Predicting Castability of Ultra Thin-Walled Parts Using Simulations

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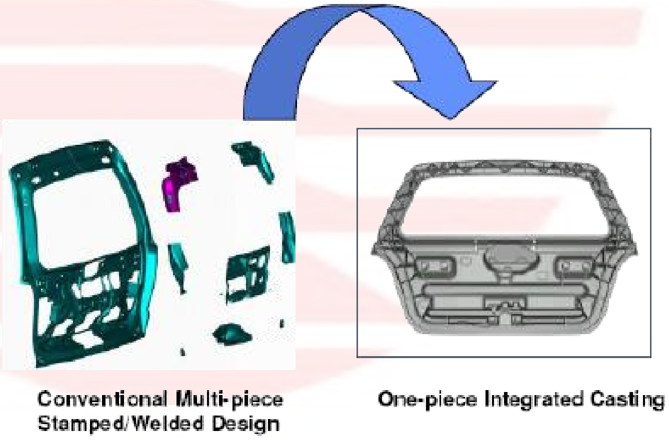
About The Presenter

Rabi has dedicated the past 18 years of his career to R&D in casting and metal forming technologies. He holds a Bachelor degree in Mechanical Engineering from the University of Waterloo and a Masters of Applied Science degree from the University of Toronto.

Started BHOLSTER Technologies in 2012

- A consulting associate of FLOW SCIENCE
- We provide simulation service and R&D support to those who wish to bring their casting process down to a science
- Cooling design, Runner Design, cycle-time reduction . . .
- Specialize in automotive structural parts

Background



Ford Report 2005: Single Integrated form
Replacing multiple welded stamped construction

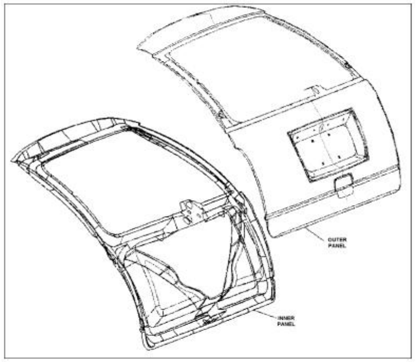


Figure 2b. Single Aluminum Cast Inner Panel

Alcoa Report - 1999

Kim et. Al.
0.8mm thick laptop cover
Korean Institute of Technology

1. Automotive industry have long reviewed the feasibility of casting ULC and thin structures
2. Renewed interest in casting thin-walled parts due to weight reduction requirements in the auto industry and the consumer electronics industry looking for low cost metallic housings for their various devices

Background

Large thin-walled parts are difficult to cast because the melt freezes before it can completely fill the die.

- ❑ The material's ability to flow into and fill a given cavity before it freezes termed "fluidity"
- ❑ There has been research done on measuring fluidity of Aluminum (see references)
- ❑ Fluidity is affected by:
  - Superheat
  - Silicon content in the alloy
  - Mould conductivity
  - Mould temperature
  - Insulating characteristics of cavity coating

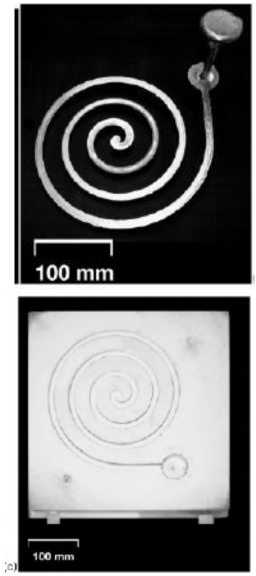


Figure 1: Mould for measuring fluidity Pucher.P, et al. [7]

Background

Large thin-walled parts are difficult to cast because the melt freezes before it can completely fill the die.

- Conclusions from these fluidity measurements are qualitative
- These experiments were under low pressures in ceramic mould (Can't directly use these results for HPDC)
- Unable to find data on fluidity for HPDC
- How can we know the distance the melt flows in a HPDC die?

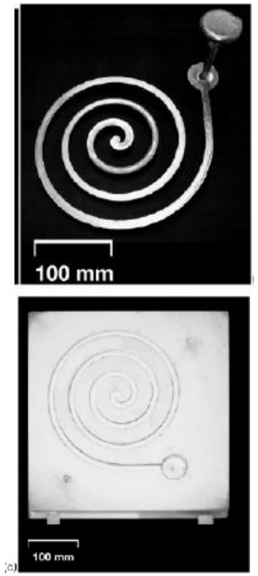


Figure 1: Mould for measuring fluidity Pucher.P, et al. [7]

The Problem

When we design a new thin-walled product…

We do not know if we can make the part or not,
Or what is required to be successful at making the part.

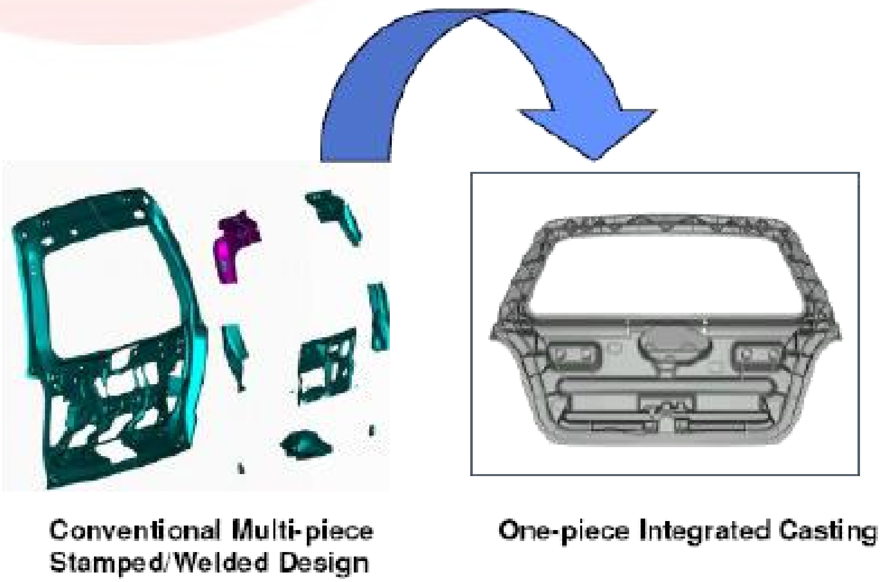
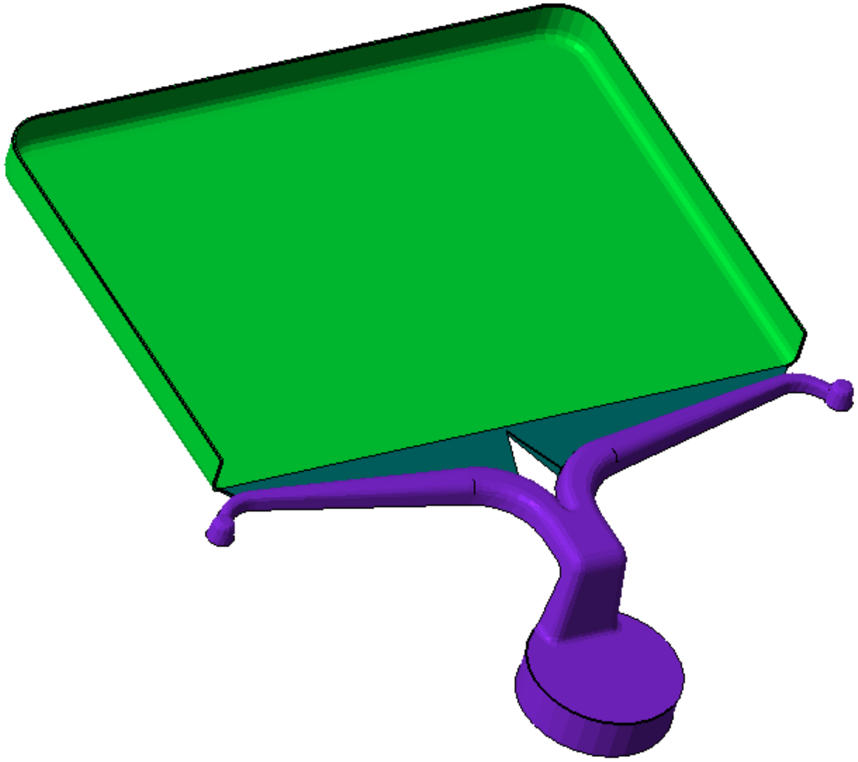


Figure 1. Single casting integrated from a multi-piece stamped steel liftgate inner structure.

