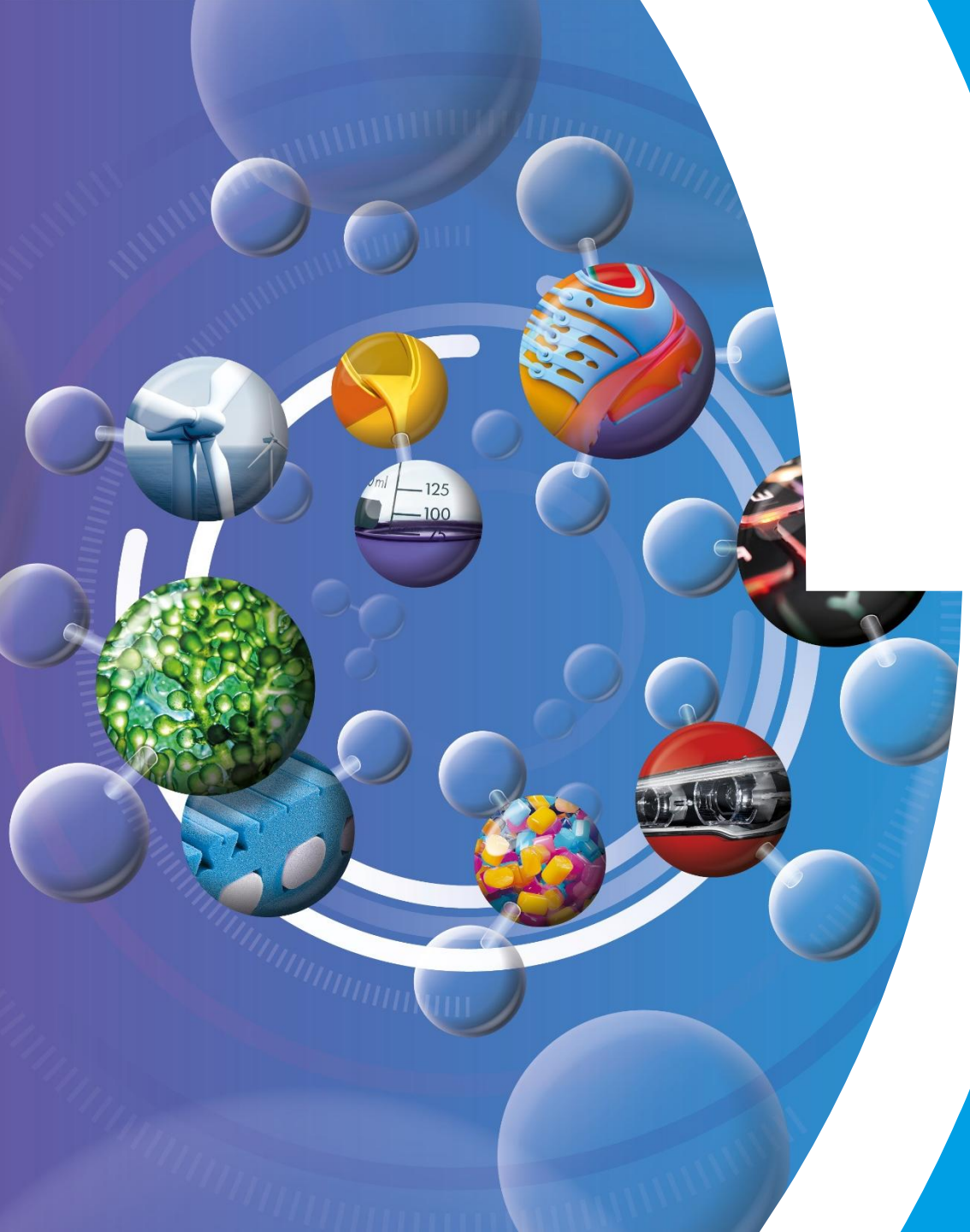


Innovative Simulation Method for Ink Washout Prediction in **F**ilm **I**nsert **M**olding

Moldflow Summit 2026

Dr.-Ing. Sarah Frauholz

April 2026

Covestro

Global plastics manufacturer

Strong and global

€12.9 bn in sales

17,600 employees

46 production sites

Game-changing and beneficial

Polymer materials of superior quality

Across numerous industry sectors

For global challenges

Innovative and sustainable

1,300 employees in research and development

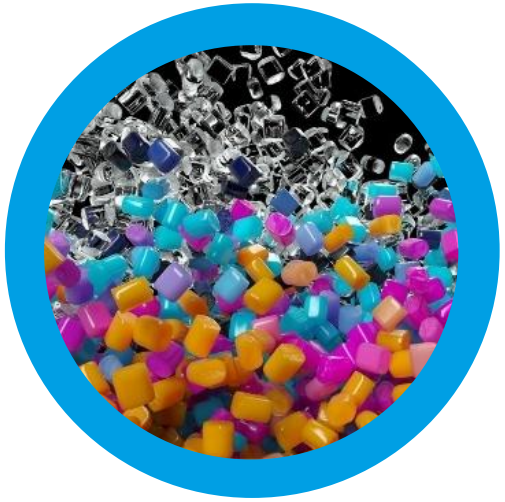
80 years of ideas and inventions

Pioneer of the circular economy

Financial year 2025
Employees calculated as full-time equivalent (FTE)

Our products

Everywhere in modern life



Polycarbonate

Components for
Polyurethanes

Solutions for various key industries

Automotive and transportation

Construction

Wood and furniture

Electrical and electronics

Sports and leisure

Health

Nutrition

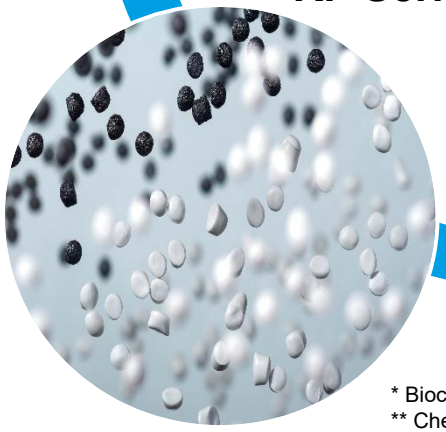
Energy

Your go-to partner on sustainability solutions

A sustainable product portfolio with innovative services and solutions

CQ Circular Intelligent Solutions

- **R Series**: partly mechanically recycled (PCR, PIR)
- **RE Series**: Drop-in solutions partly with certified renewable attributed material share*
- **RP Series**: Drop-in solutions partly with certified recycled attributed material share**



Design services

- Design for sustainability
- Imagio® CQ: visualization of product designs

Enabling circular business models

- Closed/open loop recycling
- Material tracing

* Biocircular attributed via mass balance according to ISCC PLUS
** Chemically recycled post-consumer attributed via mass balance according to ISCC PLUS

BACKGROUND MOTIVATION

Film Insert Molding (FIM)

