AUTODESK

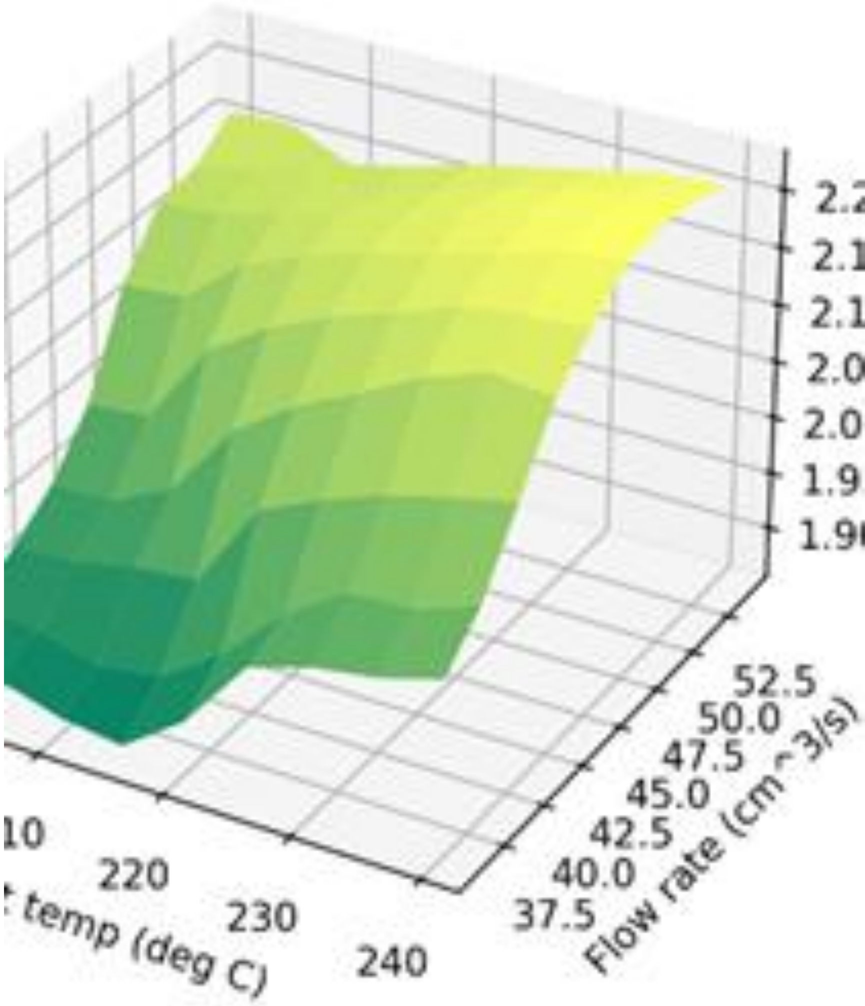
Injection Molding Simulation: Research and Development Updates

April 2025

Dr. Franco Costa

Agenda

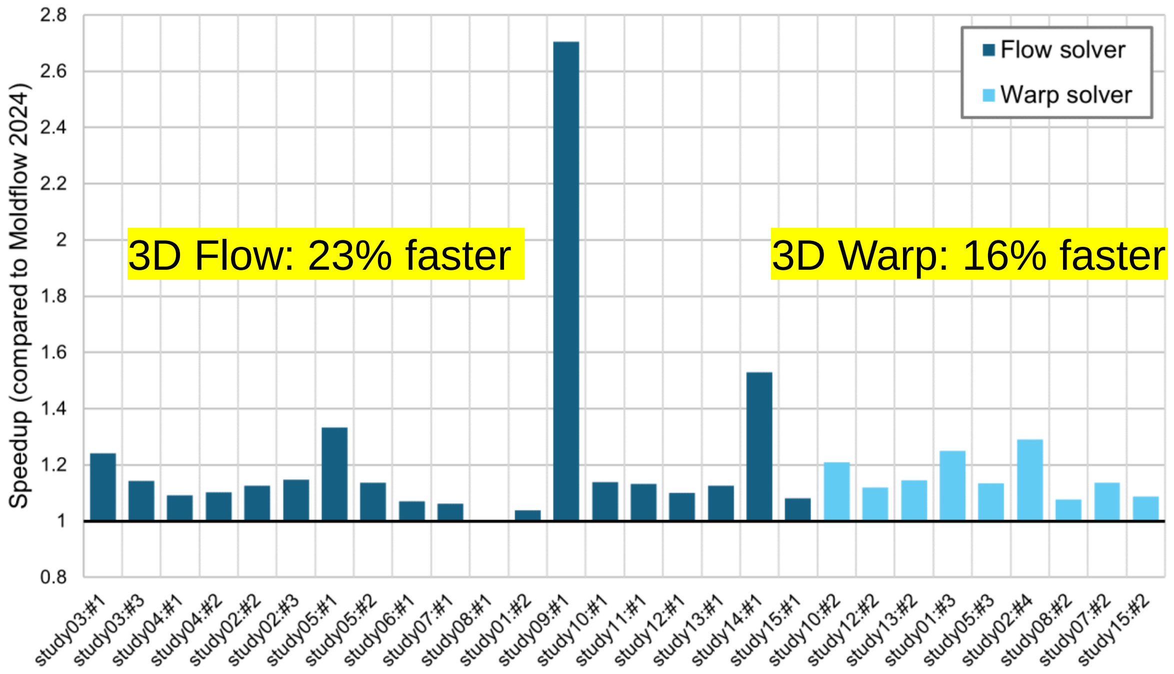
1. Moldflow 2025 Release
2. Moldflow 2026 Release
3. Current Research Work



Moldflow 2025 Release

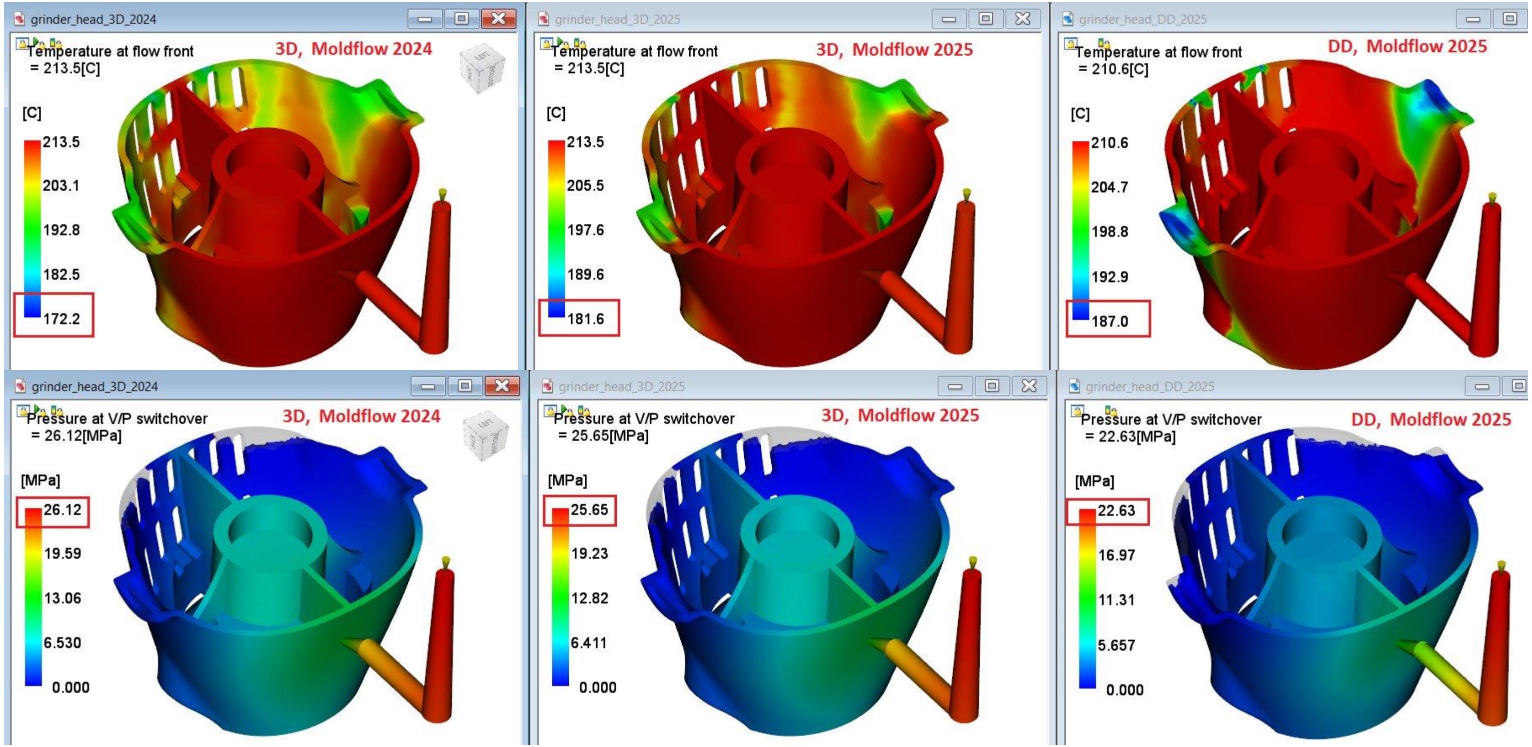
3D Solver Speed-up in 2025

Speed-up achieved by coding efficiency -> No decrease in accuracy



Improve Flow Front Temperature: 3D

- Improved thermal boundary condition at flow front



Improve Flow Front Temperature: 3D

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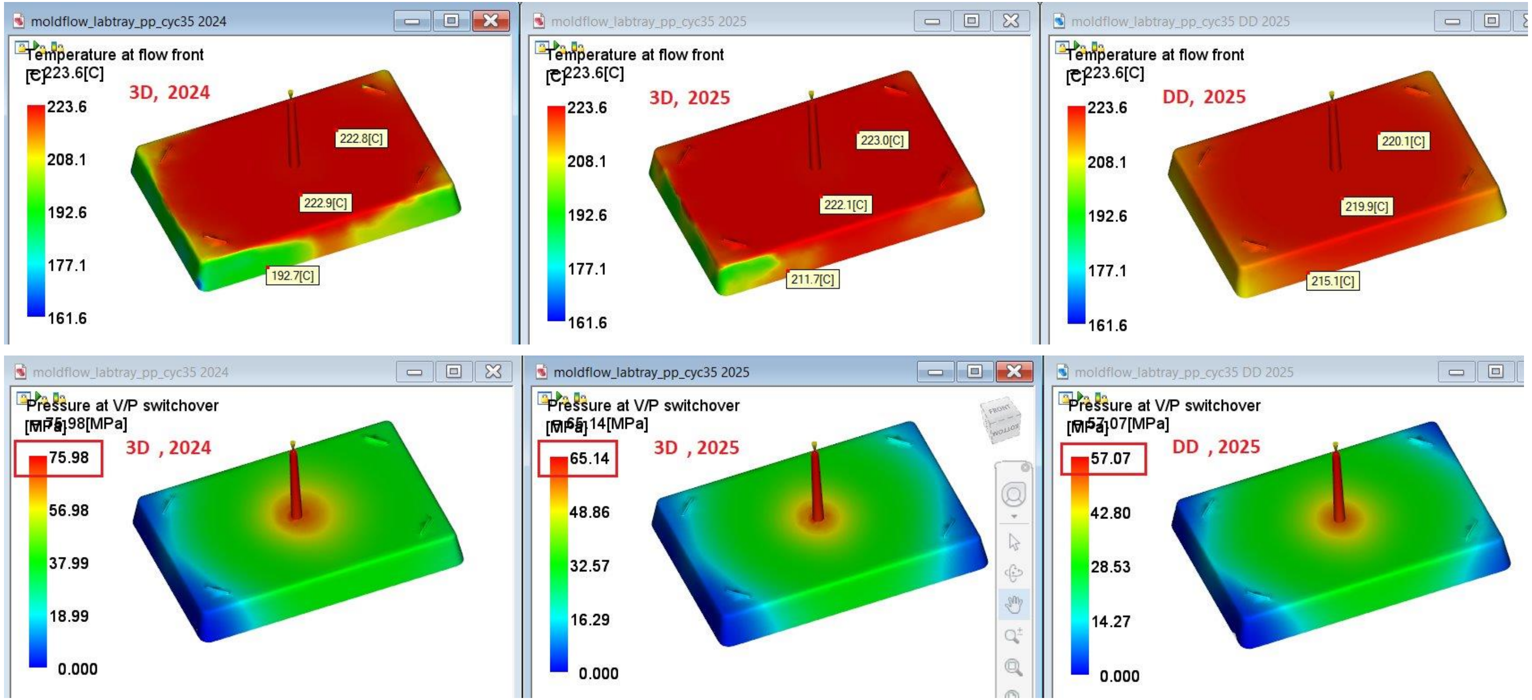
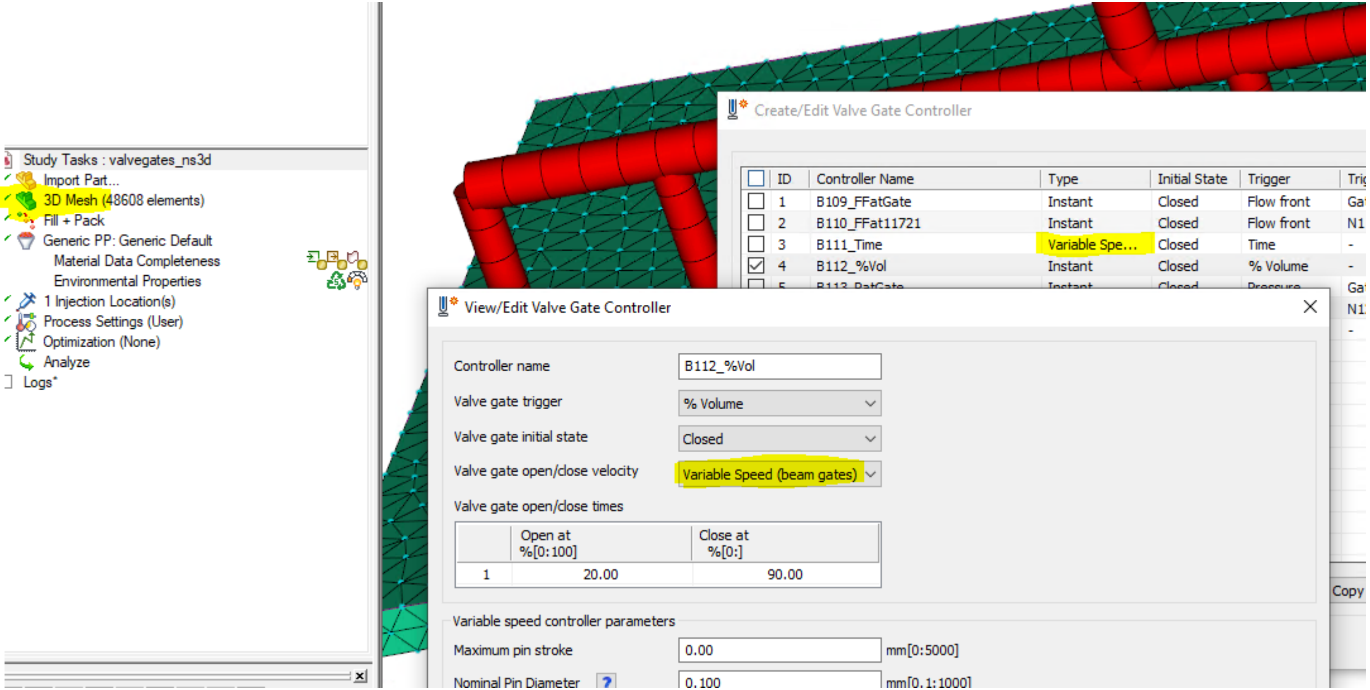


