function of material properties, surface properties and temperature

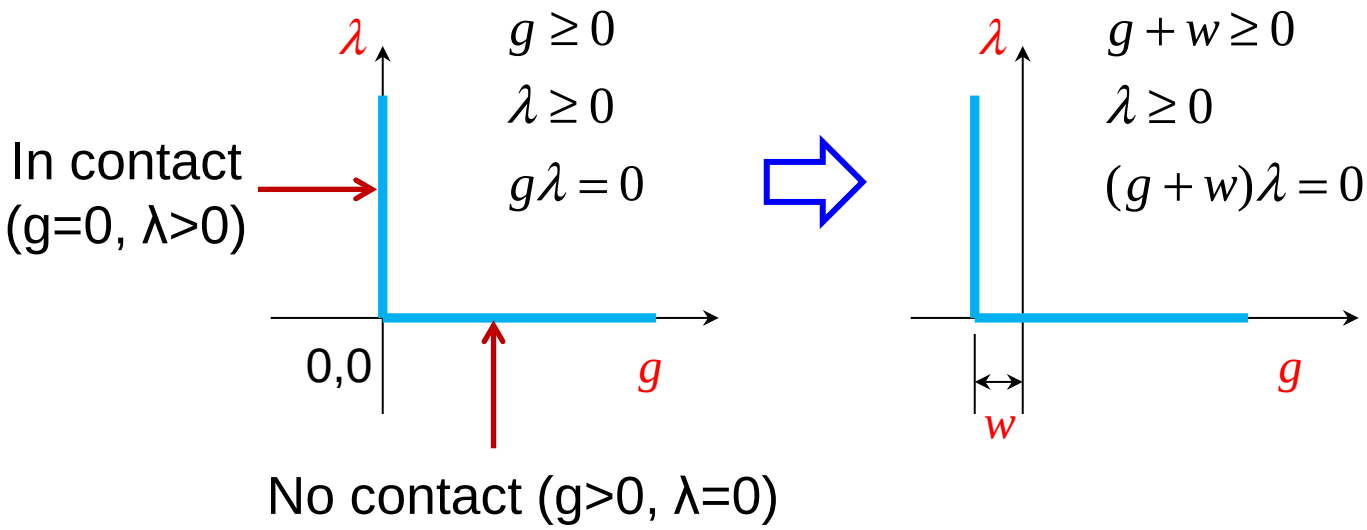
Wear Implementation

- Wear equations not directly available in FEA codes
- Straightforward to implement in COMSOL Multiphysics as Boundary Ordinary Differential Equation (ODE) defined on the contact surfaces



Wear Implementation

- Modify the gap calculation in the contact conditions to account for wear



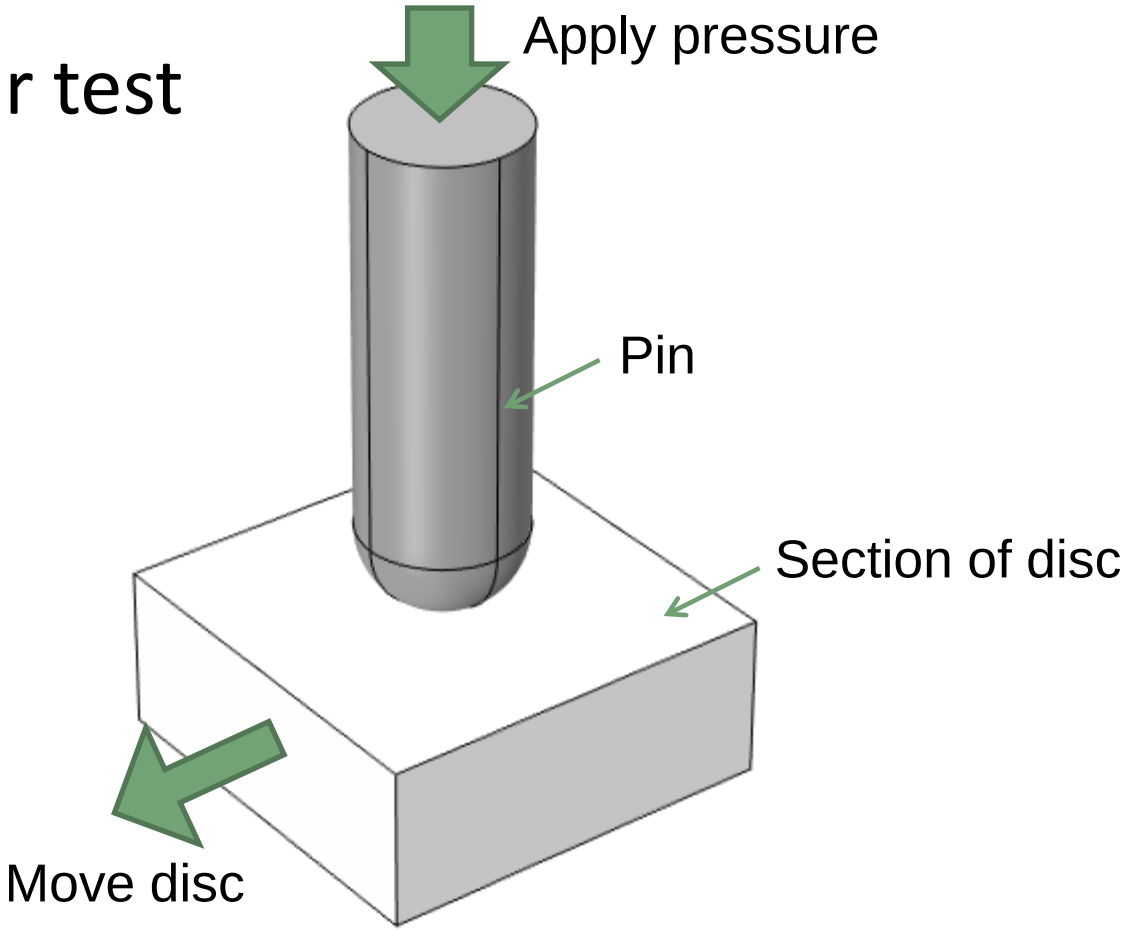
Note: g is the gap, λ is the contact pressure