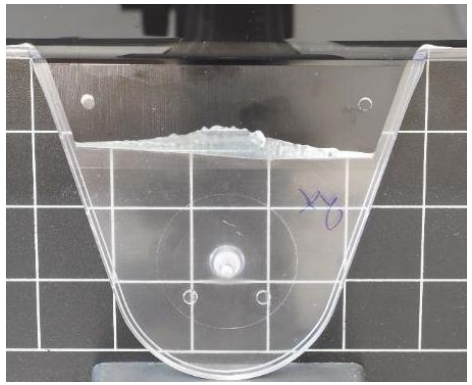
Overview

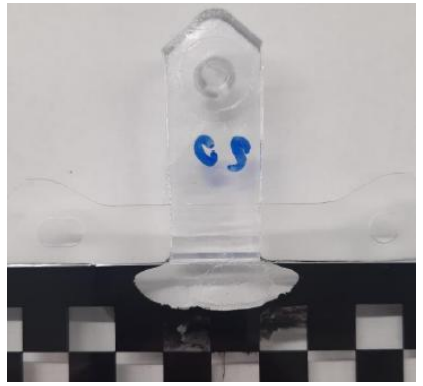
Key Benefits:

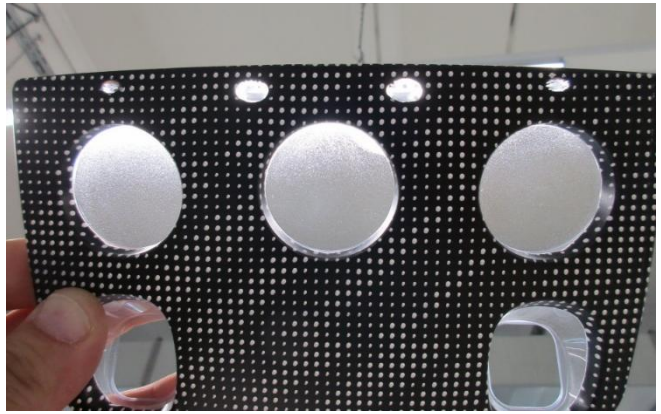
- ✓ Single-step fabrication of decorated/functional plastic components
- ✓ Eliminates separate decoration steps like coating or painting
- ✓ Extensive design flexibility
- ✓ Handles complex-shaped components
- ✓ Reproducible production results

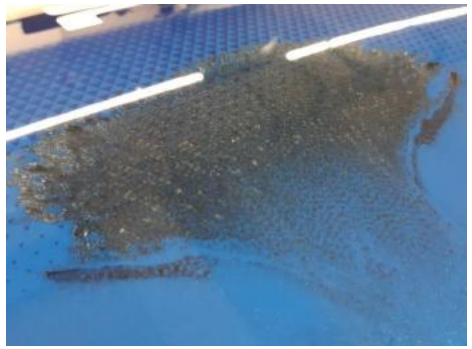
Film Insert Molding (FIM)

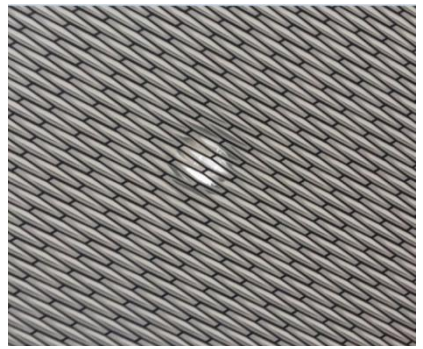
Washout defects











Reasons for FIM washouts:

- Re-melting of film base material and/or printed colors
- Transport of molten material by shear forces during filling

➢ Covestro support for FIM:

- ✓ Gate design optimization
- ✓ Cooling layout optimization
- ✓ Processing parameter optimization
- ✓ Material experts for PC films and PC backmolding

Film Insert Molding (FIM)

Motivation – Complexity factors

What is influencing washout?

- Process parameters, e.g., fill time, melt temperature
- Coolant layout and coolant temperatures
- Gate design
- Material properties of injected material, film and color

❖ These parameters interact with each other, making prediction of washout difficult

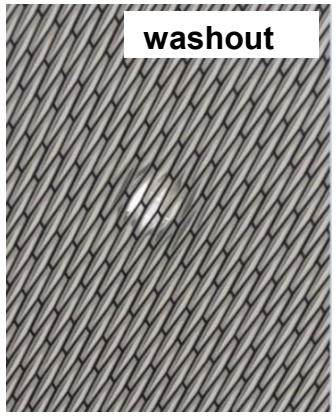
❖ Even with a lot of experience it is difficult to judge whether washout will occur or not

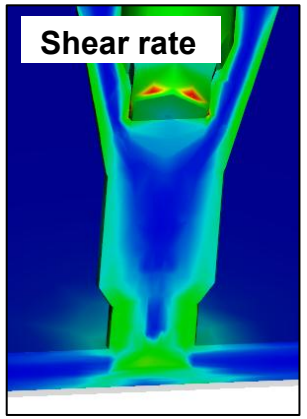
➢ Need for accurate simulation

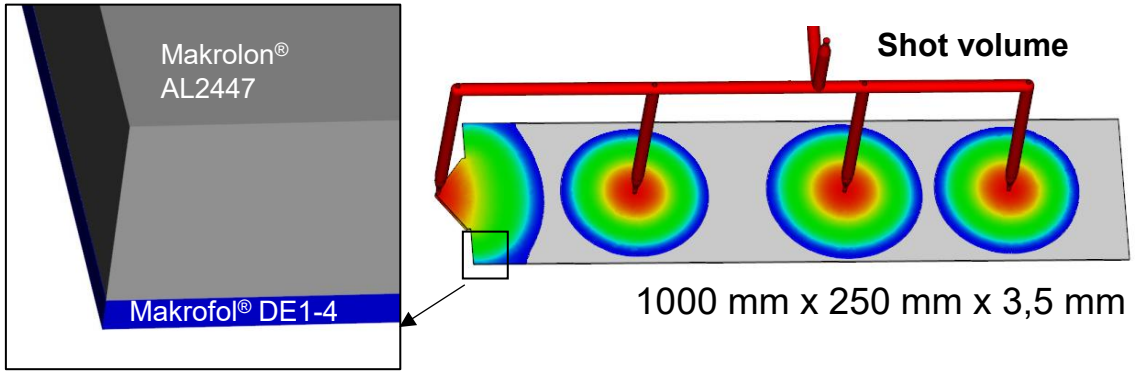
Film Insert Molding (FIM)

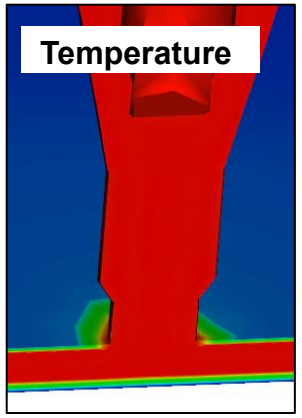
Need for physics-based simulation approach

Injection molding trials:









Simulation:

- Filling studies for different processing parameters
- Washout can be judged indirectly by looking at
  - Injection temperature
  - Shear rate
  - Shot volume

Limitations of this approach:

- Results only transferable to similar gate designs and mold sizes
- Results only valid for part thickness and film thickness used during practical trials

MODELLING APPROACH

Film washout simulation in Autodesk Moldflow

Physics modelling

Conditions for film washout:

- Film temperature > no flow temperature Makrofol®

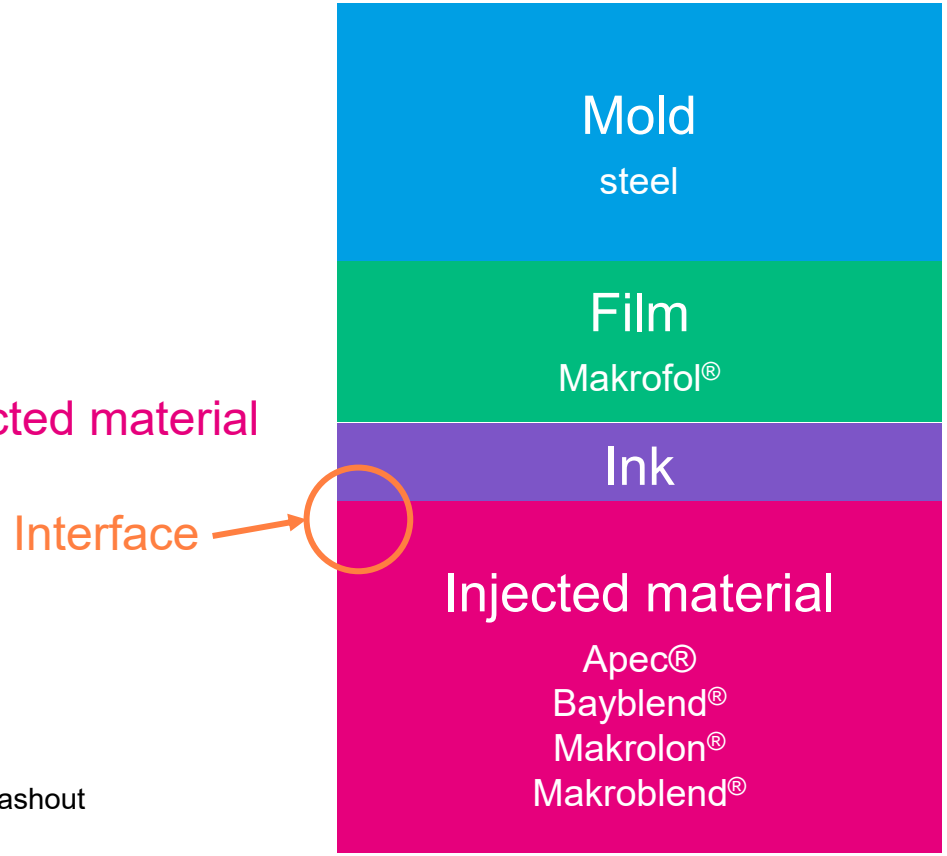
$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial y^2} \longrightarrow \text{Molten film thickness}$$

- Shear stress at the interface > 0 Pa

$$\tau = \eta \cdot \dot{\gamma} \longrightarrow \text{At the interface identical in film and injected material}$$

➢ Film washout: Movement of film layers

$$w = \int u dt \qquad \dot{\gamma} = \frac{du}{dy} = \frac{\tau}{\eta} \longrightarrow u = \int \frac{\tau}{\eta} dy$$

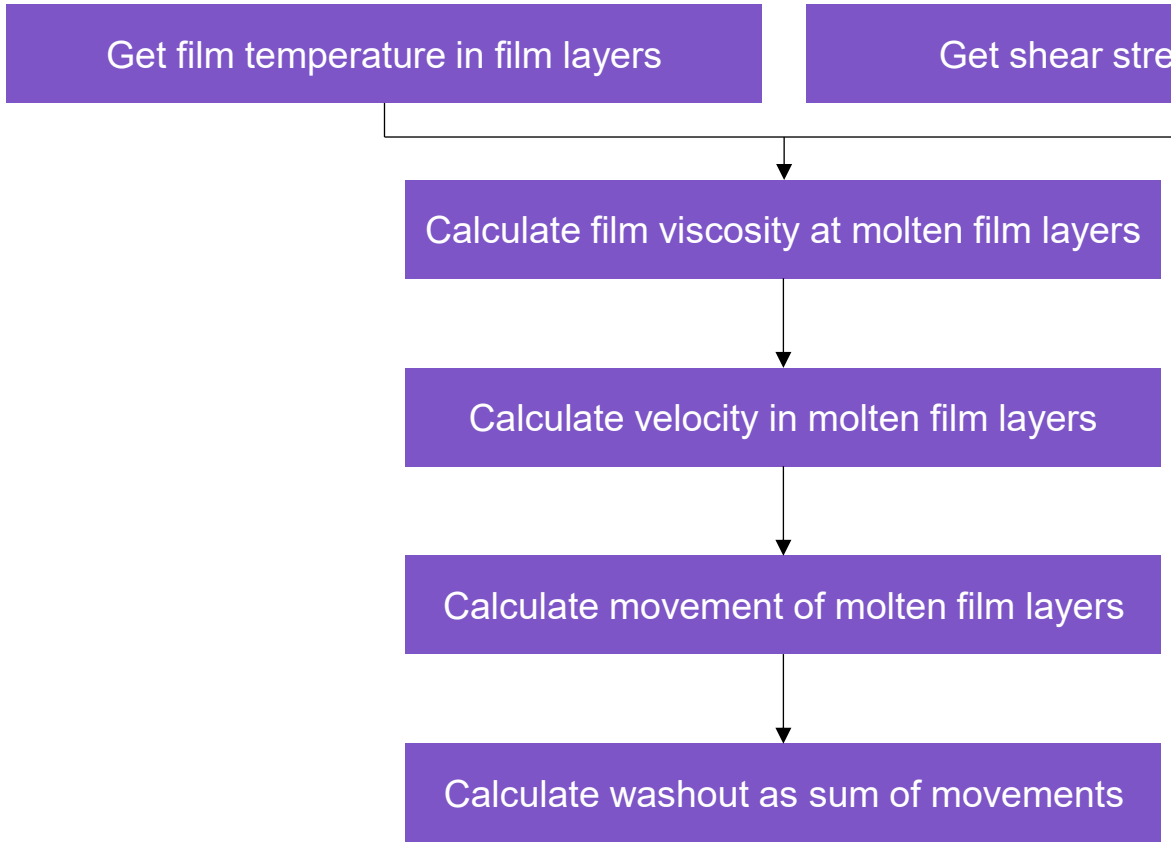


T: temperature
t: time
α: temperature diffusity
y: coordinate in film thickness direction
τ : shear stress
η: viscosity
$\dot{\gamma}$: shear rate
u: speed in flow direction
w: washout

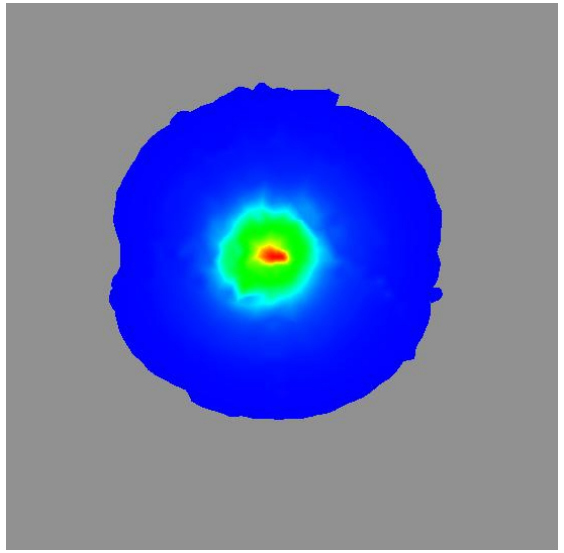
Film washout simulation in Autodesk Moldflow