Kim et. Al.
0.7mm thick laptop cover
Korean Institute of Technology

Common simulation practice - HPDC

- Product design completed
- Gating proposed
- Assume a temperature entering the biscuit
- Assume a typical die temperature (or simulate the die temperature)
- Pick a typical shot speed to fill the part
- After we build the die and setup the casting cell, it takes weeks or even months to learn how to cast the new part in the machine

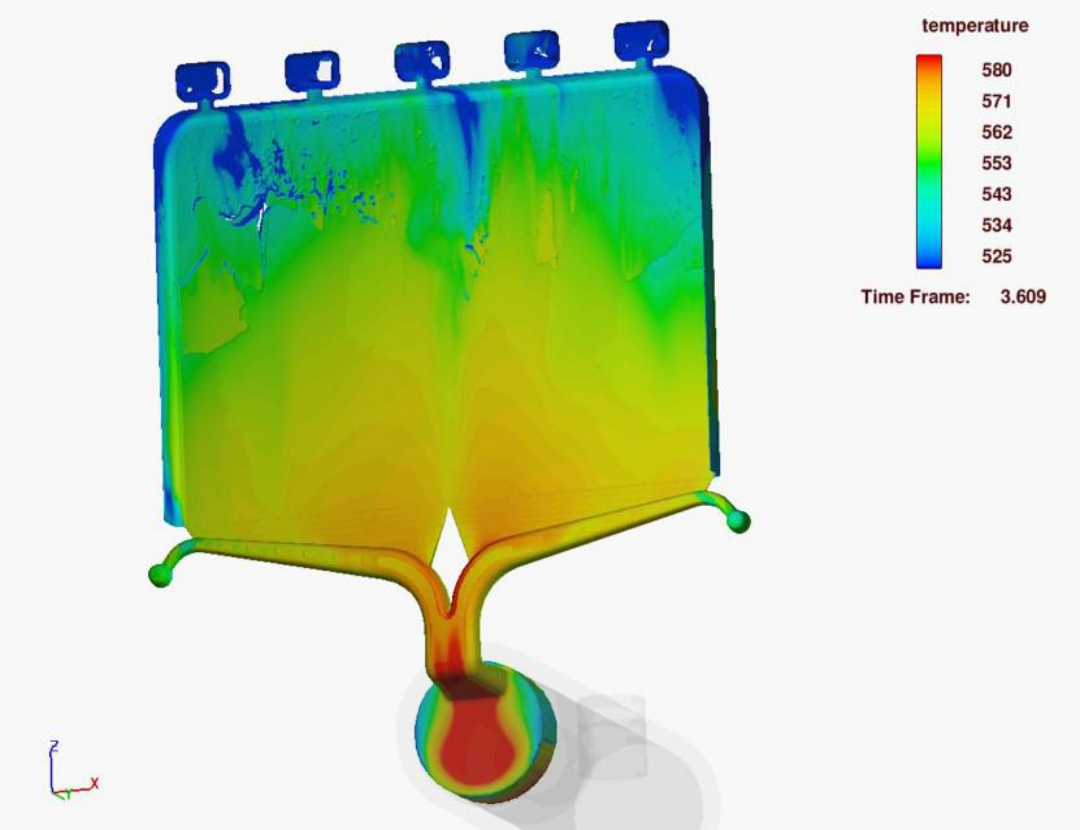


Laptop cover – 0.8mm Thick A383 Alloy

Goal of this work

To know ahead of time that we can make this part.
Or to know what must be done to successfully make this part.

Laptop cover 0.8mm thick

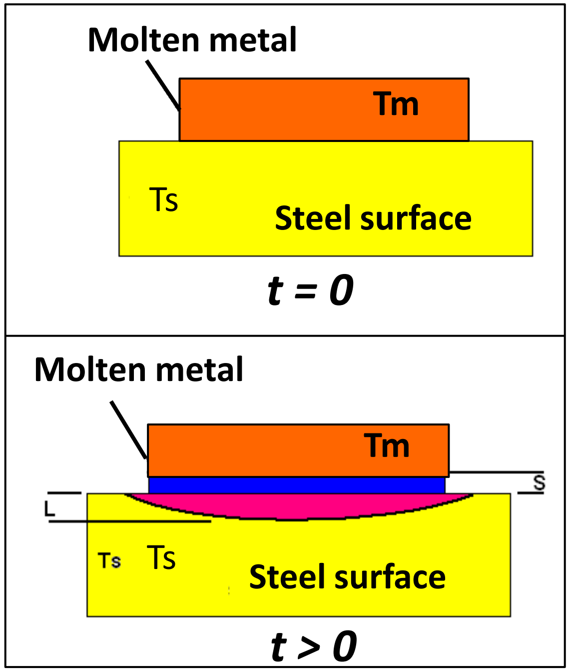


A Closer Look at Contact Heat Transfer

Perfect contact between melt and steel surface

At *t = 0*, the heat flux would be infinite

A very short time later the die steel heats up, and the melt cools down locally. This acts to dramatically reduce the very high initial heat loss

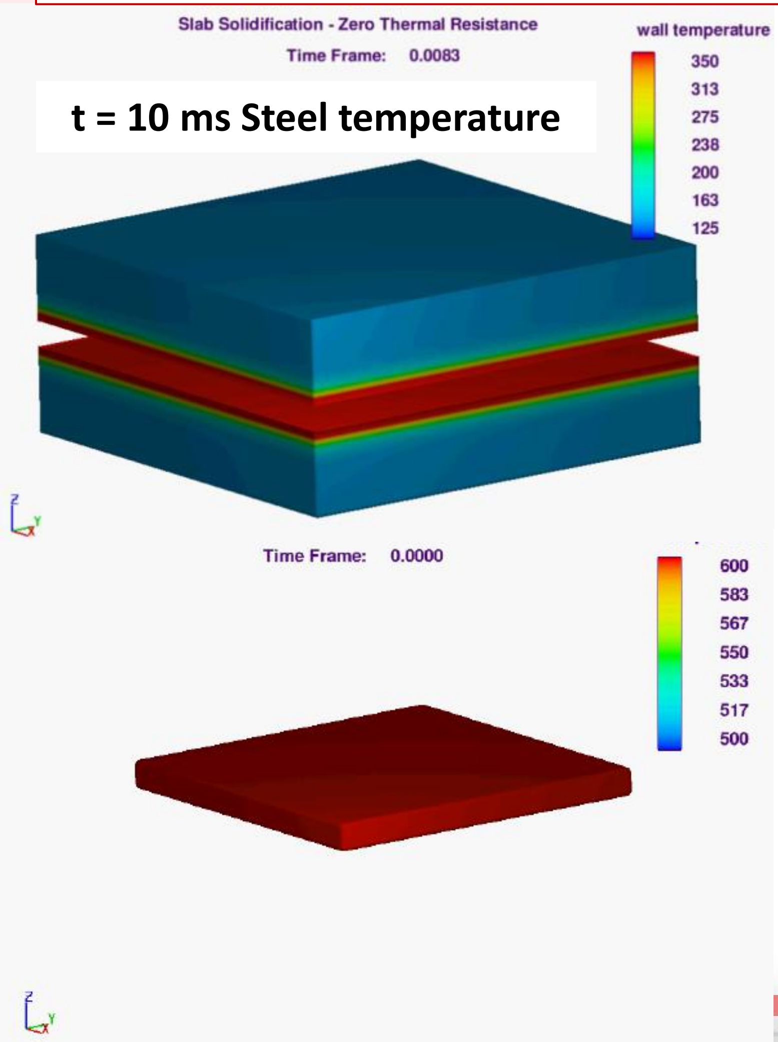


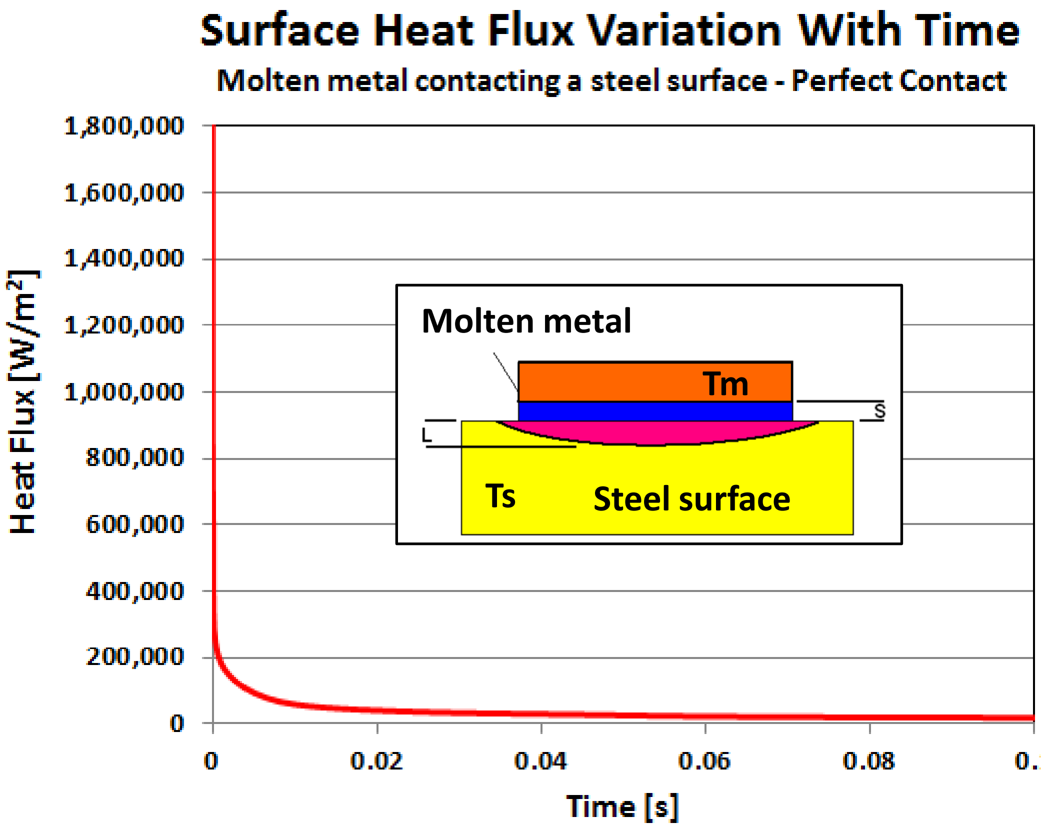
Pool of melt suddenly contacting a perfectly smooth surface