Wear Implementation

- Advantages of this wear modeling approach
  - Simple to implement
  - Does not require “structural” changes in FEA calculations
  - Fast solution times
- Disadvantages of this approach
  - Only valid for small values of wear depth

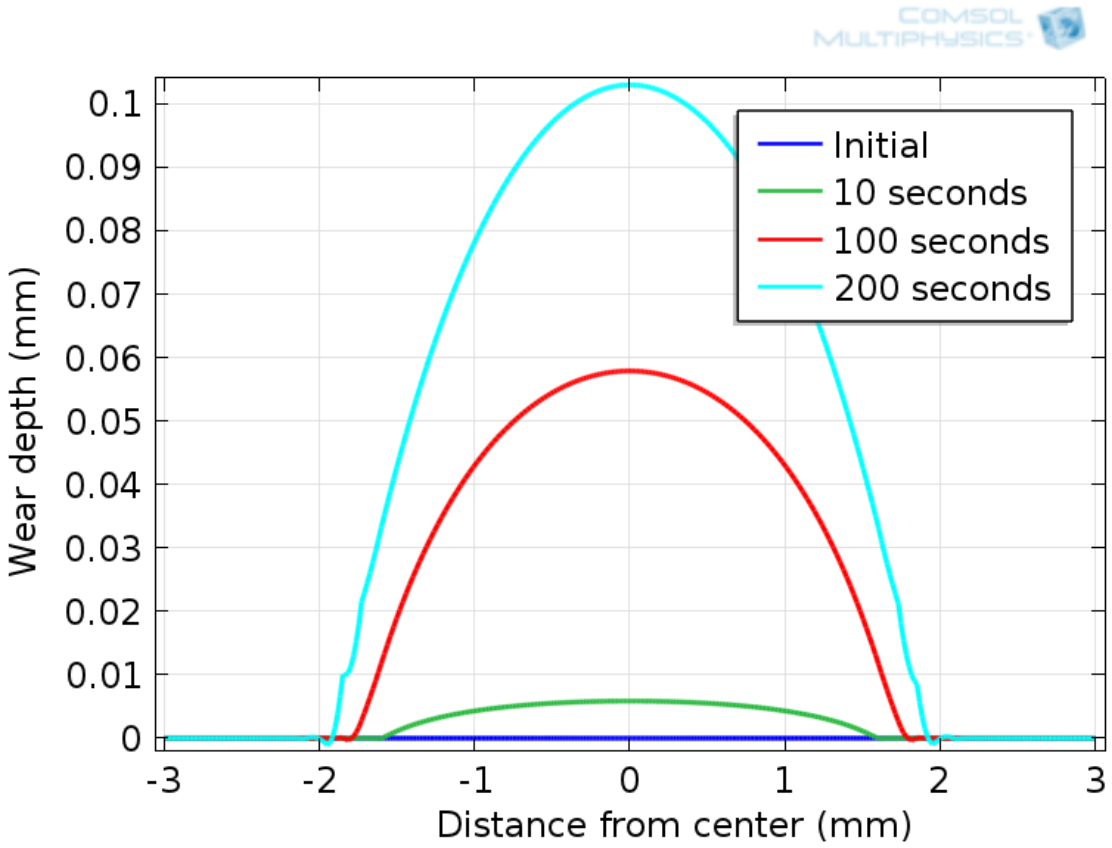
Pin-on-Disc Validation Model

- Pin-on-disc wear test



Pin-on-Disc Validation Model

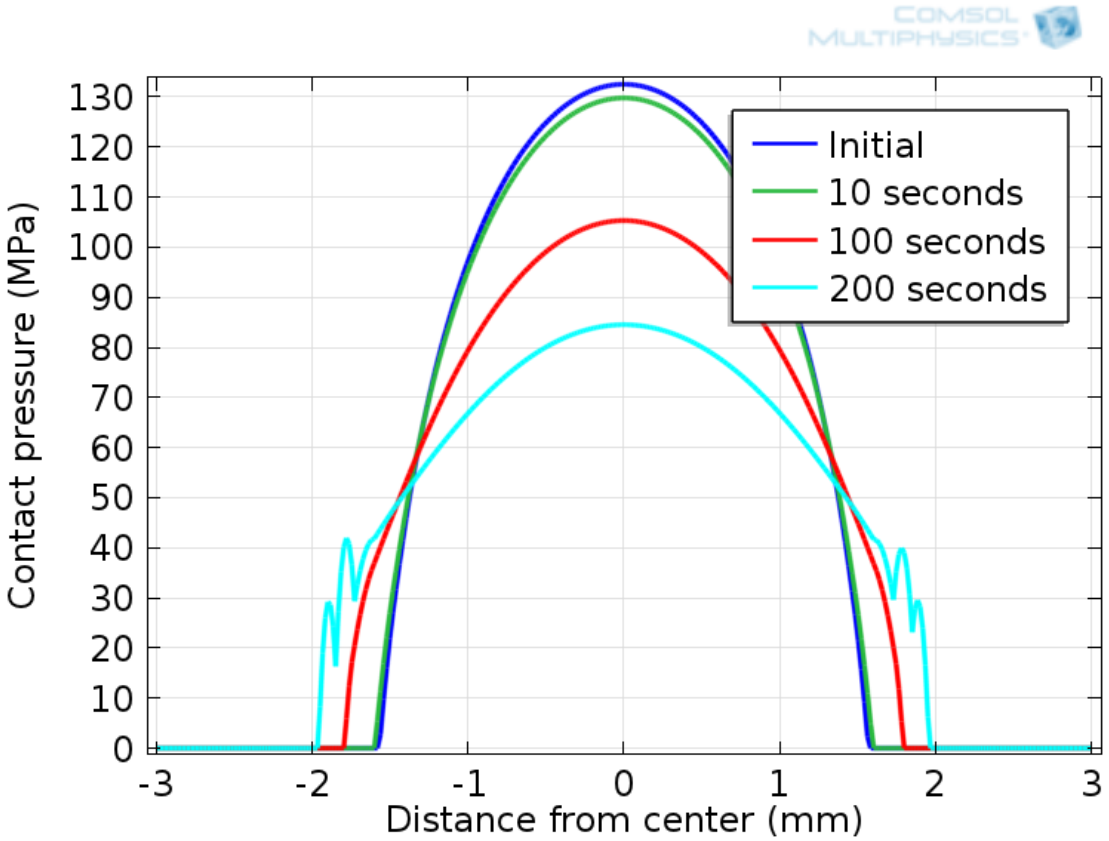
- Wear depth



- Total wear volume (integration of wear depth over pin surface) in agreement with theoretical prediction