Implementation in Moldflow Solver API

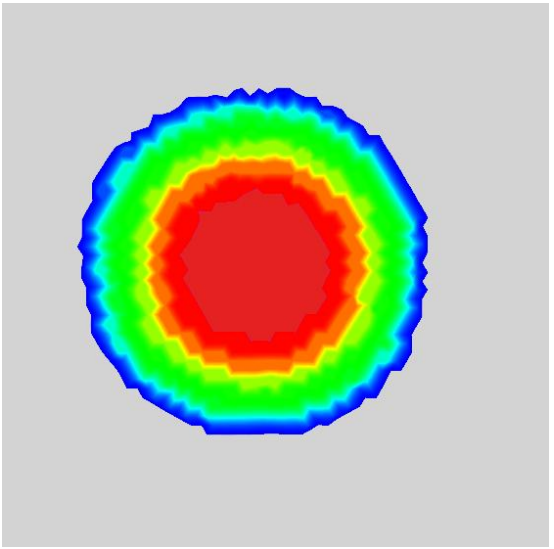
Solver API calls in every time step:



Washout:



Molten film thickness:



WASHOUT SIMULATION RESULTS

Covestro FIM Validation Mold

Part I: Test Setup

Process parameters:

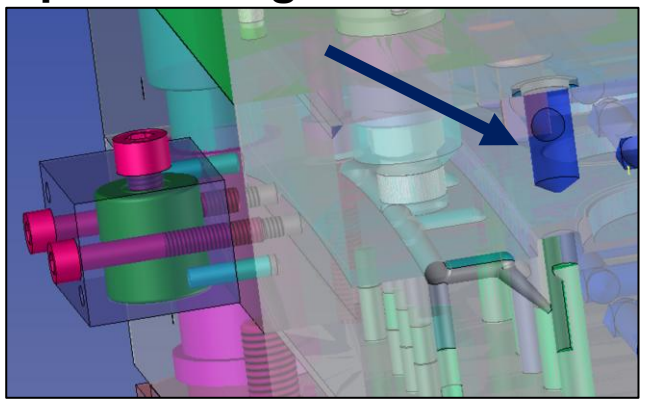
- Material: Makrolon® AL2447
- Melt temperature: 290 °C
- Mold temperature: 70 °C
  - Standard cooling: 70 °C
  - Spot cooling temperature: 40 °C
- Fill time: 2 sec

Film:

- Material: Makrofol® DE1-4
- Black ink: Noriphan HTR N 956
- Initial film temperature: 23 °C
- Film thickness: 250 µm

Standard gating:

Spot cooling:

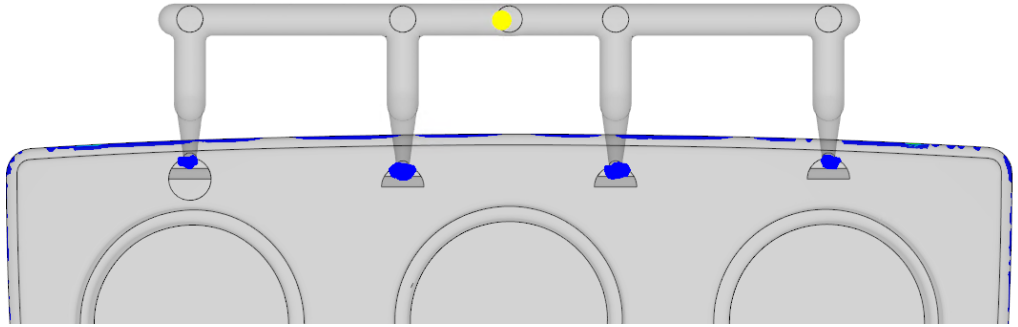


Compression gating:

Covestro FIM Validation Mold

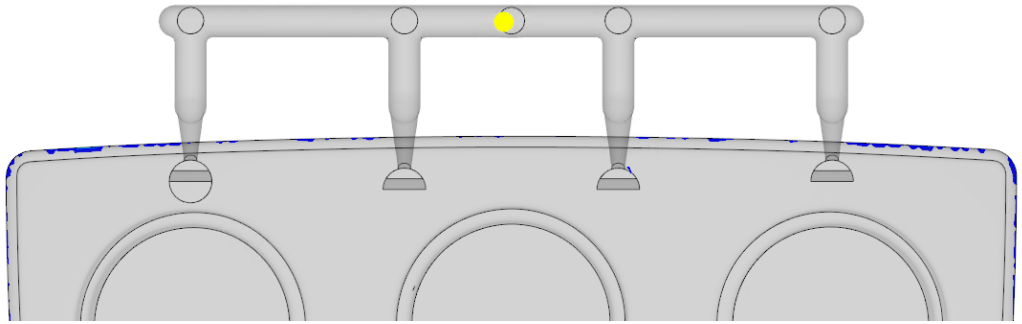
Part I: Effect of cooling design - standard gating

Standard cooling



✓ washout = correctly detected

Spot cooling

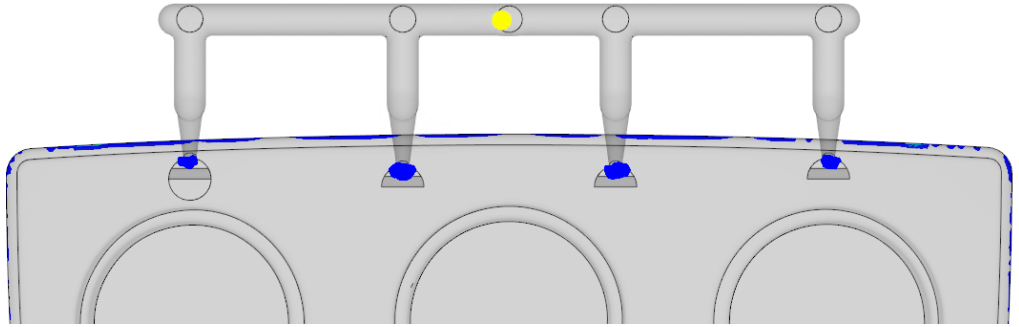


✗ No washout = correctly detected

Covestro FIM Validation Mold

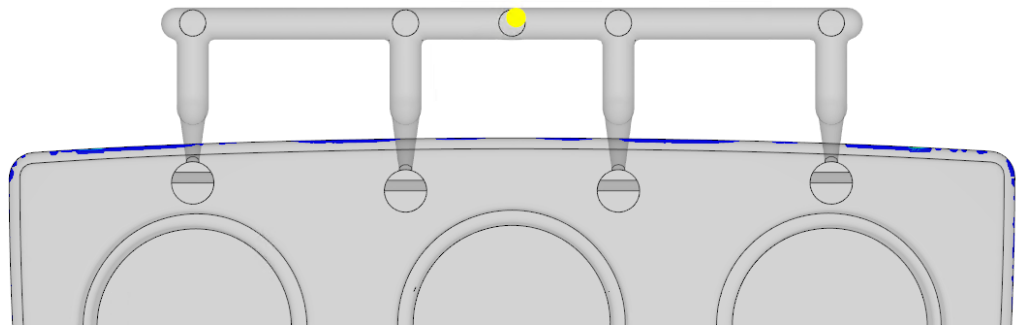
Part I: Effect of gate design - standard cooling

