Automation of Mold Thermal Analysis for CON1D Calibration

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Objectives

• Create a script to automate:
  1) calculating 3-D mold temperatures in ABAQUS and
  2) determining the thermocouple offset distance calibration parameter for CON1D
• Uses ABAQUS and Python programming
With proper offset, CON1D can match 3-D ABAQUS thermal analysis

- Hot face and thermocouple temperatures comparison between CON1D and ABAQUS

![Graph showing temperature comparison between CON1D and ABAQUS](image)

Objectives

- Automated mold geometry generation

![Mold geometry images](image)
Objectives

- Capable of 4 different channel geometries

Type 1

Type 2

Type 3

Type 4

Procedure

- Specify dimensions (eg. type 4 geometry)
Procedure – MoldModel script

```python
AbqTC = MoldModel(
    ModelName = 'Tata_DSP_WF',
    type = 4,
    W = 106.25,
    D = 80.0,
    L = 62.5,
    BoltRibWidth = 37.5,
    BoltHoleDiameter = 22.0,
    BoltHoleDepth = 20.5,
    TCHoleDiameterUpper = 6.0,
    TCHoleDiameterLower = 4.0,
    TCHoleTransitionStart = 0.0,
    TCHoleTransitionLength = 1.0,
    TCDepthFromHotFace = 15.0,
    ChannelPitch = 10.0,
    ChannelDepthFromHotFace = 20.0,
    ChannelOuterWidth = 5.0,
    ChannelInnerWidth = 0.0,
    ChannelDepth = 15.0,
    BoltChannelCenterX = 9.0,
    BoltChannelCenterY = 25.0,
    BoltChannelDiameter = 10.0
)
```

Input actual geometric details to mold model with this function call. This calls ABAQUS and returns the thermocouple temperature.
**Procedure – offset calculation script**

\[
\begin{align*}
wo &= 5.0 \\
wi &= 0.0 \\
dc &= 15.0 \\
r &= 0.5*(wo-wi) \\
A &= (wo*(dc-r))+(0.5*\pi*r*r) \\
wstar &= wo \\
dstar &= A/wstar
\end{align*}
\]

CON1D works with rectangular water channels, so calculate the effective channel depth to keep the cross-sectional area the same.

Circular channels: set the width as \(2/3\) the diameter of the channel.

```python
offset = CalculateOffset(
    ModelName = 'Tata_DSP_WF',
    MoldThickness = 35.0,
    ChannelDepth = dstar,
    ChannelWidth = wstar,
    ChannelPitch = 10.0,
    TCTemp = AbqTC,
    version = 8
)
```

This routine calls CON1D and calculates the offset. The `version` parameter is CON1D version (8 or 9).

**Procedure**

- Mold conductivity, heat load, convection coefficient, and water temperature are all defined as global variables.
- CON1D offset is independent of these, but they must be consistently defined.
  - `MoldModel` and `CalculateOffset` use the same values.
- Convection boundary defined on TC surface if accounting for heat lost along wires is desired.
  - This *will* change the offset value

\[
\frac{1}{h_{eff}} = \frac{L_{TC}}{k_{TC}} + \frac{1}{h_{TC}} + \ldots
\]
Execution

Start ABAQUS/CAE, File → Run Script...

Select mold3d.py (or whatever is the final name of the script)

Execution

- Type MoldModel and Offset calculation scripts into the Python interpreter at the bottom of the screen

```python
>>> Abaqus = MoldModel(MoldModelName=
```

- Or define a driver function, copy/paste the scripts into it, and call it
Procedure – automatic execution

• Running scripts does:
  – ABAQUS (Moldmodel)
    • Build geometry (msec)
    • Apply boundary conditions (msec)
    • Adaptive mesh analysis (minutes)
    • Extract thermocouple temperature (msec)
  – CON1D (offset calculation)
    • Generate CON1D input files (msec)
    • Execute CON1D twice (<minute)
      1) Locate distance below meniscus with same water temperature as ABAQUS model
      2) Calculate mold temperature gradient at that point
    • Calculate offset distance (msec)

• A few minutes later...
  – Offset calculated as 4.5 mm

• Next CON1D (version 9) input files should be set up as:

```bash
//MOLD THERMOCOUPLES:
4.5 Offset distance towards hot face (mm)
5 Total number of thermocouples
No. Distance beneath Distance below
   hot surface(mm) meniscus(mm)
1  13.00            20.00
2  13.00           121.00
3  13.00           226.00
4  13.00           347.00
5  13.00           446.00
```

• Version 8: subtract offset from distance from hot face
Comparisons

• M. Langeneckert MS Thesis Fig 3.1

Offset = 4.6 mm

“No TC” TC Temperature = 168 °C

TC Temperature = 102 °C
Offset = 4.1 mm

Comparisons

• M. Langeneckert MS Thesis Fig 3.16

TC Temperature = 102 °C
Offset = 4.1 mm
Comparisons

• Santillana et al. ISIJ 2008 Fig 9

TC Temperature = 144.3 °C
Offset = 2.93 mm

Offset = 2.41 mm*

Water Channels:

\[ h = 40 \text{ kW/(m}^2\text{·K)} \]

\[ T_\infty = 36 \text{ °C} \]

All other faces insulated \((Q = 0)\)

\[ \alpha = 350 \text{ W/(m·K)} \]

\[ Q = 2.6 \text{ MW/m}^2 \]

* Original work accounted differently for channel geometry complexities in CON1D

Conclusion

• Created a script to easily determine offset distance calibration parameter for CON1D
• Four different channel geometries supported
• Matches with previous work
• Ready to apply to CON1D calibration or parametric studies of mold thermal modeling
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