Pin-on-Disc Validation Model

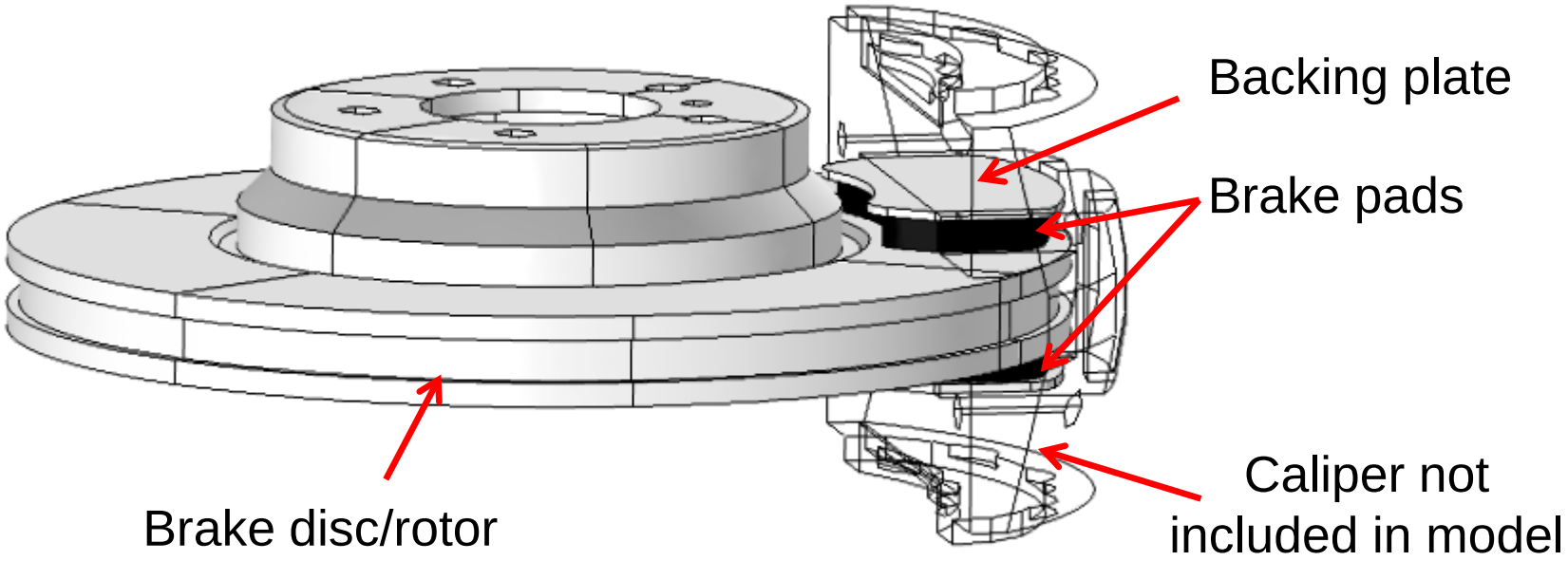
- Contact pressure evolution



- Wear decreases maximum contact pressure and increases contact area
- Wear model failing at 200 seconds

Disc Brake Wear Analysis

- Model includes brake disc, brake pads and backing plates



Disc Brake Wear Analysis

- Rotation of brake disc is not explicitly modeled
  - The intent is to ignore transients in structural analysis and focus on the steady-state solution
  - Including disc rotation requires a much smaller time step and longer solution times

Disc Brake Wear Analysis

- Effect of disc rotation included in four parts
  - As a convective term in the heat transfer analysis

$$\rho C_p \mathbf{v}_{EX} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q$$

