# *Modeling Interfacial Flux Layer Phenomena in the Shell/Mold Gap Using CON1D*

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# *Previous Work*

- Pseudo-transient analytical model of heat flux and flow in interfacial flux layers.
- Mold friction depends on powder flux consumption rate and solid flux velocity
- Predicting mold flux critical consumption rate

# *Objectives*

- What will happen if the flux fractures?
  - moving down from the mold

    → What is the solid flux velocity?
  - liquid filling the gap between the top attached part and bottom moving part

    → Gap size? If the liquid can fill in the gap?
  - solid flux re-attach to mold wall

    → If it will break again? Where and when?
  - liquid running out

    → If flux moves with steel shell?

# *Fracture Model Description*

- Fracture happens at the maximum up-stroke due to axial tensile stress
- After fracture, solid flux moves down from mold wall, the velocity depends on force balance of two side:
  - Mold/solid flux interface:

$$\tau_{mold\,/\,solid\,flux} = \phi_{moving} \cdot \rho_{steel}\, g z$$

$\phi_{moving}$, Moving friction coefficient

  - Solid/liquid flux interface:

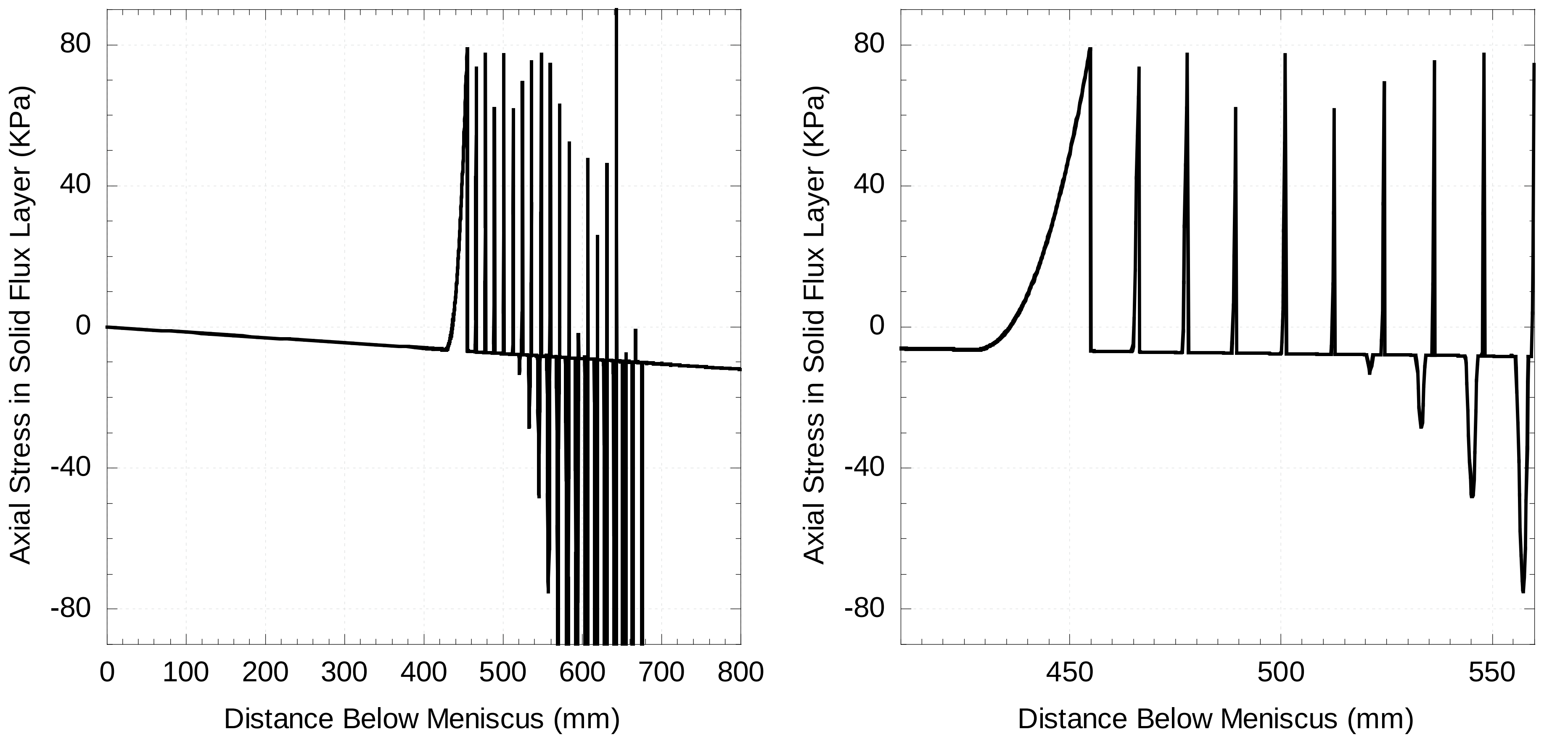
$$\tau_{s/l} = \mu_s \frac{(n+1)(V_c - V_s)}{d_l} + \frac{(n+1)}{(n+2)} \left(\rho_{flux} - \rho_{steel}\right) g d_l$$

