AUTODESK SUMMIT

Analysis of the Cooling Efficiency of Different Cooling Technologies for Slender Injection Mold Cores

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CORNING

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Learning with Purpose

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AGENDA

- **Background**
- Objective
- Cooling Technologies
  - Ideal cooling and reference performance
  - Current design
  - Multi-material solutions
  - Conformal cooling
- Conclusions

COOLING TIME

- Injection molding cycle times are primarily dictated by the cooling time of the molded parts.
  - Ensure an adequate amount of time is allocated for the part to achieve sufficient rigidity to be ejected.

- Cooling time depends on plastic and mold materials thermal properties, wall thickness, cooling system design and temperature gradient.
  - The cooling efficiency for a certain application is dictated by the interaction between all parameters.

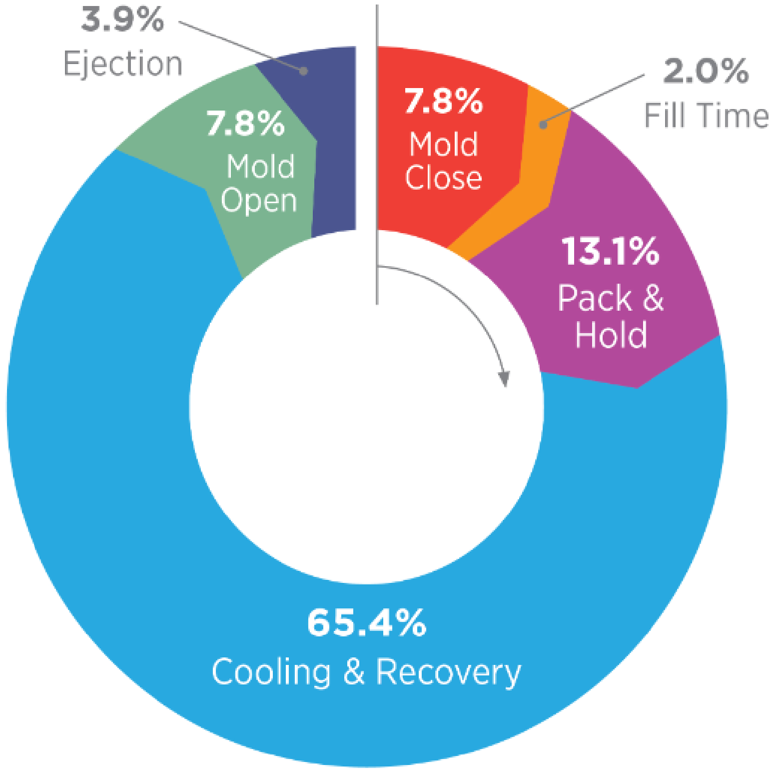
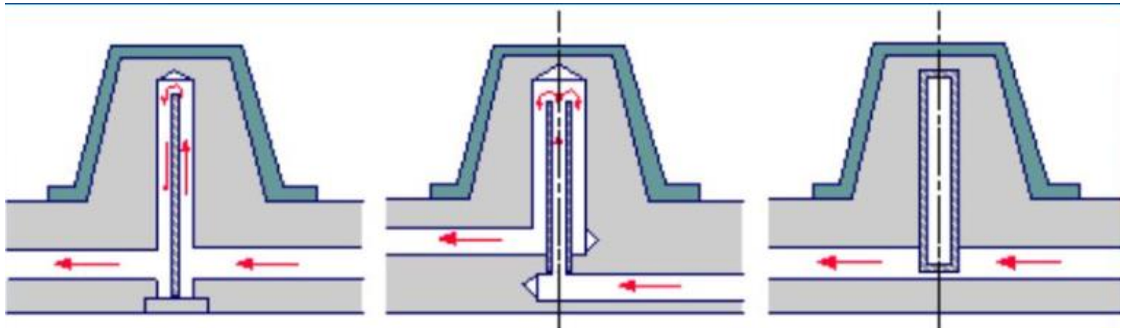


Figure. https://zetarmold.com/key-factors-injection-molding-process/

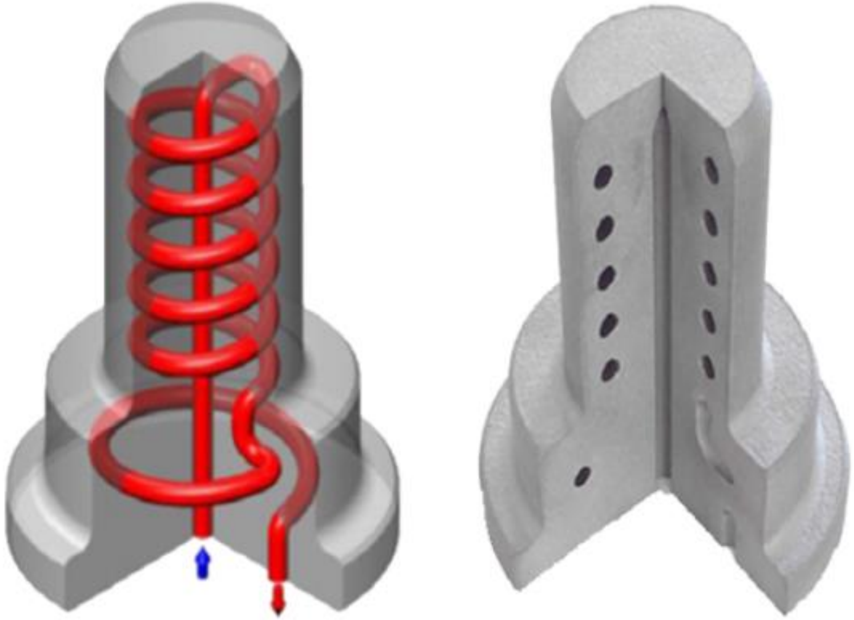
COOLING TIME

- **Enhance productivity by reducing cooling times**:
  - At the design stage:
    - Plastic part design.
    - Cooling system design: bubblers, baffles, thermal pins, conformal cooling.
    - Mold material selection.
  - At the processing stage:
    - Process parameters optimization.
    - Cooling system layout.
    - Rapid heat and cool injection molding.

- **A tradeoff exists between the cooling efficiency, material properties, and process conditions.**



Baffle Bubbler Thermal Pin



Conformal Cooling

AGENDA

- Background
- **Objective**
- Cooling Technologies
  - Ideal cooling and reference performance
  - Current design
  - Multi-material solutions
  - Conformal cooling
- Proposed Implementation
- Conclusions

OBJECTIVE

- Study the Cooling Efficiency of slender mold cores using simulation modeling. This efficiency will be obtained as the ratio between the minimum achievable cooling time (t_{ideal}) and the current cooling time ($t_{current}$).

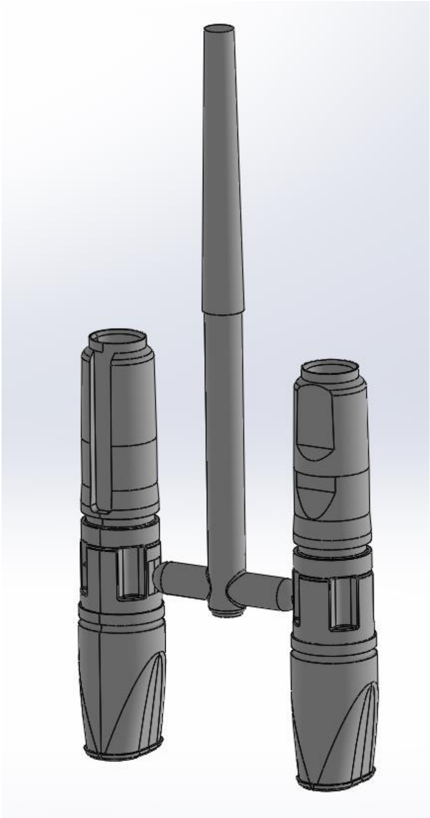
$$R\ [\%] = {t_{ideal}}/{t_{current}} * 100$$

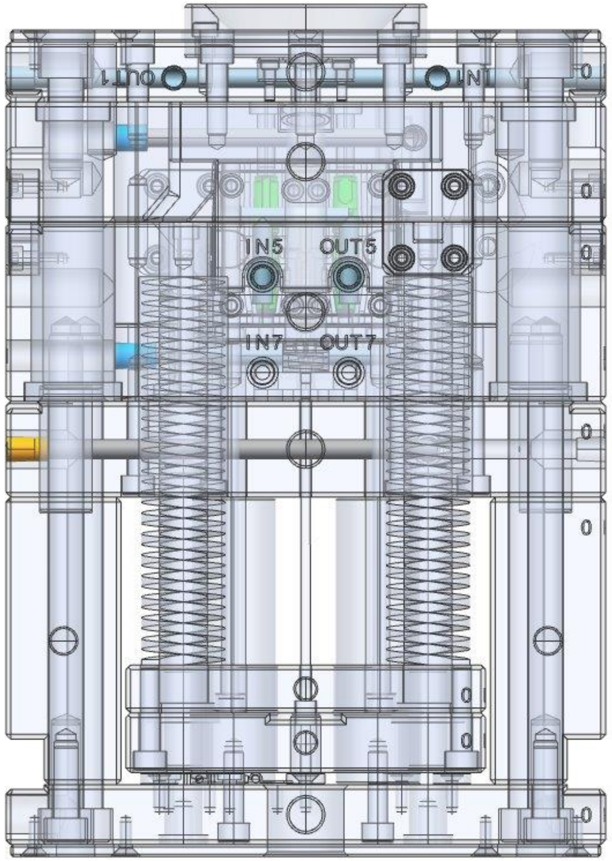
<u>Outlook:</u> This approach could serve as a workflow for identifying the most promising strategies.

PART SELECTION

- **A Two-Cavity Cable Adapter** (i.e., Corning Optical Communications) was selected because of the interesting part and mold features.

- Two plates mold
  - 2 Cavities,
  - Drilled cooling lines in the slide blocks in the cavity side and under the part,
  - ***No cooling in the cores.**

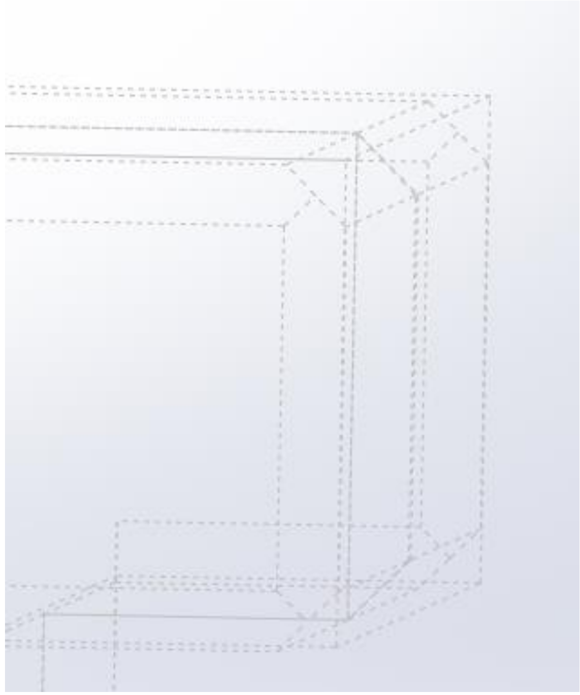




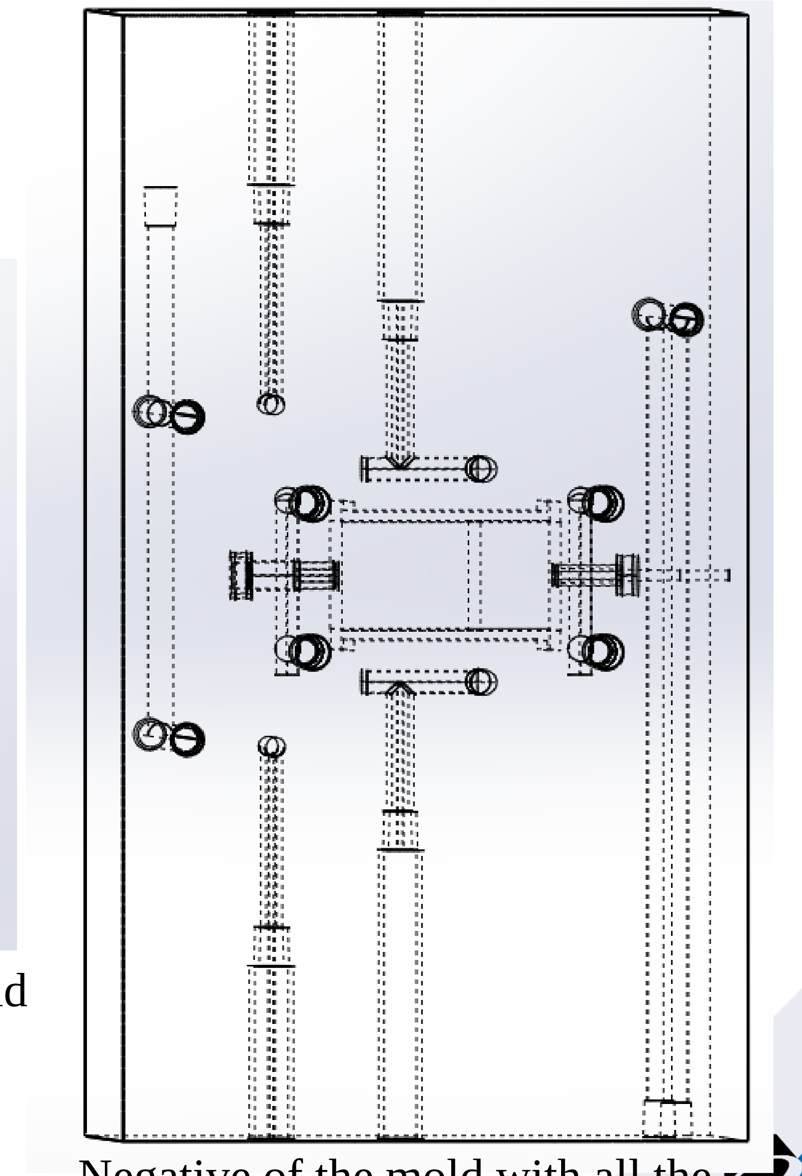
FULL 3D MODELING

- The 2-Cavity mold was modeled as a full 3D study
  - Cooling lines (3D Channels)
  - Mold Block (3D Mold, Designed in SW with the negative of all the features)
  - Mold components (3D mold inserts)
  - Parts (3D part)

- Full 3D model required more computational resources that were obtained through the UML virtual computing system.