  - In the velocity calculation for friction heat generation

$$q = \mathbf{f}_F \cdot (\mathbf{v}_T + \mathbf{v}_{EX}) \simeq \mathbf{f}_F \cdot \mathbf{v}_{EX}$$

Slip velocity resulting from FEA nodal displacements

Disc Brake Wear Analysis

- Effect of disc rotation included in four parts
  - In the calculation of friction conditions
    - Reasonable to assume constant state of slipping friction with slip velocity equal to $\mathbf{v}_{EX}$
  - In the wear equation
    - Reasonable to assume that only $\mathbf{v}_{EX}$ contributes to wear

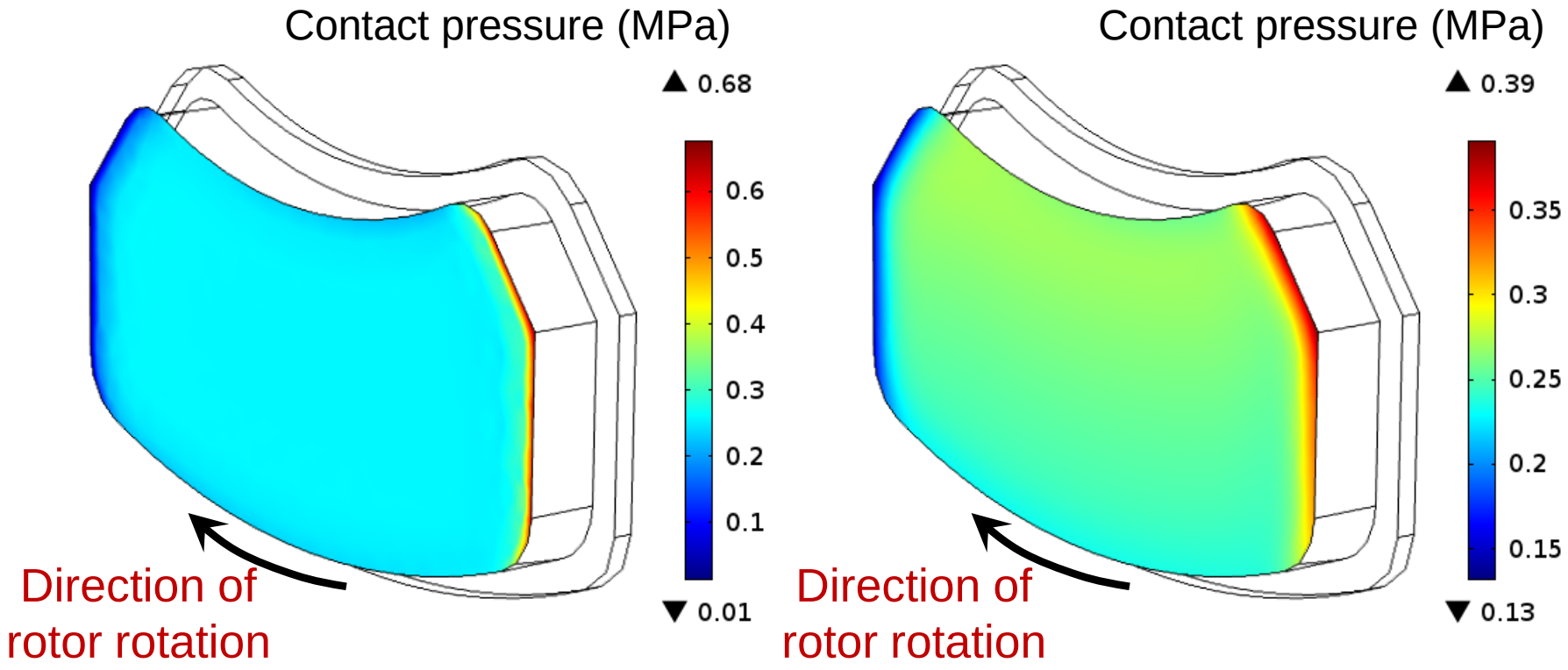
Sources of Multiphysics Coupling

- Frictional heat generation
- Thermal expansion
- Thermal contact
- Wear evolution equation