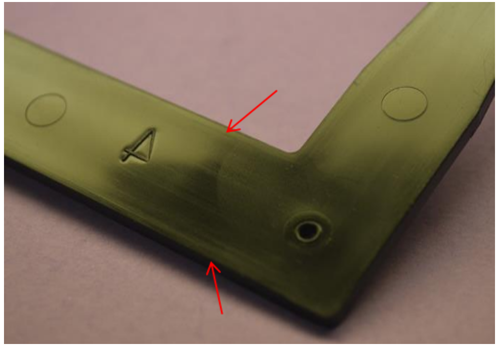
Variable Speed Valve Gate Support for 3D Flow

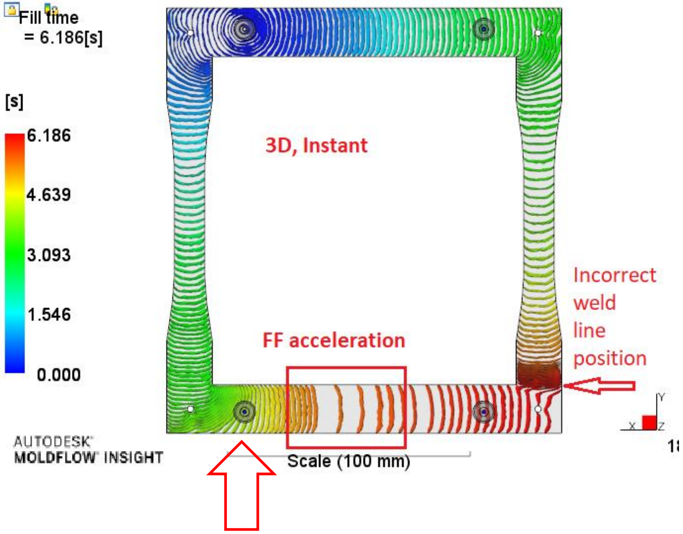
- Allow gradual opening/closing of valve gates on beam elements in 3D analyses
    - Same options as current supported for Midplane & Dual-Domain meshes



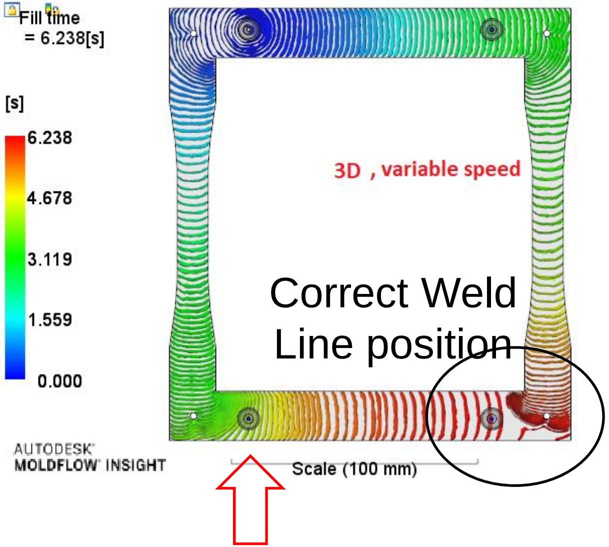
Variable Speed Valve Gates in 3D Flow: Validation

Valve Gate 3 opens slowly





Valve Gate 3
instantly



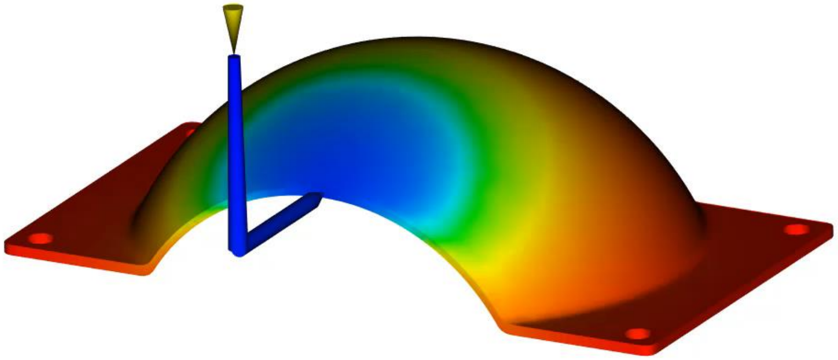
Valve Gate 3
opens slowly

Molding Case-study courtesy of Synventive® Molding Solutions

3D Injection compression molding

3D injection compression can now include a mold opening stroke during polymer injection phase.
 - Specify the Speed vs Distance Increment

