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Automation of Mold Thermal Analysis for CON1D Calibration

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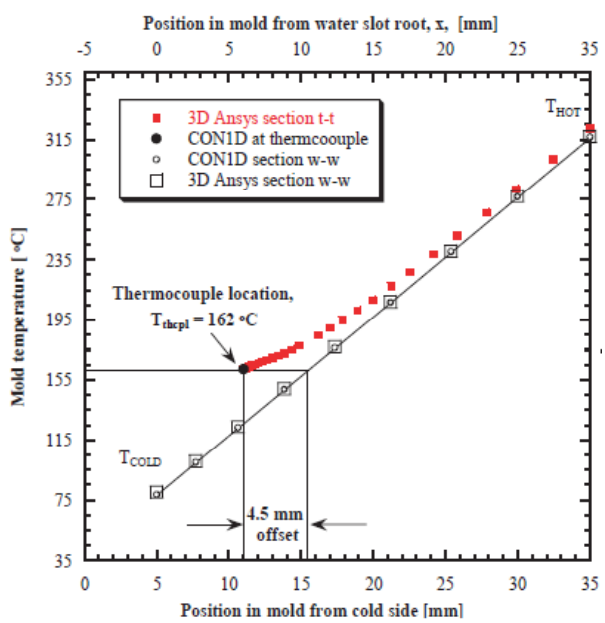
Objectives

- Create a script to automate:

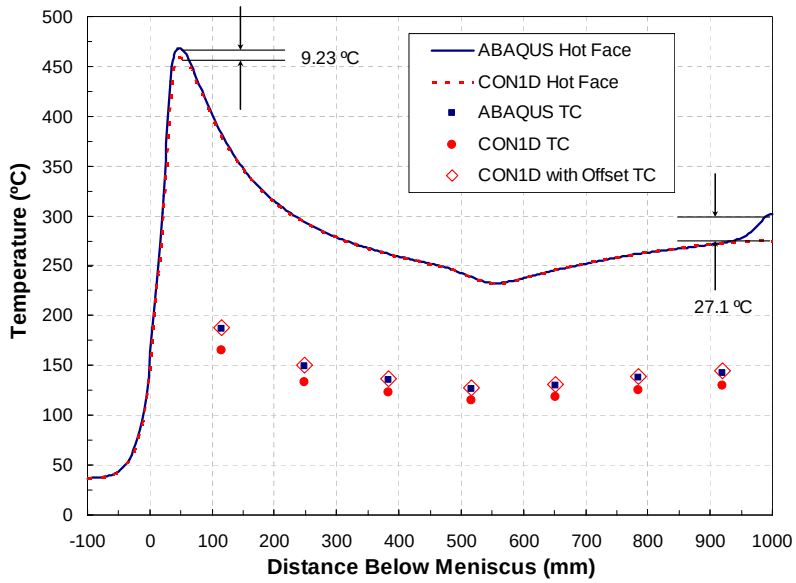
1) calculating 3-D mold temperatures in ABAQUS and
2) determining the thermocouple offset distance calibration parameter for CON1D

- Uses ABAQUS and Python programming



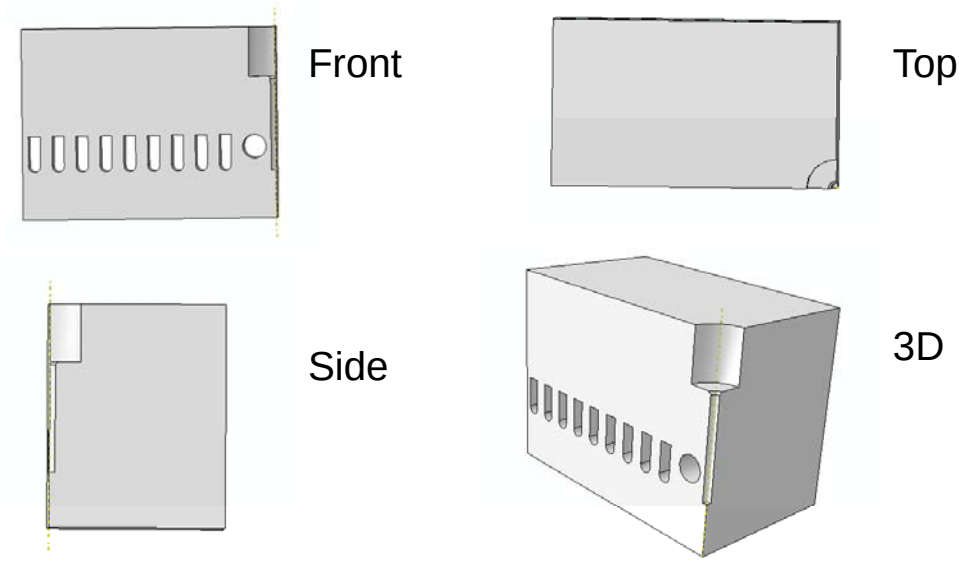
With proper offset, CON1D can match 3-D ABAQUS thermal analysis