Analysis Case 1

- Continuous braking pressure of 0.2 MPa applied to backing plates
  - Relatively soft brake pressure typical of a long steep downhill drive
  - Results similar to a more aggressive intermittent braking pattern
  - Weak stabilization spring added to help with convergence before contact is established
- Braking time = 3 minutes
- Vehicle speed = 54 km/h
- Pad modulus = 0.25 GPa
- Friction = 0.3
- Wear constant = 0.5×10^{-13}

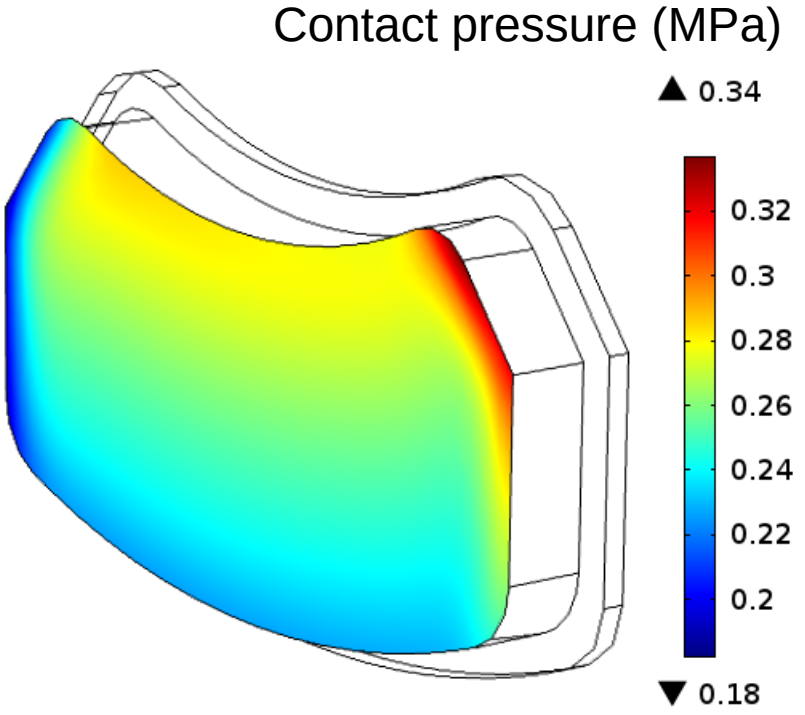
Case 1 Results: Contact Pressure

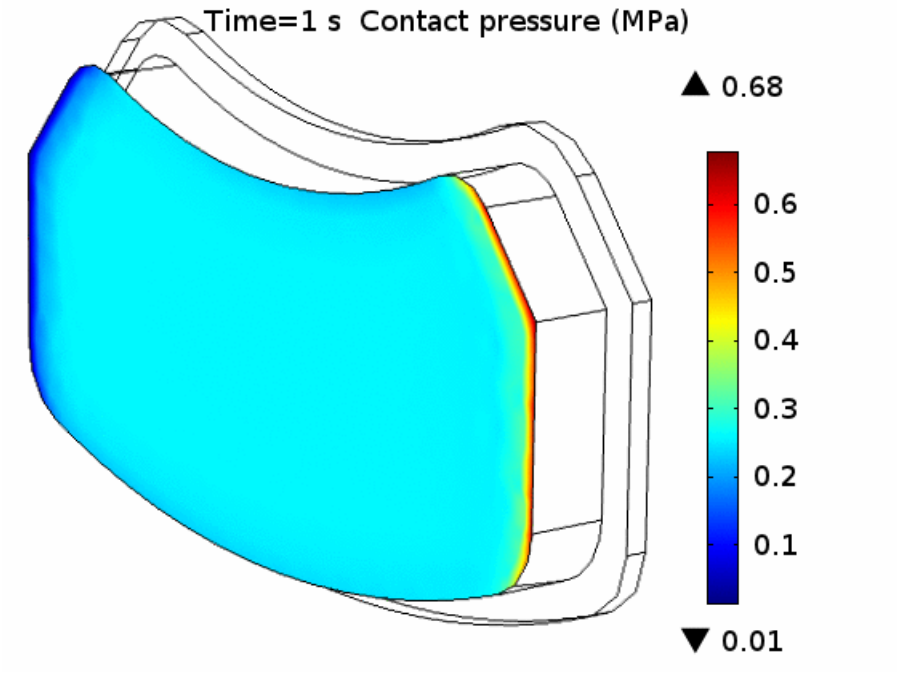


At initial contact **After 1 minute**

- Contact pressure initially concentrated at the leading edge of the pad (due to friction)
- Contact pressure gradually spreads out over wider area due to wear