New Press position screen output and result



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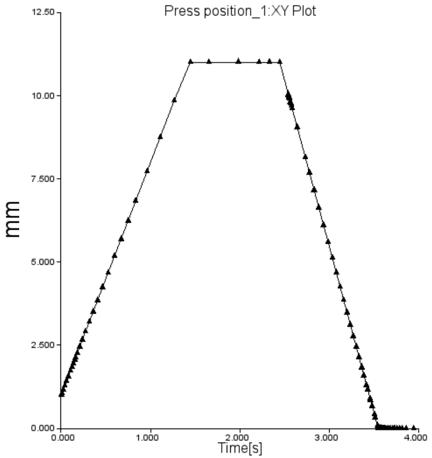
Filling Phase:          Status: V   = Velocity control
=============                   V/P = Velocity/pressure switch-over
                                P   = Pressure control
```

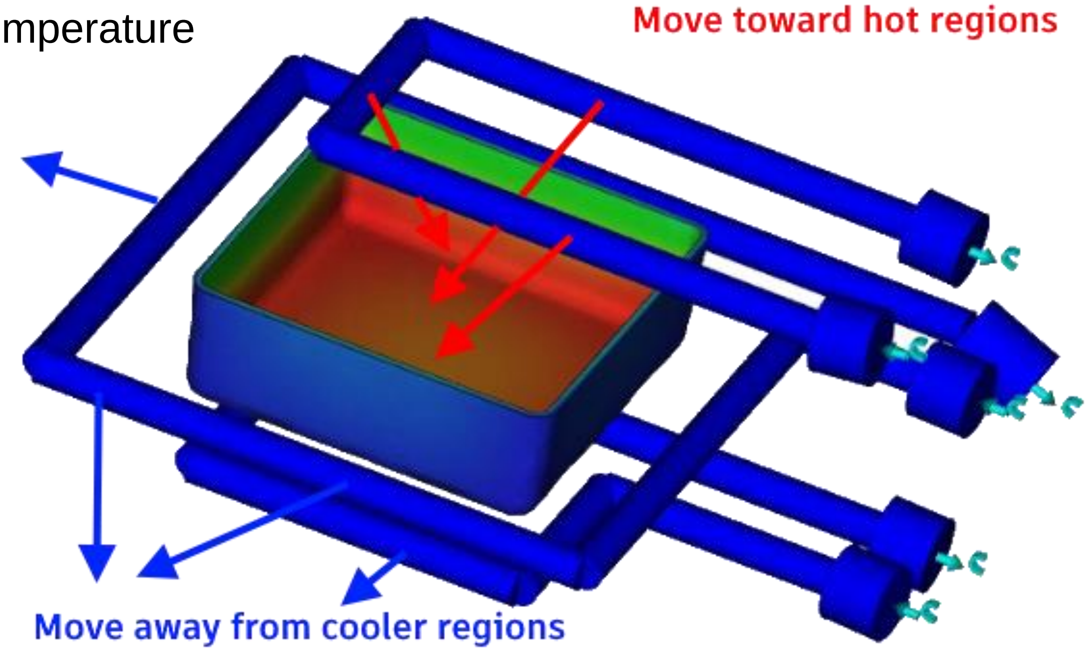
Time (s)	Fill Vol (%)	Inj Press (MPa)	Clamp F (tonne)	Flow Rate (cm^3/s)	Frozen Vol (%)	Filled Node (%)	Press Pos (mm)	Status
0.002	0.039	7.120e-01	4.49e-09	20.212	0.00	0.000	1.015e+00	V
0.003	0.071	1.055e+00	7.45e-09	11.244	0.00	0.002	1.022e+00	V
0.009	0.103	3.120e+00	3.80e-08	3.604	0.00	0.005	1.067e+00	V
0.023	0.225	7.079e+00	1.41e-07	6.918	0.00	0.007	1.160e+00	V
0.041	0.452	1.236e+01	4.34e-07	9.857	0.00	0.014	1.286e+00	V
0.059	0.736	1.738e+01	8.38e-07	12.613	0.00	0.018	1.416e+00	V
0.081	1.127	2.263e+01	1.45e-06	16.457	0.00	0.025	1.568e+00	V
0.104	1.558	2.772e+01	6.64e-03	19.939	0.00	0.034	1.730e+00	V
0.122	1.902	3.159e+01	5.19e-02	21.710	0.00	0.041	1.852e+00	V
0.137	2.247	3.507e+01	1.31e-01	22.207	0.00	0.048	1.960e+00	V



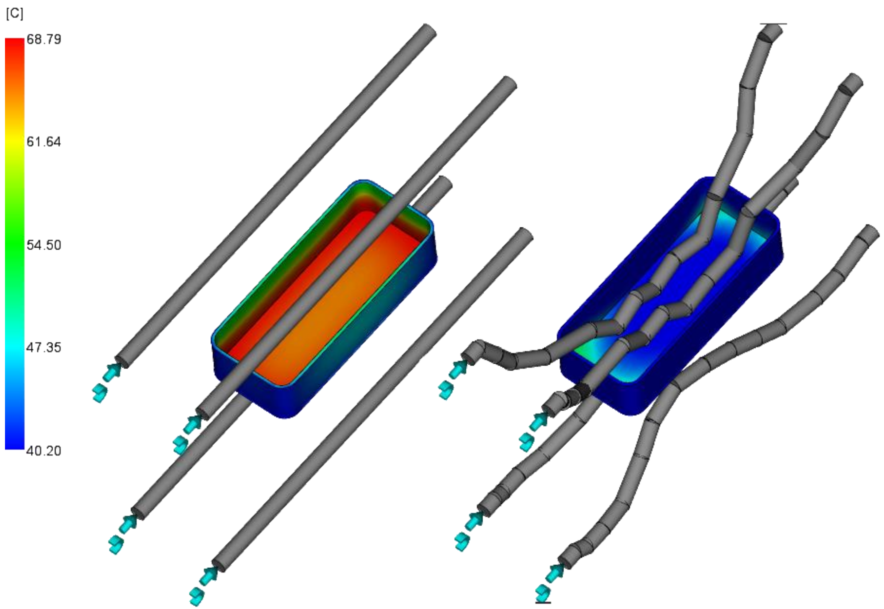
Cooling Circuit Optimization

Optimize cooling channels:

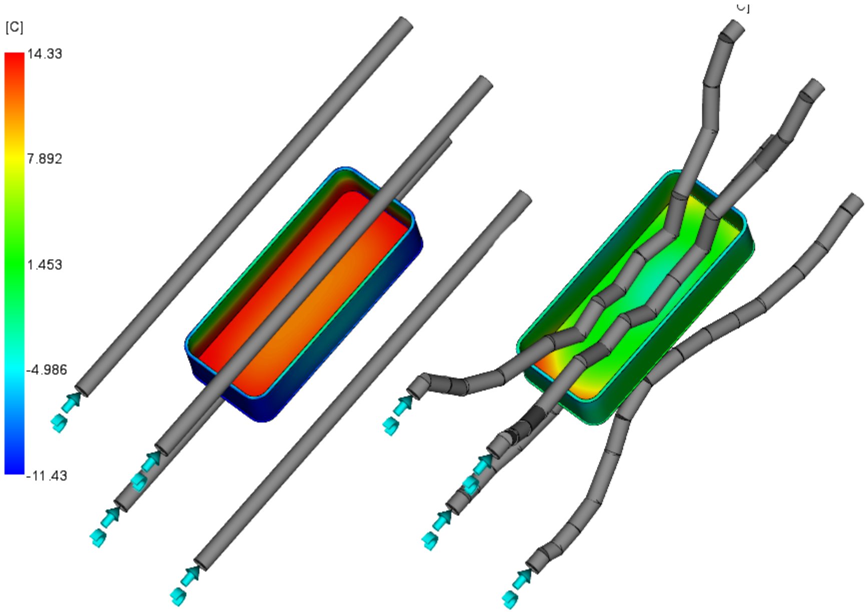
- Minimize temperature differences
- Minimize average cavity temperature



Cooling Circuit Optimization

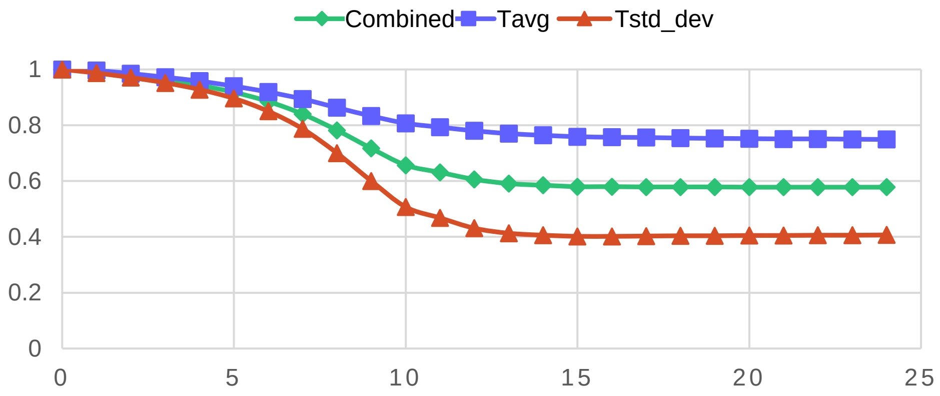


Mold temperature for initial and optimized layouts



Temperature variance for initial and optimized layouts

Cooling Circuit Optimization Results



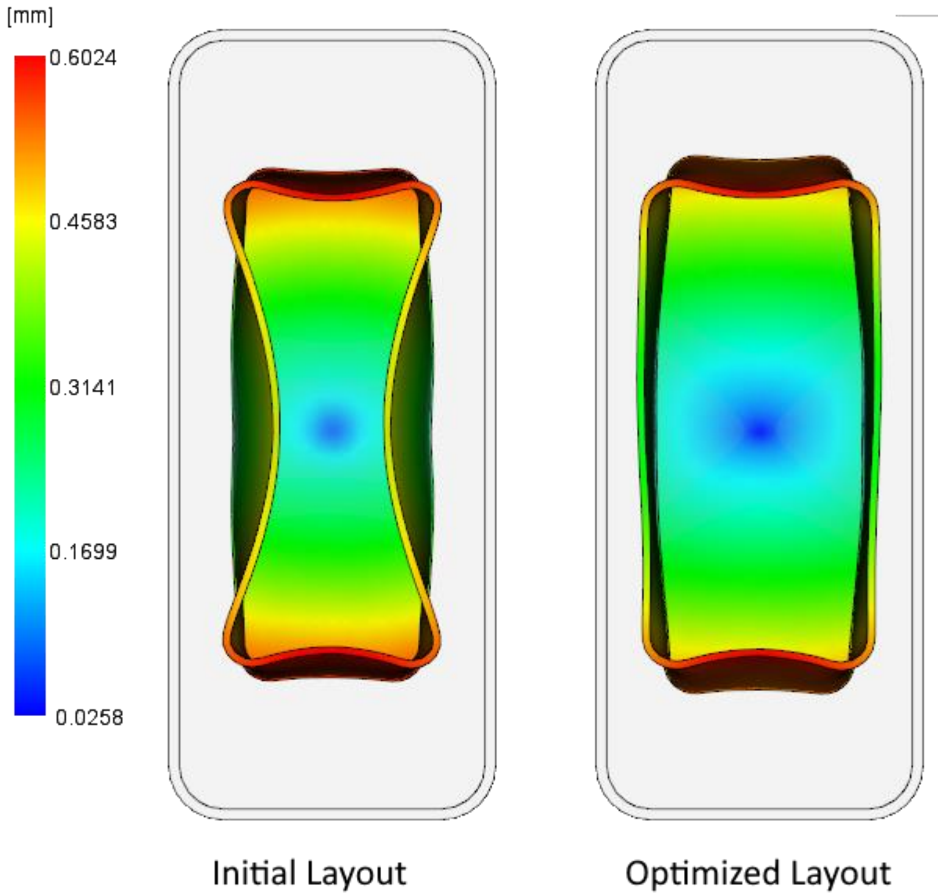
Model	Combined Metric	Tavg ° C	σ °C	T_{Range} ° C	T_m	std_m
Initial	1.0	53.1	9.6	26.0	1.0	1.0
Optimized	0.58	39.7	3.9	18.6	0.75	0.41