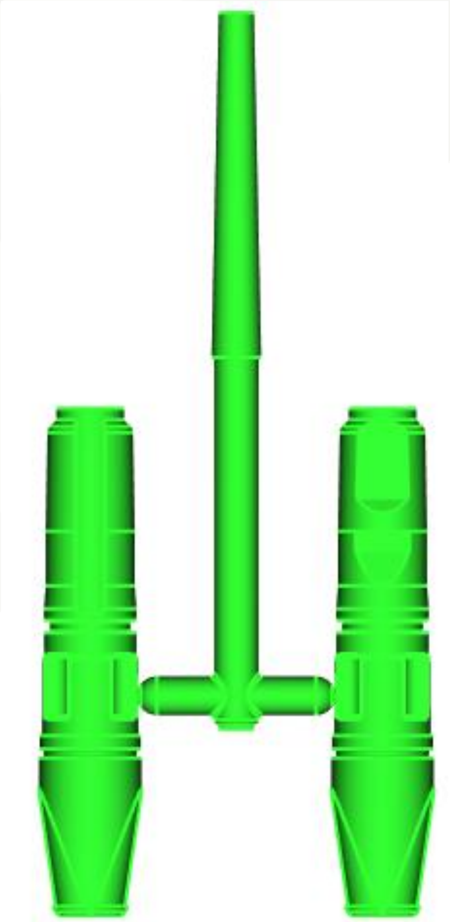


Modeling of air gaps in the mold

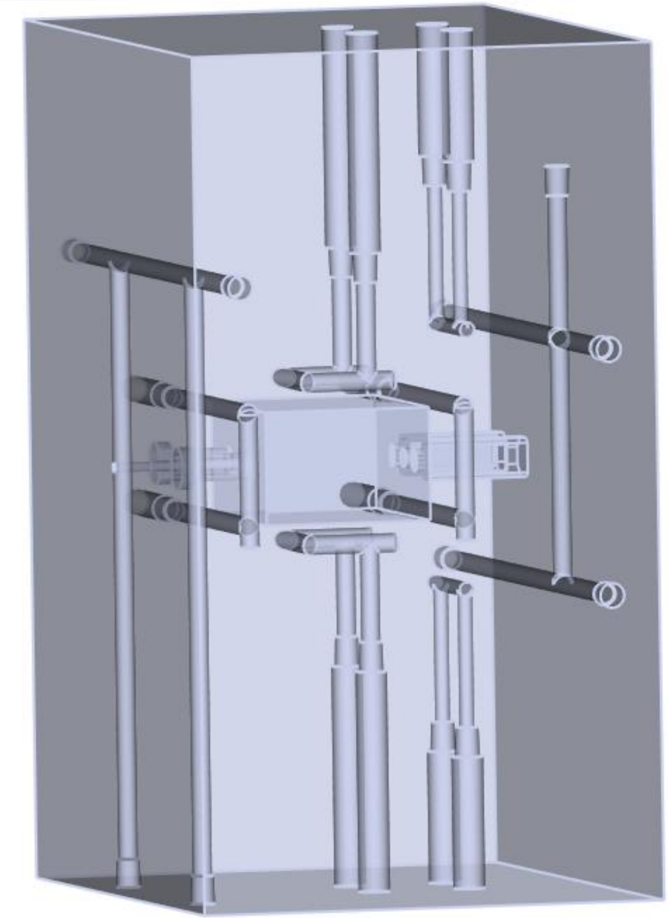


Negative of the mold with all the features inside

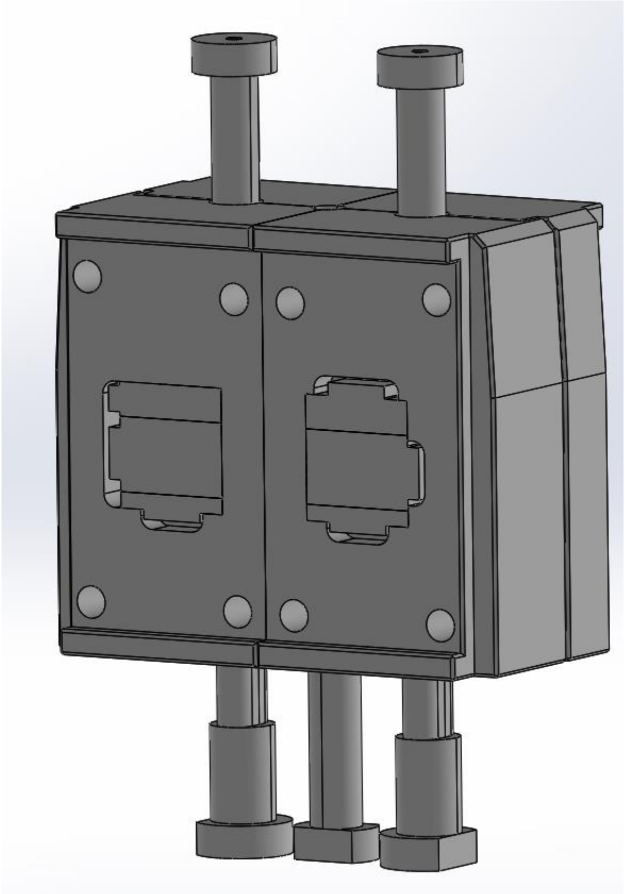
2-CAVITY CABLE ADAPTER MODELING APPROACH



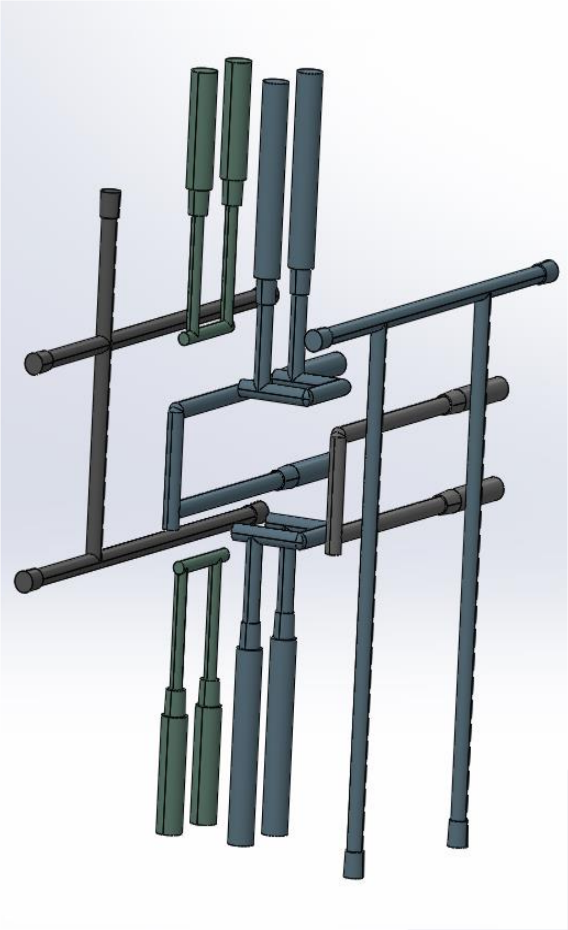
2-Cavity geometry



3D - Simplified mold block



Mold components



Cooling lines

MATERIAL SELECTION AND MESH APPROACH

Components	Materials	Modeling approach	Mesh element types	Number of elements
2-Cavity Cable Adapter (Including runner system)	Ultem 2210 (PEI + 20% gf)	3D – as received from Corning	Tetrahedral	557,242
Simplified mold block	Tool Steel S7	3D Mold designed in SW with the negative of all the important features		8,433,485
Slide Block	Uddeholm Tyrax Steel	3D – as received from Corning		
A side Core pins	Tool steel H13			
B side Core pins,	Tool Steel S7			
Cooling lines	N/A			905,779

****The materials may be subject to change based on the specified approach**

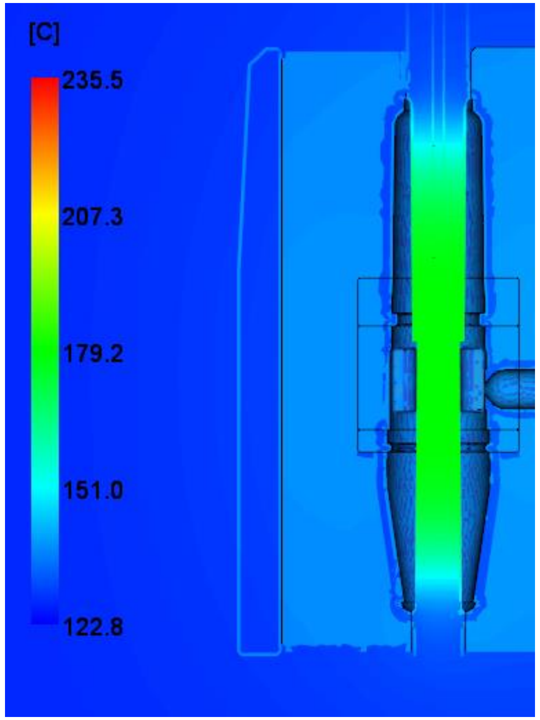
APPROACH TO TECHNOLOGY SELECTION

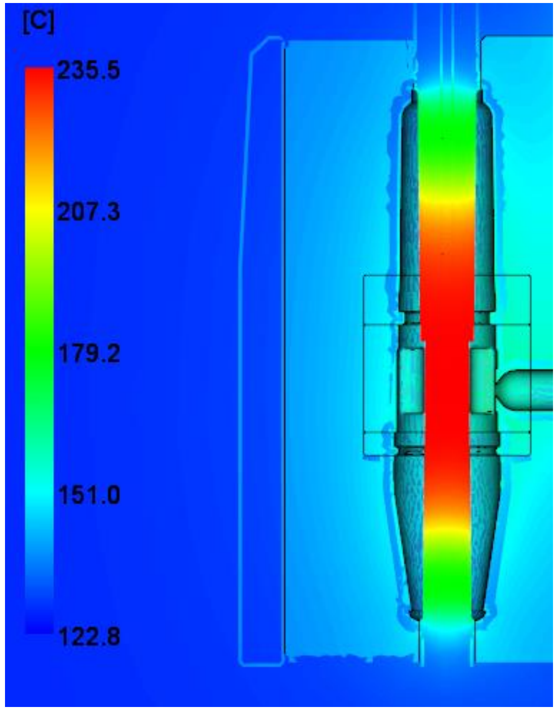
- Using simulation to calculate **cooling efficiency (*R*)** as the ratio between the minimum achievable cooling time (t_{ideal}) and the current cooling time ($t_{current}$).

$$R\ [\%] = {}^{t_{ideal}}/_{t_{current}} * 100$$

Ideal

Time obtained assuming a constant mold temperature during cycle.