Case 1 Results: Contact Pressure



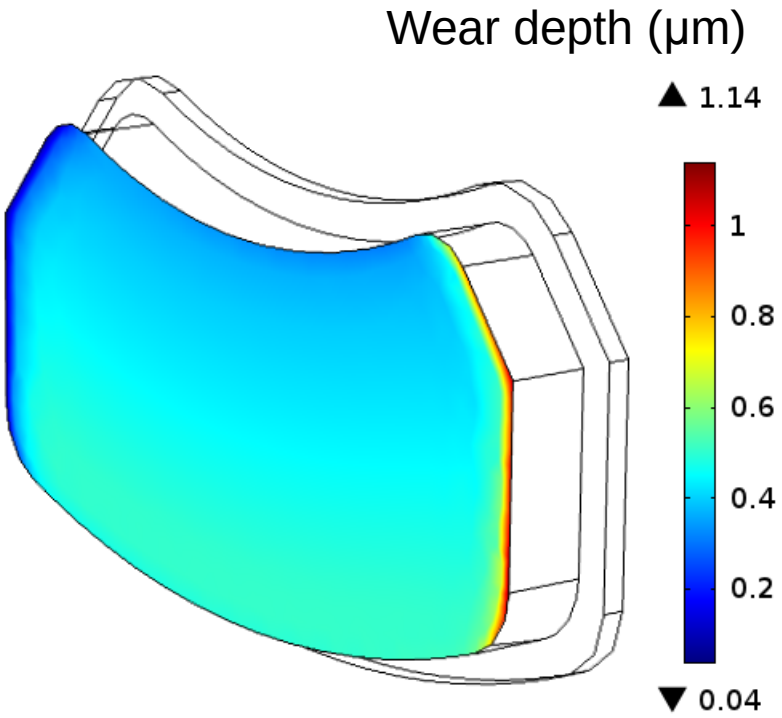


At 2 minutes

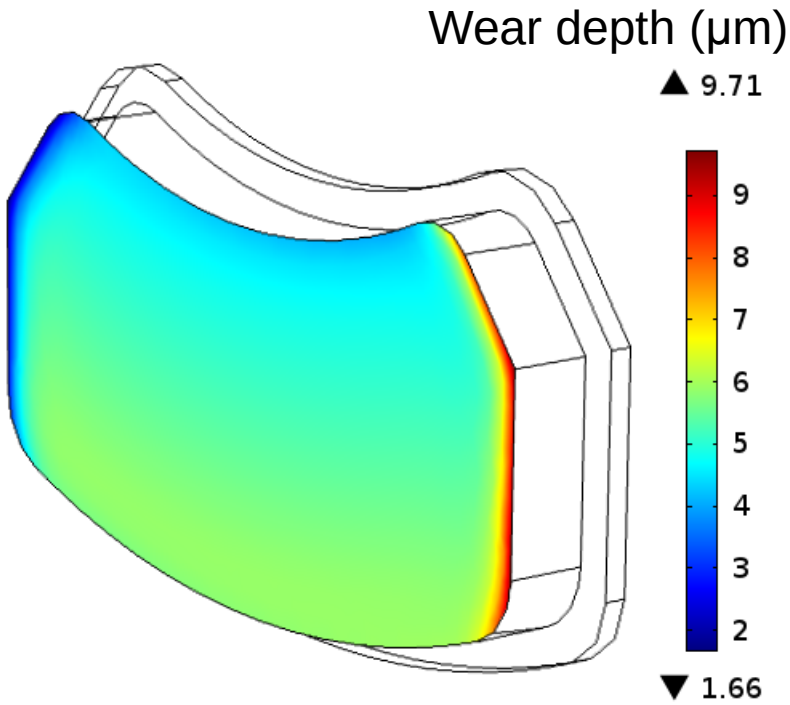
Animation

- Contact pressure gradually spreads out over wider area due to wear
- Contact pressure higher at inner radius of pad