- 42% improvement with the optimized cooling channel layout Combined Metric
- Reduction in cycle time
  - 13.4° C reduction in average mold-part surface contact temperature, T_{avg}
- Reduction in temperature variance
  - 59% improvement in the standard deviation of the temperature variances, **std**$_m$

Cooling Circuit Optimization

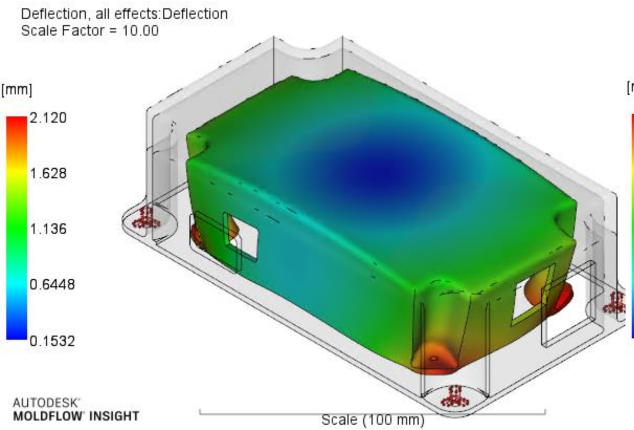
Part Warpage

Optimized layout has less temperature induced warpage

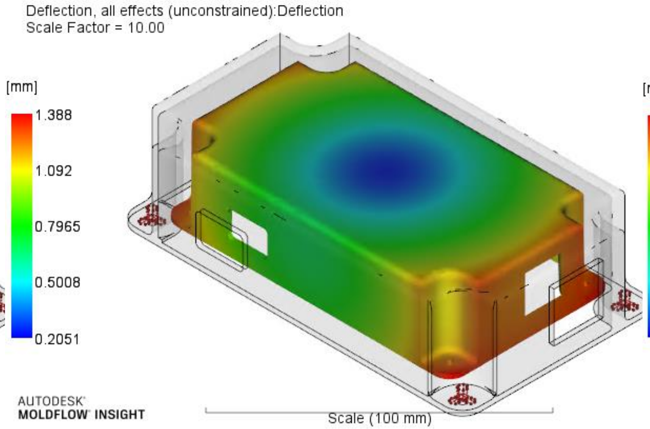


Additional Insights for Over-Constrained Warp

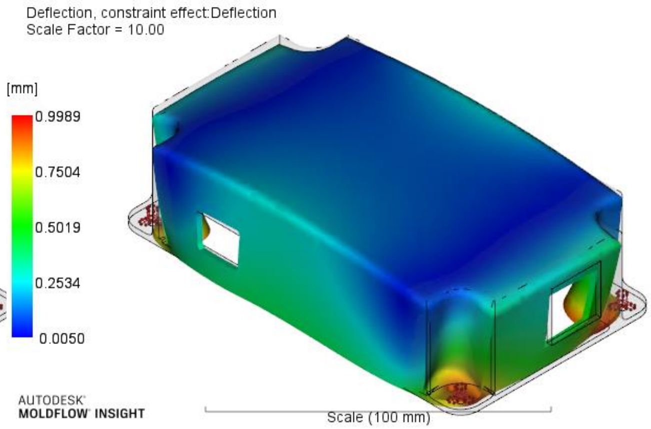
Useful when modeling assembly onto a rigid structure



Total deflection,
over-constrained



Deflection,
Without constraints



Deflection,
Constraint Effect
(Isolate Causes of Warpage)

- No longer include constraint effects in other causes of warp
- Works also with automatic adjustment of constraint according to mold shrinkage allowance

Barrel Compression

- Midplane / Dual-Domain with large Hot Runnners
  - Better ramp-up of flow rate existing barrel
    - Accounting for compressibility of polymer in the hot runner system
    - Better match to 3D and reality

Before fix

V/P= Velocity/pressure switch-over

Time (s)	Volume (%)	Pressure (MPa)	Clamp force (tonne)	Flow rate (cm^3/s)	Status
0.000	0.00	"VG01" # 1 (Elem# 57502) opened.			
0.152	2.41	103.61	5.22	412.24	V
0.305	5.13	99.98	7.52	429.14	V
0.456	7.82	96.10	11.19	420.84	V
0.500	8.62	"VG02" # 2 (Elem# 57549) opened.			
0.500	8.62	"VG02" # 2 (Elem# 57567) opened.			
0.607	11.33	79.64	26.67	493.12	V
0.761	14.25	72.57	31.26	419.72	V
0.911	16.71	71.58	37.69	398.58	V
1.065	19.13	72.40	45.91	392.25	V
1.217	21.49	73.74	55.08	391.03	V

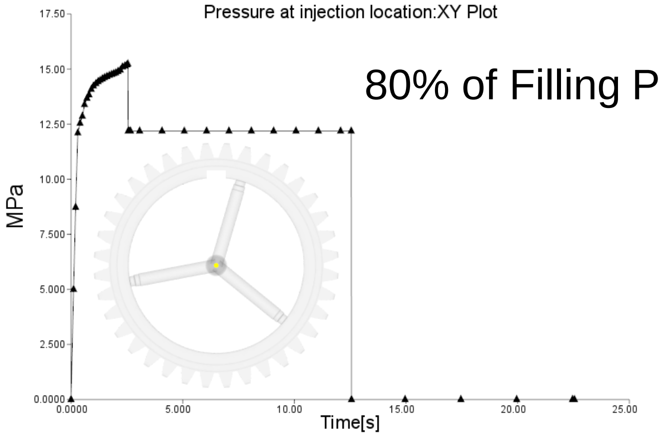