Current

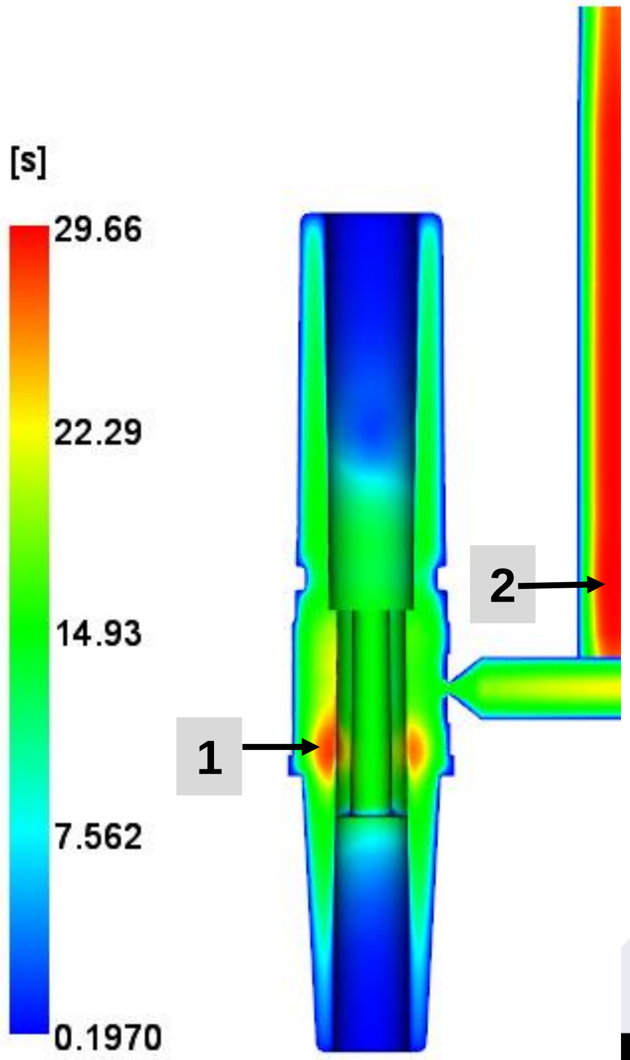
Time obtained from each cooling technologies.

MODELING APPROACH

- The efficiency ratio will be determined by measuring the time to reach the ejection temperature (Suggested by Moldflow), at the hottest spot location in the part
  - In the thickest section of the part (1)
  - In the center of the sprue (2)

$$R\ [\%] = {}^{t_{ideal}}/_{t_{current}} * 100$$

- **Mold and part temperature uniformity, shrinkage and warpage are not considered in the cooling efficiency calculations.**



COOLING TECHNOLOGIES

Different cooling technologies were modeled and compared considering cooling efficiency and temperature parameters.

Case #	Cooling Technology	Analysis type	Note
1	N/A	Fill + Pack	Assuming a constant mold temperature **(Ideal heat transfer)**
2	Drilled lines	Cool (FEM)	Current cooling design
3	Multi-material solutions		Highly conductive material for the entire core pins
4			Highly conductive core with a mechanically resistant shell
5			Thermal pins
6	Conformal cooling		Water lines closer to high thermal gradient regions

ANALYSIS PARAMETERS APPROACH

- The same process parameters were used for all simulations, aligning with the information provided in the Cable Adapter datasheet.
- *A Reynolds number of 10,000 was assumed to guarantee turbulent flow.
- *The ejection temperature was assumed to be the suggested by Moldflow, and the driver of the cooling time.

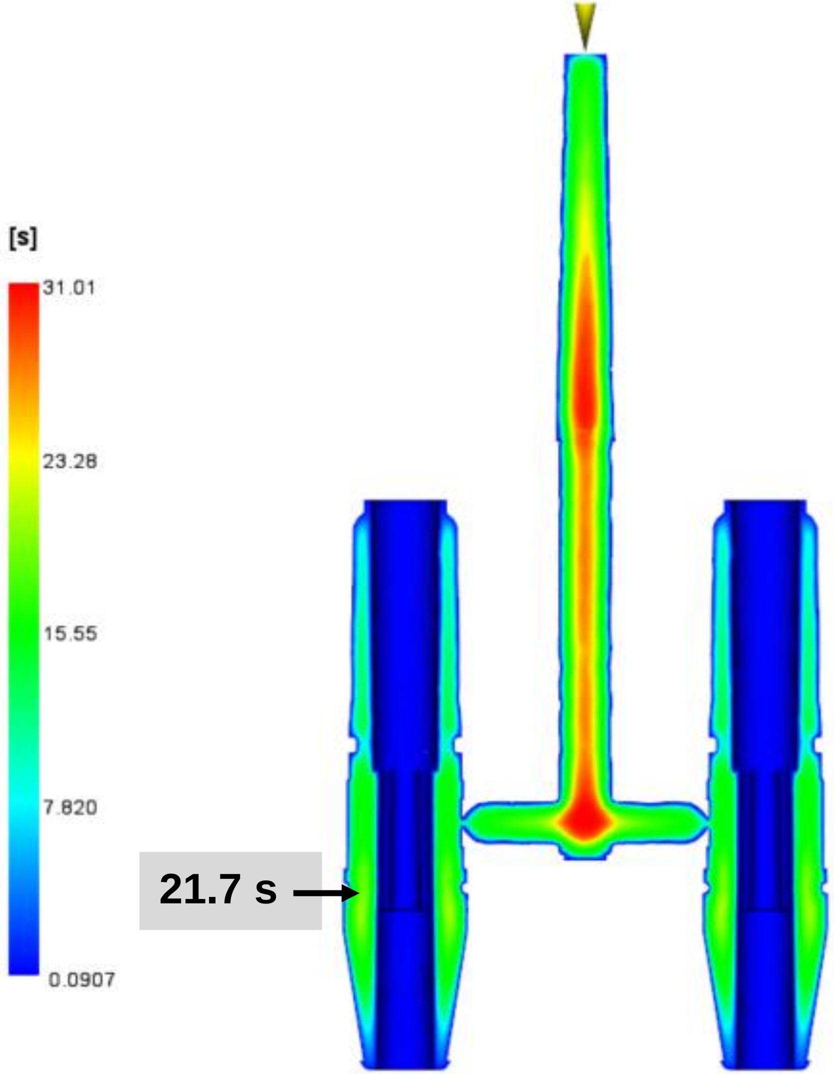
Molding Parameters	
Coolant	Water
Ejection temperature [°C]	200*
Reynolds Number	10,000*

AGENDA

- Project Overview & Executive Summary
- Introduction & Approach
- **Cooling Technologies**
  - **Ideal cooling and reference performance**
  - **Current design**
  - **Multi-material solutions**
  - **Conformal cooling**
- Conclusions

CASE 1. IDEAL COOLING

- Modeling: 2-Cavity Cable Adapter, and runner system were only modeled.
  - Type of analysis: Fill + Pack
- Assumptions:
  - Constant mold temperature during cycle
  - Ideal heat transfer from the polymer to the mold
- This analysis served to:
  - Trace the ideal cooling time that can be achieved based on the assumption of a constant mold temperature
- The minimum time to reach the ejection temperature is **21.7 s (perfect cooling → reference)**



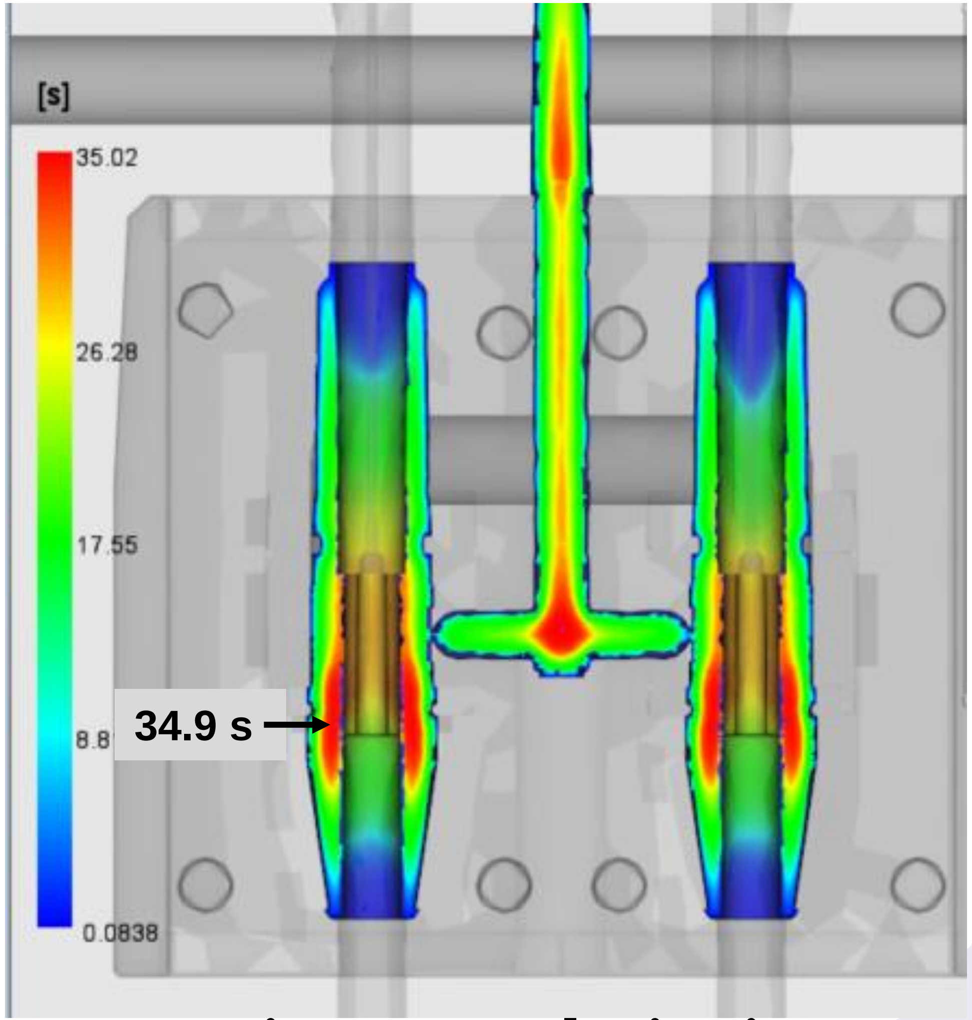
Time to reach ejection temperature

CASE 2. CURRENT DESIGN

- Modeling: 2-Cavity Cable Adapter, runner system, 8 cooling lines, mold block, and mold components.
  - Type of analysis : Cool (FEM)

- Assumptions:
  - Surface roughness was not considered
  - Considers the influence of the different mold components materials and the cooling lines design

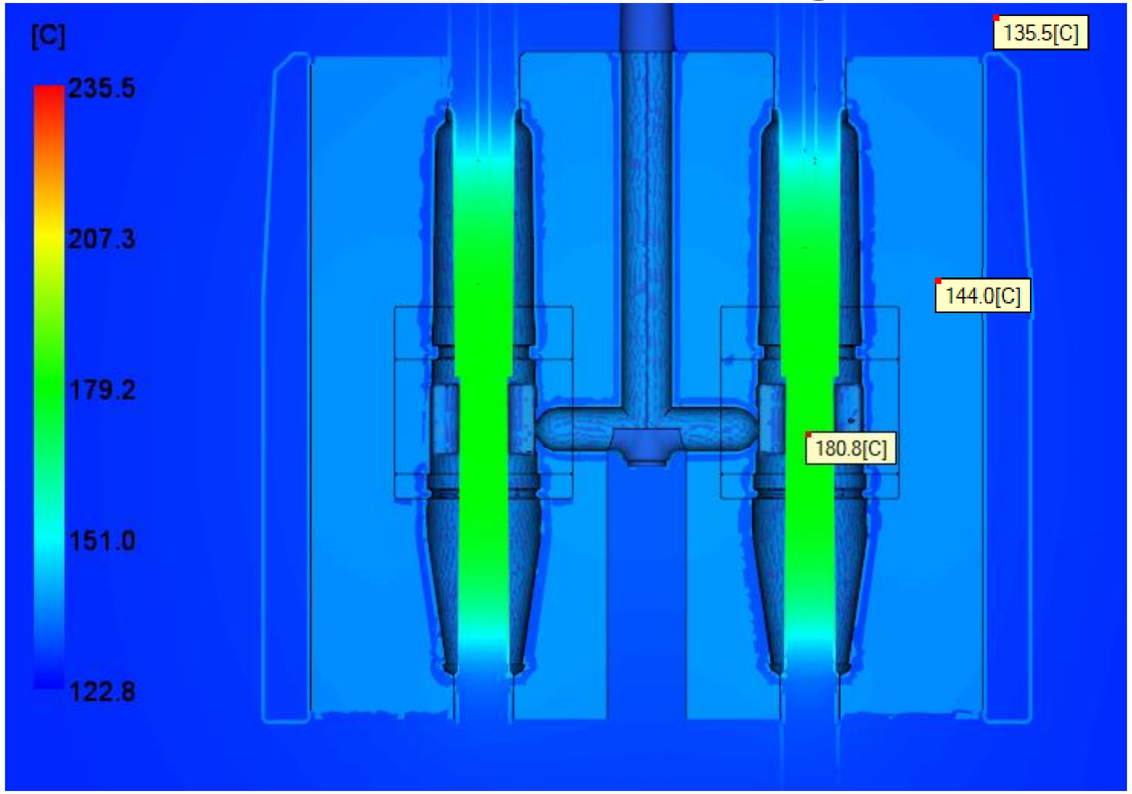
- The current time to reach the ejection temperature is **34.9 seconds.**