$$So:\ \tau_{s/l} = \tau_{m/s} \quad \Rightarrow \quad V_s \quad can\ be\ calculated$$

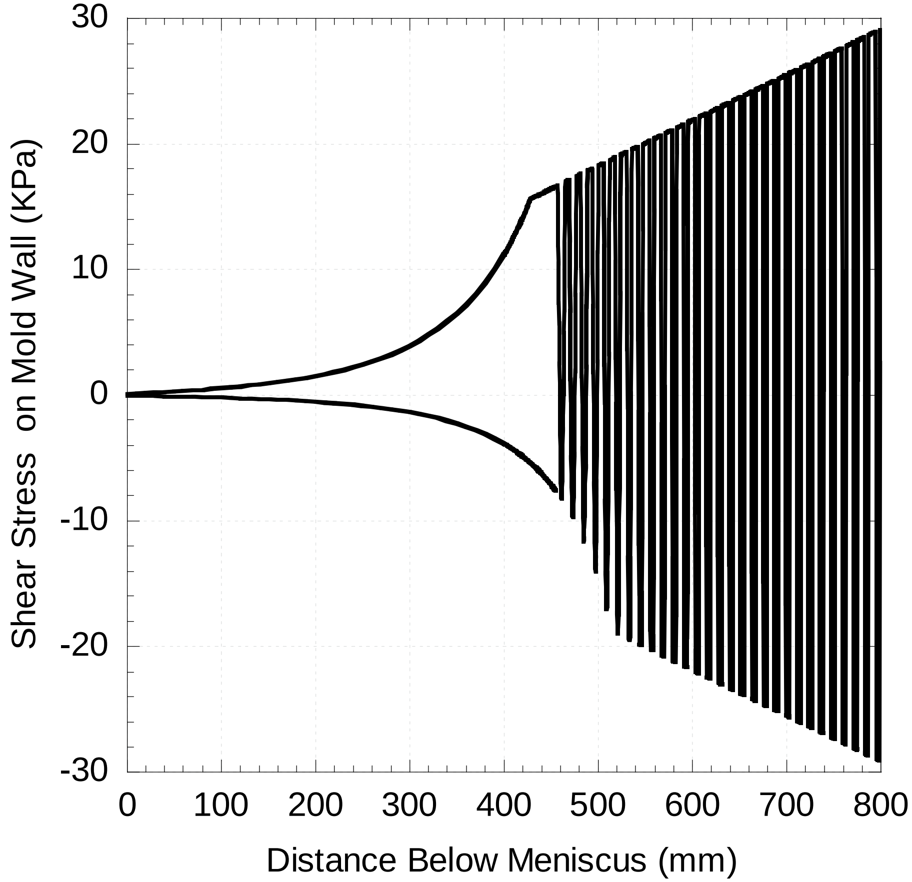
# *Example Application: Input Conditions*