After fix

V/P= Velocity/pressure switch-over

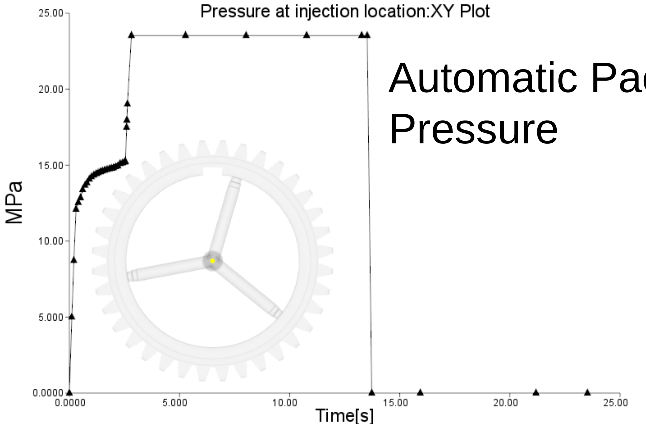
Time (s)	Volume (%)	Pressure (MPa)	Clamp force (tonne)	Flow rate (cm^3/s)	Status
0.000	0.00	"VG01" # 1 (Elem# 57502) opened.			
0.159	0.08	27.38	0.01	150.21	V
0.304	0.46	51.17	1.81	185.56	V
0.456	1.26	75.05	3.82	244.83	V
0.500	1.61	"VG02" # 2 (Elem# 57549) opened.			
0.500	1.61	"VG02" # 2 (Elem# 57567) opened.			
0.608	3.99	72.30	10.60	442.34	V
0.760	6.65	69.40	14.64	406.49	V
0.911	9.09	69.39	19.14	395.85	V
1.064	11.53	70.25	24.66	393.39	V
1.215	13.91	71.27	31.01	393.37	V

Other 2025 Solver Enhancements

- Automatic Packing Profile is now Default
    - No longer 80% of filling pressure
- Improve DD Warp
    - Fix problem in constraints linking top and bottom surface
        - Problems were noticed in symmetric models



80% of Filling Pressure



Automatic Packing Pressure

Moldflow 2026 Release

Improve Warp Accuracy using shrinkage data

STAMP shrinkage model is now default for 3D analyses when data is available

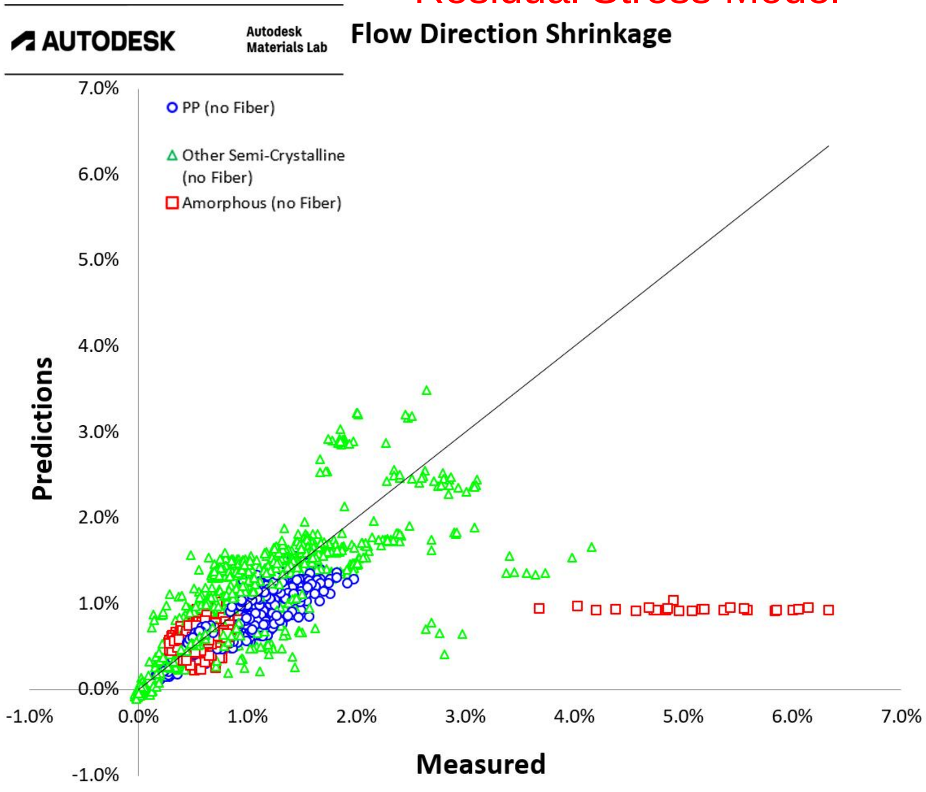
- Use the measured shrinkage data to calibrate thermo-mechanical properties
  - Coefficient of Thermal Expansion (CTE) (anisotropic)
  - Young’s modulus
- For fiber-filled polymer, calibration is done on the polymer matrix properties

- **Shrinkage Test Adjusted Mechanical Properties (STAMP)**
  - US patent application 17/959,221
- Use on analyses of 3D Part geometries
  - Analyses of shell geometries use the CRIMS method of shrinkage calibrations

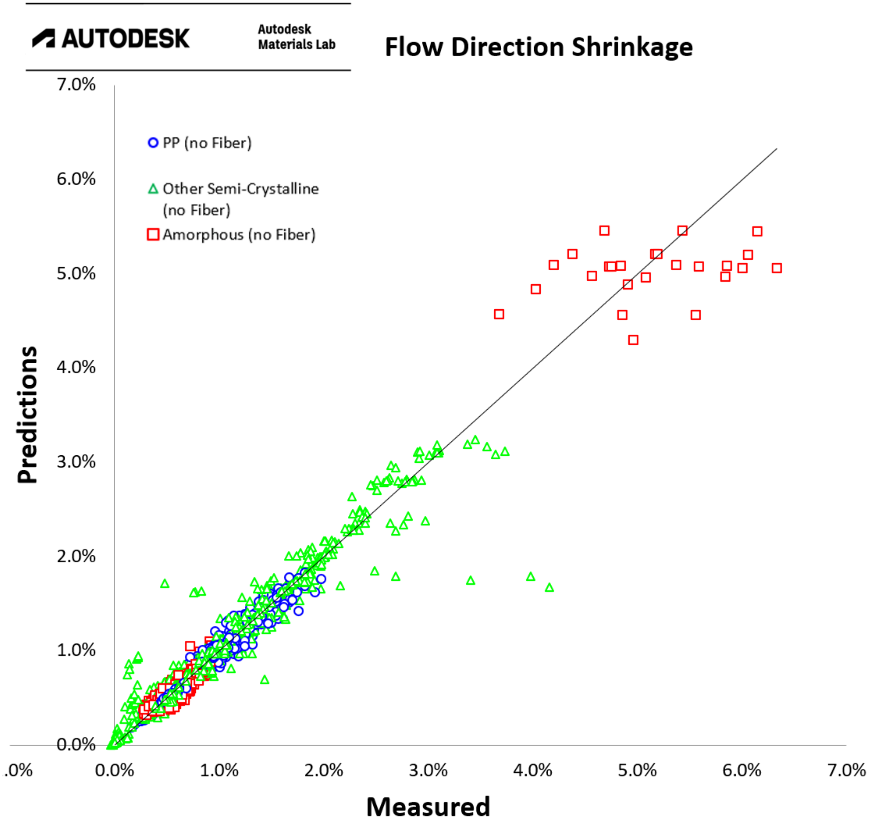
STAMP vs Residual Stress Model

171 Unfilled Polymers – Flow Direction

Residual Stress Model



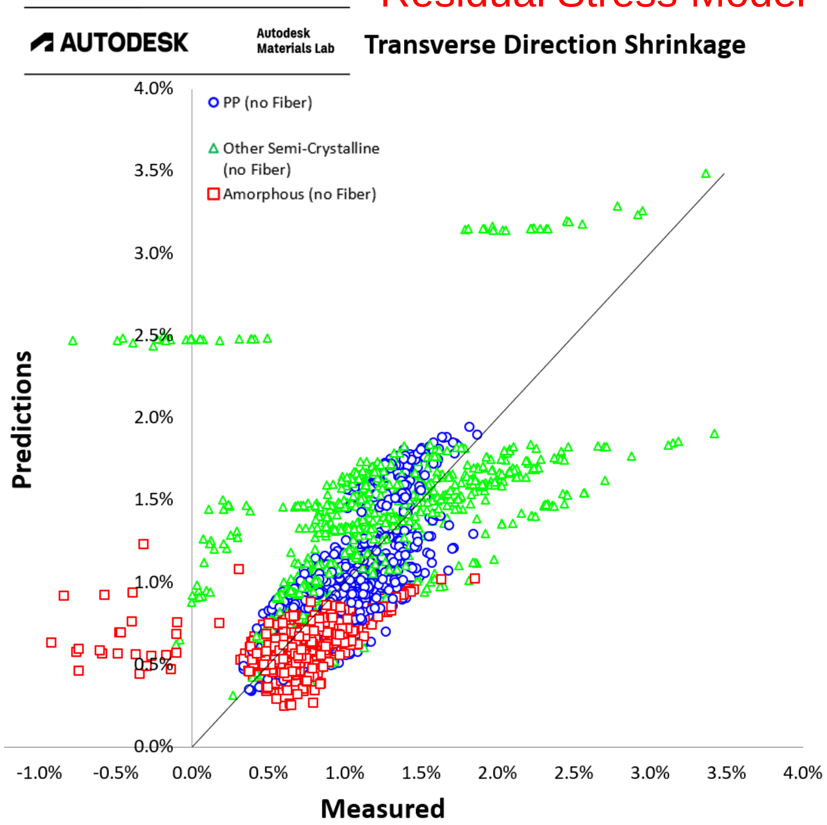
STAMP