Case 1 Results: Wear Depth



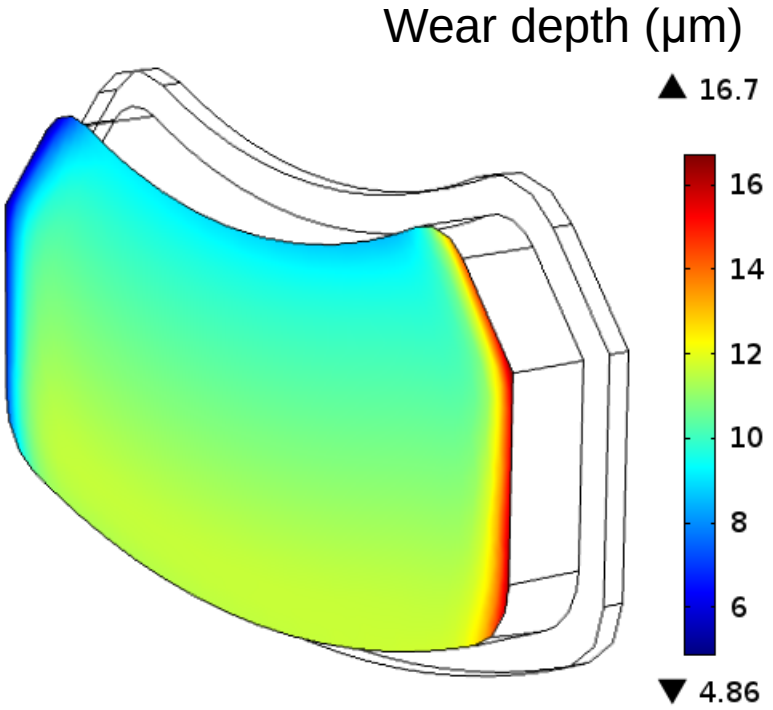
After 5 seconds

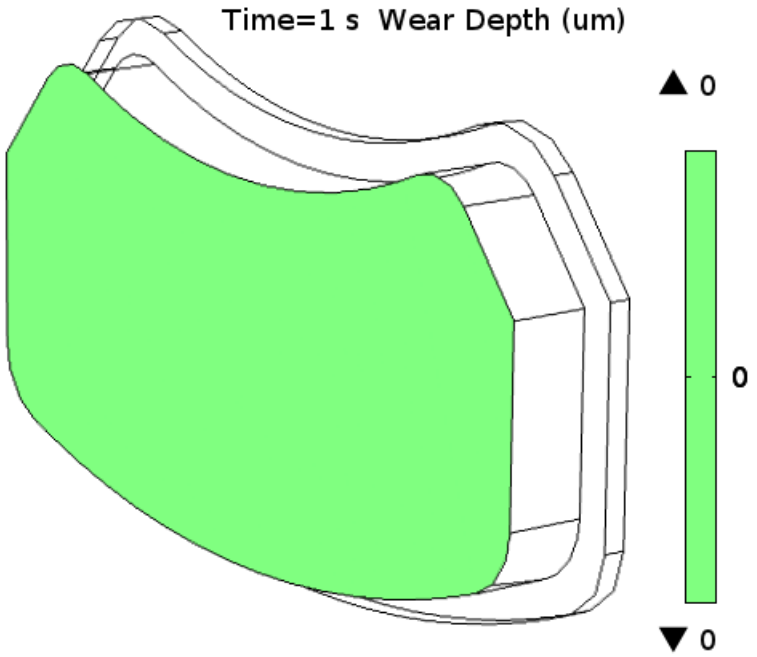


After 1 minute

- Wear initially concentrated at the leading edge of the pad
- Wear gradually spreads out over wider area of pad