Standard gating



washout = correctly detected

Compression gating

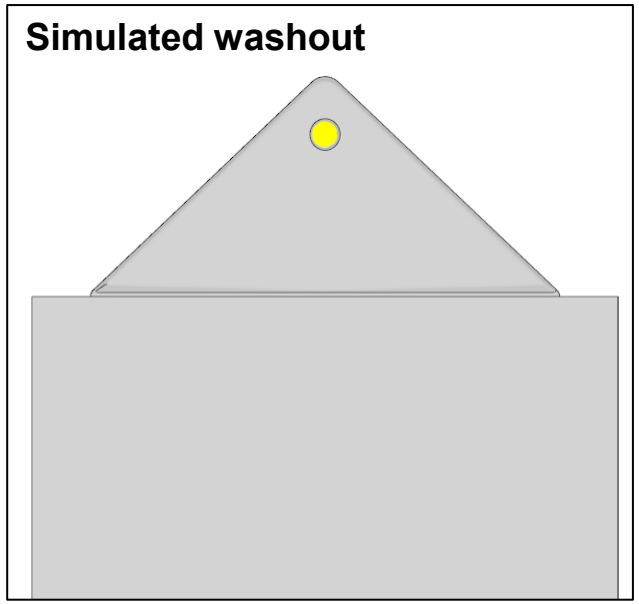


No washout = correctly detected

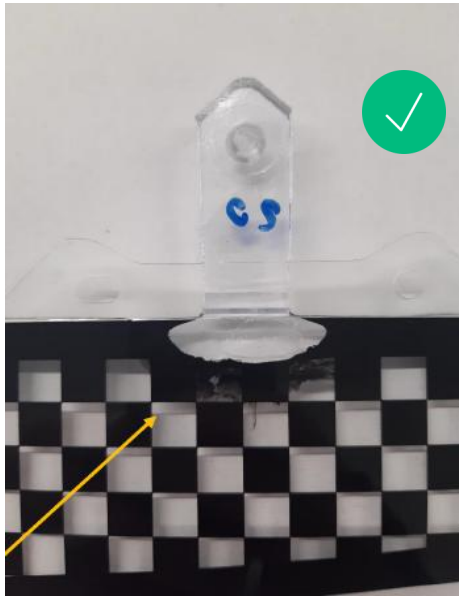
Covestro Test Plate Mold

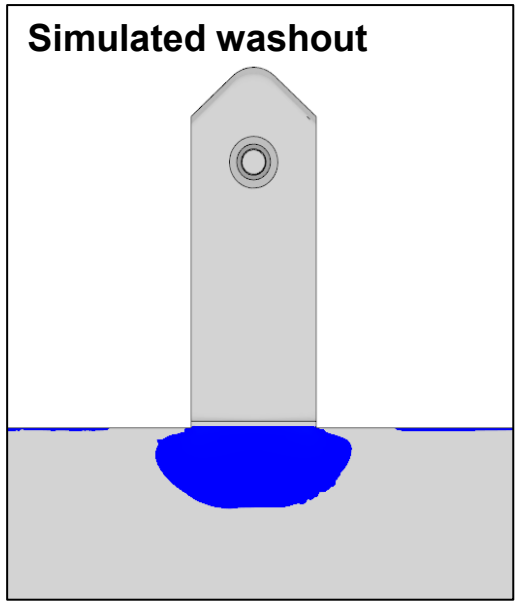
Influence of gate design / gate size

120 mm film gate



20 mm film gate

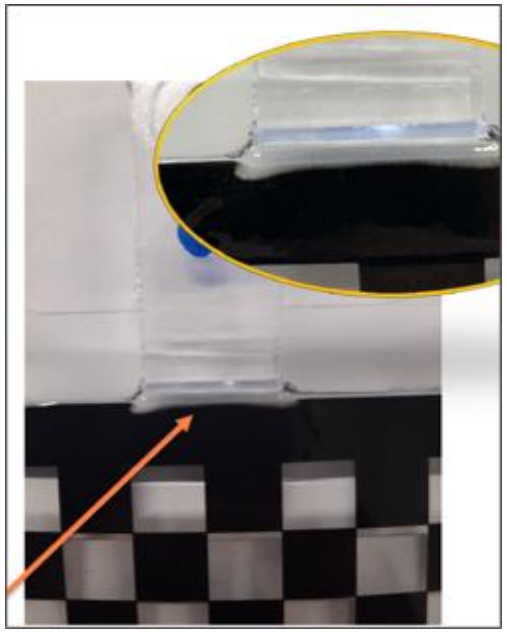


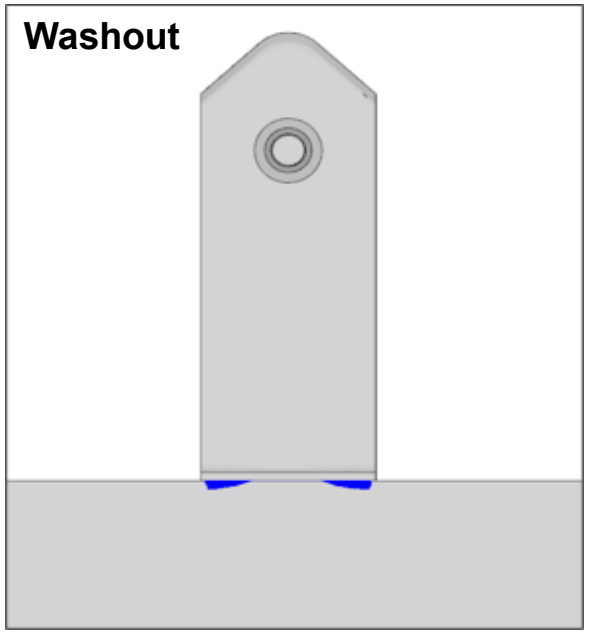


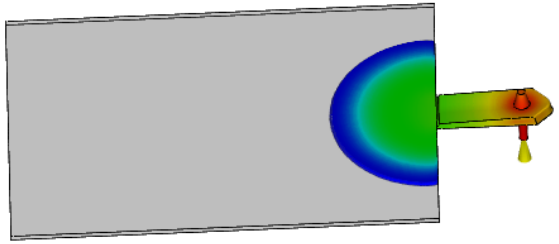
Covestro Test Plate Mold

Influence of shot volume

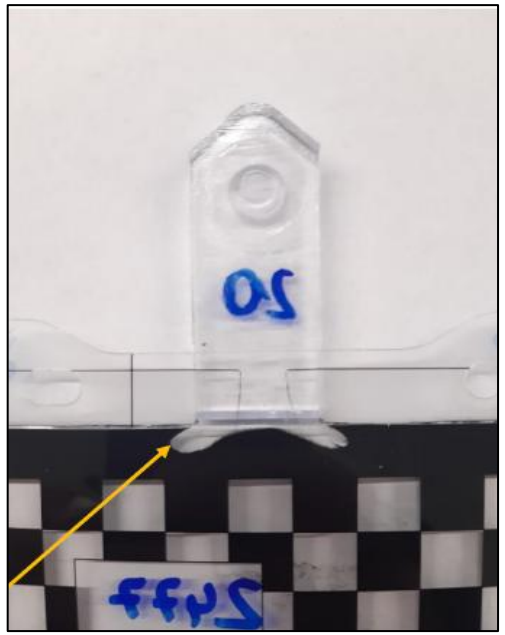