Solidification on contact

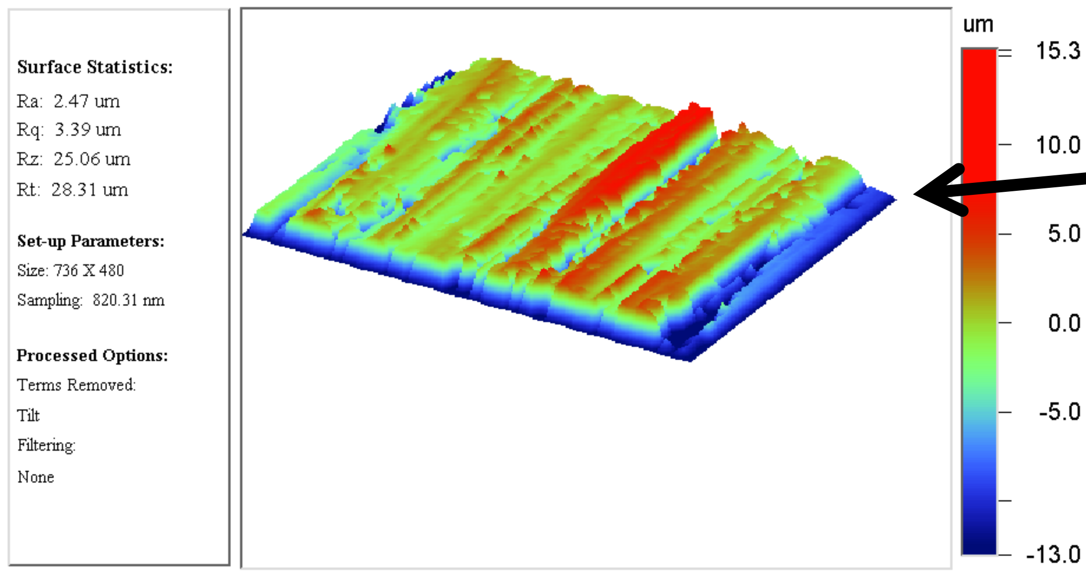
Perfect Contact

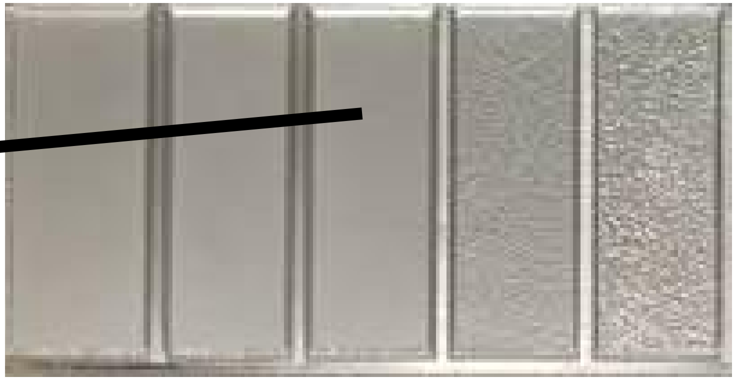
1.0 mm Aluminum slab (A383) suddenly contacting steel surface



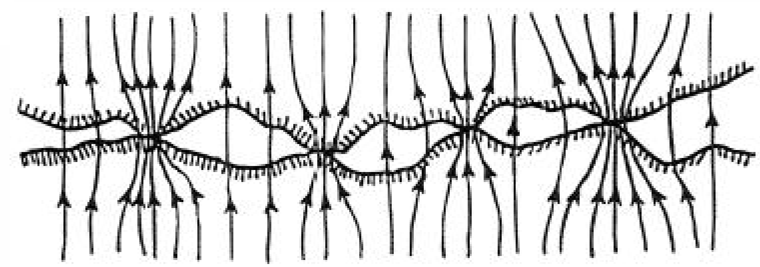


Real surfaces



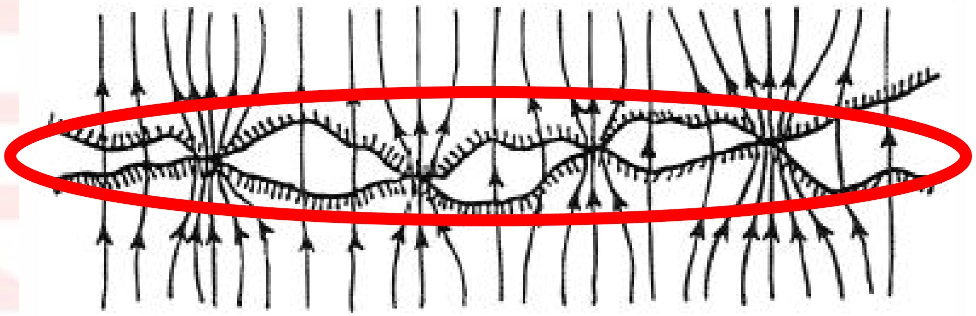


Surface profile of typical die cavity H13 steel (Courtesy of University of Toronto)



Real surfaces never have perfect contact

Real surfaces



- Heat transfer across interface of real surfaces have a "Interface Resistance" or R_i.

- In simulation, we treat this thermal resistance as a Heat Transfer Coefficient (HTC)

- HTC is simply the inverse of R_i

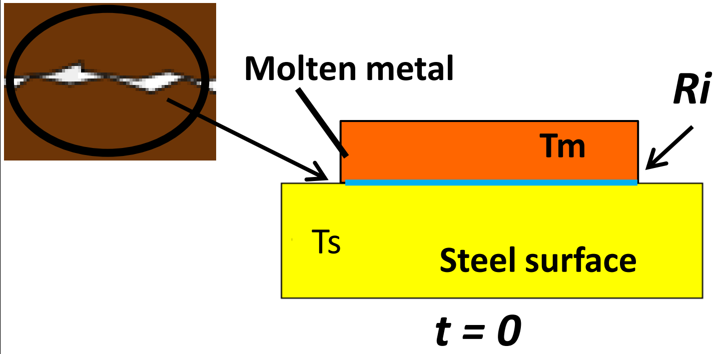
$$HTC = 1/\,R_i$$

Solidification on contact

Real Surfaces

1. At *t = 0*, the heat flux is no longer infinite

2. Initial rate of heat loss is affected by the surface roughness and any contaminations that separates the melt from the surface (eg. Oxidation, die lube, etc.)



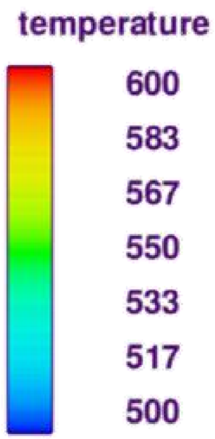
Pool of melt suddenly contacting a real surface

Slab Solidification

Effect of Surface HTC

1.0 mm Aluminum slab (A383) suddenly contacting steel surface

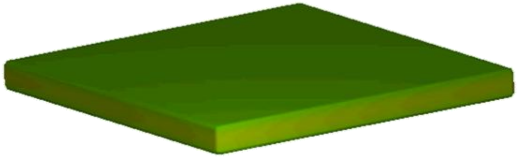
1. **Different HTC affects results dramatically**
2. **The question is, which value is correct? (Industry's perception varies from *2e-4 m²K/W to 8e-6 m²K/W*)**
3. **If we are to accurately calculate heat loss for very thin parts, we must have a very accurate measurement of the surface HTC.**



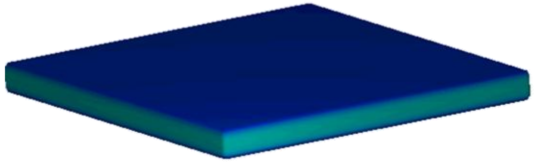
A383

Liquidus: 582°C

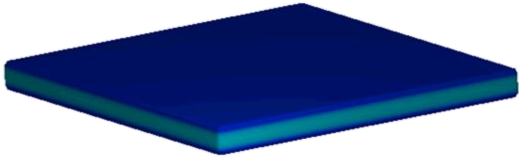
Solidus: 516°C



HTC = 5e-5 m²k/W
t = 0.02 s
Die Temp = 150°C



HTC = 2.4e-6 m²k/W
t = 0.02 s
Die Temp = 150°C



Perfect Contact
t = 0.02 s
Die Temp = 150°C

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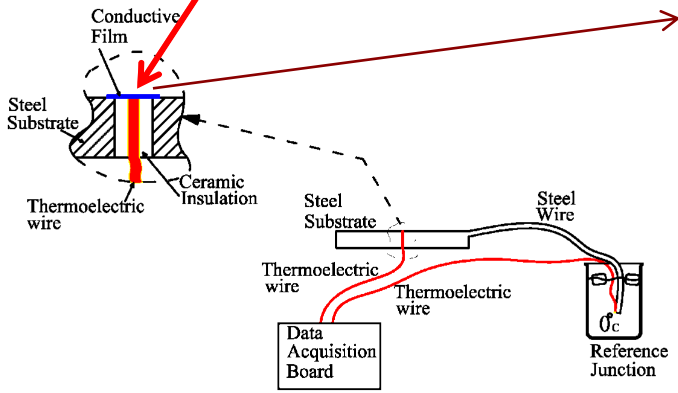
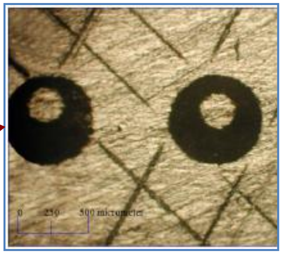
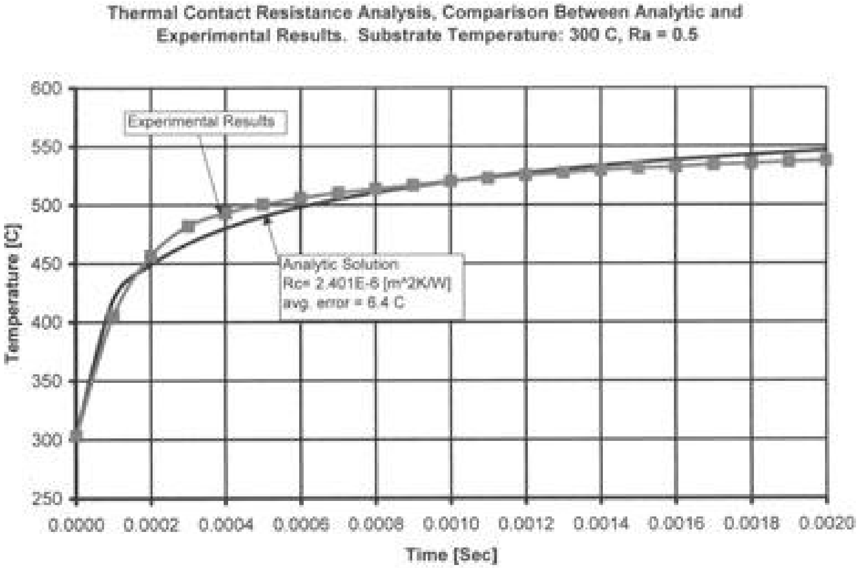
Measuring Surface HTC

(University of Toronto)

Temperature sensor
40 *ns* response time!



