3D Simulation of Mold Heat Flow

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Consulting Project: Columbus Stainless
3-D Model of Mold
Temperature Near Meniscus

Domain (showing slots)

Bolt holes containing Thermocouples

Finite Element Mesh
(4-node tetrahedrons)

water slots
Finite Element Model

Solve 3-D heat conduction equation:

\[
\frac{\partial}{\partial x} k_x \frac{\partial T}{\partial x} + \frac{\partial}{\partial y} k_y \frac{\partial T}{\partial y} + \frac{\partial}{\partial z} k_z \frac{\partial T}{\partial z} = -Q
\]

Using 4-node tetrahedral elements:

Using 8457 node - 41266 elements (small mesh)
3-D Model of Mold Temperature Near Mold Bottom

constant $q = 1.75$ MW/m$^2$

Interior view (showing slots)  
Hotface Temperature

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Heat Flux Profiles
From Calibrated Model

Constant Heat flux (1.75 W/m²)
45 mm mold thickness (new)
h_water = 45 kW/m²
t_water = 25 °C
wideface (near center) eg. TC 5,6
3-D Model of Mold
Temperature Near Meniscus

Interior view (showing slots)  Temperature Predictions
3-D Model of Mold
Temperature Near Meniscus

Bottom view (water slots)  Top view (hotface)
Heat Flux Profiles
From Calibrated Model

![Graph showing heat flux profiles from a calibrated model. The graph plots heat flux (MW/m²) against distance below the top of the mold (mm). Two cases are compared: Case 1 (solid line) and Case 2 (dashed line). The graph includes data points at various distances, such as 4.08 MW/m² at 0.20 mm, 2.86 MW/m² at 0.50 mm, and 1.60 MW/m² at 0.30 mm.](image)
3D Model Application: Meniscus Level Monitoring

Effect of meniscus level on mold temperature

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Effect of Meniscus Level on Thermocouple Temperature

Meniscus level can be inferred from thermocouple temps.

Effect of meniscus level on thermocouple temperature
Solidification Model (CON1D): Validation with 3D model

(based on heat flux profile in Fig. 1; 4.08 MW/m² max at 100mm)
Heat Flux Profiles
From Calibrated Model

![Graph showing heat flux profiles](image)

- Heat Flux Profiles from Calibrated Model
- Heat Flux (MW/m²) vs Distance below top of mold (mm)
- Narrow Face
- Wide Face
Heat Flux Profiles
From Calibrated Model

Real Conditions

Hotface Temperature (Degrees C)

Distance below top of mold (mm)
Conclusions

Efficient and accurate 3D model has been developed. The model features complete copper geometry including details of the thermocouple rod, paste, and hole, and the curved water slot geometry in each symmetric section of the mold.

Offset distances for CON1D can be determined from the 3D model results.

CON1D model matches within 10°C of the real 3D model temperature predictions for both hotface and thermocouple predictions (based on the constant-heatflux offsets). The more the heat flux profile deviates from a constant, and axial heat conduction through the mold becomes important, the less accurate the offset method becomes.

CON1D model predictions might be used to determine metal level and its fluctuations if:

* Several rows of thermocouple data can be measured and evaluated simultaneously
* The 5-10 °C accuracy problem above the meniscus can be reduced.
* The heat flux profile can be determined reliably
* Transient effects can be taken into account