Case 1 Results: Wear Depth

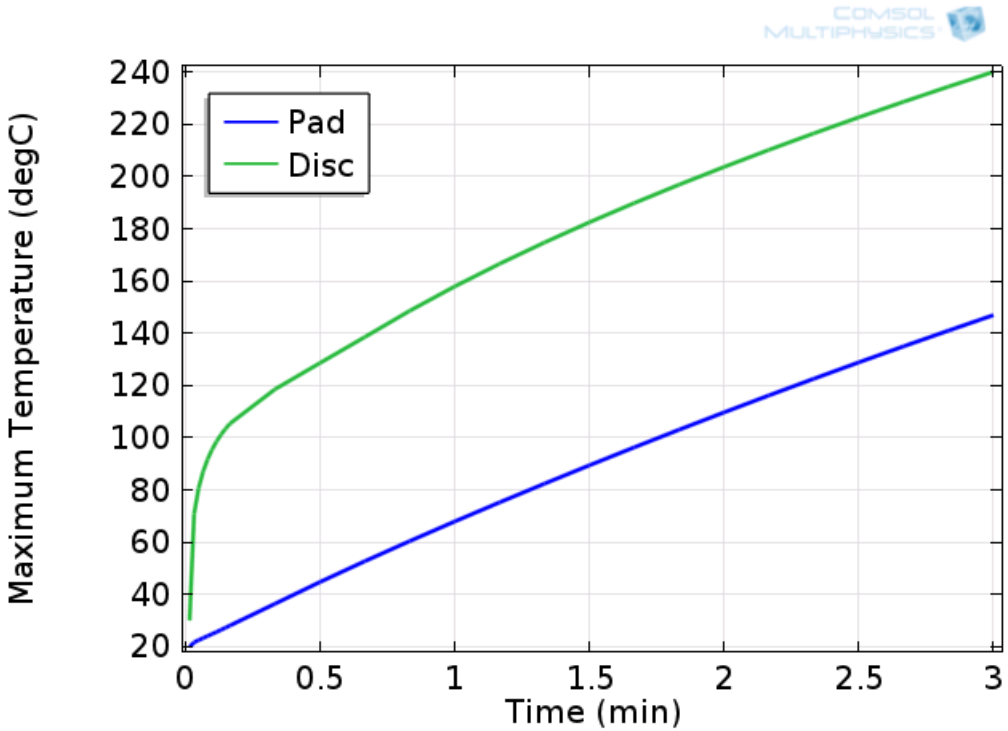




After 2 minutes **Animation**

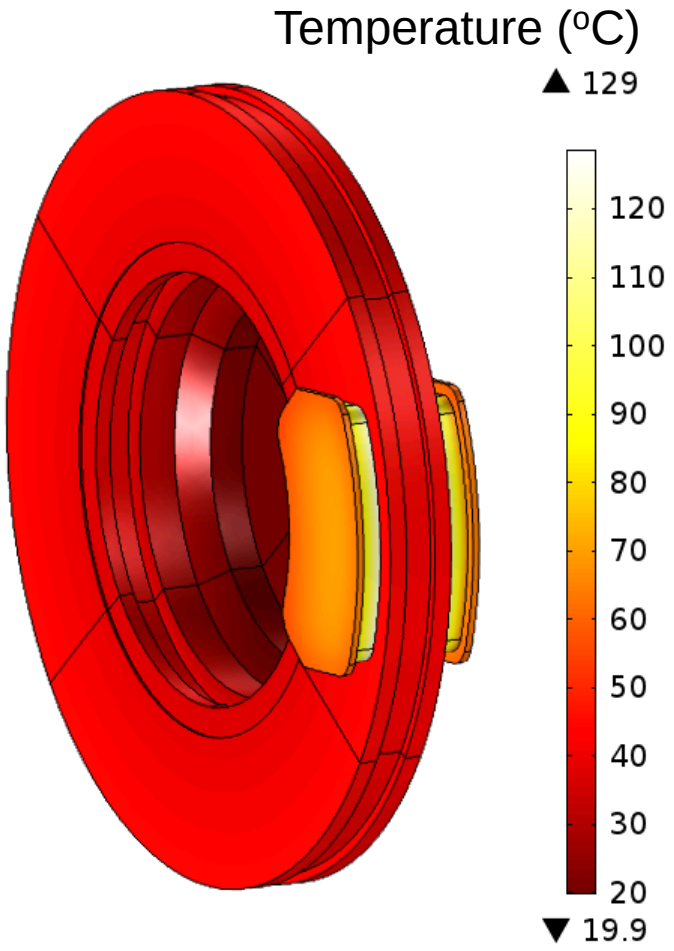
- Wear higher at outer radius of pad due to higher sliding velocity

Case 1 Results: Temperature

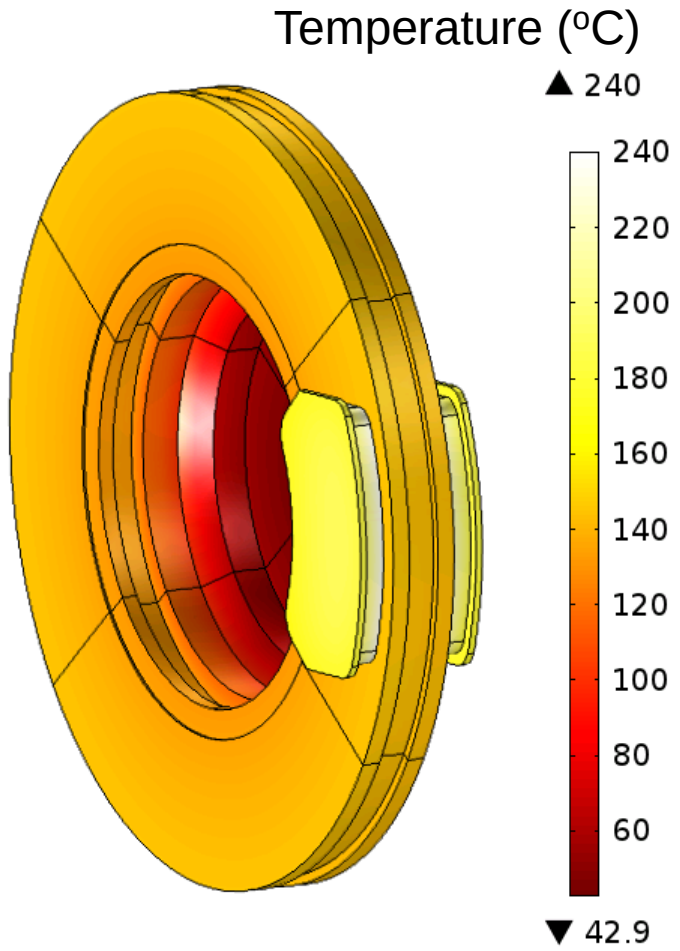


- Initial temperature rise severe in disc
- Steady state temperatures not reached even after 3 minutes

Case 1 Results: Temperature



After 30 seconds



After 3 minutes

Summary

- Developed a wear model in COMSOL
  - Boundary ODE representing wear rate equation
  - Wear depth modifies contact gap condition
- Validated model with pin-on-disc problem
- Simulated wear in automotive disc brakes