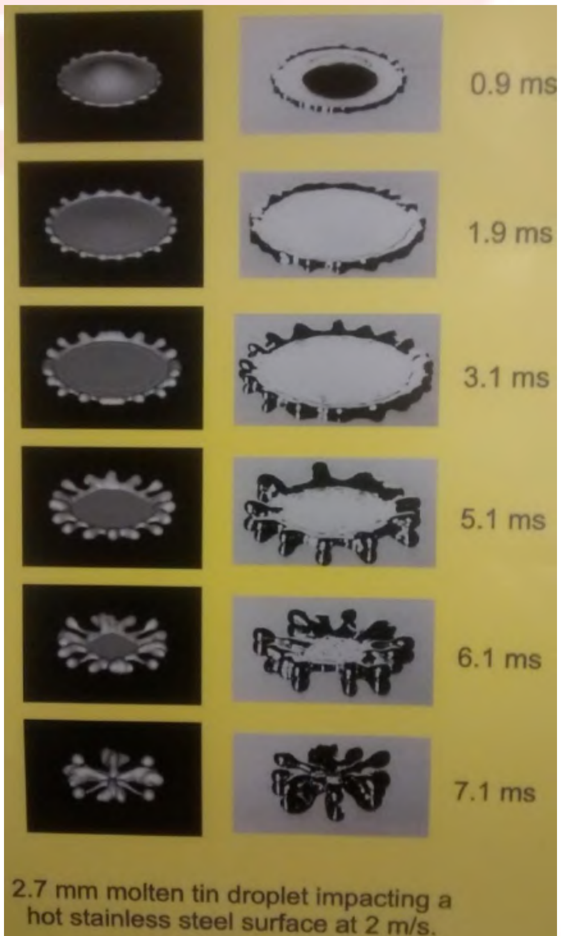




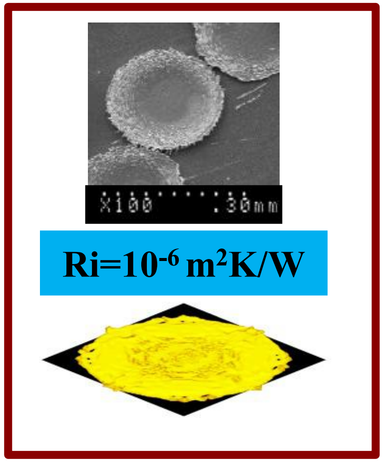
Metal Droplet Impact

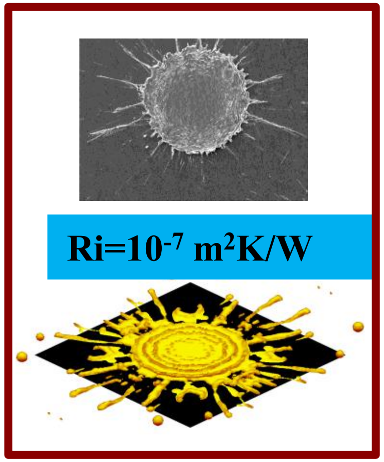
University of Toronto

No Freezing During Impact
Simulation vs Actual Impact



With Freezing During Impact





Measured Thermal Resistance

For typical HPDC process . . .

$R_c = 2.4 \times 10^{-6}\ m^2K/W$

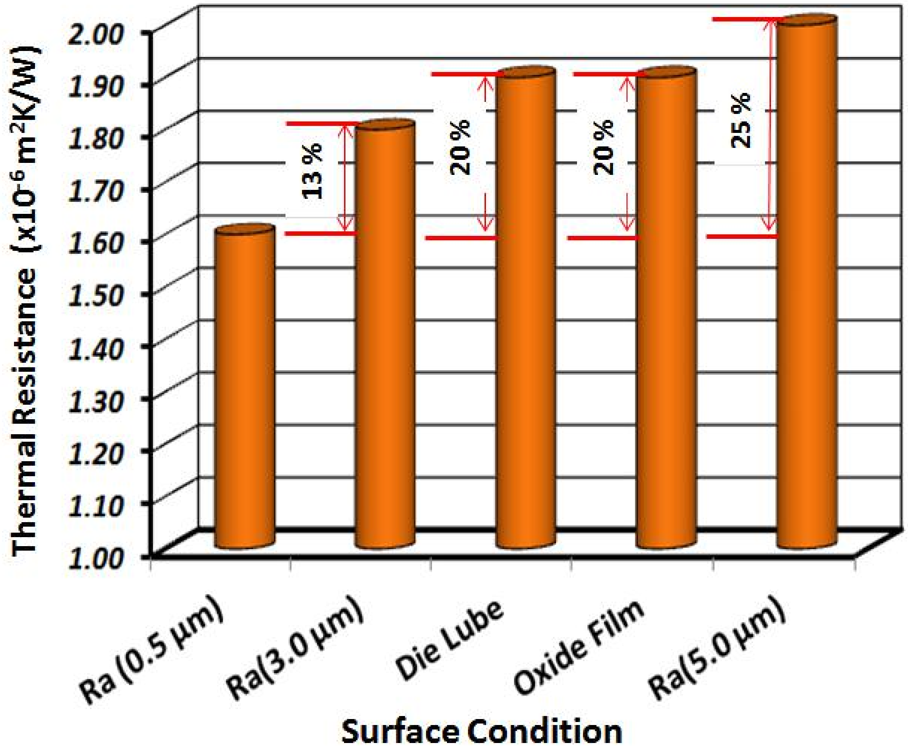
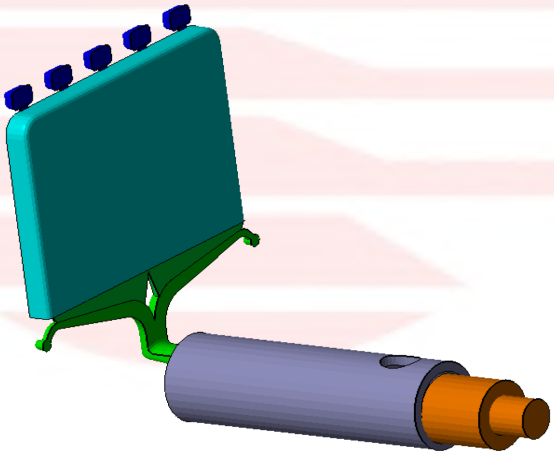


Figure 2: Thermal resistance for different surface conditions (Y. Heichal, 2004). H-13 Die Steel

Case Study



Casting geometry simulated. Laptop housing 0.8 mm thick.

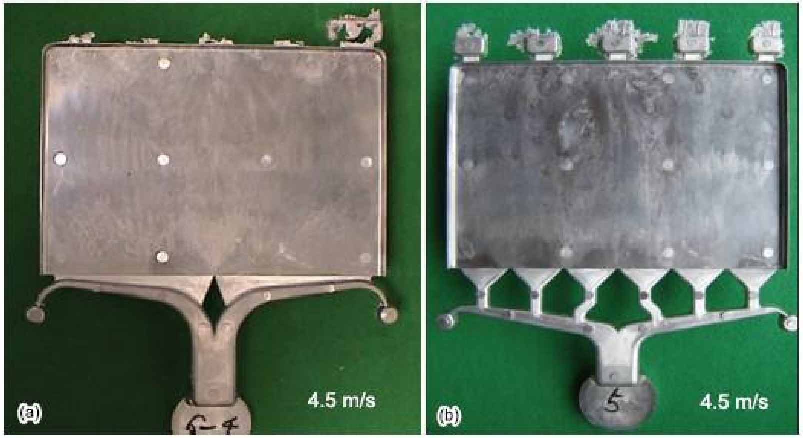


Fig.10 Results of actual casting experiment: (a) tangential type gating system, (b) split type gating system

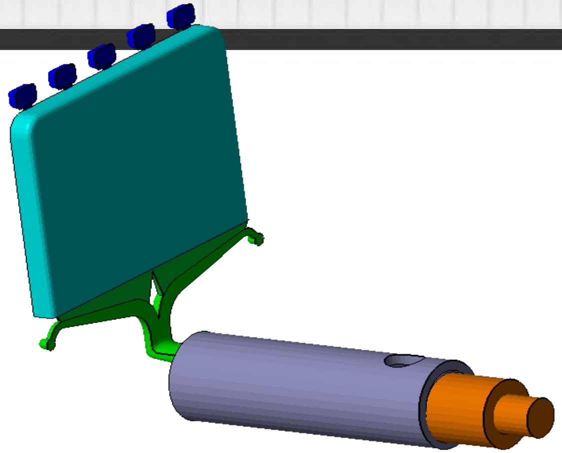
Laptop casting courtesy of Kim et al

Korea Institute of Industrial Technology

"Defects including misrun and cracks were observed in the specimens in the tangential type gating system while the split type resulted in sound casting with the highest injection speed of 4.5 m/s"