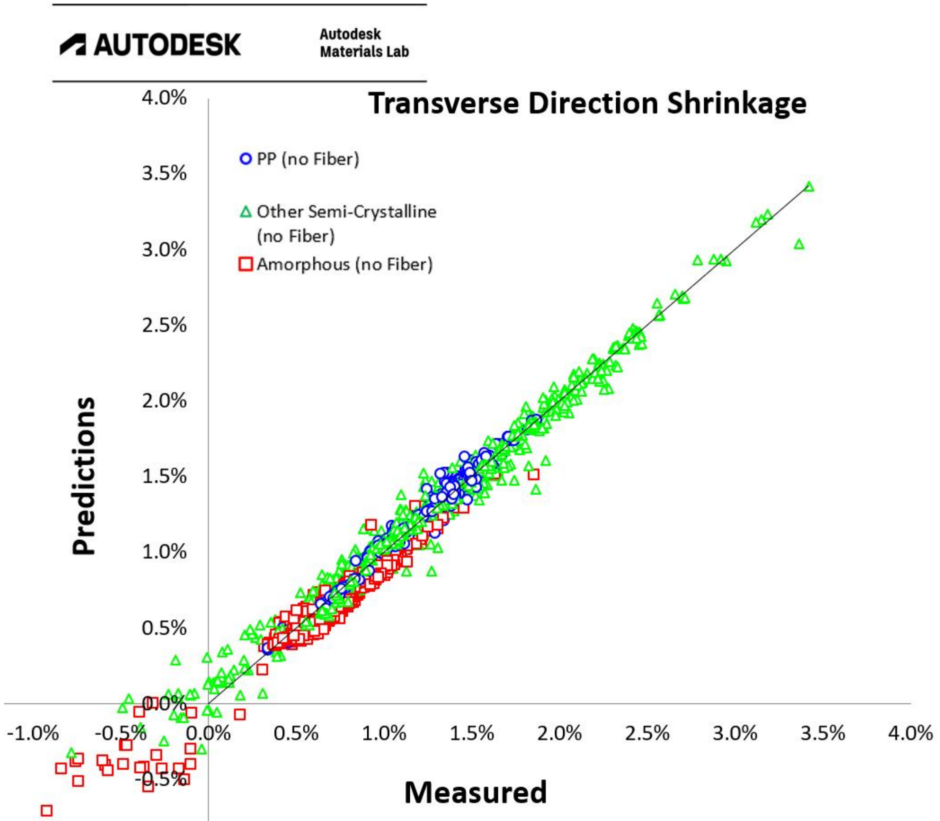
STAMP vs Residual Stress Model

171 Unfilled Polymers – Transverse Direction

Residual Stress Model



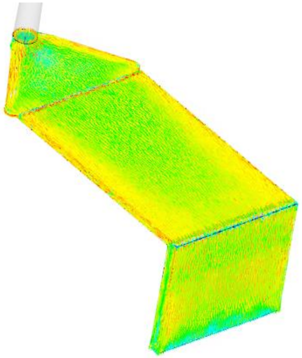
STAMP



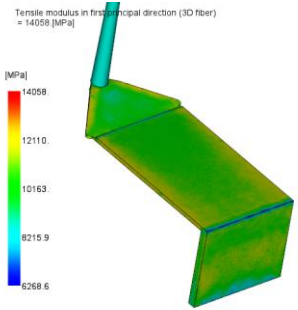
Calibrated Local Anisotropic Mechanical Properties

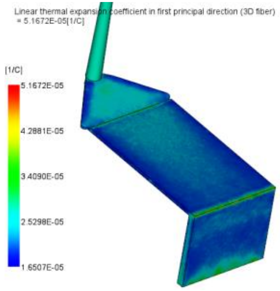
Using Fiber Orientation

Fiber Orientation Fiber Length Fiber Properties	+	Calibrated Matrix Properties	=	Composite Properties



$$
\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix} =
\begin{bmatrix}
\frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\
-\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\
-\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{2G_{23}} & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{2G_{13}} & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{2G_{12}}
\end{bmatrix}
\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{bmatrix}
$$

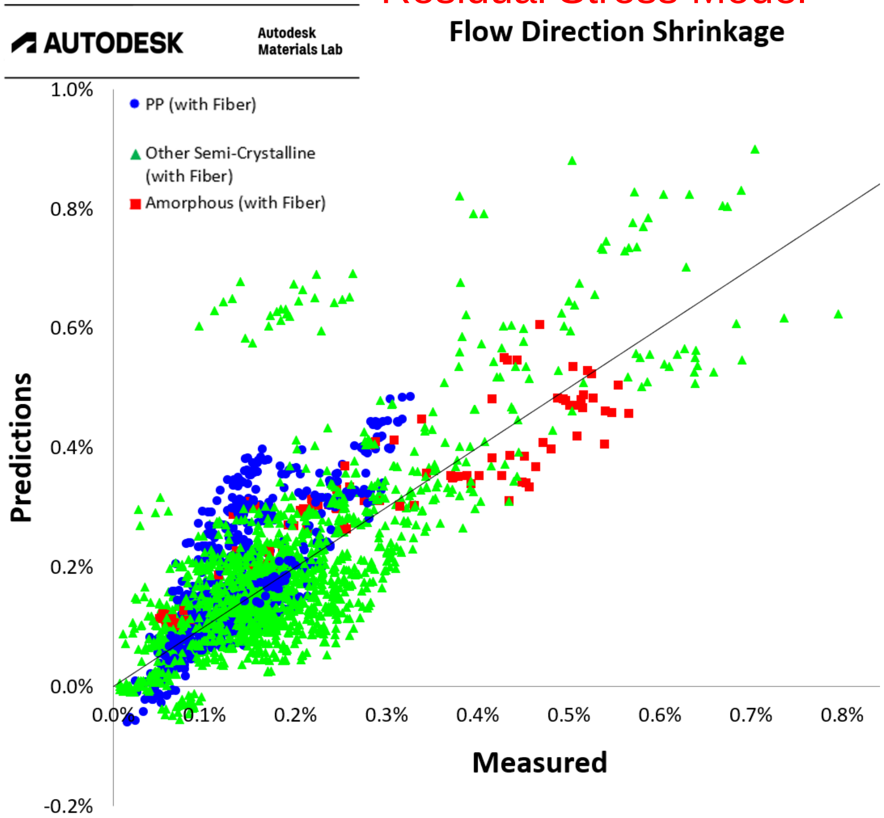




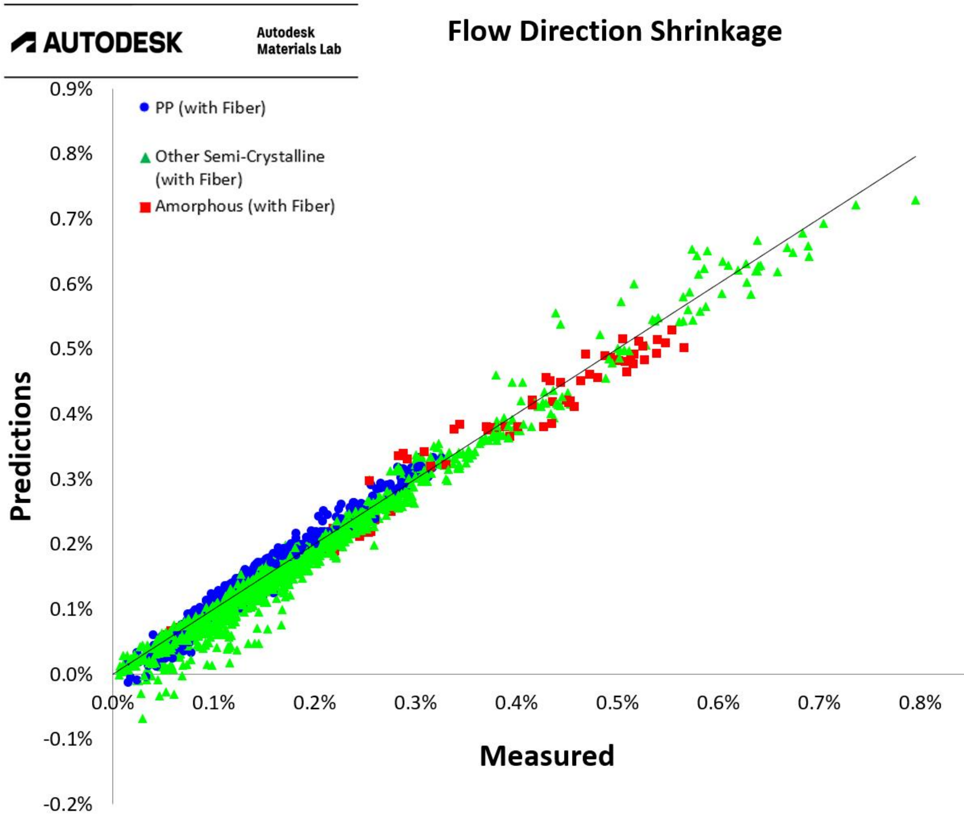
STAMP vs Residual Stress Model

106 Fiber Filled Polymers – Flow Direction

Residual Stress Model



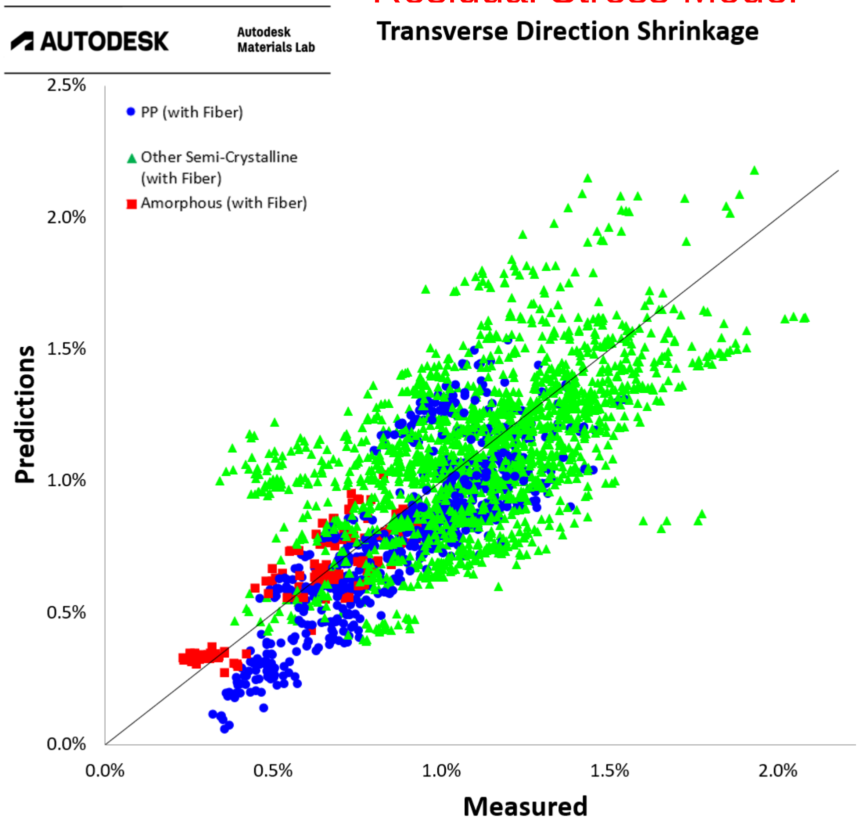
STAMP



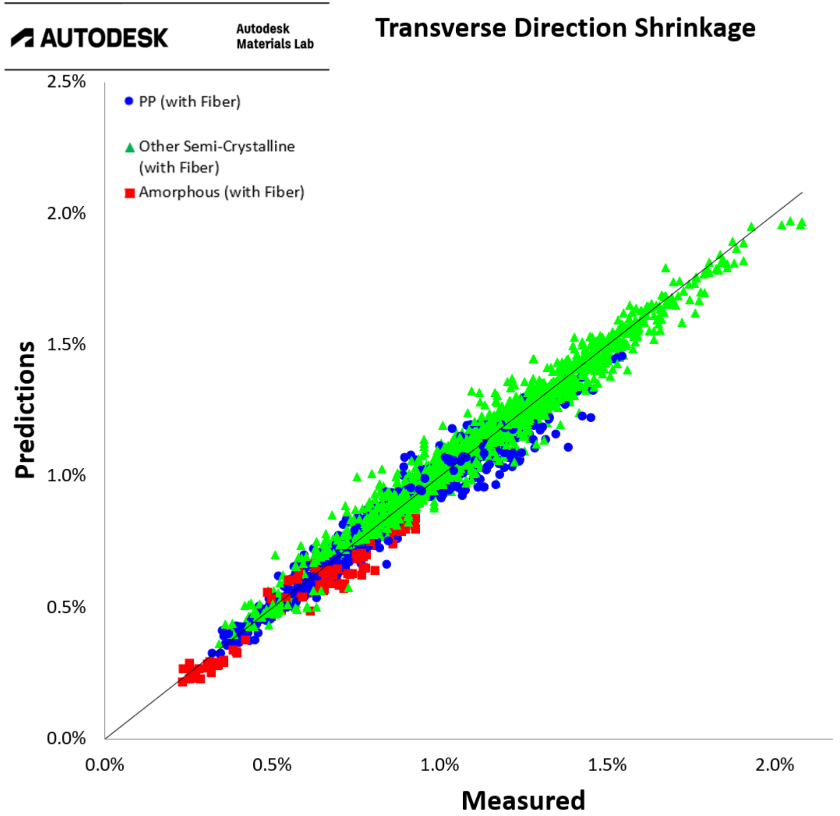
STAMP vs Residual Stress Model

106 Fiber Filled Polymers – Transverse Direction

Residual Stress Model



STAMP



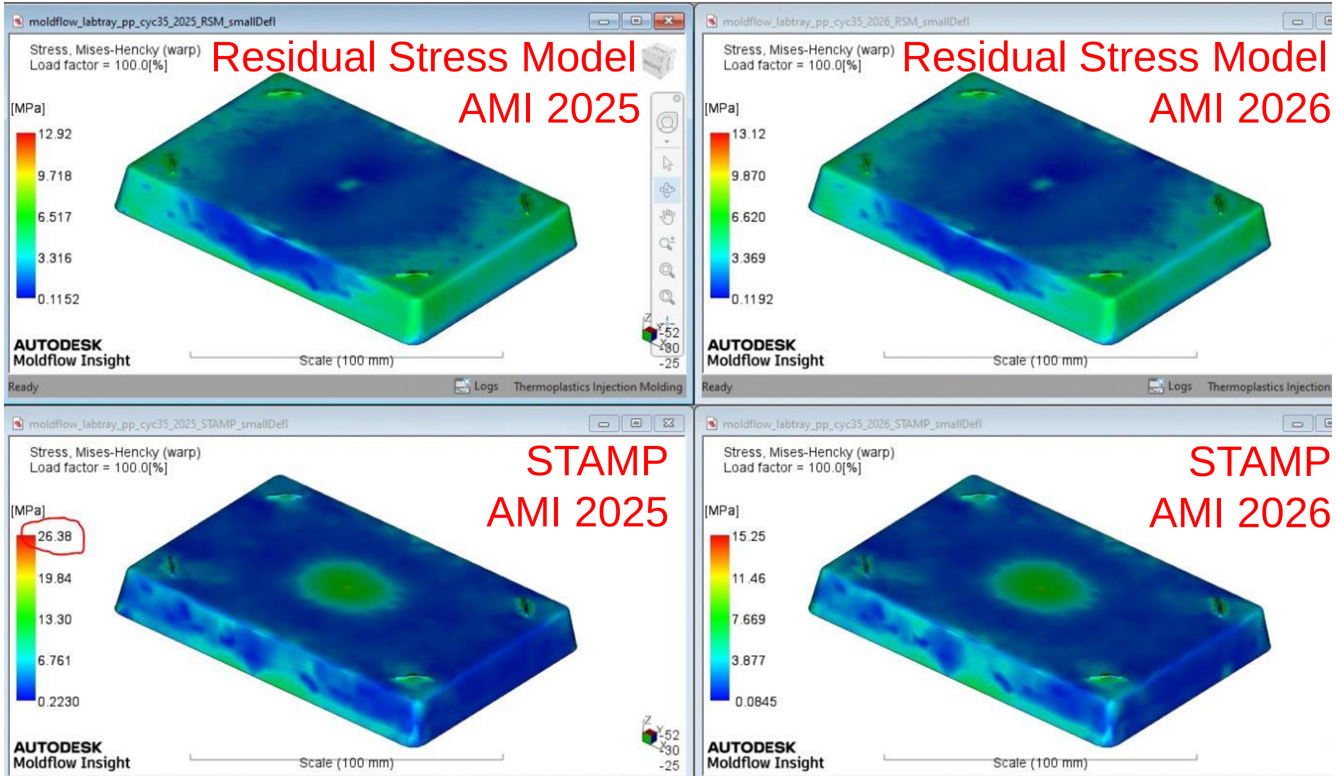
STAMP Improvement

Post-molding residual stress

- In AMI 2024 & 2025 the post-warp residual stress from STAMP was sometimes unrealistic

Max Stress = 13MPa

Max Stress = 26MPa



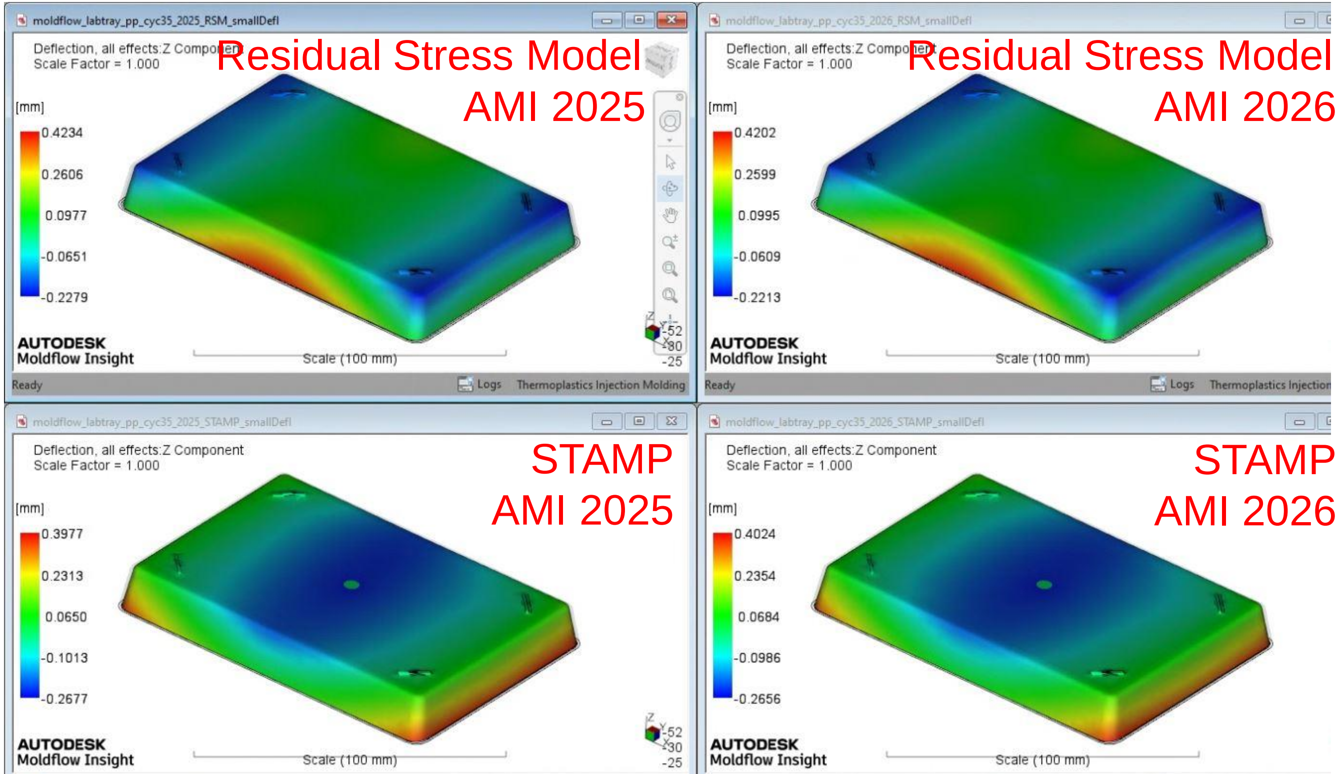
Max Stress = 13MPa

Max Stress = 15MPa

STAMP Improvement

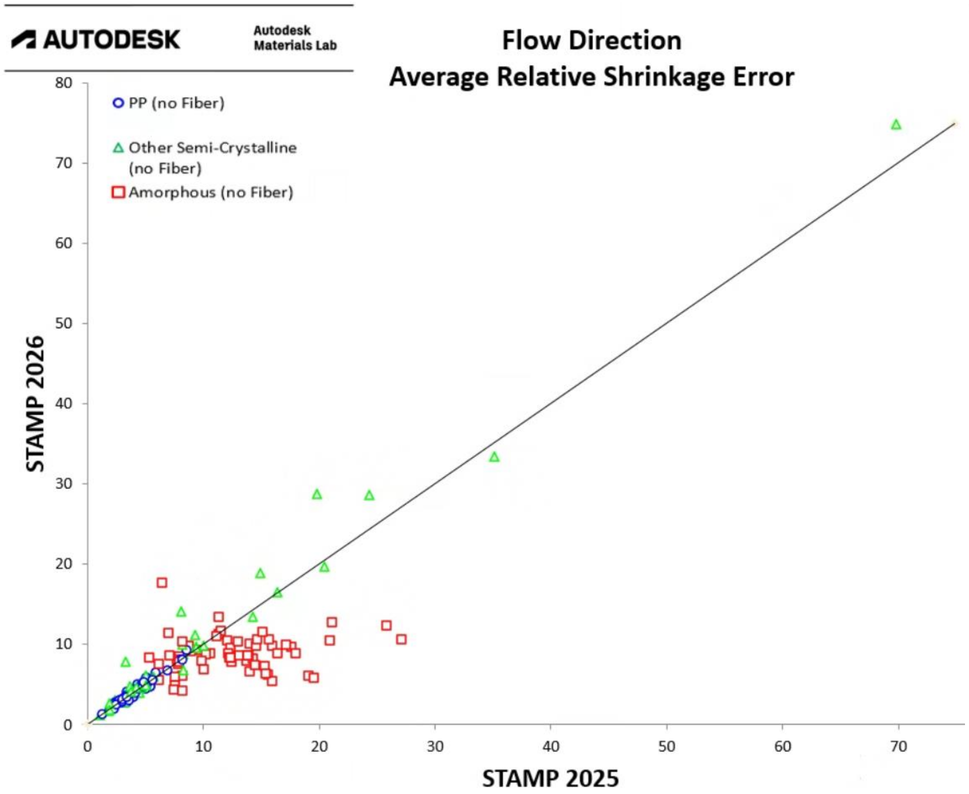
Post-molding residual stress