- Hot face and thermocouple temperatures comparison between CON1D and ABAQUS



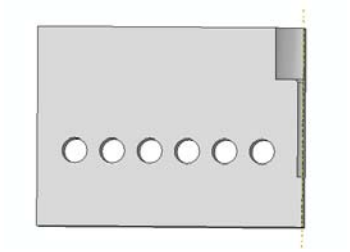
Objectives

- Automated mold geometry generation

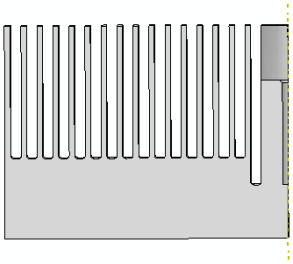


Objectives

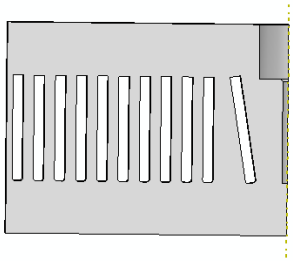
- Capable of 4 different channel geometries



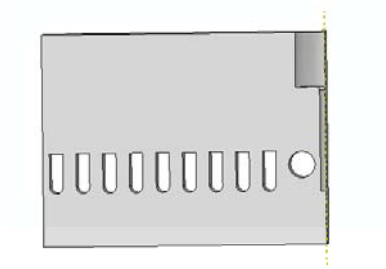
Type 1



Type 2



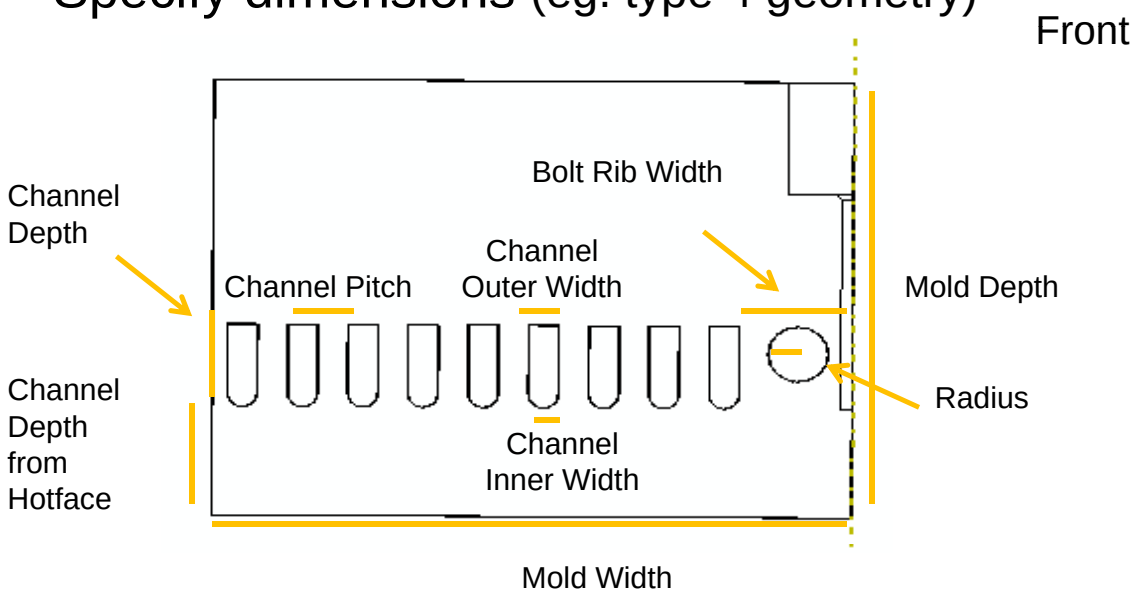
Type 3



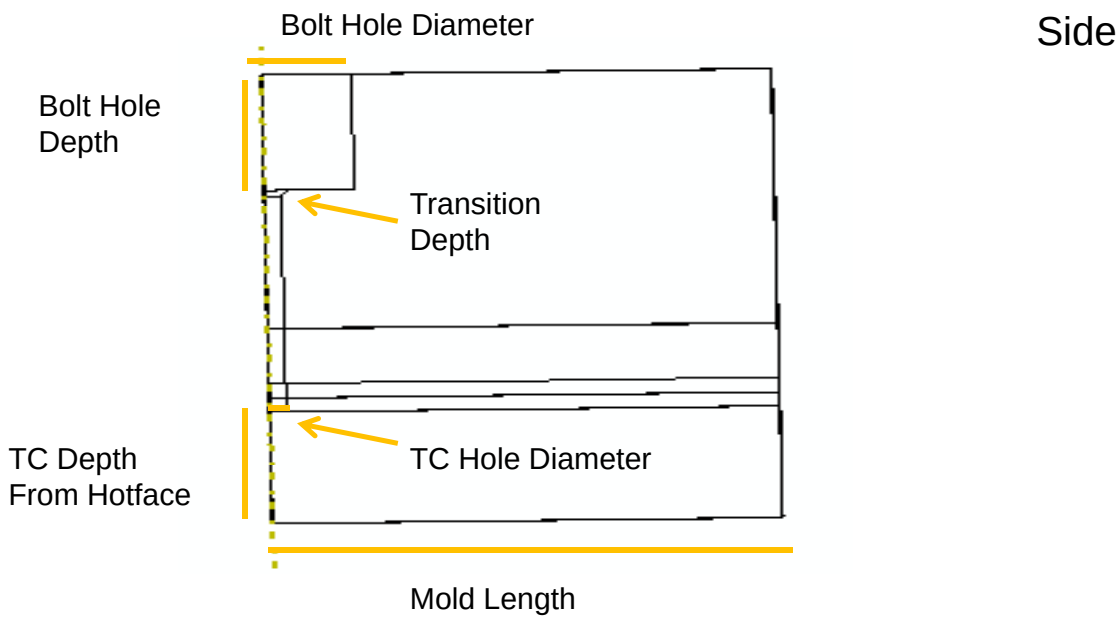
Type 4

Procedure

- Specify dimensions (eg. type 4 geometry)



Procedure



Procedure – MoldModel script

```
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

```
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

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

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

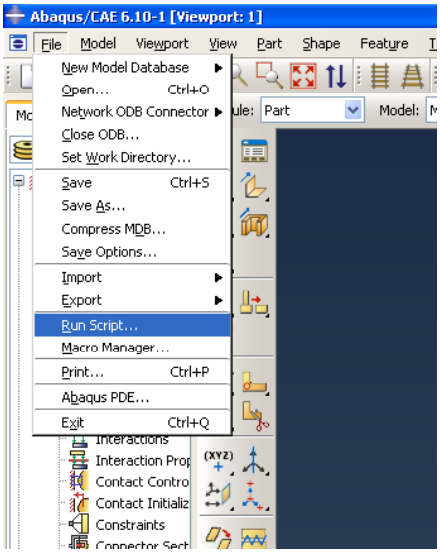
This routine calls CON1D and calculates the offset. `version` parameter is CON1D version (8 or 9)