Case Study Simulated

Pour weight	0.59 kg	1.298 lb
Casting weight	0.147 kg	5.180 Oz
Pour temperature	670 ° C	1238 °F
Pour time	3.0 s	3.0 s
Sleeve percent filled	25%	25%
Shot sleeve initial temperature	220°C	428 °F
Slow shot speed	0.35 m/s	13.78 in
Active sleeve length	250 mm	9.84 in
Plunger diameter	70 mm	2.76 in
Plunger initial temperature	50°C	122°C
Plunger material	Copper Beryllium	
Die initial temperature	150°C	302°C
Thermal Resistance	2.4 x 10^{-6} m^2K/W	



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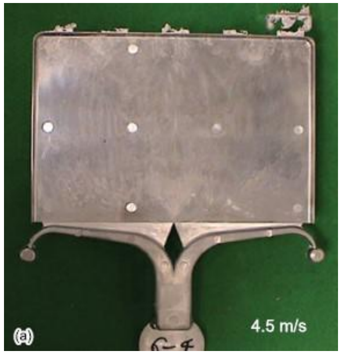


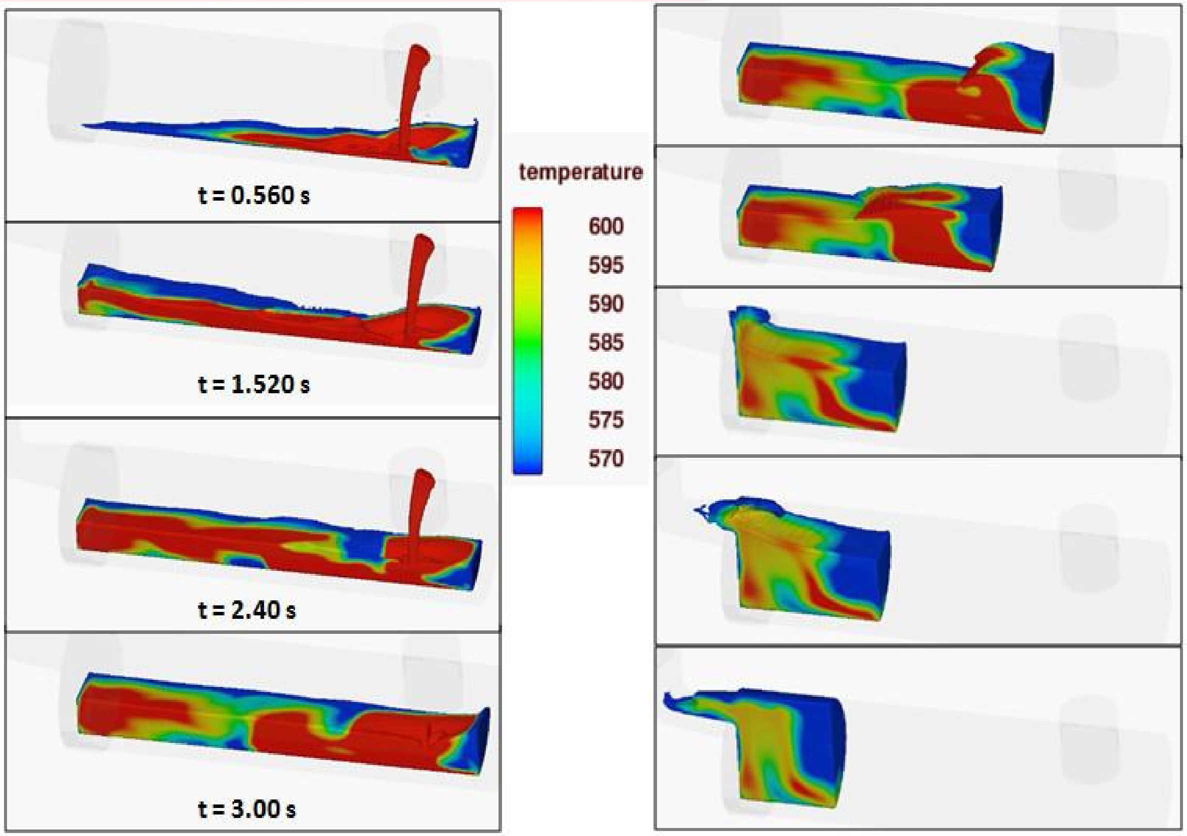
Laptop casting courtesy of Kim et al

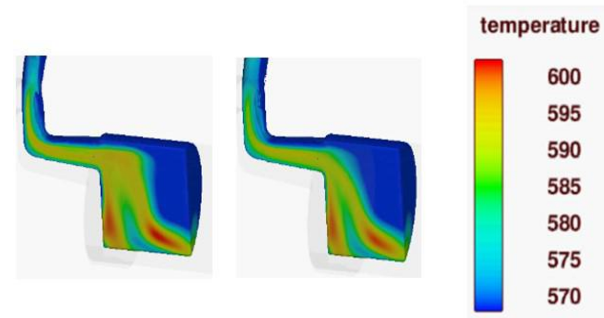
Korea Institute of Industrial Technology

We tested the effect of:

1. ***HTC***
2. ***Shot speed***
3. ***Shot position***
4. ***Temperature drop during pouring***

Results - Heat Loss During Pour





Temperature drop during fast shot phase showing the actual temperature entering the runner system being in the range of 585°C to 595°C.

Temperature drop during the pouring, and slow shot phase of the casting process. Pour temperature 670°C, slow shot speed (0.35 m/s)

<u>A383</u>
Liquidus: 582°C
Solidus: 516°C

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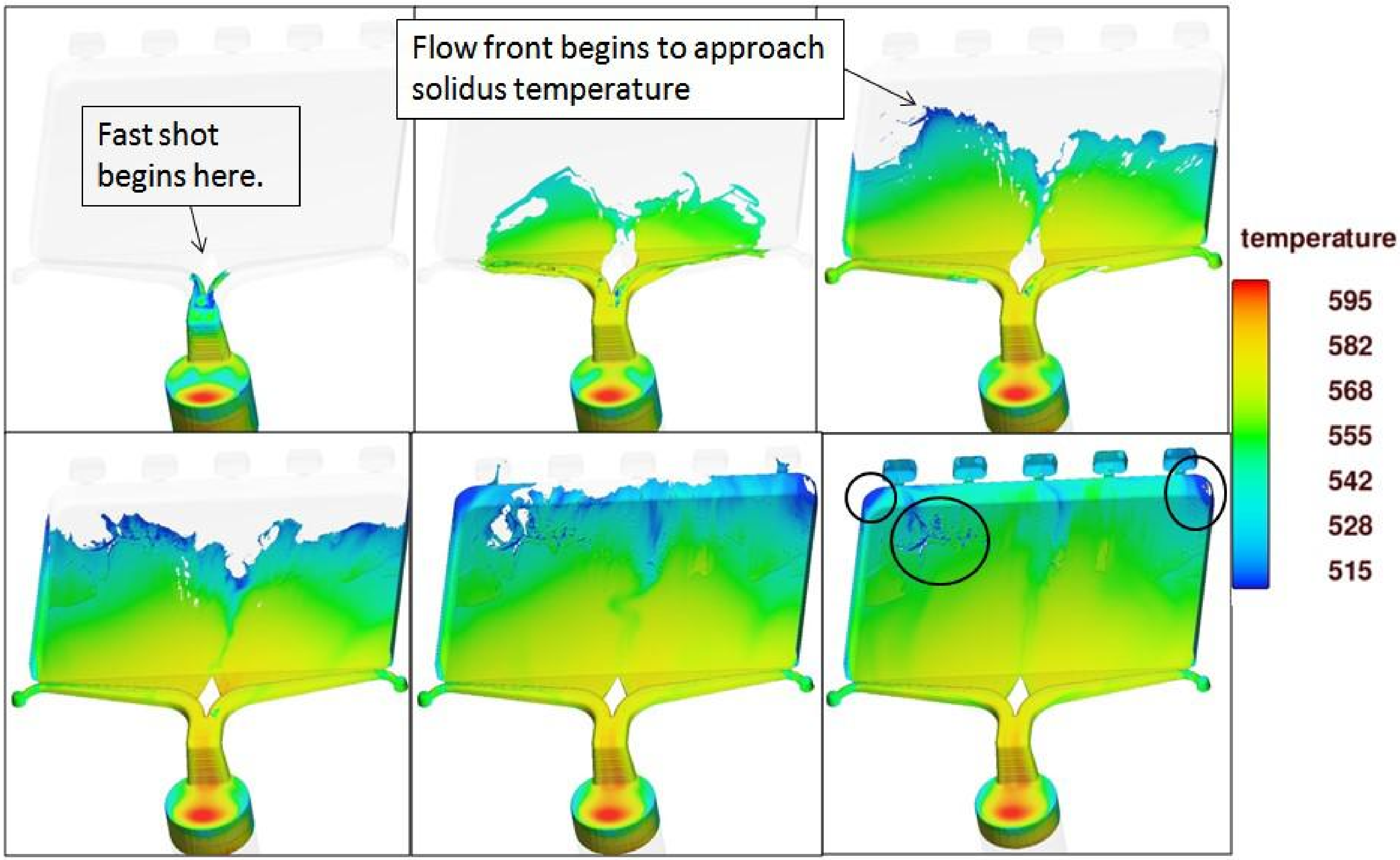
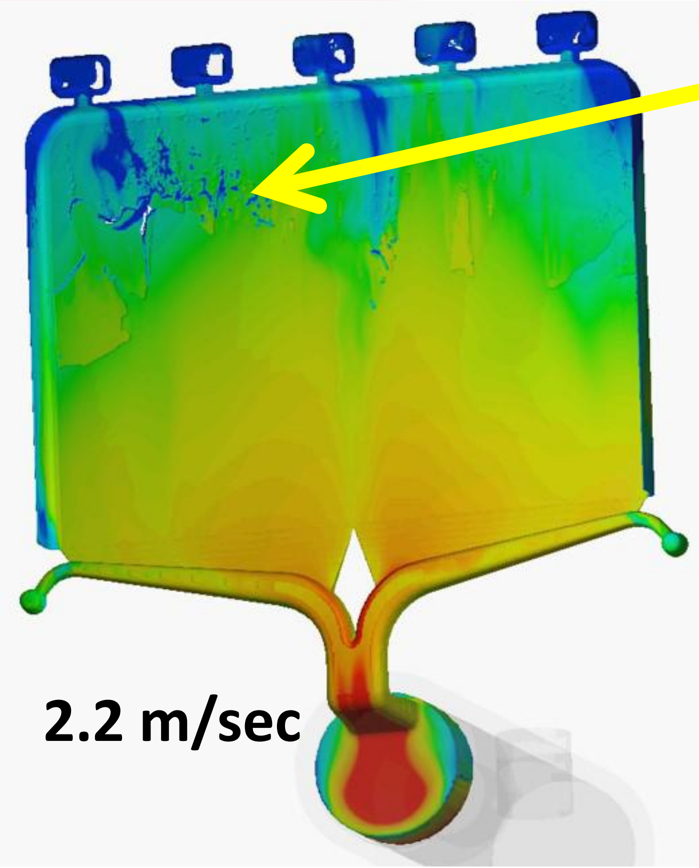
Results - Heat Loss During Filling