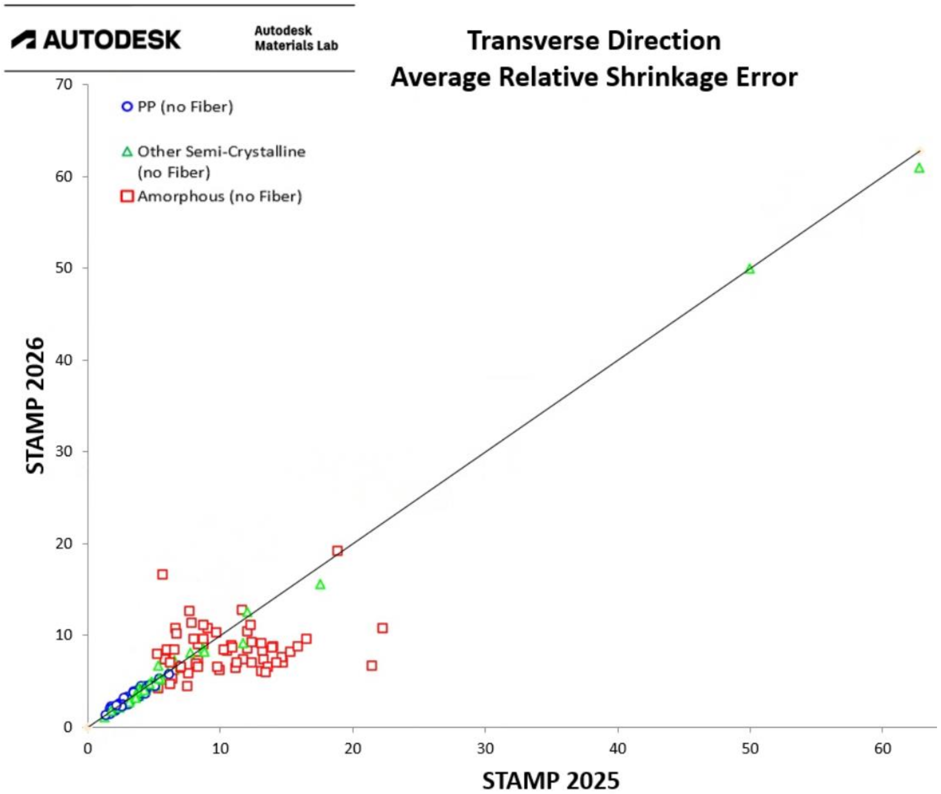
- In AMI 2024 & 2025 the post-warp residual stress from STAMP was sometimes unrealistic



STAMP 2026 vs STAMP 2025

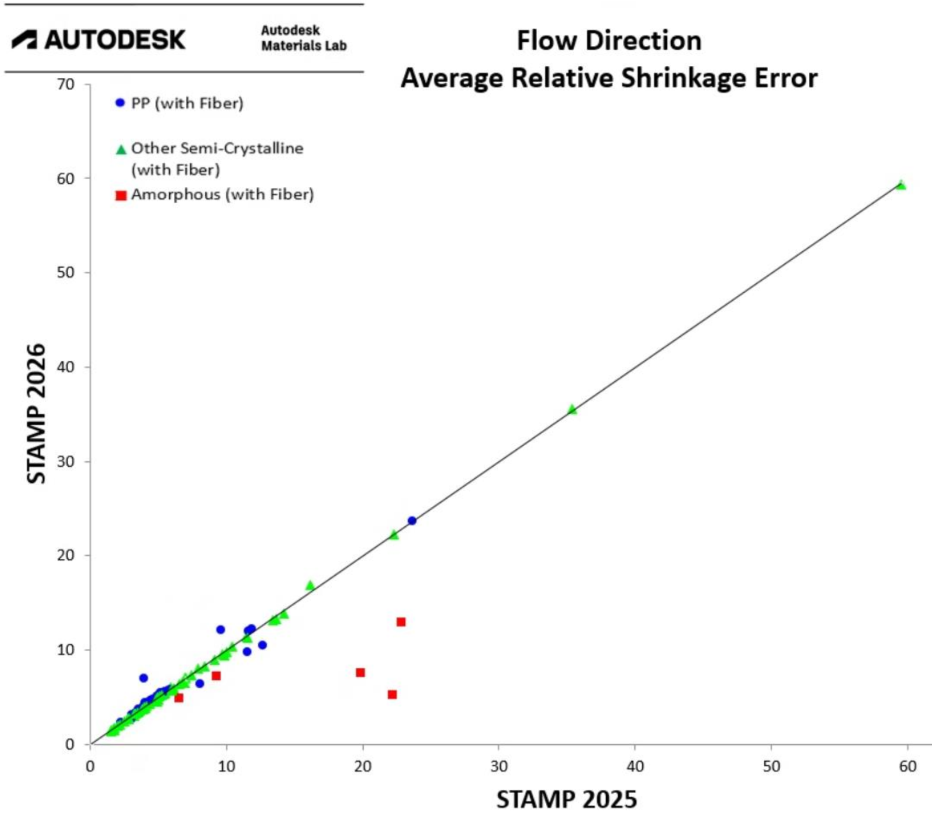
106 Unfilled Polymers

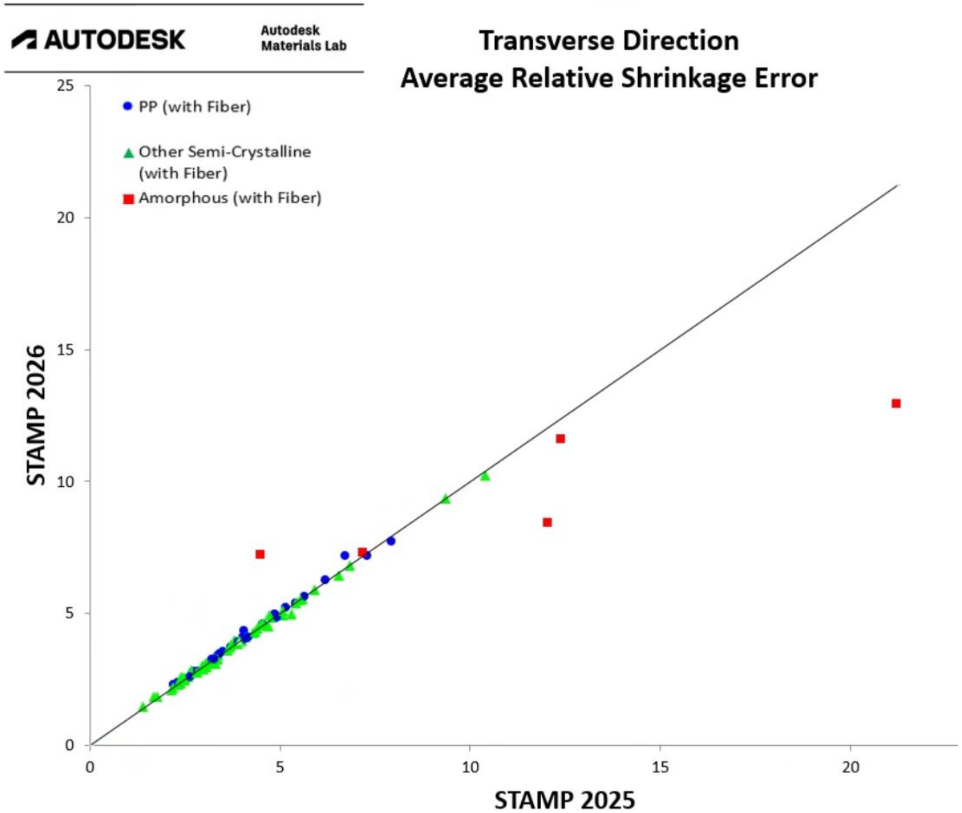




STAMP 2026 vs STAMP 2025

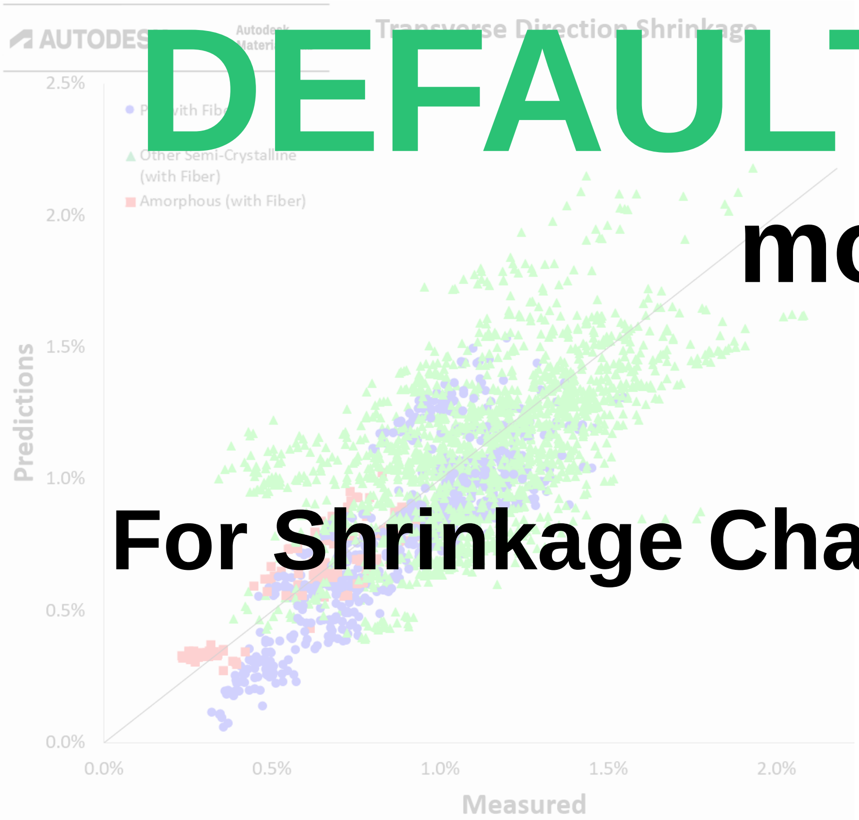
171 Fiber Filled Polymers

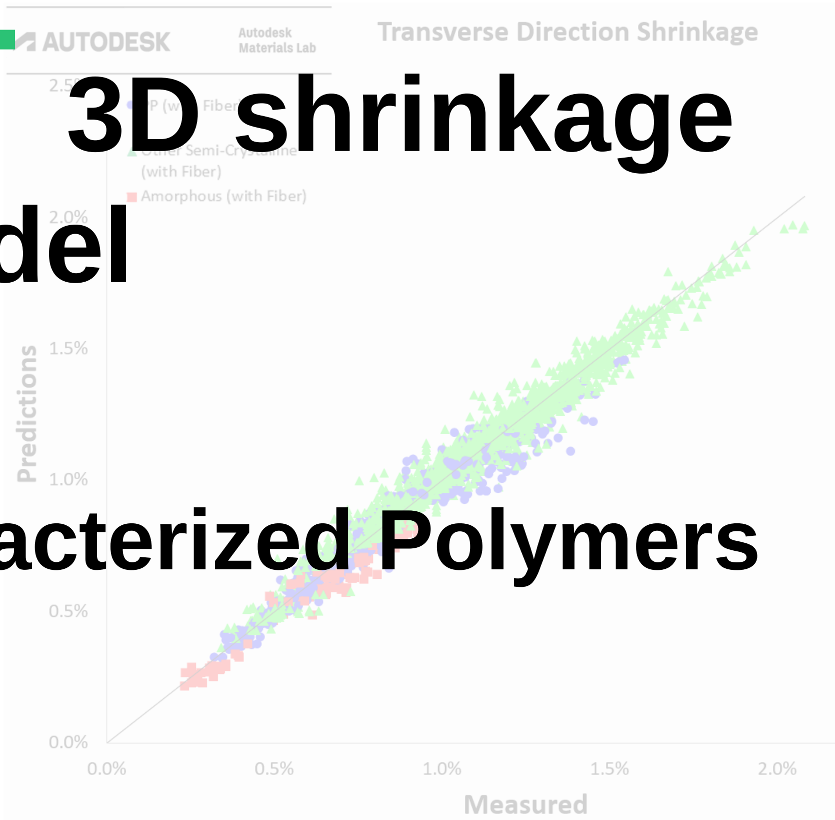




AMI 2026

STAMP is now the **DEFAULT** 3D shrinkage model





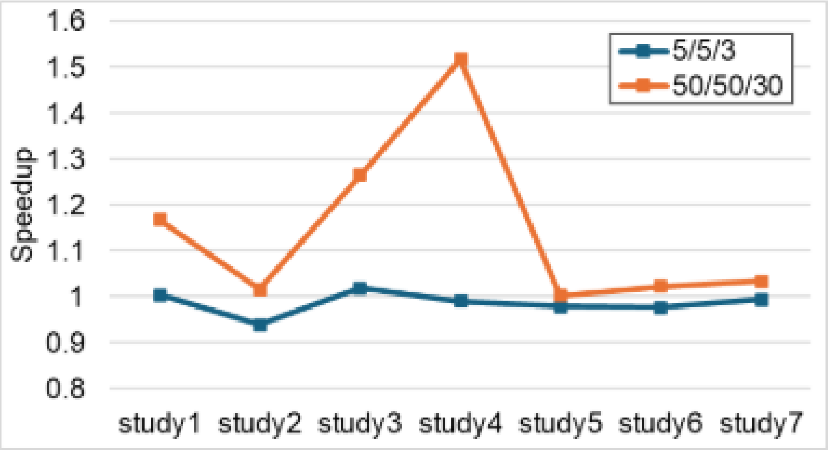
For Shrinkage Characterized Polymers

3D Solvers Speed Improvements

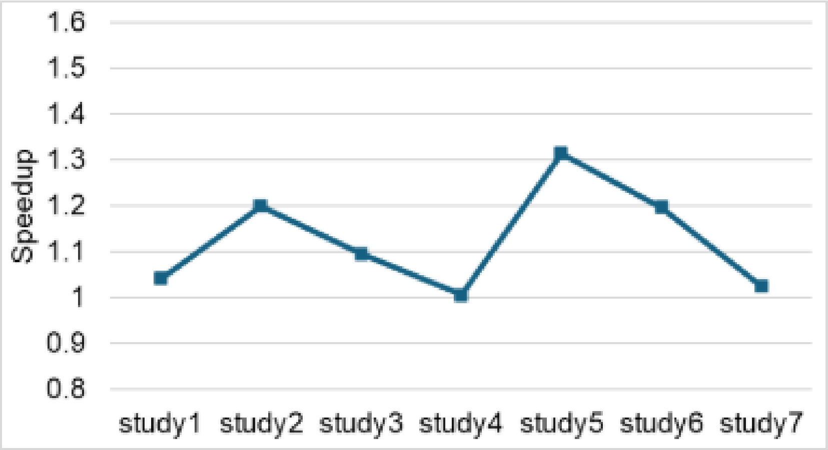
No decrease in of accuracy or resolution

- 3D Flow: Improve SCM file transfer speed when number of intermediate results is high
  - <u>Cannot view results in previous Moldflow releases</u>

- 3D Warp: Speed-up by removing disk operations (increases memory requirement)



3D Flow: Up to 50% speed up

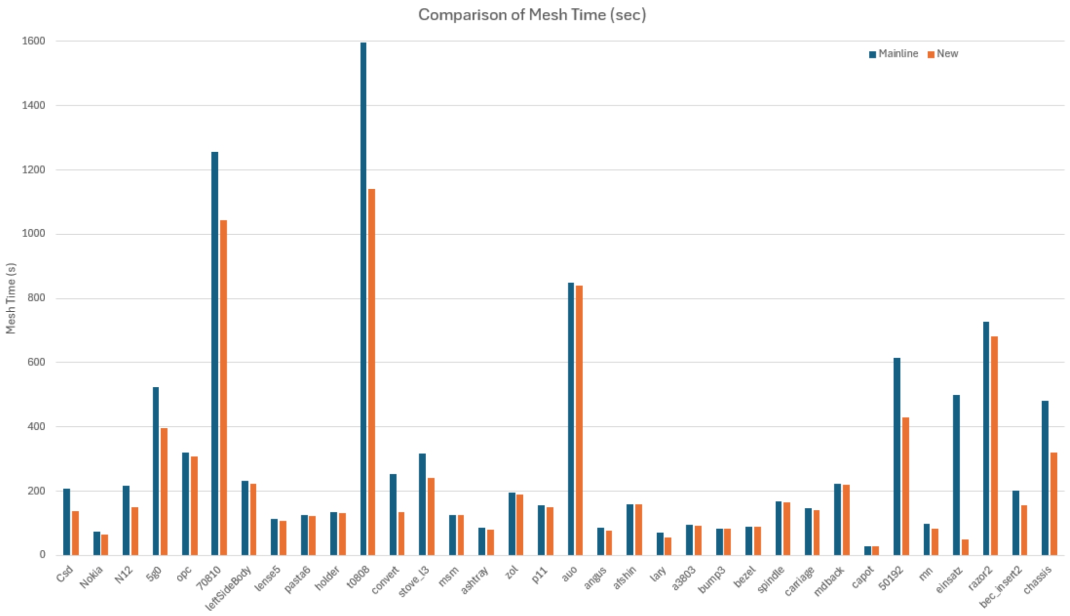


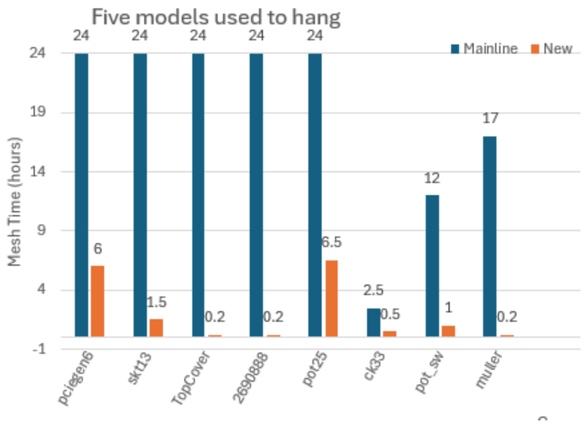
3D Warp: Up to 30% speed up

Meshing Speed Improvements

Without loss of accuracy or mesh resolution

- Faster Dual-Domain surface meshing (up to 30%)
- Speed & Quality mesh improvements for many 3D models
- Fix problem of a few models which required too long to mesh

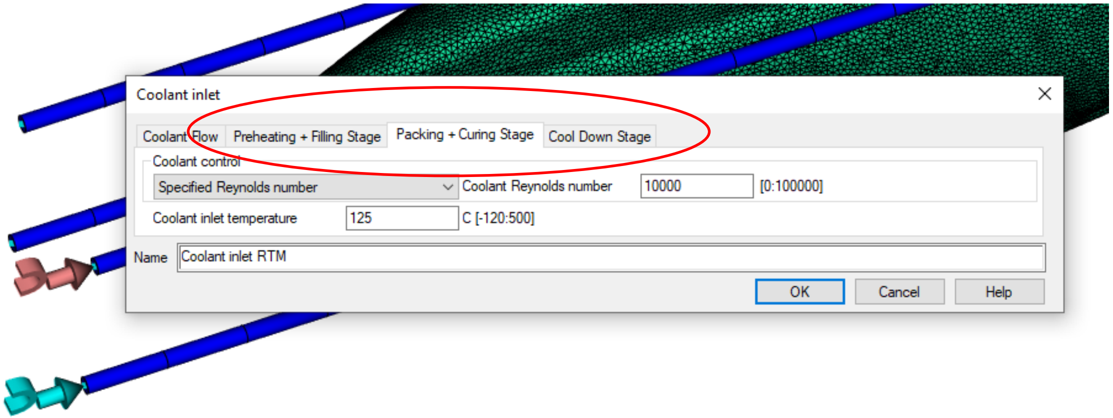


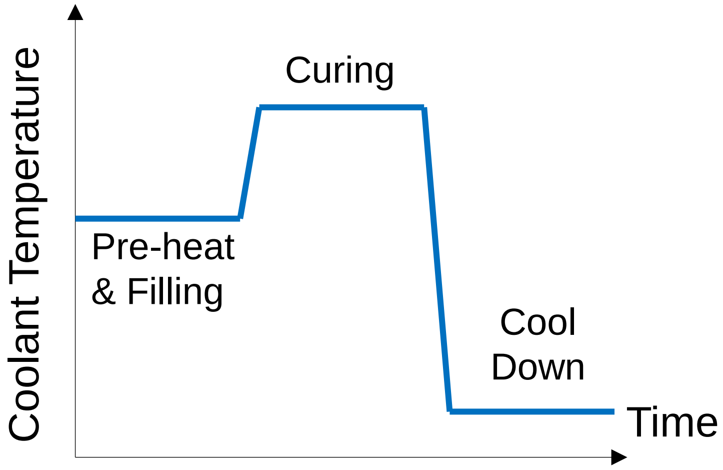


Mold Thermal Analysis for RTM (3D)

Add Cool(FEM) analysis for the Resin Transfer Molding process in 3D

- Allow different coolant (heating fluid) temperatures during various phases of the process:
- Pre-heating phase by time or thermocouple control

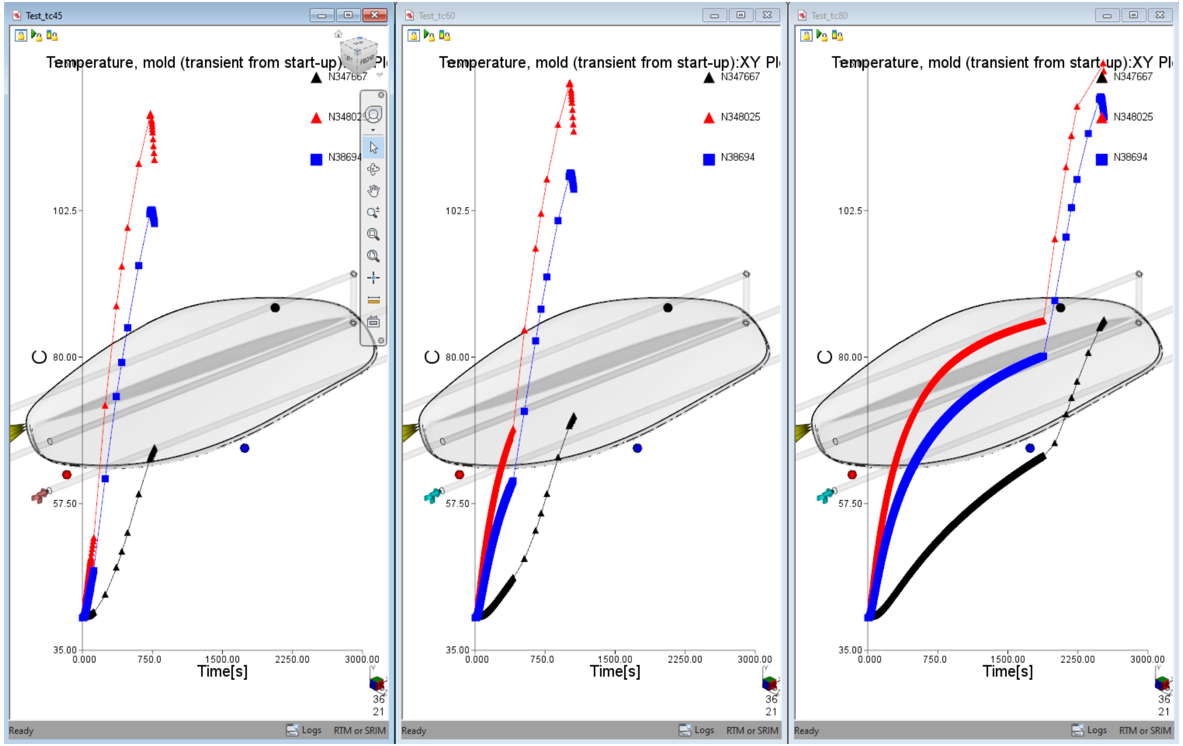




Mold Thermal Analysis for RTM (3D)