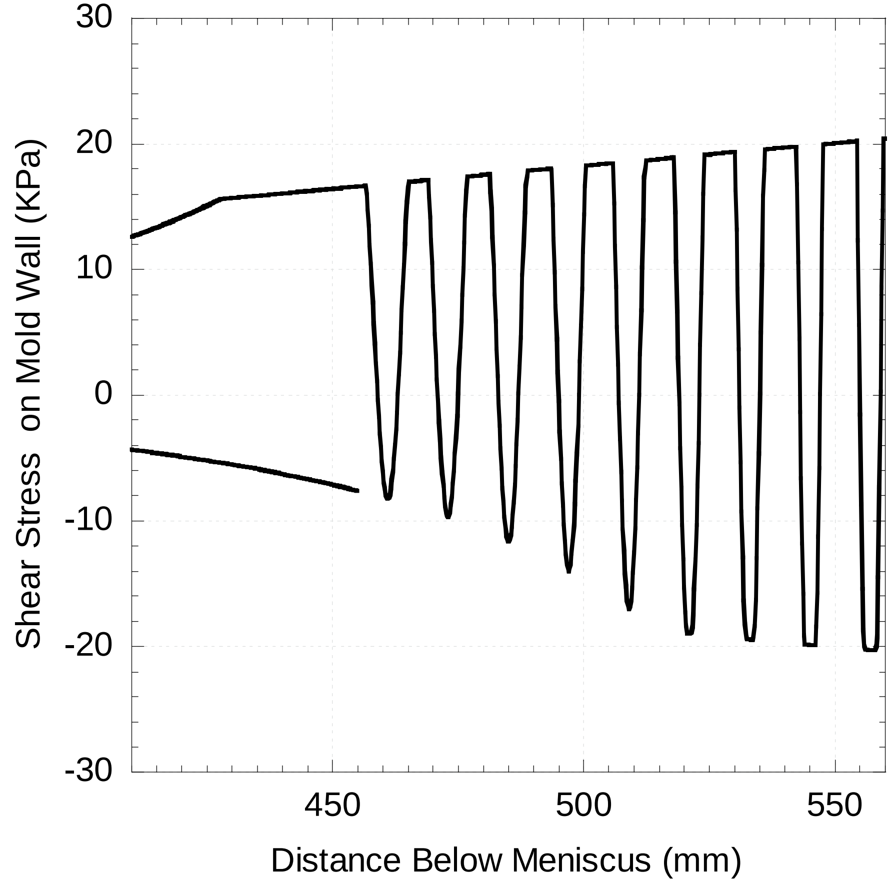
| | | |
|---|---|---|
| • Casting Speed: | 1.0 | m/min |
| • Pour Temperature: | 1550 | $^{o}C$ |
| • Slab Geometry: | 1500*230 | $mm^2$ |
| • Nozzle Submergence depth: | 265 | mm |
| • Working Mold Length: | 800 | mm |
| • Time Step: | dt=0.001 | s |
| • Mesh Size: | dx=0.5 | mm |
| • Fraction Solid for Shell Thickness location: | 0.3 | |
| • Carbon Content: | 0.05 | % |
| • Mold Powder Solidification Temperature: | 950 | $^{o}C$ |
| • Mold Powder Conductivity (solid/liquid): | 1.5/1.5 | W/mK |
| • Mold Powder Density: | 2500 | $kg/m^3$ |
| • Mold Powder Viscosity at 1300 $^{o}C$: | 4.2 | poise |
| • Exponent for temperature dependency of viscosity: | 1.6 | - |
| • Fracture strength (tensile/compress): | 80/8000 | KPa |
| • Mold Powder Consumption Rate: | 0.45 | $kg/m^2$ |
| • Solid Flux Velocity: | 0.1 | - |
| • Mold/flux coefficient (static/moving): | 0.5/0.5 | - |
| • Oscillation Mark Geometry (depth*width): | 0.45*4.5 | $mm^2$ |
| • Mold Oscillation Frequency: | 83.3 | cpm |
| • Oscillation Stroke: | 7.8 | mm |
| • Mold Thickness (including water channel): | 51 | mm |
| • Initial Cooling Water Temperature: | 30 | $^{o}C$ |
| • Water Channel Geometry (depth*width*distance): | 25*5*29 | $mm^3$ |
| • Cooling Water Flow rate: | 7.8 | m/s |