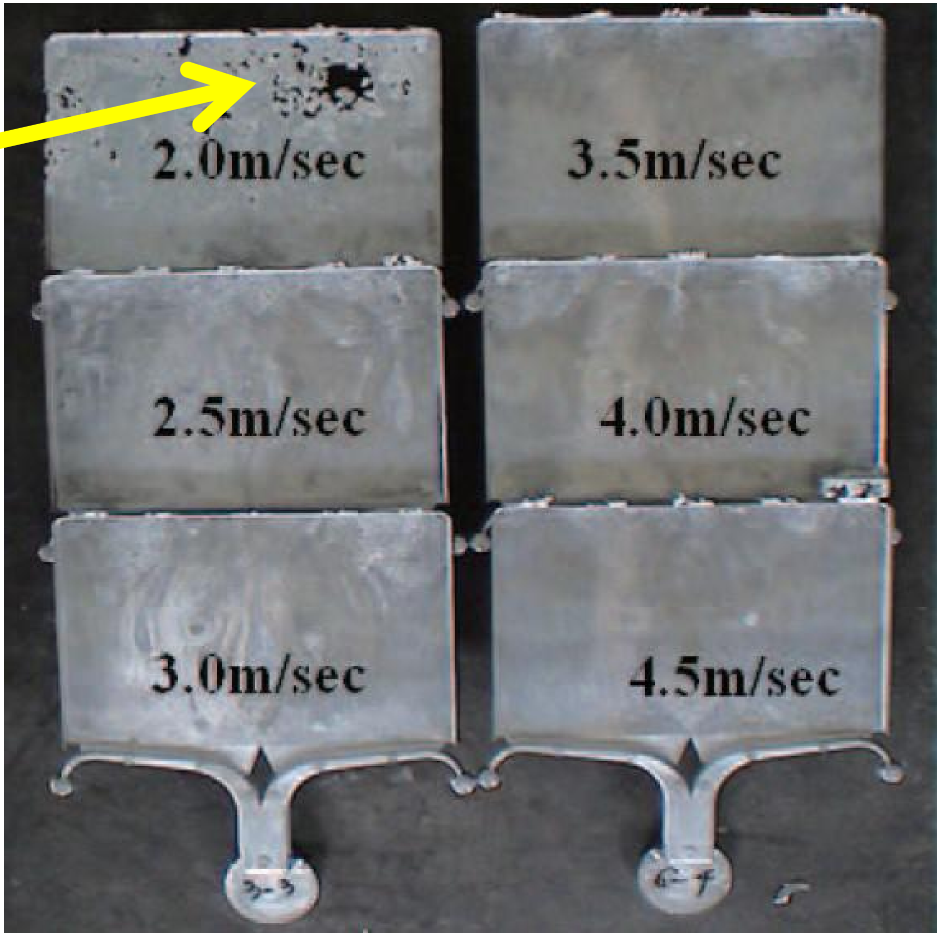
(Shot Speed: 2.2 m/s, HTC = 417,000 W/m²K)



Filling simulation, fast shot (2.2 m/s) starts well before metal reaches the gate; splashing during the fast shot solidifies before the shot is complete. This resulted in visible no-fill defects predicted by simulation where the solidified material no longer flows.

Comparison to Actual Castings

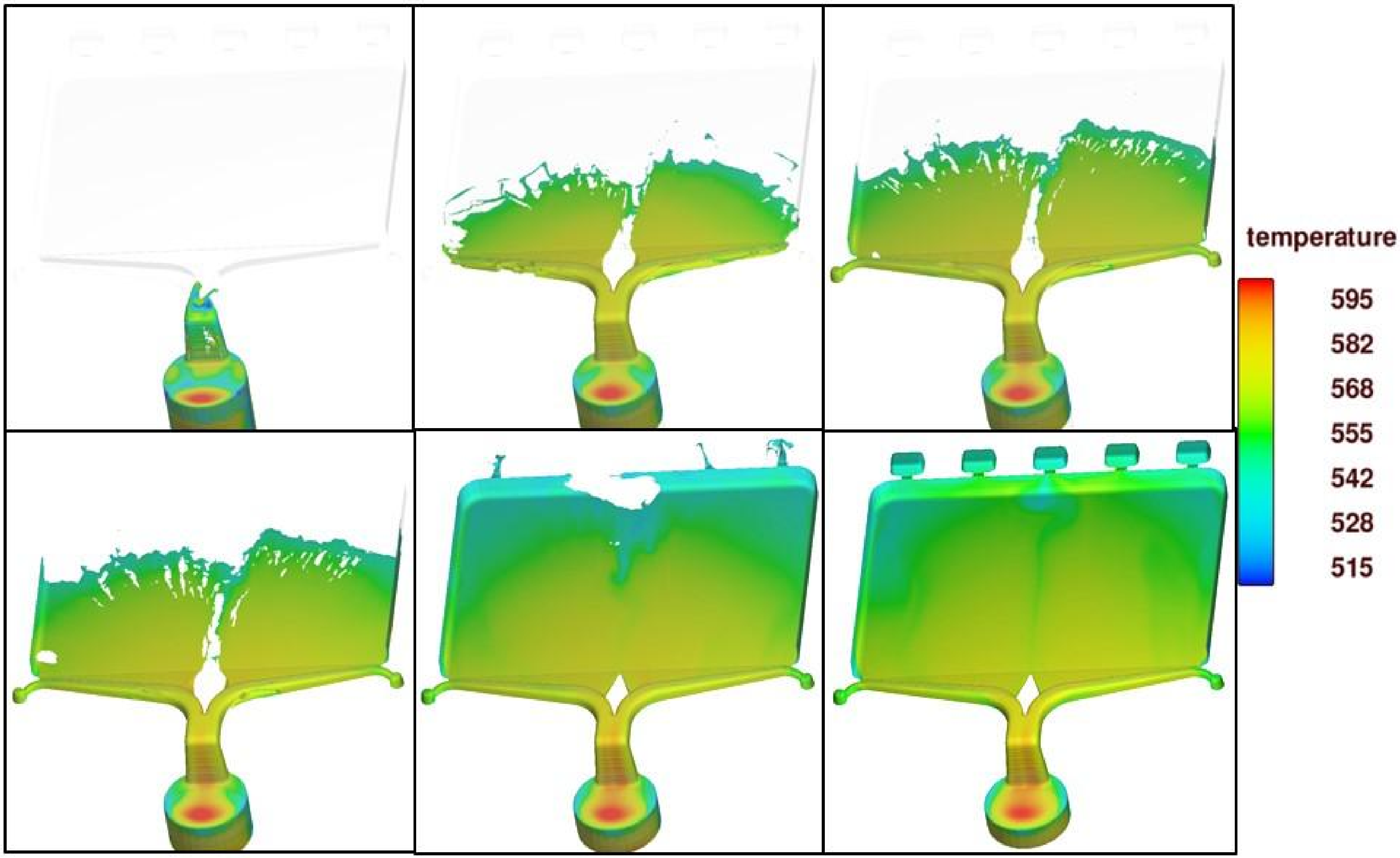




With a Resistance of 2.4 x 10^{-6} m^2K/W, we were able to observe similar no-fill defects as seen on the actual castings.

Heat Loss During Filling

(Shot Speed: 2.2 m/s, HTC = 120,000 W/m²K)



Results show no defects forming with these settings. Researchers was unable to make a good casting at this settings. Confirming that even this HTC is too low to match the foundry results.