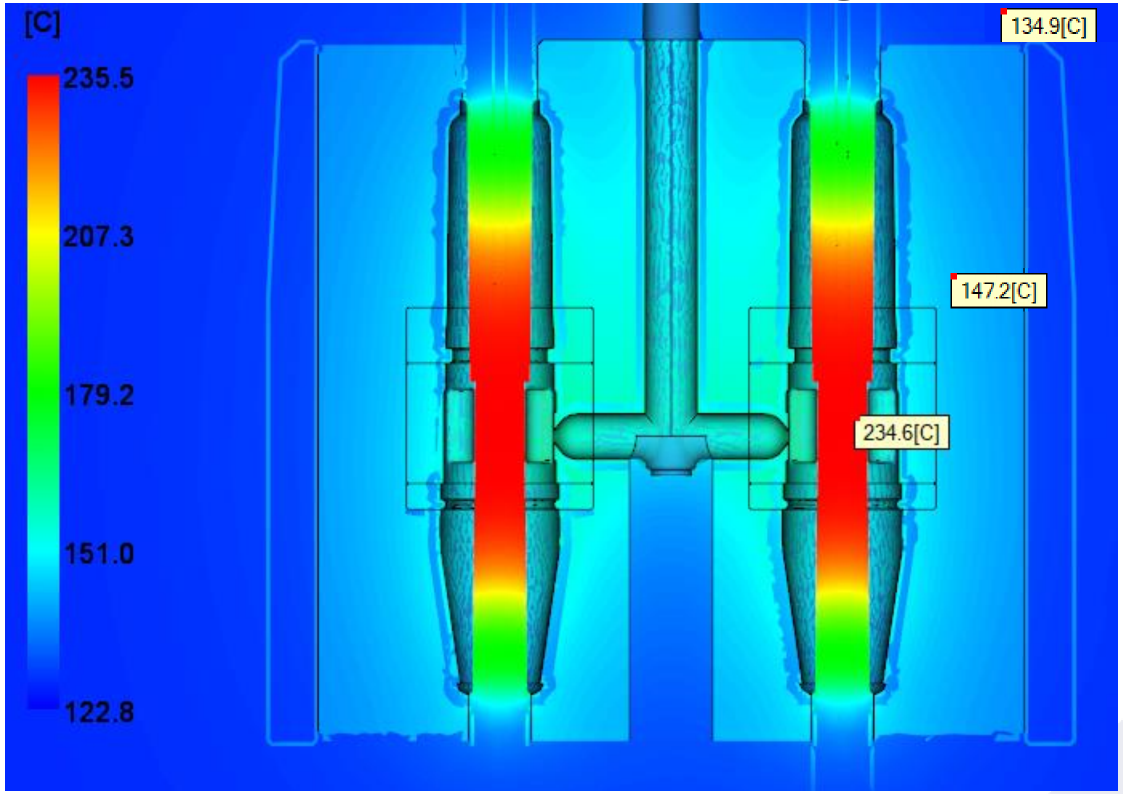
Time to reach ejection temperature

CASE 1 & 2. TEMPERATURE OF THE MOLD (TRANSIENT WITHIN CYCLE)

1. Ideal cooling



2. Current design



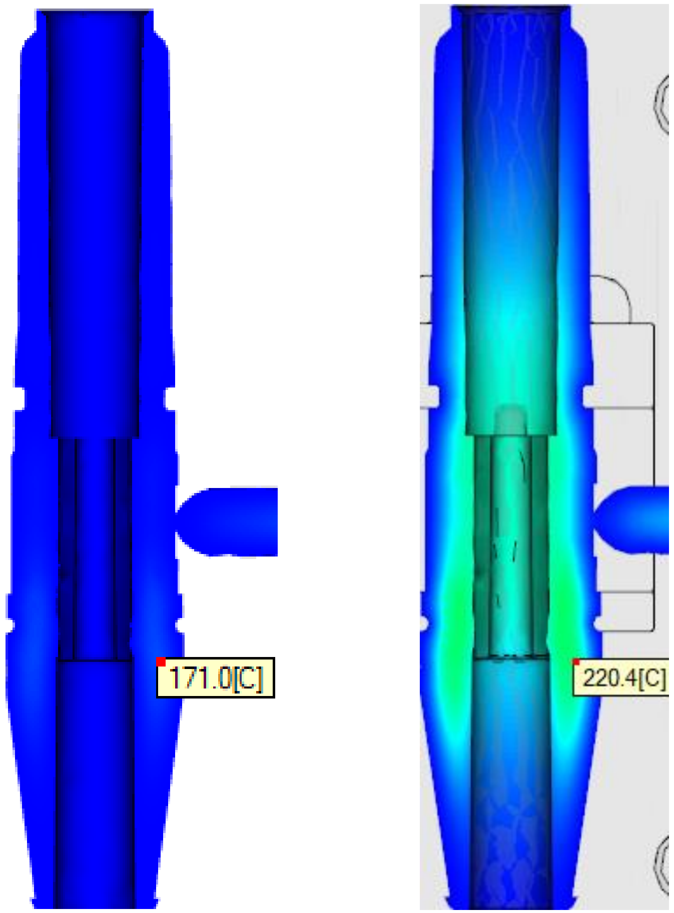
Localization of the hottest part of the mold during cycle

CASE 1 & 2. PART TEMPERATURE AT 25 S COMPARISON

- Using the time to reach ejection temperature result, the cooling efficiency ratio was calculated:

$$R\ [\%] = {}^{t_{ideal}}/_{t_{current}} * 100$$

- **Recommended ejection temperature 200 °C**



Approach	1. Ideal	2.Current design
Time (s)	21.7	34.9
Cooling Efficiency (%)	-	62.2

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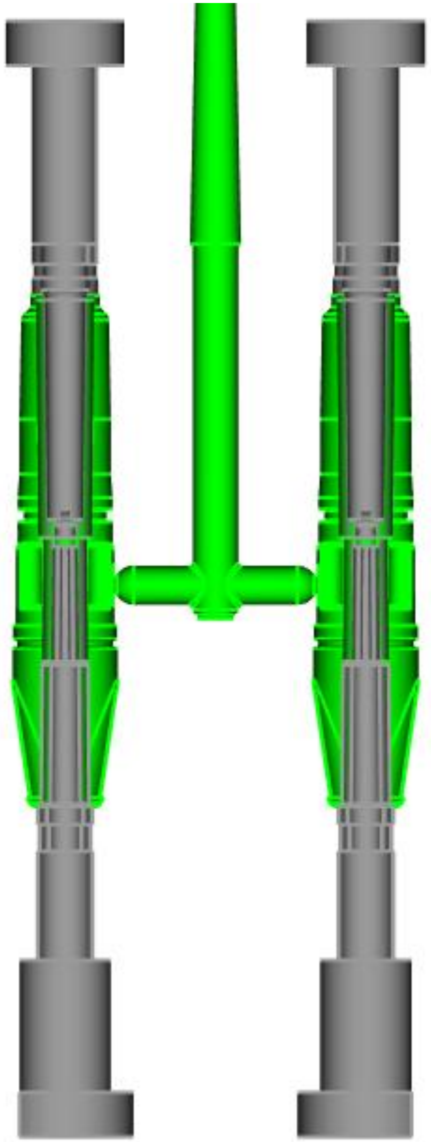
CASE 3. HIGH THERMAL CONDUCTIVE CORE PINS

- Modeling: 2-Cavity Cable Adapter, runner system, 8 cooling lines, mold block, and mold components
  - **Core pins: Moldmax HH 40HRC**
    - ***The rest of the mold features remain unchanged**
  - Type of analysis: Cool FEM

- Assumptions:
  - Surface roughness was not considered
  - Default interface conductance of 30,000 W/m^2.C



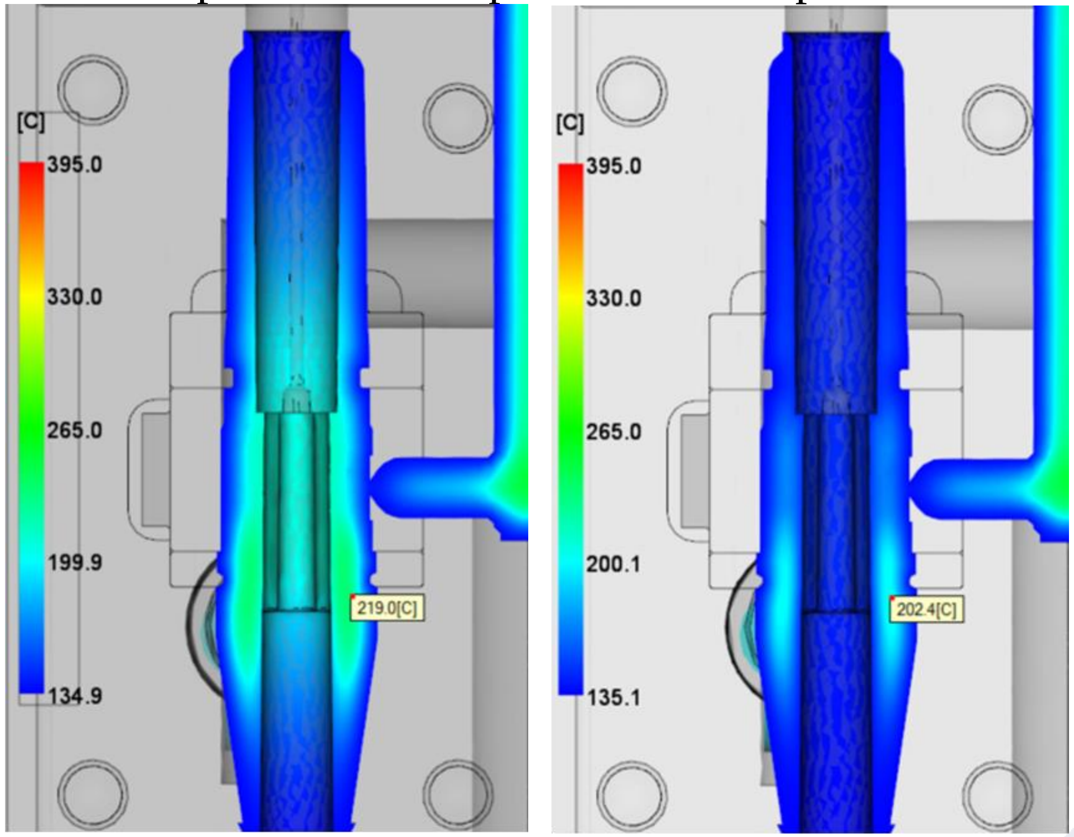
Cross-section view of the Cable Adapter + Core pins

CASE 3. HIGHER THERMAL CONDUCTIVE CORE PINS

- The impact of using high thermal conductive materials was evaluated by replacing core pins with **Moldmax HH 40HRC** to enhance heat transfer from the part to the mold, with the expectation of reducing cooling time.

- **Recommended ejection temperature 200 °C**

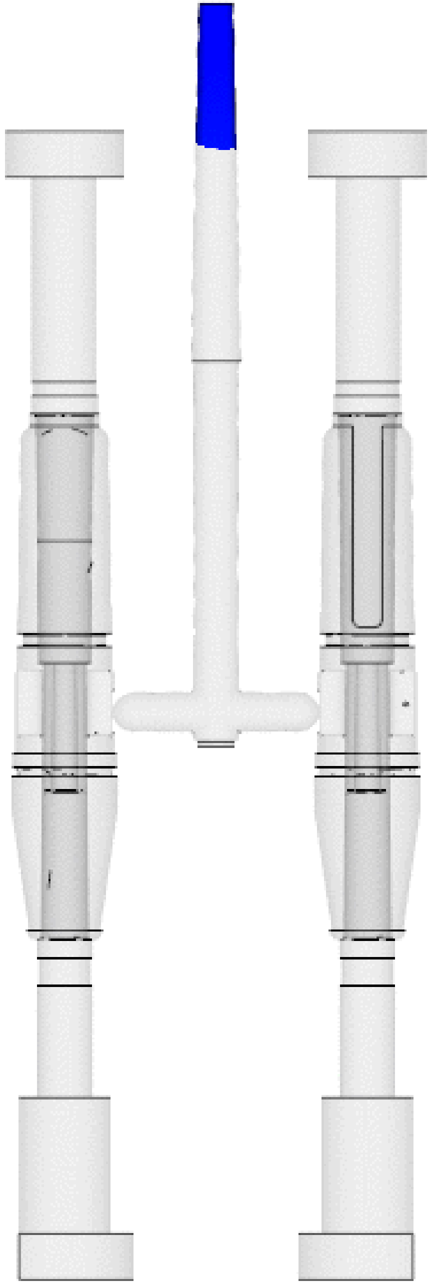
Temperature of the part at 25 s comparison



Approach	2. Current design	3. Moldmax pins
Ejection Time [s]	34.9	26.9
Cooling Efficiency [%]	62.2	80.7