# *Axial Stress in Solid Flux Layer*

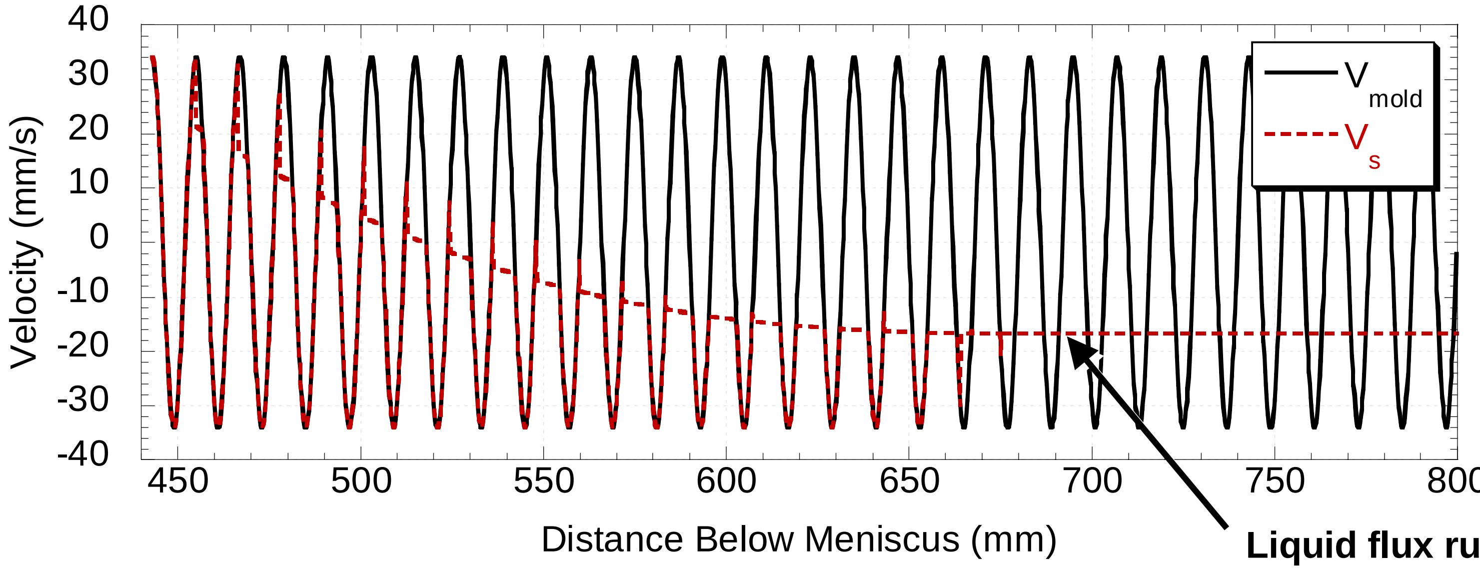


# Shear Stress on Mold Wall

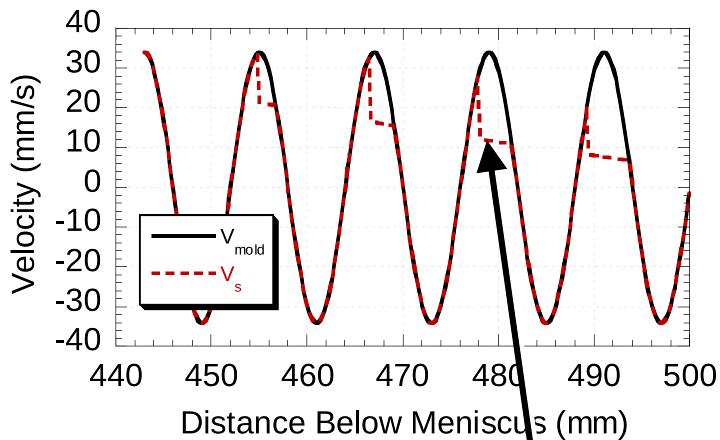


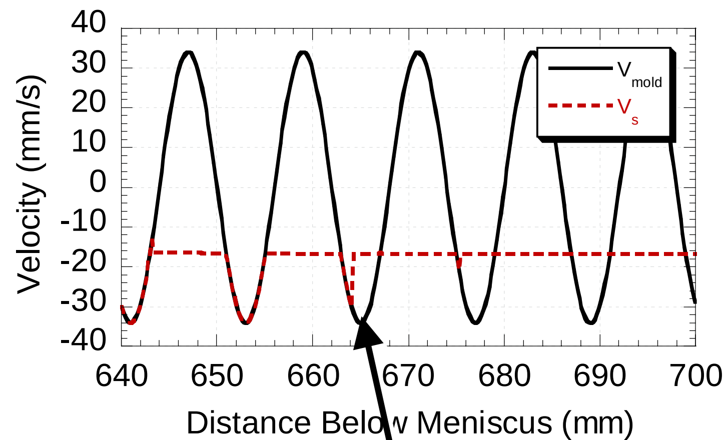



# *Mold & Solid Flux Velocity*




**Liquid flux runs out**

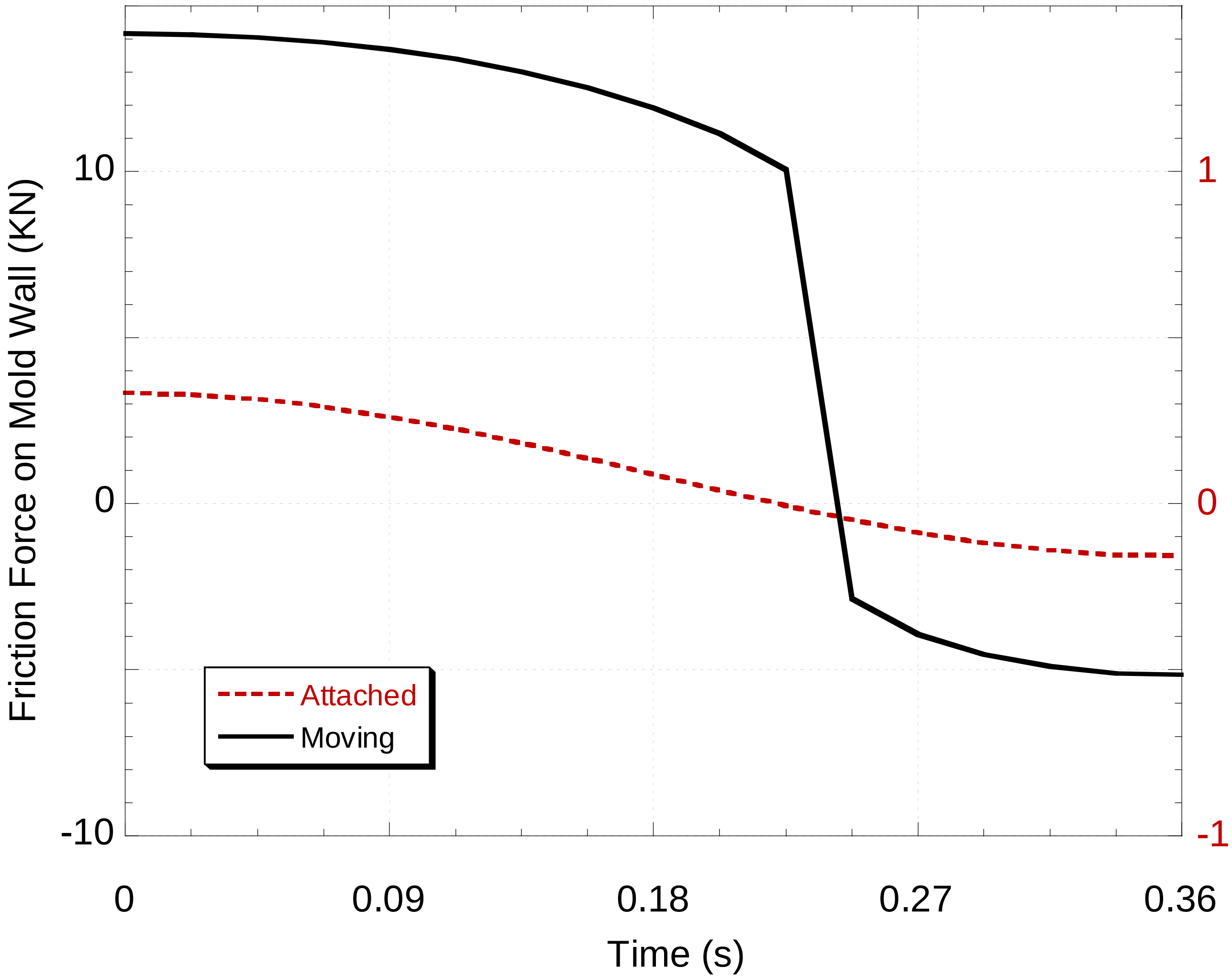


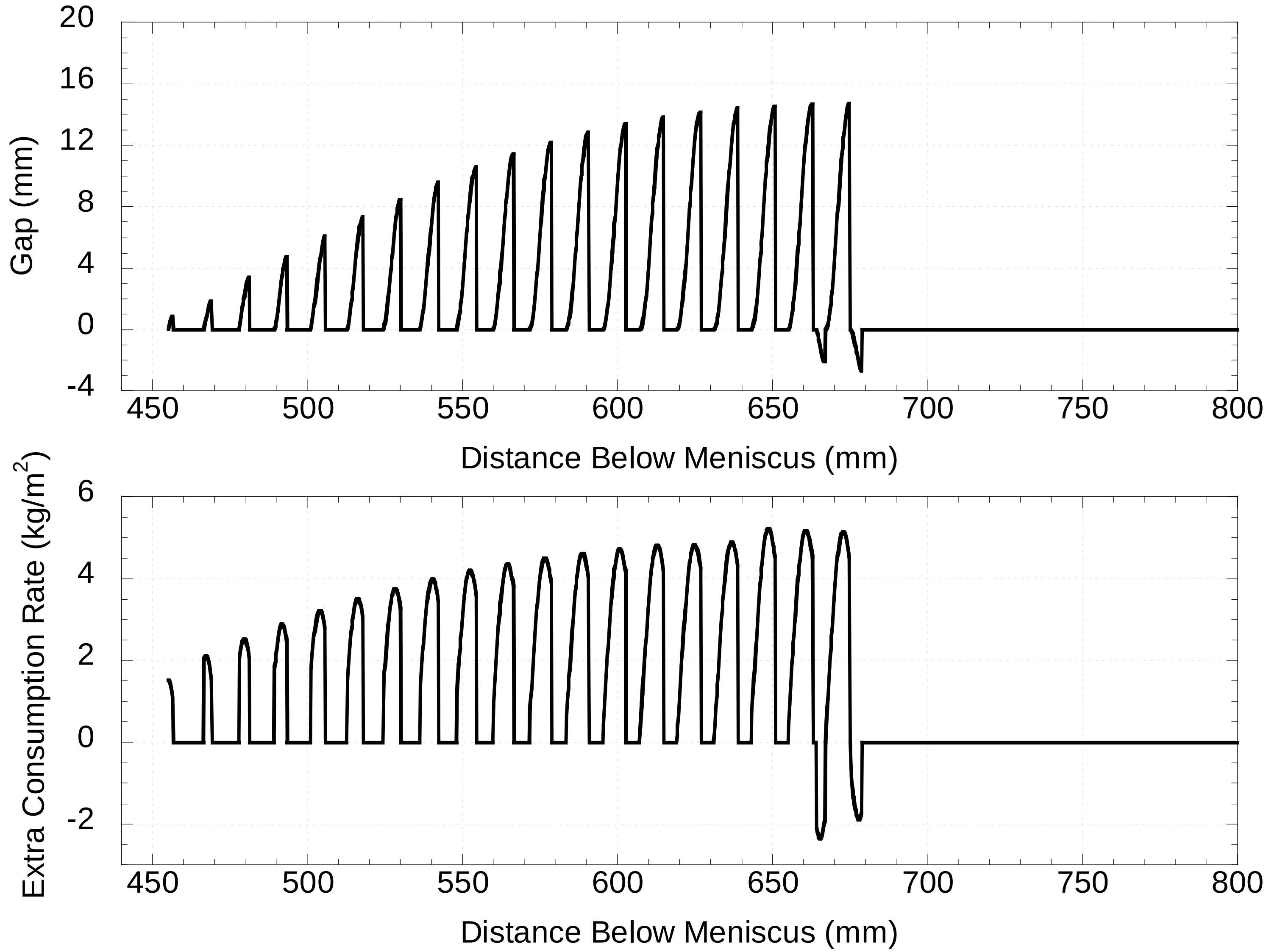

**Fracture due to tensile stress**

**Fracture due to compress stress**

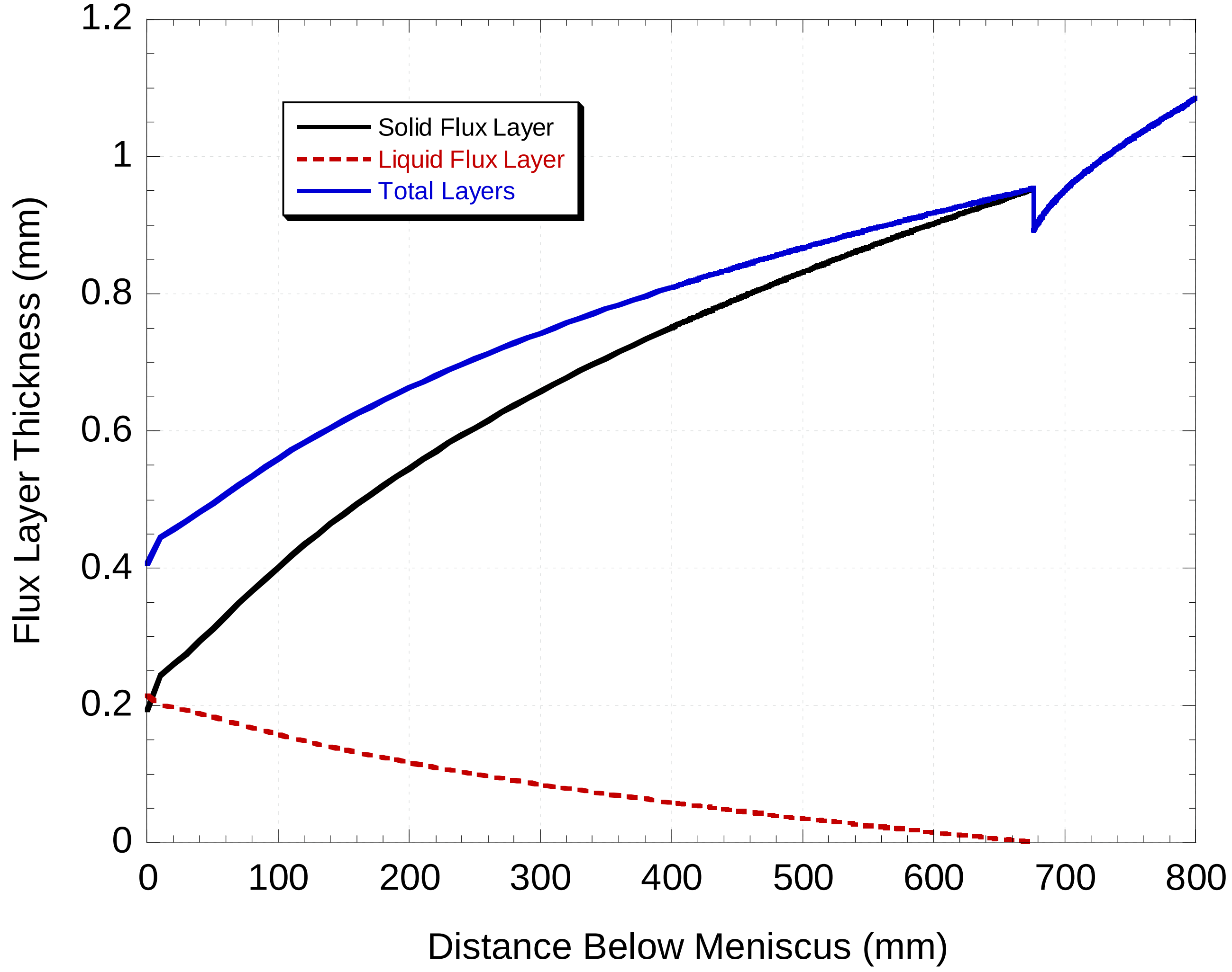