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

$$\frac{1}{h_{eff}} = \frac{L_{TC}}{k_{TC}} + \frac{1}{h_{TC}} + \cdots$$

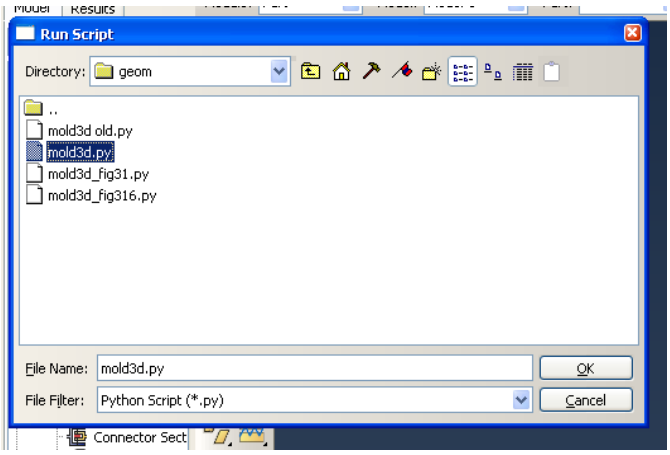
Execution



Start ABAQUS/CAE,

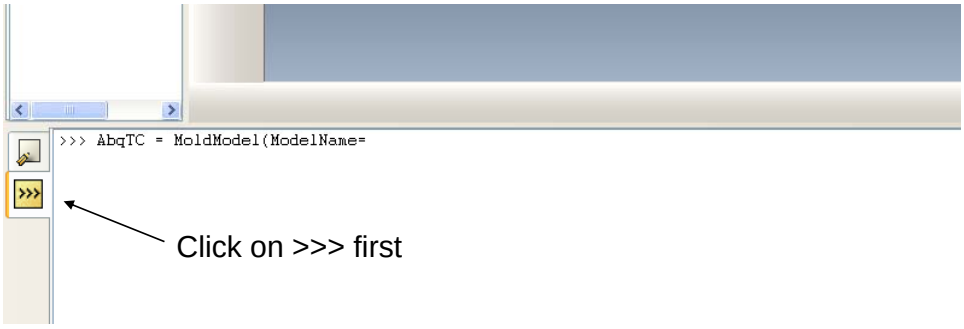
File → Run Script…

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



Execution

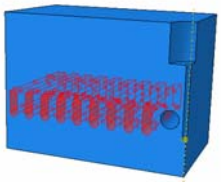
- Type MoldModel and Offset calculation scripts into the Python interpreter at the bottom of the screen

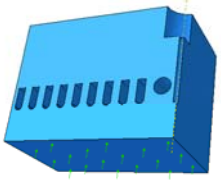


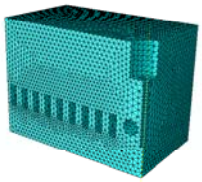
- Or define a driver function, copy/paste the scripts into it, and call it

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)







Procedure

- A few minutes later…
  - Offset calculated as 4.5 mm
- Next CON1D (version 9) input files should be set up as:

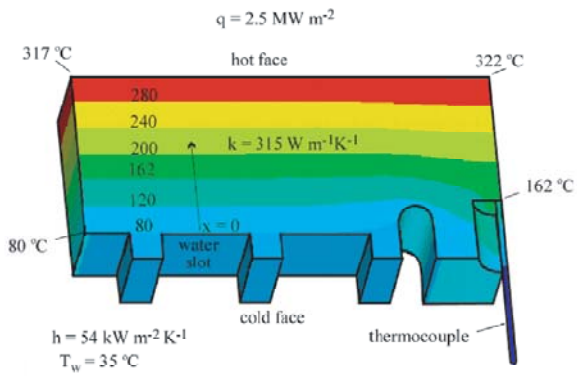
```
//MOLD THERMOCOUPLES:
4.5   Offset distance towards hot face (mm)
5     Total number of thermocouples
No.    Distance beneath Distance below
        hot surface(mm) meniscus(mm)
1          13.00            20.00
2          13.00           121.00
3          13.00           226.00
4          13.00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

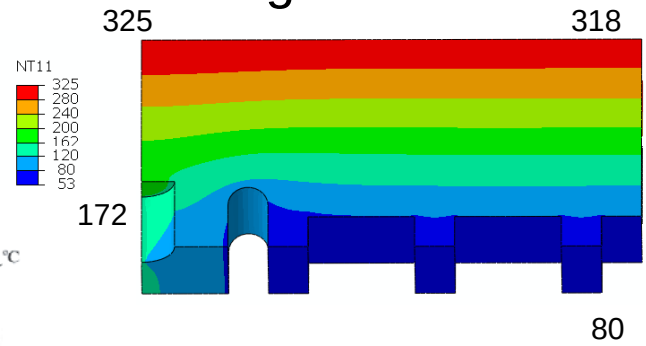
- Version 8: subtract offset from distance from hot face

Comparisons

- M. Langeneckert MS Thesis Fig 3.1

Offset = 4.6 mm



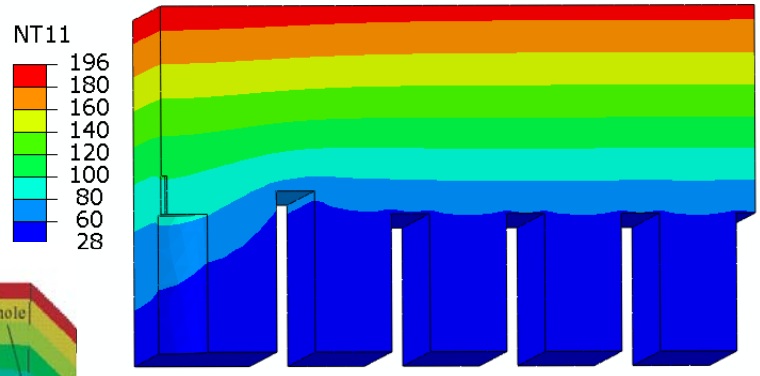


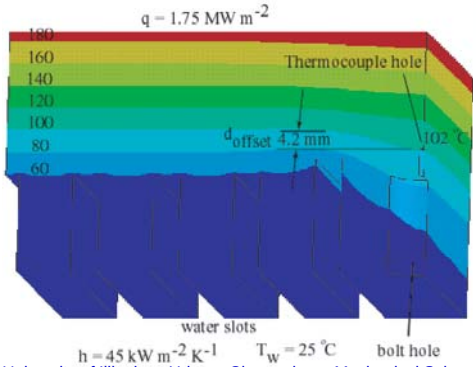
Offset = 5.1 mm

"No TC" TC Temperature = 168 ºC

Comparisons

- M. Langeneckert MS Thesis Fig 3.16





TC Temperature = 102 ºC

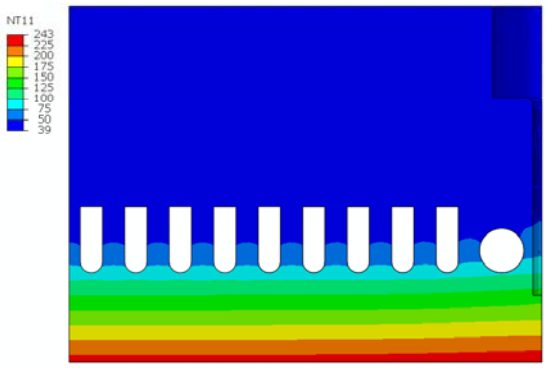
Offset = 4.1 mm

Comparisons

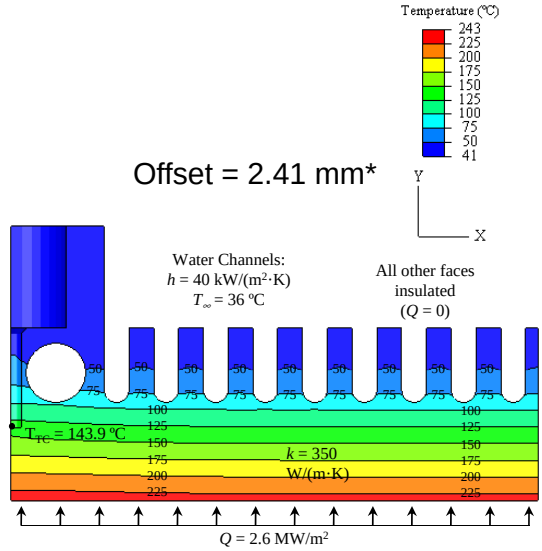
- Santillana et al. ISIJ 2008 Fig 9

TC Temperature = 144.3 ºC

Offset = 2.93 mm



Offset = 2.41 mm*



* 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

Acknowledgements

- Continuous Casting Consortium Members (ABB, Arcelor-Mittal, Baosteel, Tata Steel, Magnesita Refractories, Nucor Steel, Nippon Steel, Postech, Posco, SSAB, ANSYS-Fluent)