CORE DEFLECTION

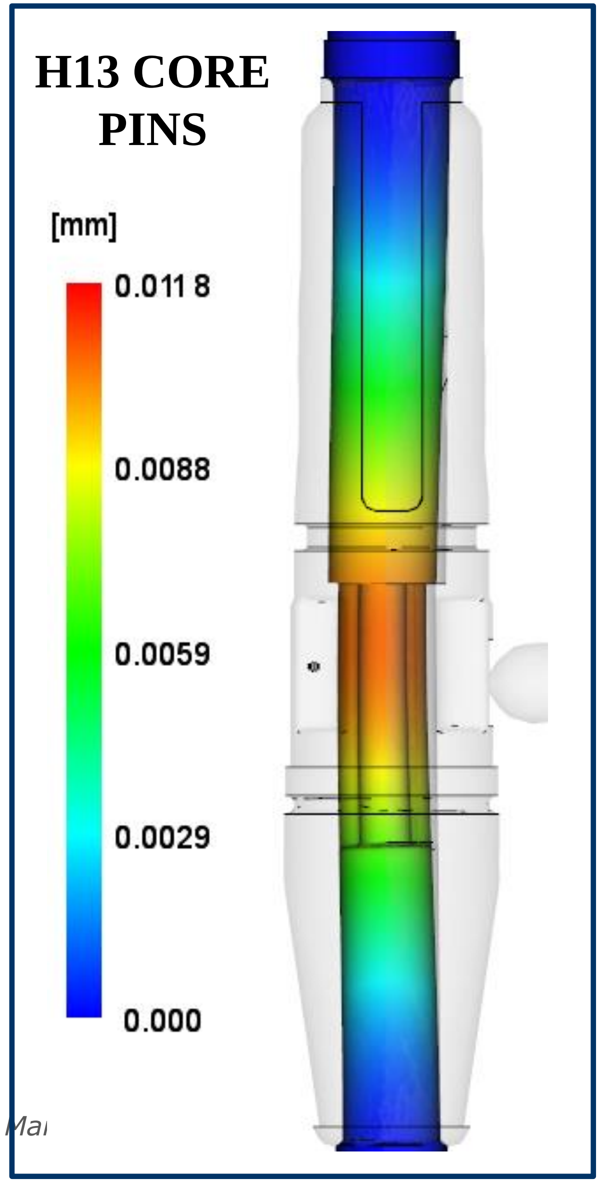
- Side gating, mold material and variations in melt pressure around the core's periphery, is a common issue in slender cores (length 10x diameter)

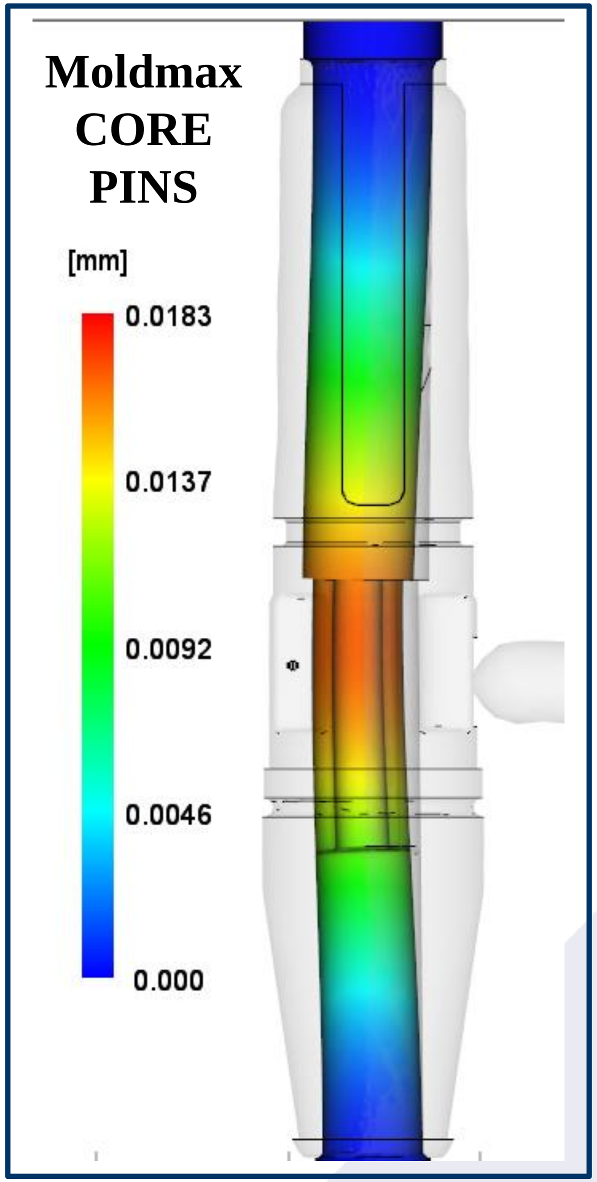


CORE SHIFT - MATERIAL COMPARISON

Assuming **bonded contact at the cores interlock** ,the core shift analysis was used to compare the mechanical stability of the cores loaded by the pressure flow when made with different materials.

Deflection at 2 s, scale factor of 50





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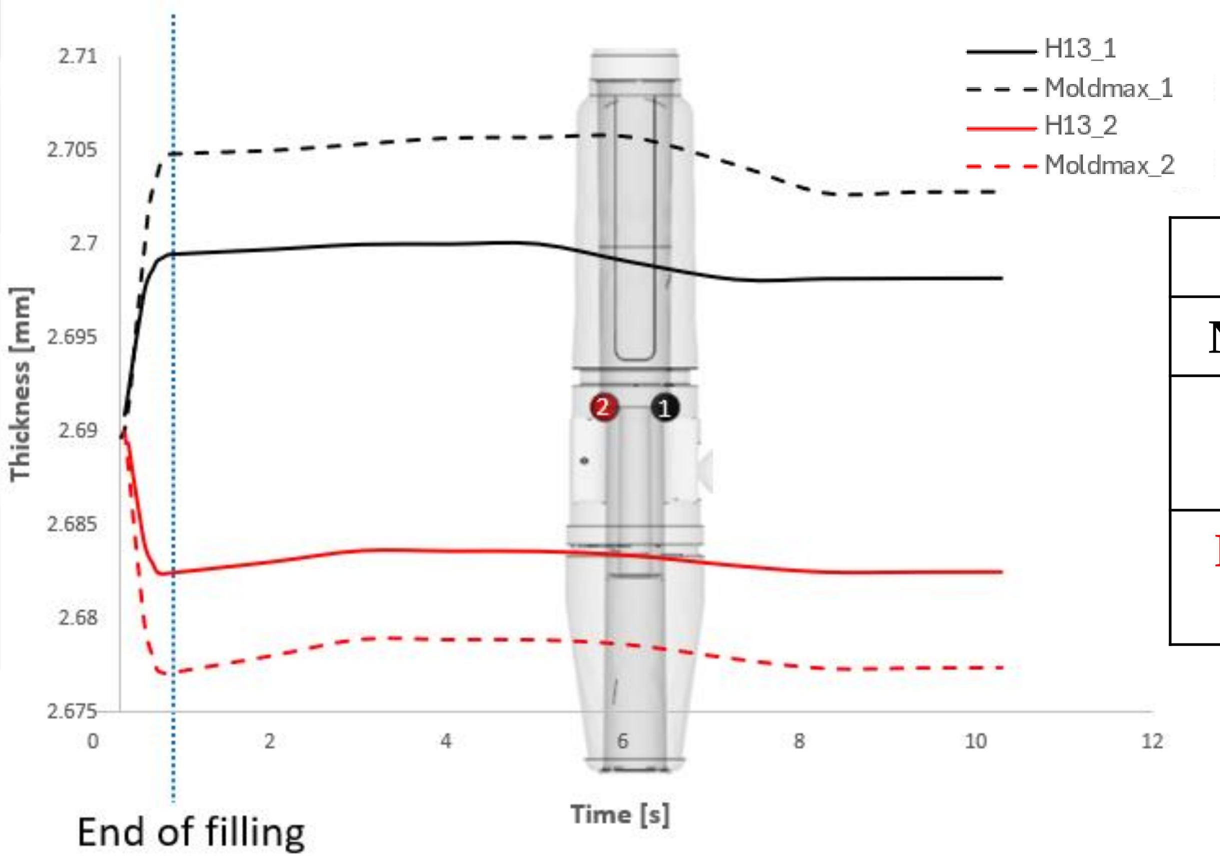
BONDED CONTACT – MATERIAL COMPARISON

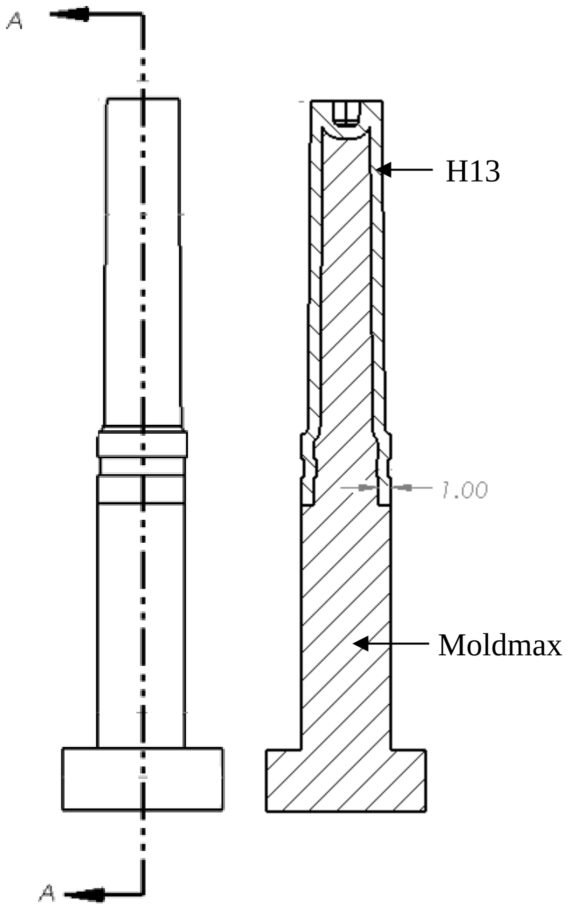


	H13	Moldmax
Nominal thickness [mm]	2.689	
Increase in thickness at Point_1 [mm]	0.010	0.015
Decrease in thickness at Point_2 [mm]	0.007	0.012

- The Moldmax core pins, being the softer material, exhibited the highest core deflection, leading to the greatest variation in part thickness

CASE 4. MULTI-MATERIAL CORE PIN

- Modeling: 2-Cavity Cable Adapter, runner system, 8 cooling lines, mold block, and mold components
  - **Use a conductive material for the core with a 1mm mechanically resistant outer shell**
  - Type of analysis : Cool FEM
- Assumptions:
  - Surface roughness was not considered
  - Perfect contact between core and layer
  - Default interface conductance of 30,000 W/m^2.C

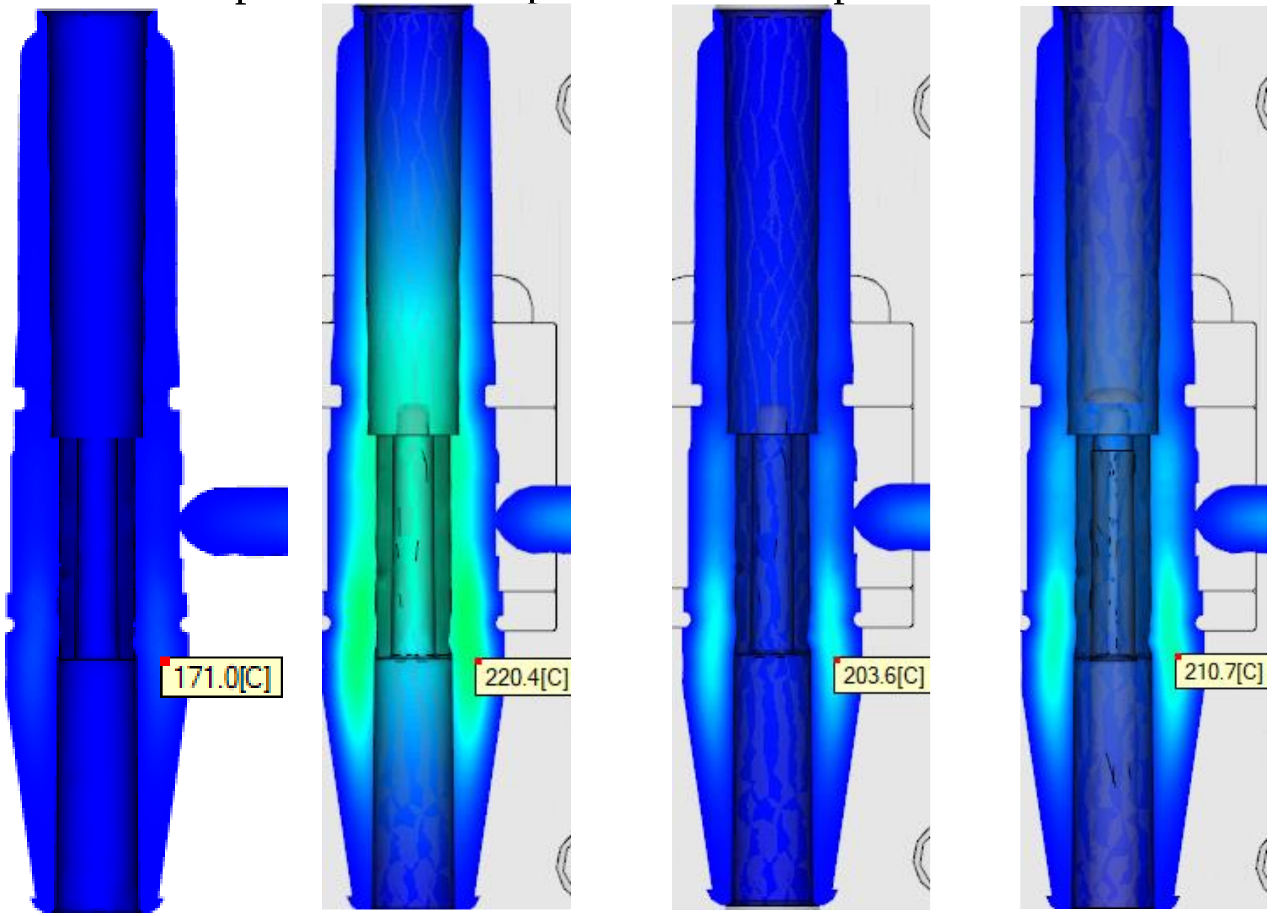


Technical drawing of the current and modified core pins

Geometry	Material	Thermal Conductivity W/m.C	Tensile Modulus (GPa)	Hardness (HRC)
A & B side core pins	Moldmax HH 40HRC	115	128	38-42
Outer layer	H13	24.3	210	46-50