# Friction Force on Mold Wall



# *Gap after Fracture*



# Flux Layer Thickness



# *Example Application: Output Results*

| | | |
|---|---|---|
| • Liquidus Temperature: | 1529 | °C |
| • Solidus Temperature: | 1509 | °C |
| • Negative Strip Time: | 0.24 | s |
| • Positive Strip Time: | 0.48 | s |
| • Negative Strip Ratio of Velocity: | 0.3 | - |
| • Velocity Amplitude of Mold Oscillation: | 34.03 | mm/s |
| • Pitch (spacing between oscillation marks): | 12 | mm |
| • Maximum Mold Hot Face Temperature: | 376.56 | °C |
| • Maximum Mold Cold Face Temperature: | 168.75 | °C |
| • Mold Cooling Water Temperature Increase: | 7.56 | °C |
| • Mean Heat Flux in Mold: | 1.5715 | $MW/m^2$ |
| • Basic Consumption Rate, $CONS_{basic}$: | 0.239 | $kg/m^2$ |
| • Shear Stress in Mold at Maximum Up-stroke: | 11.8032 | KPa |
| • Shear Stress in Mold at Maximum Down-stroke: | -4.3052 | KPa |
| • Calculated solid flux velocity ratio | 0.24 | - |
| Variables Calculated at Mold Exit: | | |
| • Shell Surface Temperature: | 951.04 | °C |
| • Mold Hot Face Temperature: | 189.03 | °C |
| • Shell Thickness: | 22.69 | mm |
| • Liquid Flux Film Thickness: | 0.000 | mm |
| • Solid Flux Film Thickness: | 1.086 | mm |
| • Heat Flux: | 0.975 | $MW/m^2$ |

# *Conclusions*

- First fracture happens at the maximum up stroke.
- After fracture the solid flux moving down from mold wall, the velocity is calculated according to force balance.
- When mold velocity equals to solid flux's, the solid flux re-attaches to the mold wall.
- The above procedure may repeat, when accumulated axial stress exceeds the fracture strength.
- When liquid flux runs out, the solid flux layer moves with steel shell as casting speed.

# *Future Work*

- Improve model so output matches input consumption.
- Parametric study about static friction coefficient and moving friction coefficient between mold and solid flux.
- Measure flux viscosity and friction coefficient at low temperature using High Temperature Tribometer.
- Calculate friction force due to mismatch taper using normal stress calculation from CON2D.