16 g shot weight

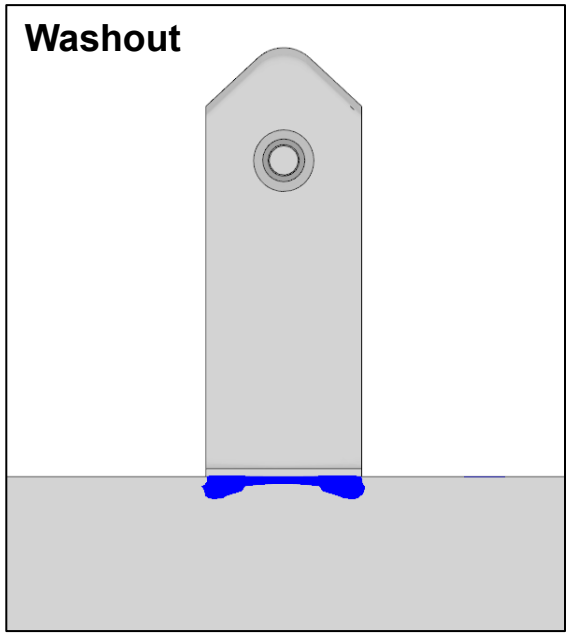


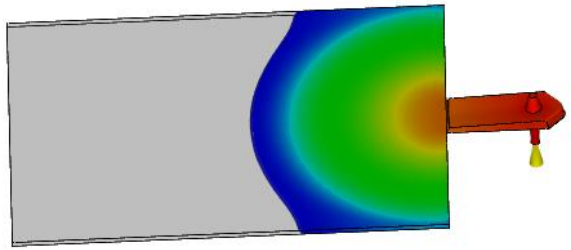




35 g shot weight







Covestro LiDAR Mold

Test Setup

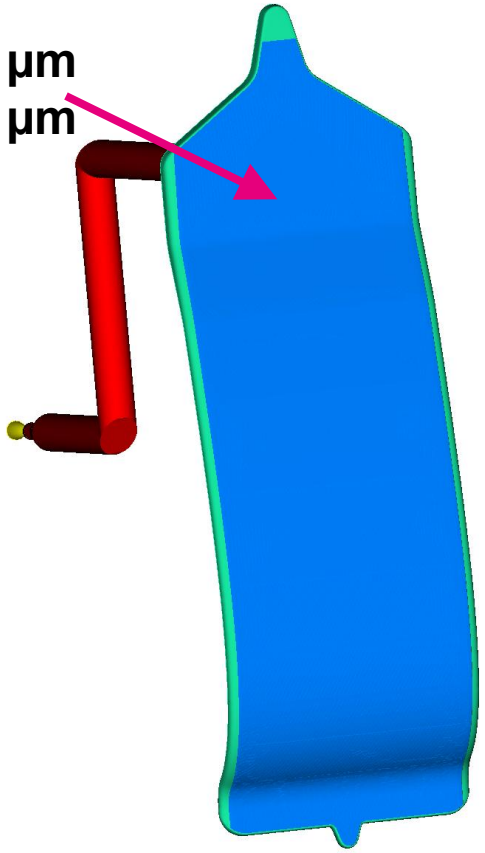
Process parameters:

- Material: Makrolon® AG2447
- Melt temperature: 270 °C
- Mold temperature: 70 °C
- Hot runner nozzle direct gating
- Fill time: 2,4 sec

Film:

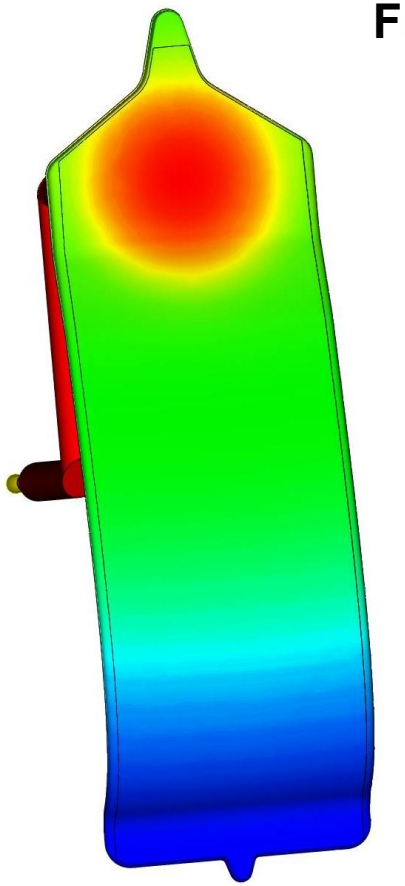
- Material: Makrofol® DE1-4
- Black ink: Noriphan HTR N 956
- Initial film temperature: 23 °C
- Film thickness: 250 µm / 375 µm