CASE 4. MULTI-MATERIAL CORE PINS

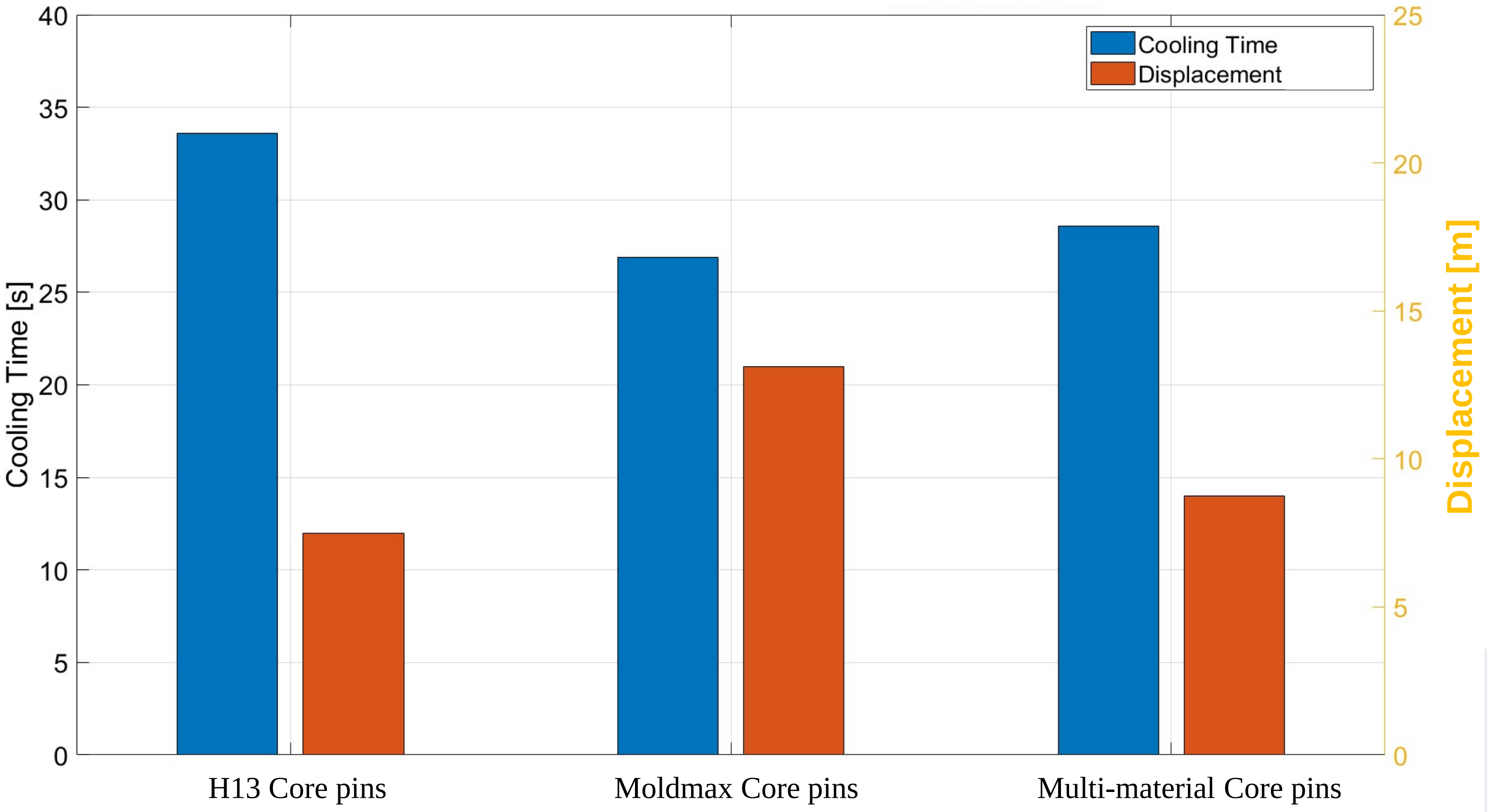
Temperature of the part at 25 s comparison



Approach	1. Ideal	2. Current design	3. Moldmax pins	4. Multi-material pins
Ej. Time [s]	21.7	34.9	26.9	28.8
Cooling Eff. [%]	-	62.2	80.7	75.3

CORE SHIFT ANALYSIS COMPARISON

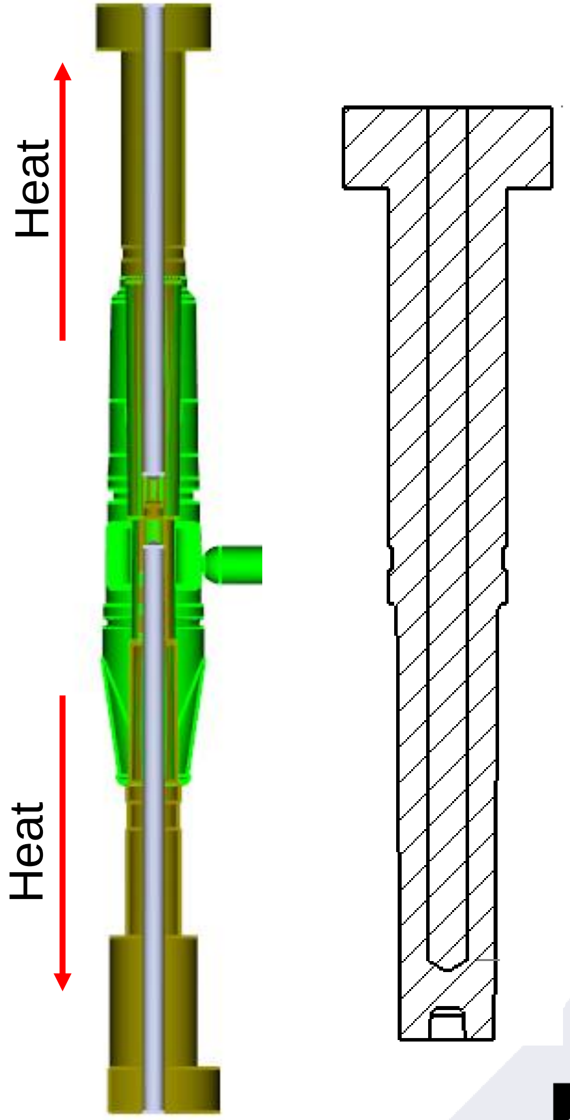
When a hard steel layer is added to the core pin, it enhances the material's resistance to deflection while also exhibiting good conductive properties



CASE 5. THERMAL PIN

- Modeling: 2-Cavity Cable Adapter, runner system, 8 cooling lines, 4 thermal pins, mold block, and mold components
  - **The thermal pins were not modeled in contact with the cooling lines, the intention behind this study was to assess the direction of heat flow.**
  - Type of analysis: Cool (FEM)

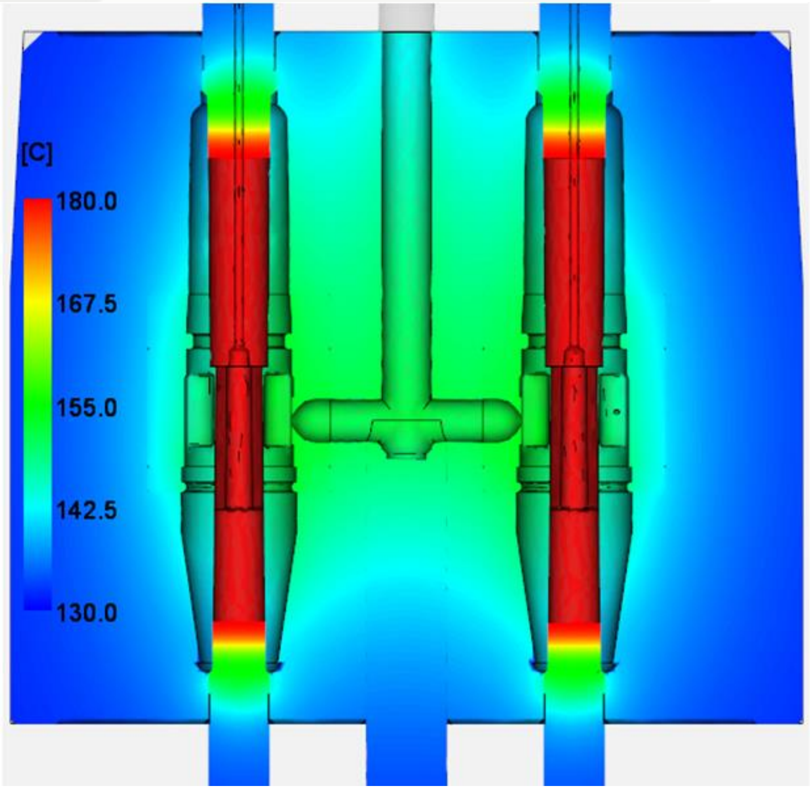
- Assumptions:
  - Surface roughness was not considered
  - A perfect contact was assumed to be between the pin and the cores
  - The time to reach ejection temperature is not expected to decrease
  - Mold temperature should show a difference in its temperature



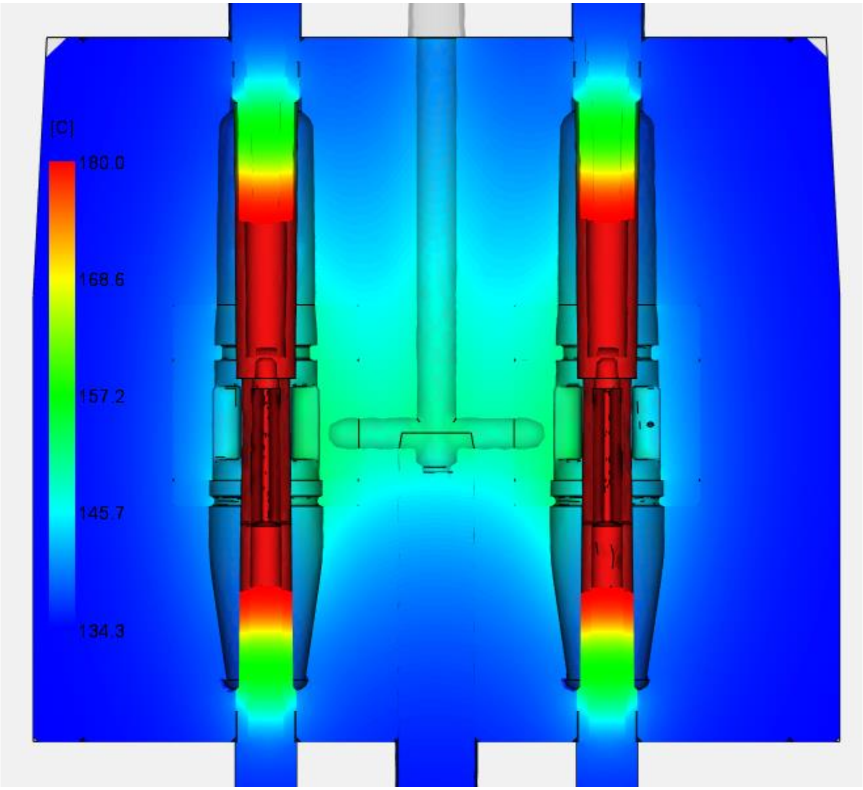
Cross-section view of the modeled thermal pins

CASE 5. THERMAL PINS

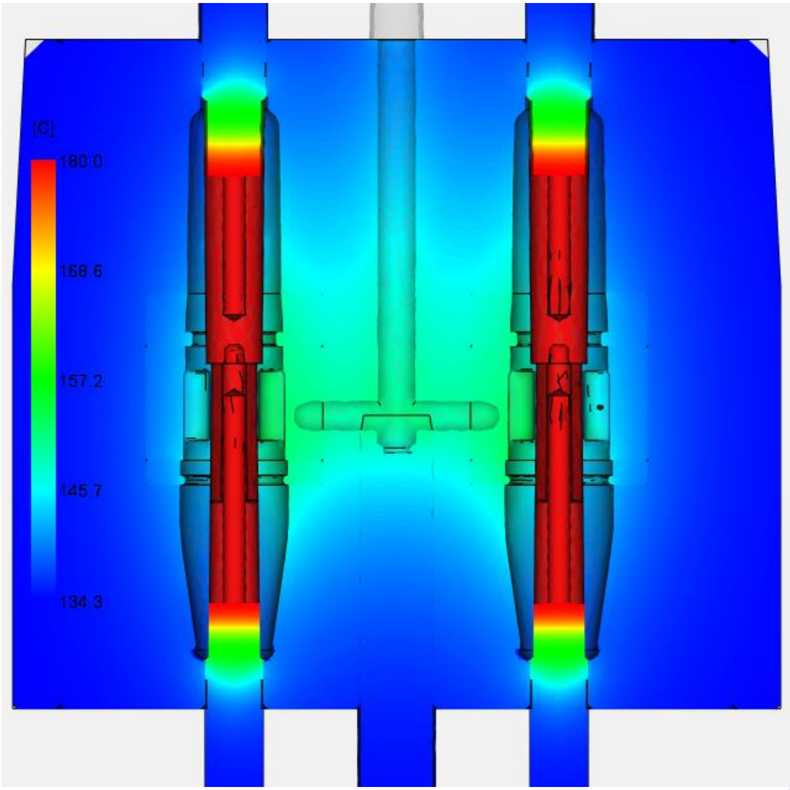
Mold insert temperature at 13 s comparison



