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:
    \[ \tau_{\text{mold/solid flux}} = \phi_{\text{moving}} \cdot \rho_{\text{steel}} g z \]
    \( \phi_{\text{moving}} \), Moving friction coefficient
  - Solid/liquid flux interface:
    \[ \tau_{s/l} = \mu_s \frac{(n+1)(V_c - V_s)}{d_l} + \frac{(n+1)}{(n+2)} \left( \rho_{\text{flux}} - \rho_{\text{steel}} \right) gd_l \]

So: \( \tau_{s/l} = \tau_{m/s} \implies V_s \text{ can be calculated} \)
Example Application: Input Conditions

- Casting Speed: 1.0 m/min
- Pour Temperature: 1550 °C
- Slab Geometry: 1500*230 mm²
- 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 °C
- Mold Powder Conductivity (solid/liquid): 1.5/1.5 W/mK
- Mold Powder Density: 2500 kg/m³
- Mold Powder Viscosity at 1300 °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/m²
- Solid Flux Velocity: 0.1
- Mold/flux coefficient (static/moving): 0.5/0.5
- Oscillation Mark Geometry (depth*width): 0.45*4.5 mm²
- Mold Oscillation Frequency: 83.3 cpm
- Oscillation Stroke: 7.8 mm
- Mold Thickness (including water channel): 51 mm
- Initial Cooling Water Temperature: 30 °C
- Water Channel Geometry (depth*width*distance): 25*5*29 mm³
- Cooling Water Flow rate: 7.8 m/s
Axial Stress in Solid Flux Layer

![Graph showing axial stress in solid flux layer](image-url)
Shear Stress on Mold Wall

![Graph showing shear stress on mold wall with distance below meniscus on the x-axis and shear stress on the y-axis. The graph depicts a smooth curve transitioning into a periodic pattern as the distance increases.](image-url)
Mold & Solid Flux Velocity

Liquid flux runs out

Fracture due to tensile stress

Fracture due to compress stress

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Gap after Fracture

![Graph showing gap after fracture vs distance below meniscus.

- Two graphs are plotted.
- The top graph shows the gap in millimeters (mm) vs distance below meniscus (mm).
- The bottom graph shows the extra consumption rate in kg/m² vs distance below meniscus (mm).

The graphs demonstrate the relationship between the gap and extra consumption rate as the distance below the meniscus changes.
Flux Layer Thickness

![Graph showing the thickness of flux layers as a function of distance below the meniscus. The graph includes lines for solid flux layer, liquid flux layer, and total layers.]
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/m²
- Basic Consumption Rate, CONS_{basic}: 0.239 kg/m²
- 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/m²
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.