Film:
V1: 250 µm
V2: 375 µm

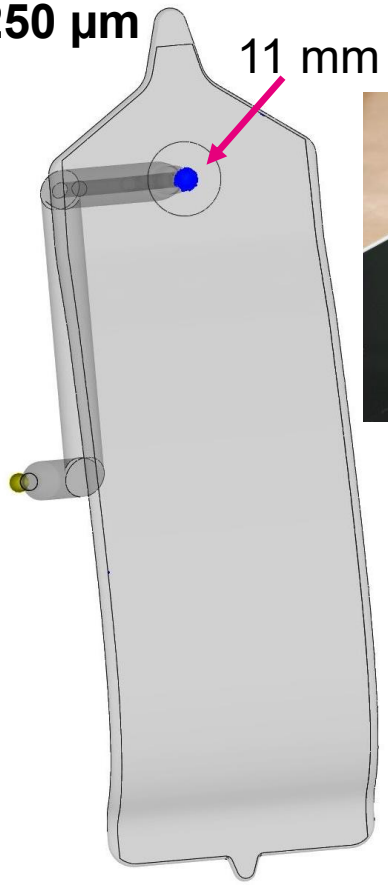


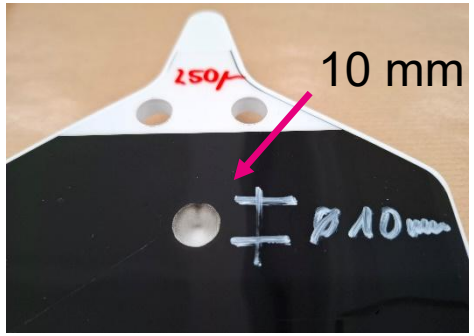
Covestro LiDAR Mold

Effect of film thickness

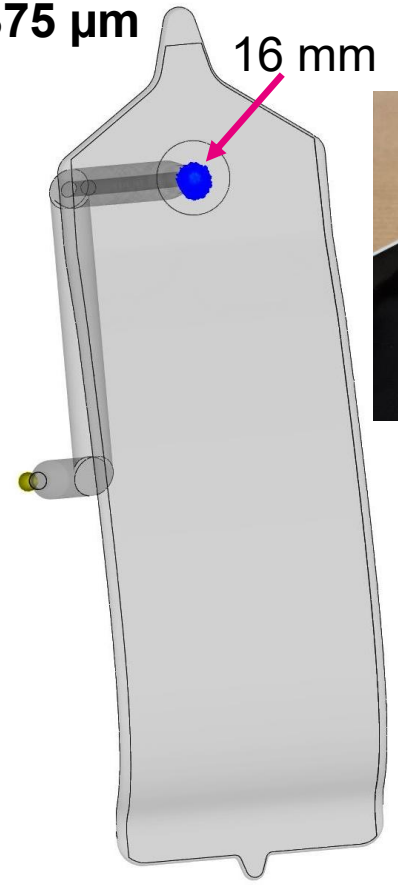


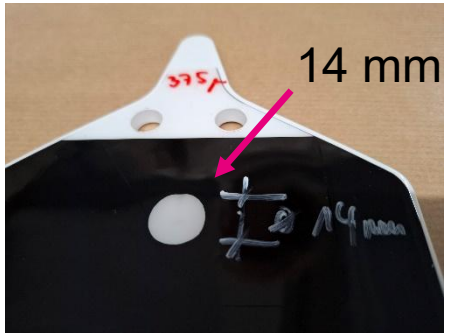
Film: 250 µm





Film: 375 µm



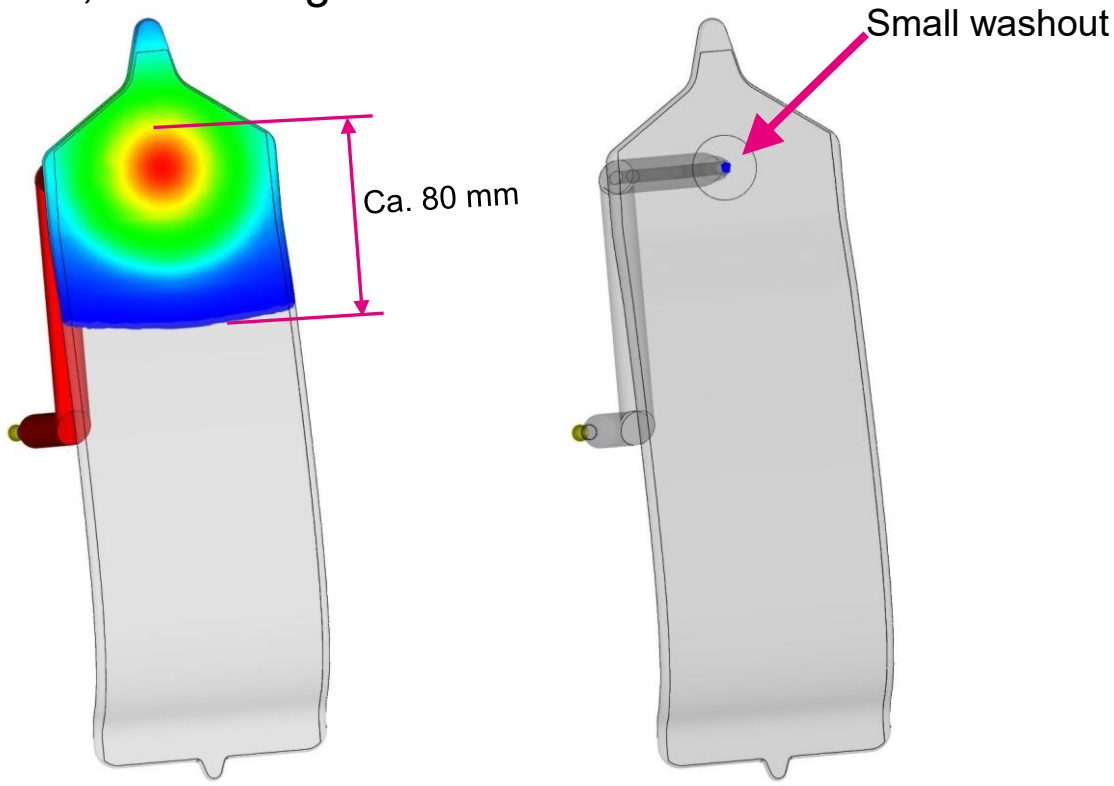


Covestro LiDAR Mold

Washout Onset

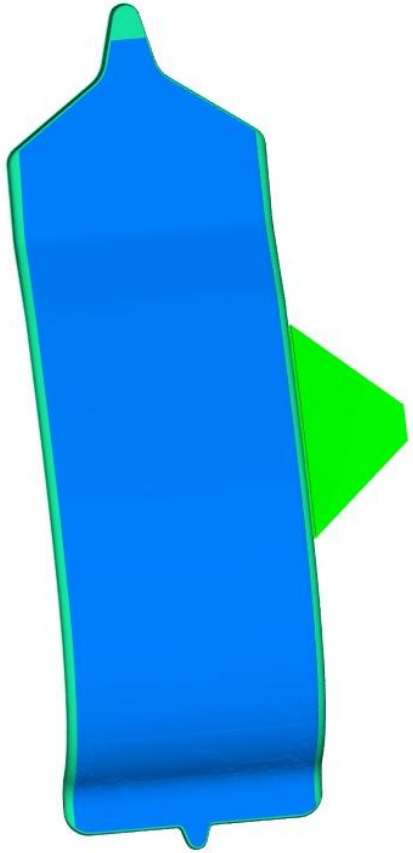
Version 1: Film thickness 250 µm

after 1,1 sec filling / ca. 80 mm

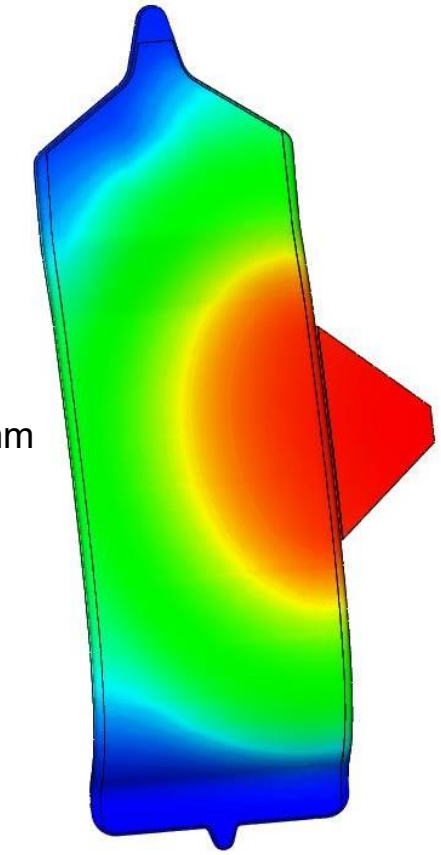


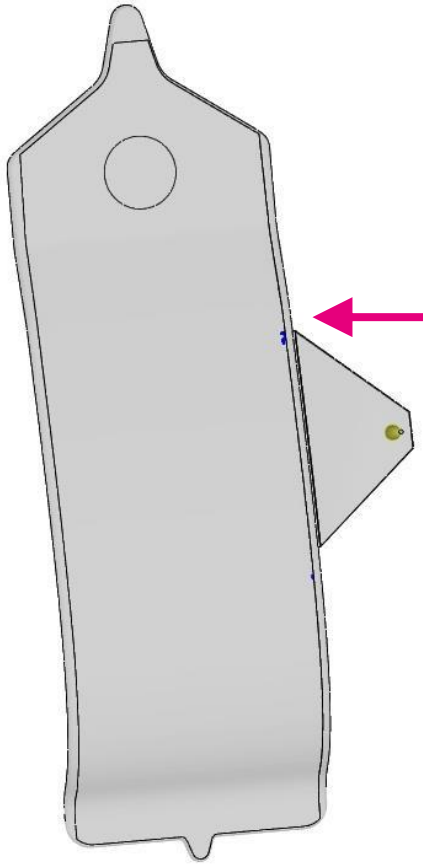
Covestro LiDAR Mold

Film Gate

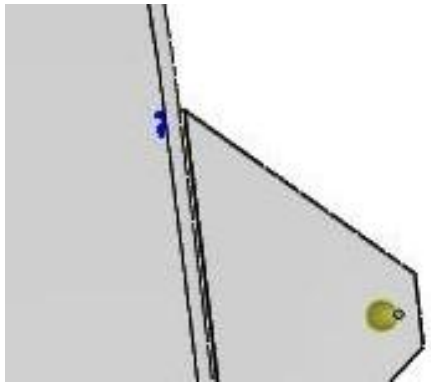


Film gate 100 mm





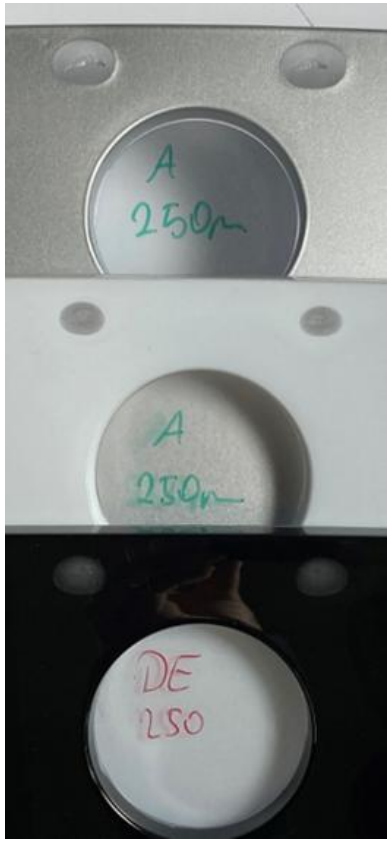
small washout
due to numerical
artefacts



Covestro FIM Validation Mold

Part II: Extension to white and silver color

DE 250 µm standard



DE 250 µm standard molding

DE 250 µm standard molding + spot cooling

DE 250 µm partial compression molding + spot cooling

Covestro FIM Validation Mold

Part II: Result overview

Film Color	Makrofol® DE1-4 black (N 956)				Makrofol® DE1-4 white (N 944)				Makrofol® DE1-4 silver (N 790/200)			
Film thickness	250 µm		375 µm		250 µm		375 µm		250 µm		375 µm	
Gating	Std.	Compr.	Std.	Compr.	Std.	Compr.	Std.	Compr.	Std.	Compr.	Std.	Compr.
Standard Cooling	✓	✗	✓	✗	✓	✗	✓	✓	✓	✗	✓	✓
Spot Cooling	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗

✓ Washout correctly detected

✗ No washout correctly detected

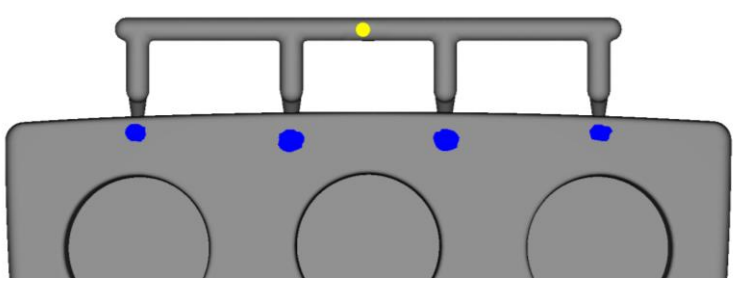
✓ Washout falsely detected