2. Current design



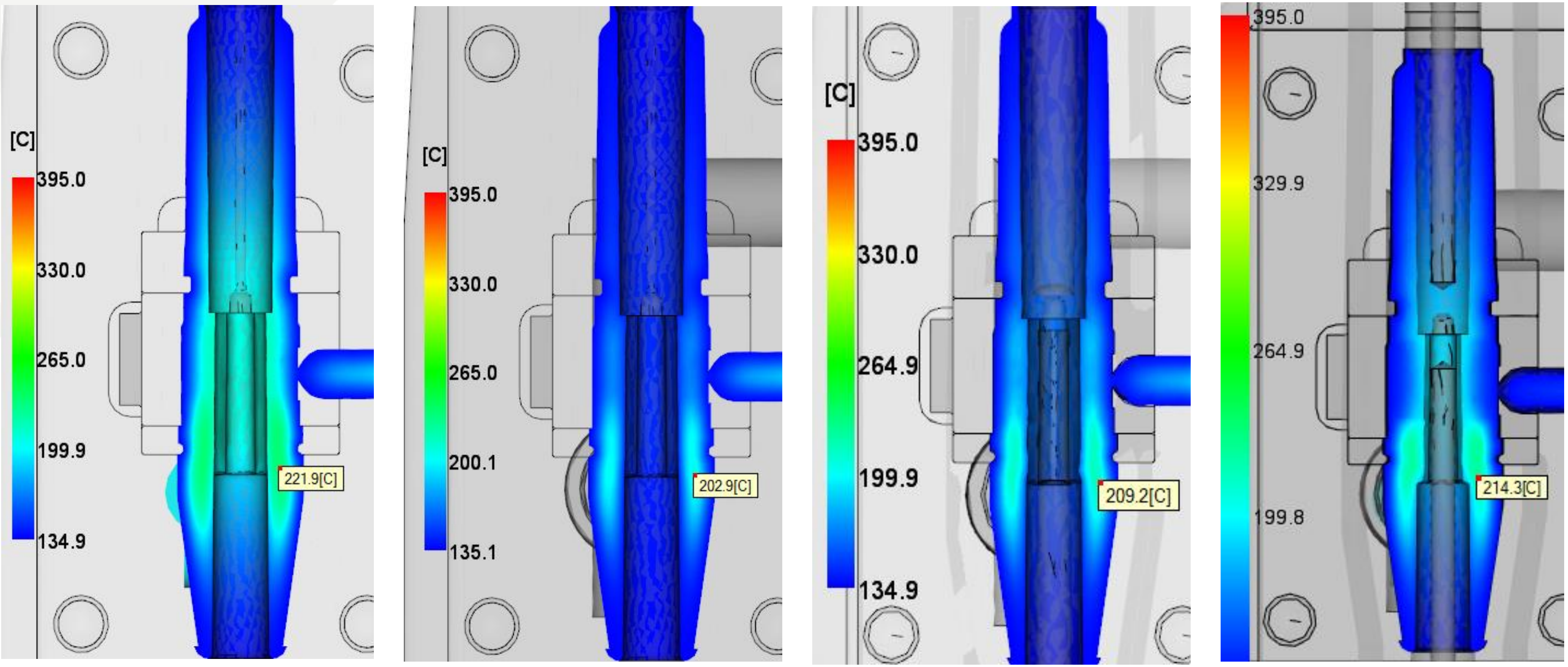
4. Multi-material pins



5. Thermal Pins

- Thermal pins do not have a significant influence in driving the heat away from the part.
- It was expected to see an increase in temperature in the upper direction of the thermal pin

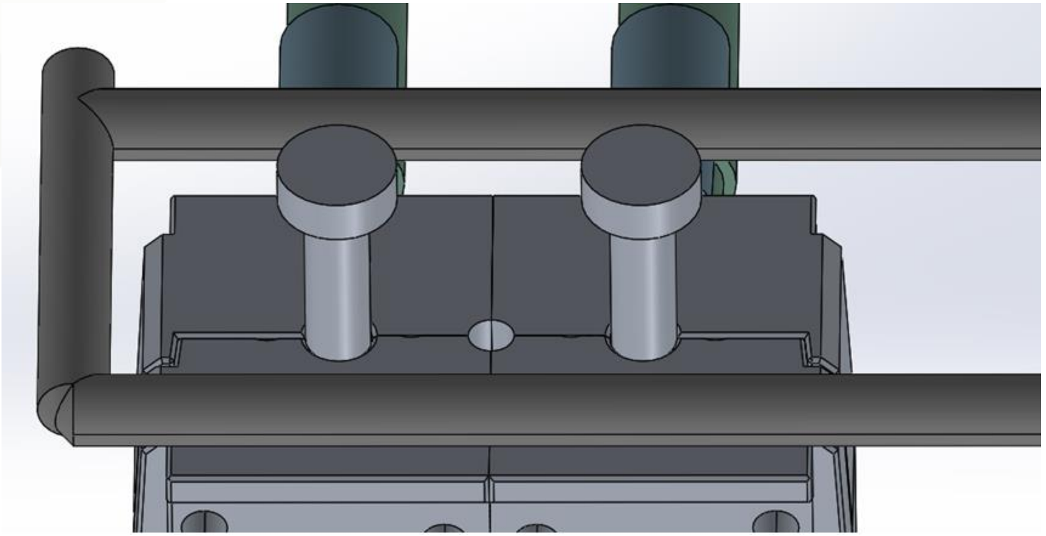
PART TEMPERATURE (TRANSIENT) - 25 S



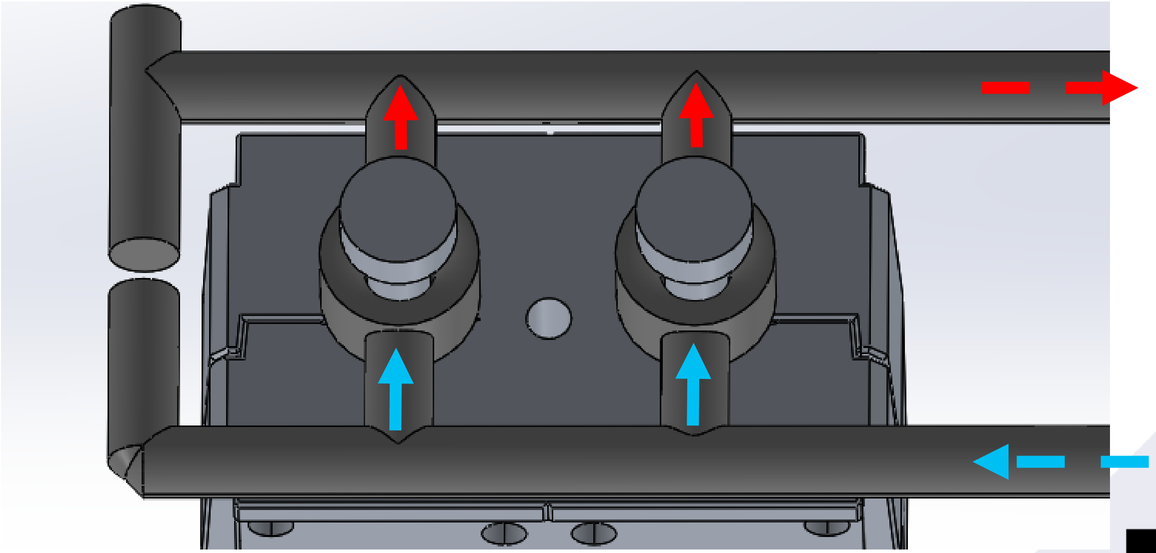
Approach	2. Current case	3. Moldmax pins	4. Multi-material pins	5. Thermal pins
Ej. Time [s]	34.9	26.9	28.8	33.1
Eff. [%]	62.2	80.7	75.3	65.6

CASE 6. CONFORMAL COOLING

- Modeling: Modeling: 2-Cavity Cable Adapter, runner system, 8 cooling lines, mold block, and mold components
  - **Utilizing the existing cooling lines, a new cooling channel was created to surround the core pins**
  - Type of analysis : Cool (FEM)