Heat Loss During Filling

(Shot Speed: 4.5 m/s, Standard Fast Shot Position
R =*2.4 x 10⁻⁶ m²K/W*
)

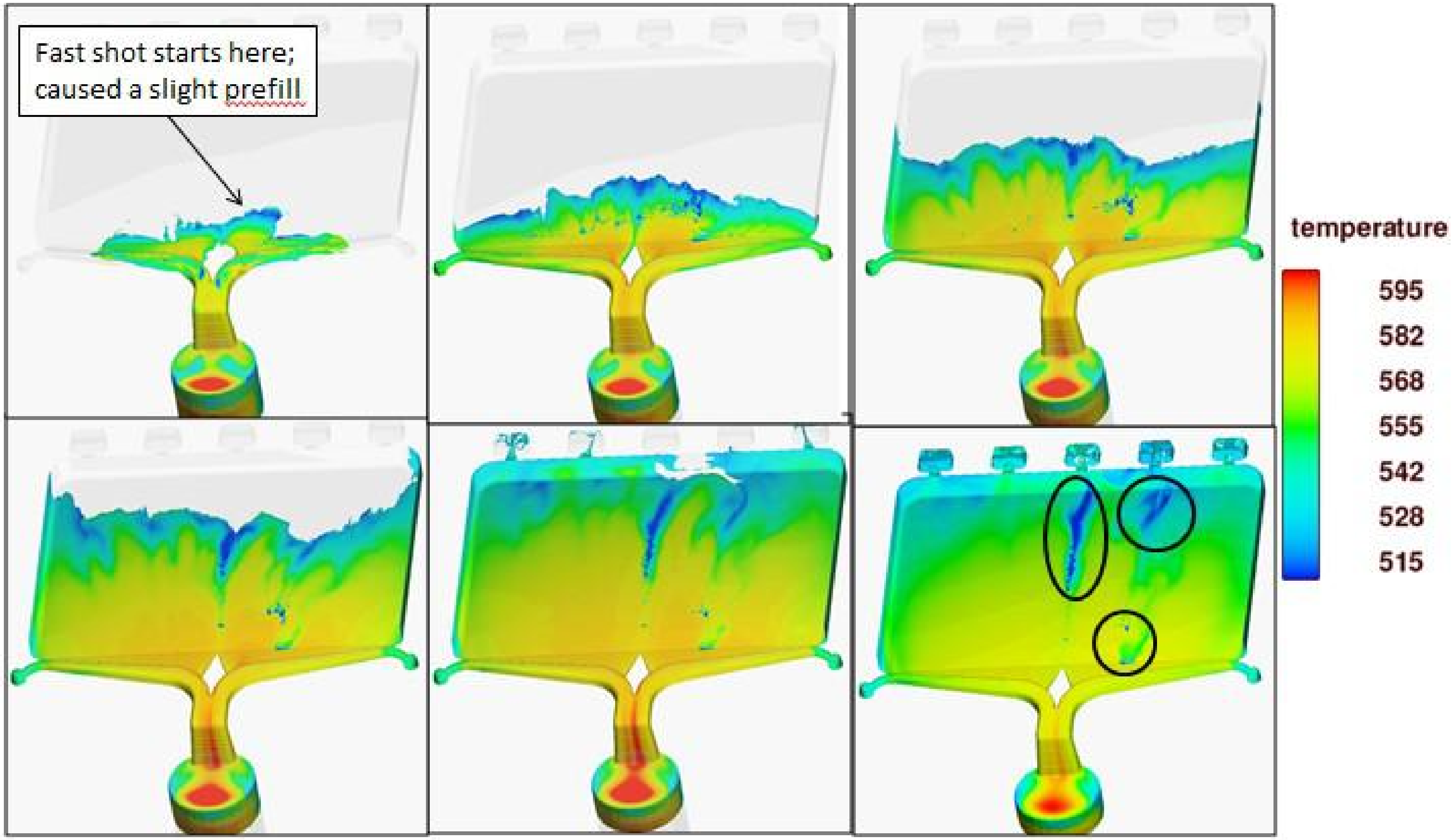


Figure 7. Calculated fast shot position to fill runner caused a slight pre-fill and made it impossible to make a good casting.

Heat Loss During Filling

(Shot Speed: 4.5 m/s, Standard Fast Shot Position $R = 2.4 \times 10^{-6}\ m^2K/W$) – New Runner

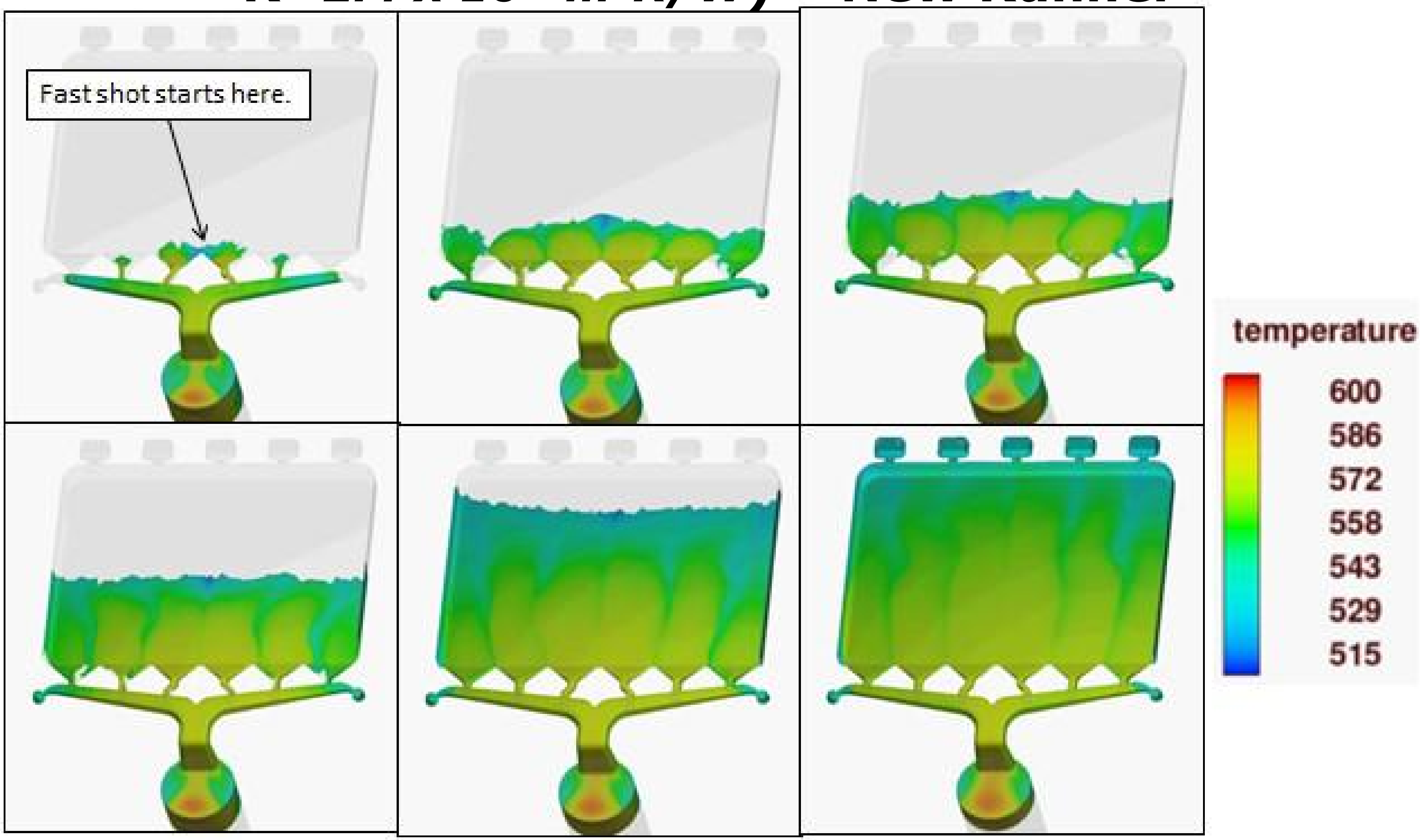
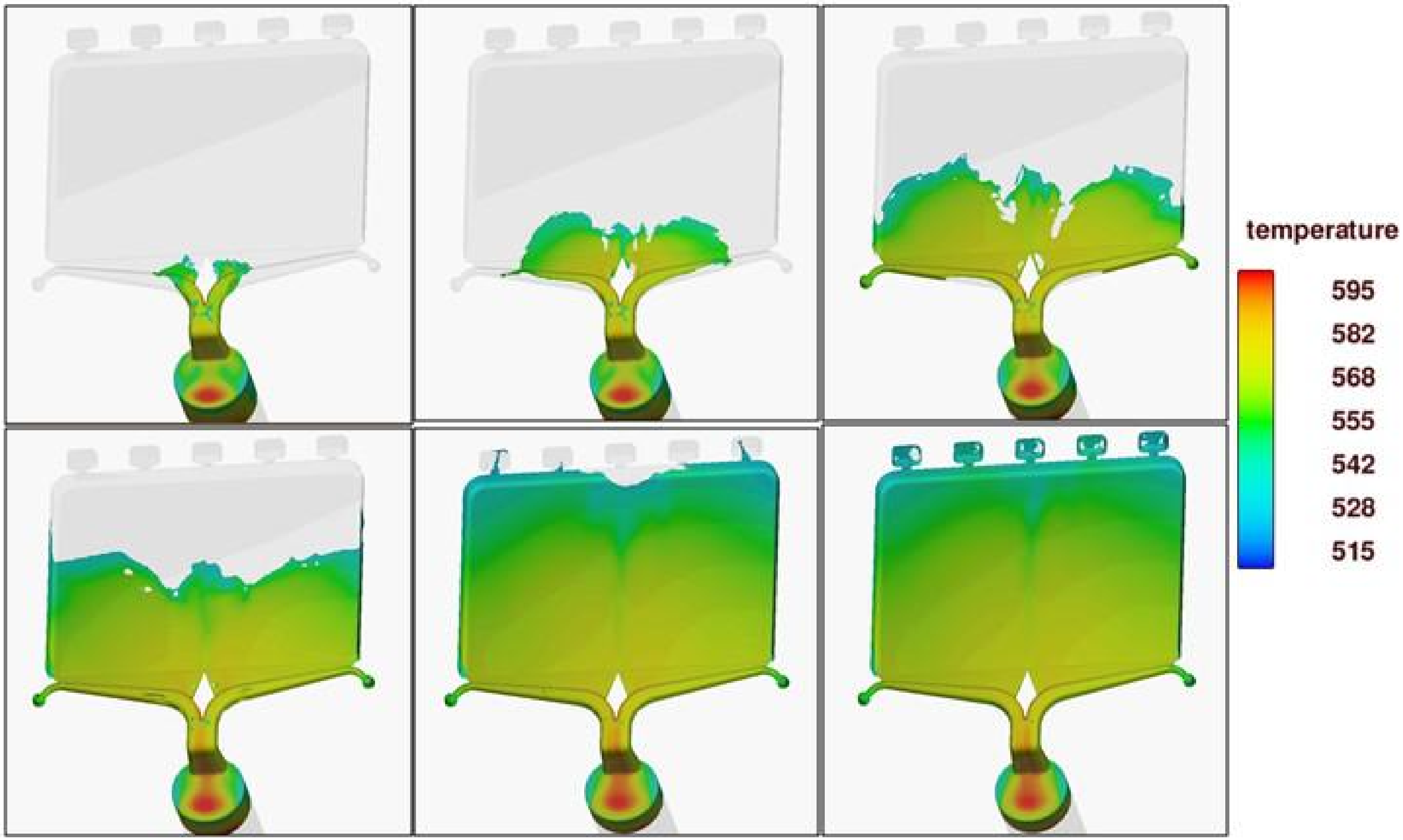