✗ No washout falsely detected

Covestro FIM Validation Mold

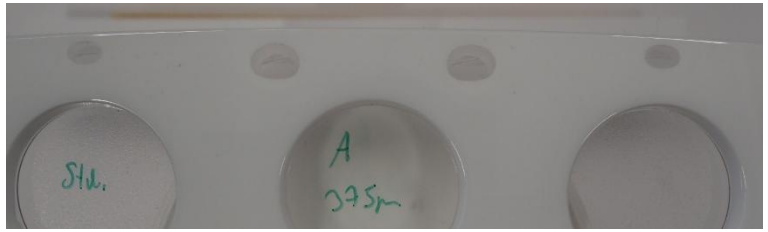
Part II: Effect of color - standard gating - film thickness 375 µm

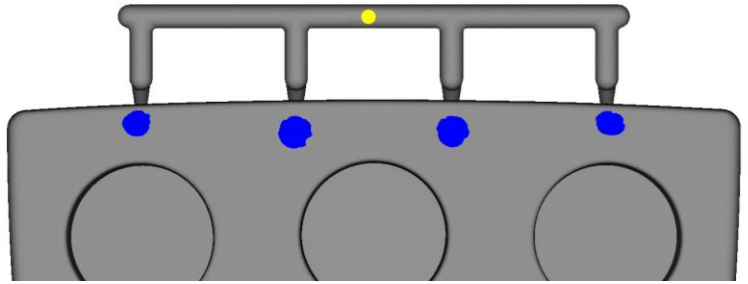
Black color
Noriphan HTR N 956



✓ washout = correctly detected

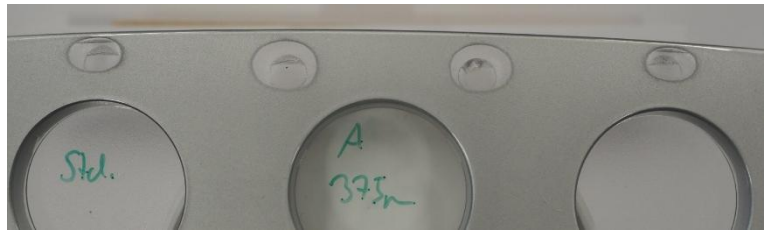
White color
Noriphan HTR N 944

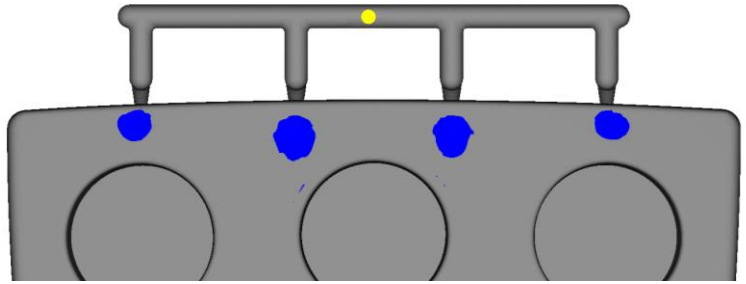




✓ washout = correctly detected

Silver color
Noriphan HTR N 790/200





✓ washout = correctly detected

SUMMARY AND OUTLOOK

Summary and Outlook

- ✓ The developed simulation approach for predicting washout during Film Insert Molding, based on fundamental physics, shows very high correlation with practical molding trials:
  - ✓ Washout increase with increasing film thickness
  - ✓ The effectiveness of local spot cooling in preventing washout at gates
  - ✓ Impact of gate design on local washout patterns
  - ✓ Washout development as shot volume increases
  - ✓ Influence of colored ink on washout dimensions
- ✓ The implementation into the Moldflow Solver API enables usage for new applications with limited need for practical trials and strengthen the continuous virtual development process
- ❖ This method can be readily adapted for other overmolding technologies to predict potential interface defects between different components (e.g., re-melting of the first component during two-component molding)

Thank you for your attention!

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