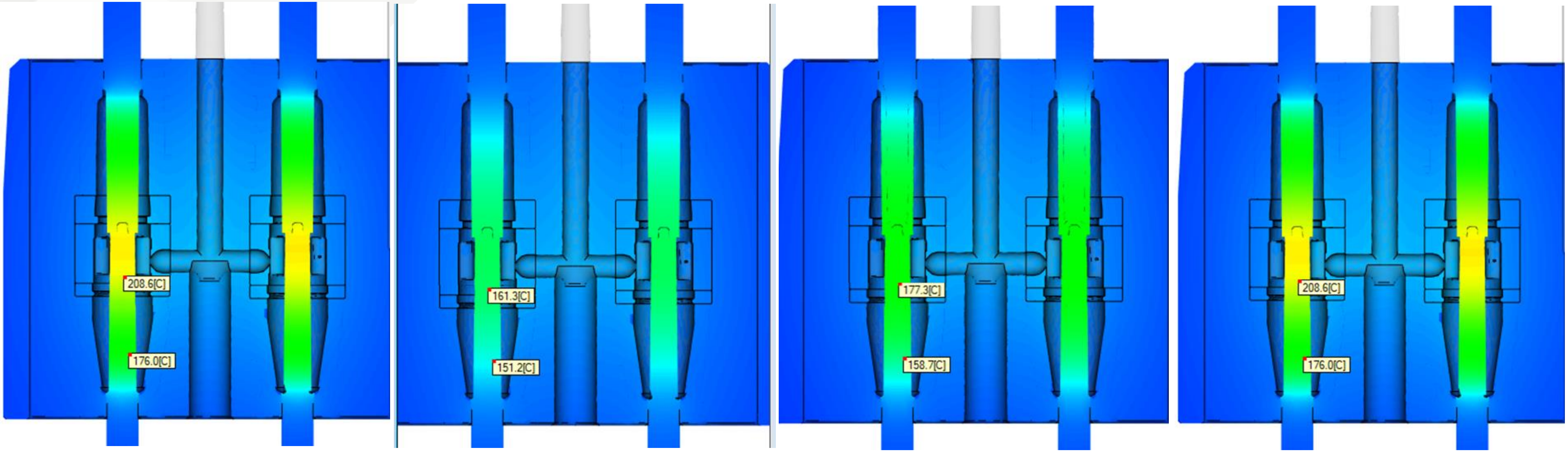
Straight cooling – Cable Adapter



Conformal cooling – Cable Adapter

CASE 6. CONFORMAL COOLING

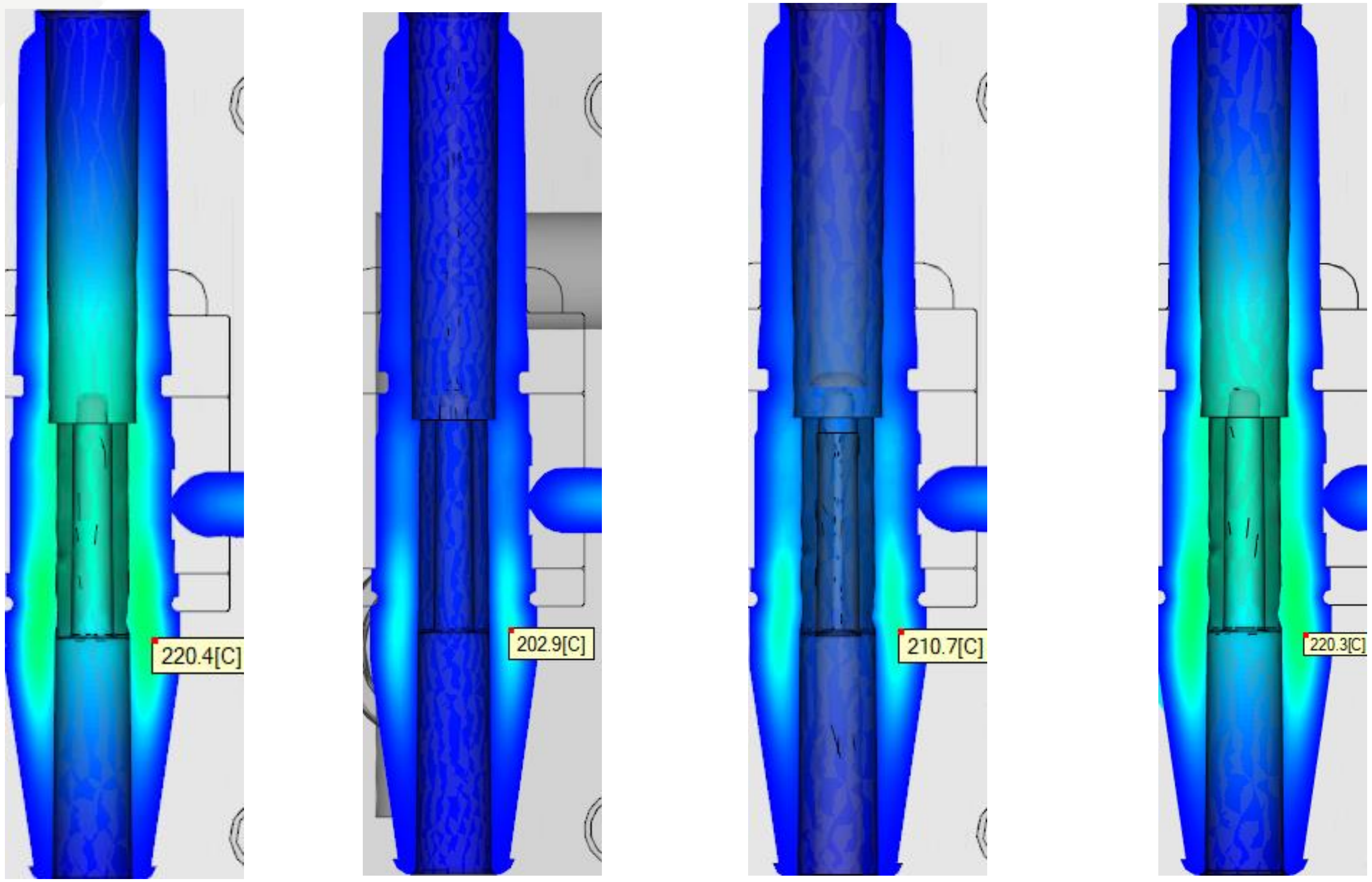
Temperature of the mold insert 25 s comparison



2. Current design
3. Moldmax pins
4. Multi-material pins
6. Conformal cooling

- Based on the mold temperature results, it appears that cooling the core pins at that specific height is not significantly contributing to heat dissipation from the part

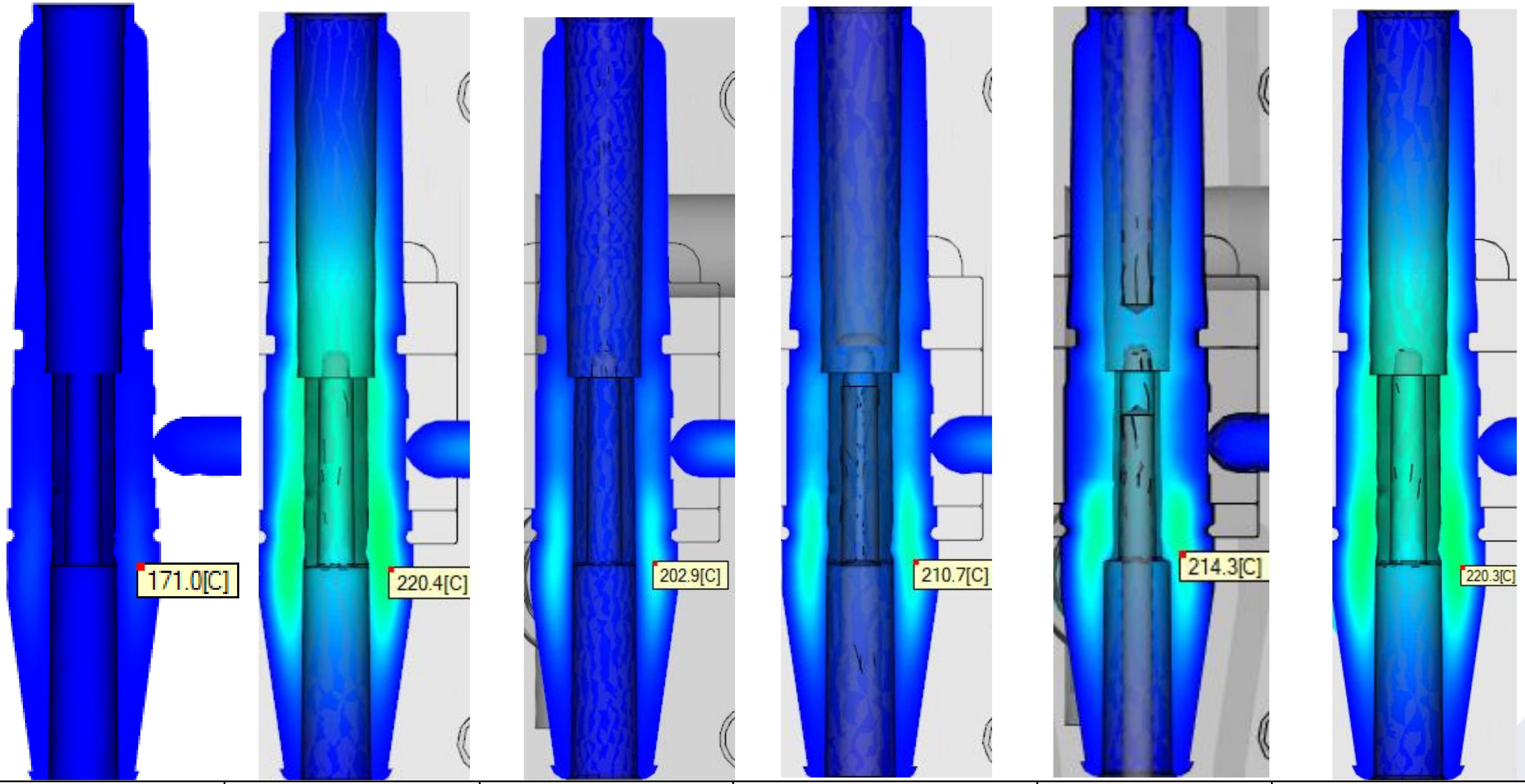
CASE 6. CONFORMAL COOLING COMPARISON



Approach	2. Current design	3. Moldmax pins	4. Multi-material pins	6. Conformal Cooling
Ej. Time [s]	34.9	26.9	28.8	34.6
Eff. [%]	62.2	80.7	75.3	62.7

EJECTION TIME RESULTS SUMMARY

High conductive core pins showed the most promising alternative to reduce cycle time, due to core shift results, the Multi-material approach was the chosen alternative



Approach	1. Ideal	2. Current design	3. Moldmax pins	4. Multi-material pins	5. Thermal pins	6. Conformal Cooling
Ej. Time [s]	21.7	34.9	26.9	28.8	33.1	34.6
Eff. [%]	-	62.2	80.7	75.3	65.6	62.7

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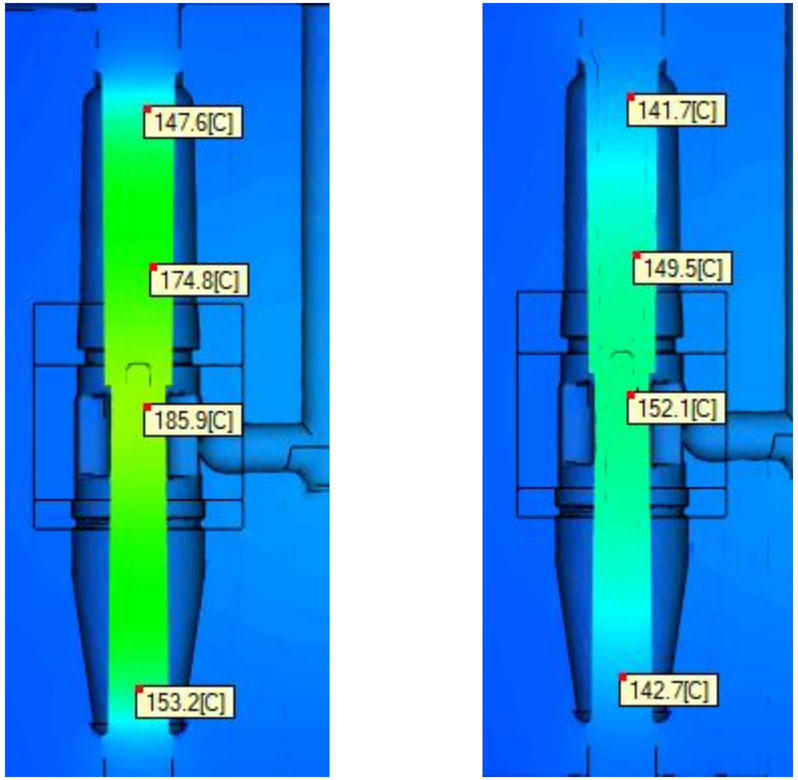
MOLD TEMPERATURE RESULTS

The mold temperature evaluation shows a more uniform temperature distribution across the mold with the multi-material technology.



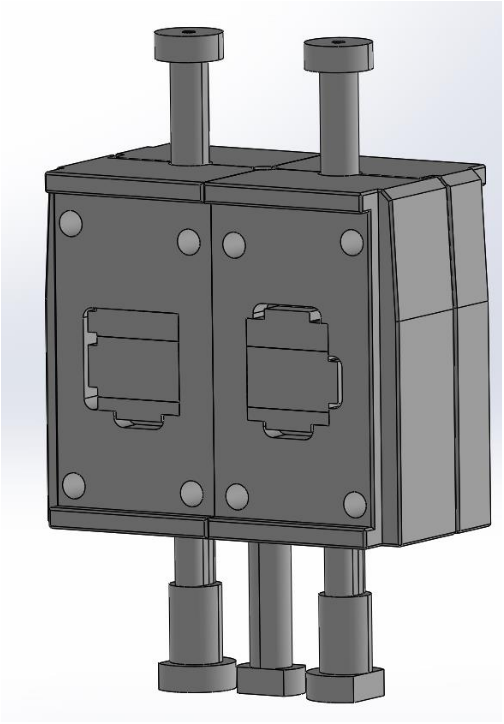
Approach	2. Current design	4. Multi-material pins
Ej. Time [s]	34.9	28.8
Eff. [%]	62.2	75.3
Mold Temp. Std. Dev. [°C]	18	5

AGENDA

- Project Overview & Executive Summary
- Introduction & Approach
- Cooling Technologies
  - Ideal cooling and reference performance
  - Current design
  - Multi-material solutions
  - Conformal cooling
- **Conclusions**

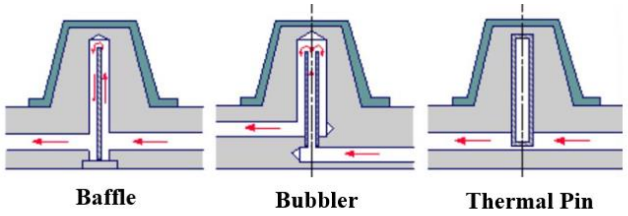
CONCLUSIONS

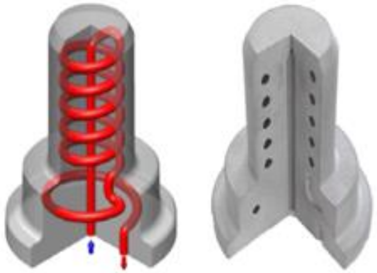
Current Design



- Efficiency = 62%
- Cycle Time = 36 s
- Mold Temp. Std. Dev. = 18°C

Investigation of Different Cooling Technologies

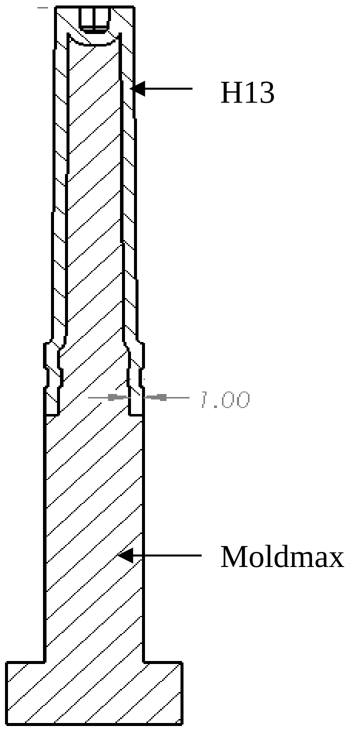




Conformal Cooling

- Numerical simulation
- Multiple cooling technologies and designs

Proposed Implementation



- Efficiency = 75% **(+130%)**
- Cycle Time = 28.8 s **(-20%)**
- Mold Temp. Std. Dev. = 5°C **(-72%)**

AUTODESK SUMMIT

Analysis of the Cooling Efficiency of Different Cooling Technologies for Slender Injection Mold Cores

A. Gruber, M. Ambasana, G. Riddell, A. Rammohan, J. Payne, J. Meng, D. Kazmer, S. Johnston, D. Masato

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Questions?

CORNING

March 21, 2025

Learning with Purpose

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