Figure 7A: Die filling with 4.5 m/s shot speed with $R = 2.4 \times 10^{-6}\ m^2K/W$ These results show that we can make a good casting at this setting, in agreement with experiments.

Heat Loss During Filling

(Shot Speed: 4.5 m/s, Starts well before runner is filled



Fast shot (4.5 m/s) starting well before the metal arrives at the gate, showing that the melt did not solidify at the end of shot – should make a good casting

Summary of Observations

1. **The greatest amount of heat loss occurred during the pouring of the melt into the shot sleeve. Shorter pour times can reduce this heat loss**
2. **The slow shot phase had a smaller temperature drop in the shot sleeve, this is due to the sleeve surface being heated during the pouring stage much less convection with shot piston travel**
3. **Very rapid heat loss occurs as the melt fills the cavity; due to the very large ratio of die surface area to volume molten metal**
4. **Surface resistance of *$2.4 \times 10^{-6}\ m^2K/W$ allowed us to specify the shot speed, the furnace temperature and die temperature required to successfully make this part:***
   a) **We correctly predicted that we cannot make a good part with a shot speed of 2.2 m/s**
   b) **We correctly predicted that the split gate will make a good part at 4.5m/s**
   c) **We correctly predicted that we will still produce scrap casting at 4.5 m/s unless we start fast shot very early for the Tangental Gate.**
   d) **When we used the highest HTC value found in the industry, we incorrectly predicted that we will make a good part at 2.2 m/s**

Conclusions and Future Work

Simulation successfully predicted castability of very thin parts when we simulate full casting process and used a surface resistance value of $2.4 \times 10^{-6}\ m^2K/W$

FUTURE WORK

The precision of these predictions can be further improved through additional research in the following areas:

1. **Die lube thermal resistance measurements: Effect of lube type, concentration, applied thickness on HTC values**
2. **Measurement of the thermal resistance of oxide layer on the die surface**

Practical Applications

Rather than wait for researchers to invent alloys with greater fluidity, we can look at current foundry conditions that affect fluidity and develop ways to control these conditions.

For example:

1. Roughen die cavity
2. Use die lube that is more insulating
3. Increase die lube concentration
4. **Design runners to prevent melt from entering part during slow shot**
5. Use lower thermal conductivity steel for die cavity area
6. Coat die cavity with insulating coating

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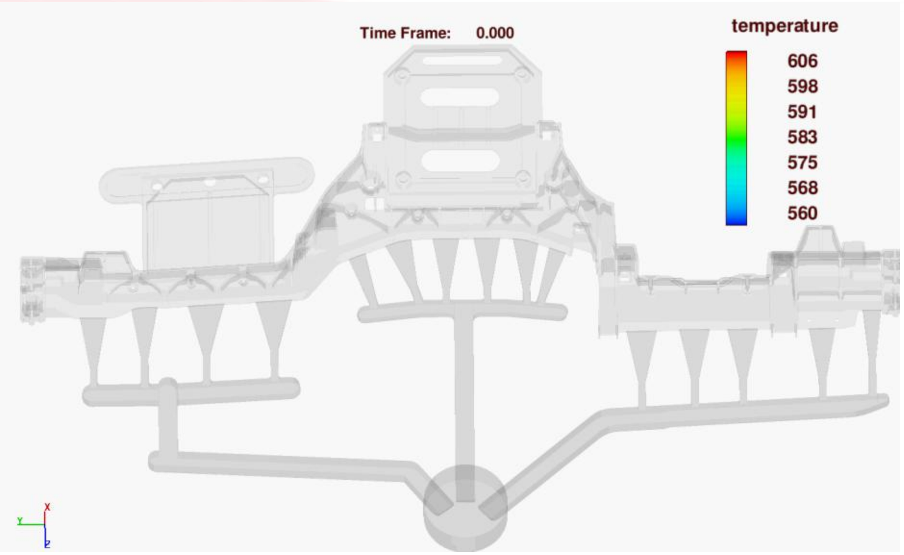
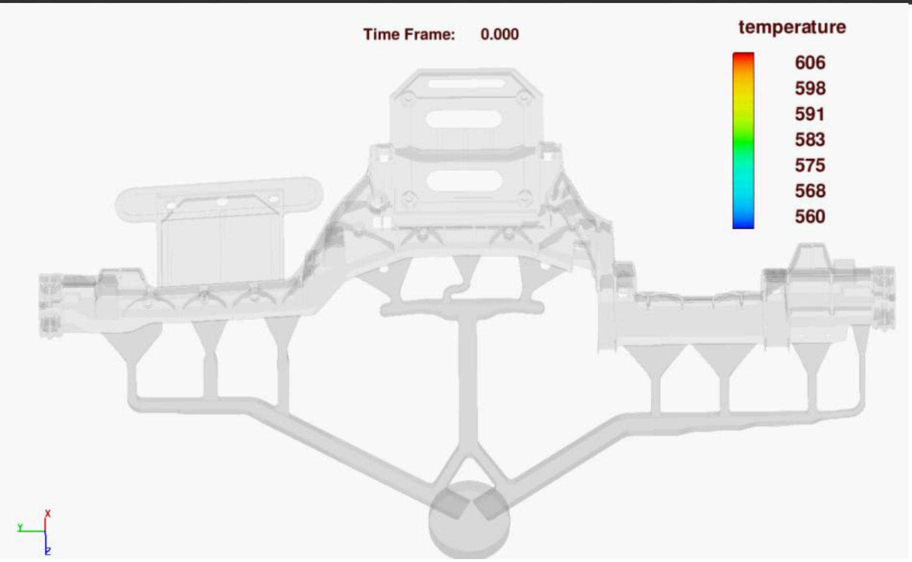
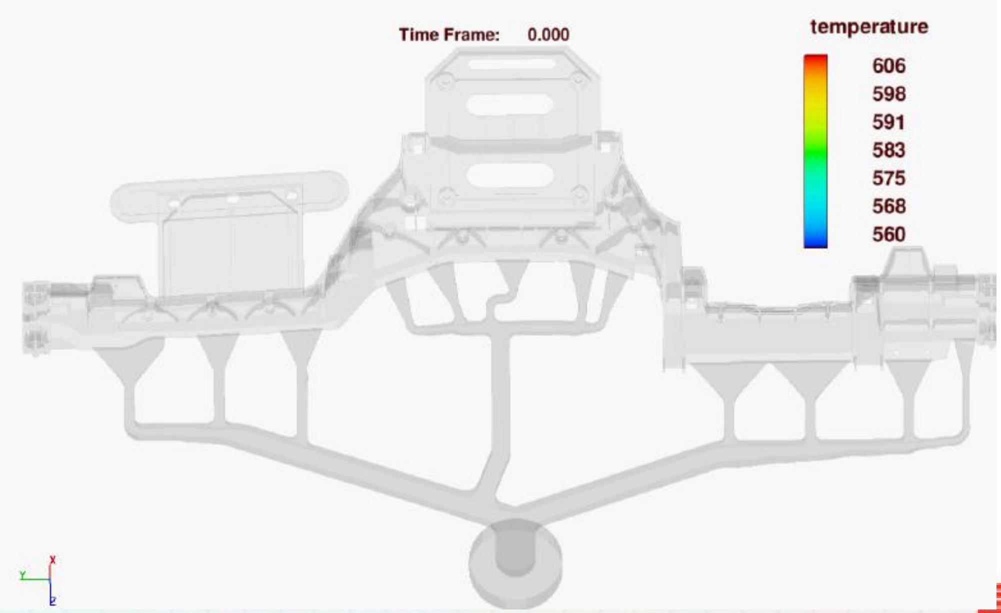
Practical Applications







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Thank You!

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