Add Cool(FEM) analysis for the Resin Transfer Molding process in 3D

Influence of pre-heating duration (solid lines) on temperature evolution



Other Solver Improvements

- Improved barrel compressibility calculation for Midplane and Dual-Domain solves when using **Absolute Ram Position/Speed Profiles**

AMI2025

3.099	93.64	65.06	966.17	455.92	35.64	V
3.167	95.23	58.95	972.61	249.72	34.29	V
3.233	96.43	55.69	931.96	238.67	33.36	V
3.304	97.47	54.30	919.47	233.47	32.40	V
3.370	98.31	53.98	927.59	230.98	31.52	V
3.429	99.01	54.14	947.71	228.61	30.73	V/P
3.436	99.08	50.70	949.83	46.16	30.69	P
3.440	99.13	49.00	949.11	17.00	30.69	P
3.503	99.71	49.00	925.33	157.23	30.27	P
3.570	100.00	49.00	1013.52	147.30	29.67	P
3.571	100.00	49.00	1015.27	147.01	29.67	P
3.572	100.00	49.00	1017.47	146.67	29.66	Filled

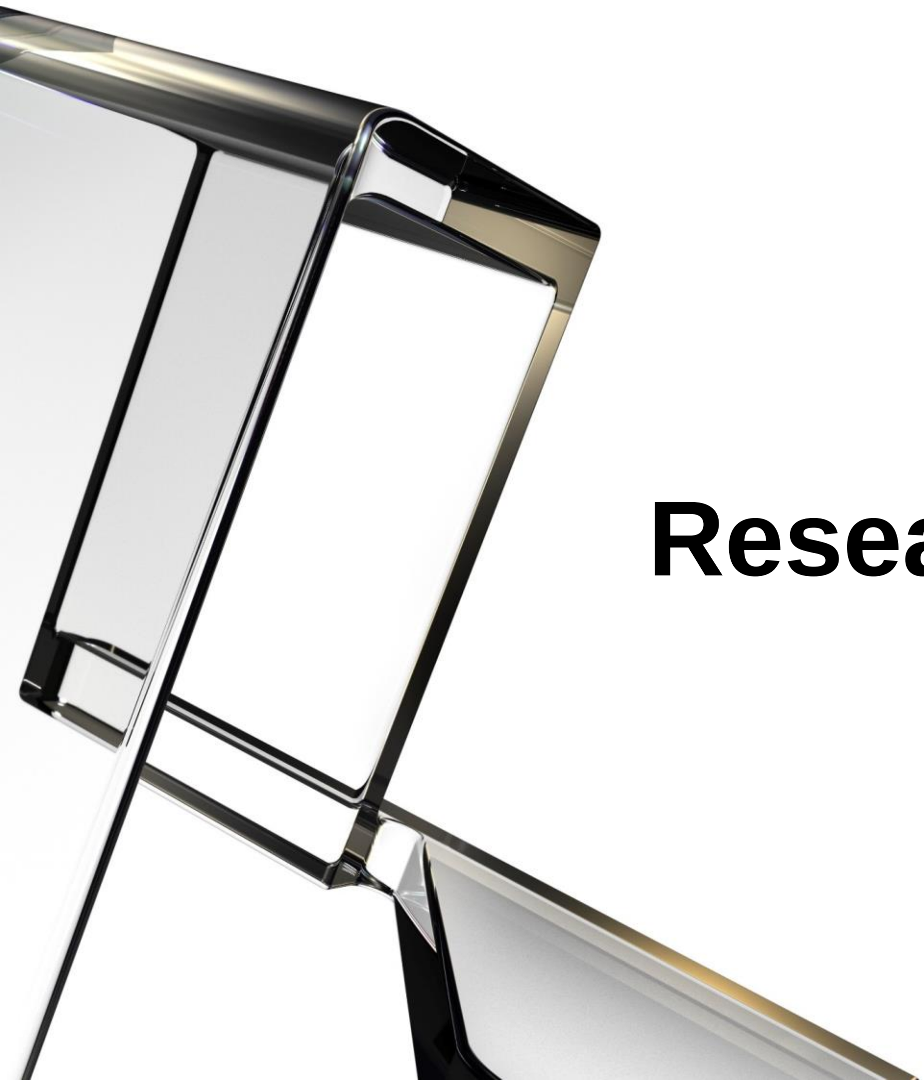
AMI2026

3.441	95.85	51.18	891.39	228.84	26.49	V
3.508	96.60	51.85	931.22	228.14	25.55	V
3.573	97.31	52.66	970.61	227.86	24.65	V
3.638	98.02	53.57	1011.98	227.77	23.76	V
3.708	98.77	54.63	1059.74	227.75	22.79	V
3.731	99.00	54.94	1076.61	224.32	22.48	V/P
3.741	99.11	49.00	1081.34	-0.48	22.57	P
3.773	99.41	49.00	1060.84	109.04	22.47	P
3.840	99.84	49.00	1077.42	139.94	21.94	P
3.888	99.99	49.00	1150.82	127.71	21.57	P
3.890	100.00	49.00	1153.15	127.32	21.56	Filled

- Improved coefficient of thermal expansion calculation for fiber and disk filled polymers in Midplane and Dual-Domain analyses

- Improved accuracy of part-weight during 3D Compression molding analyses

- Improved Automatic Switchover from Velocity Control to Pressure Control for 3D Flow analyses when large hot runner volumes are present



Research Projects

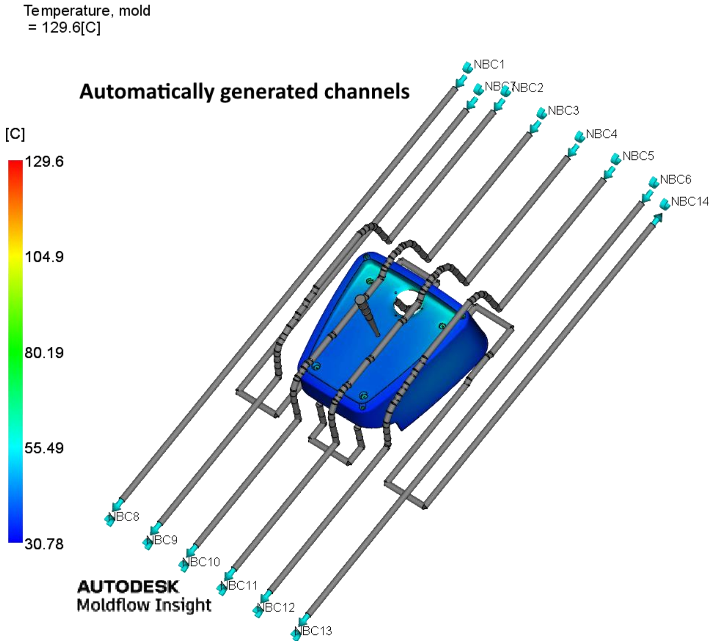
Research Disclaimer

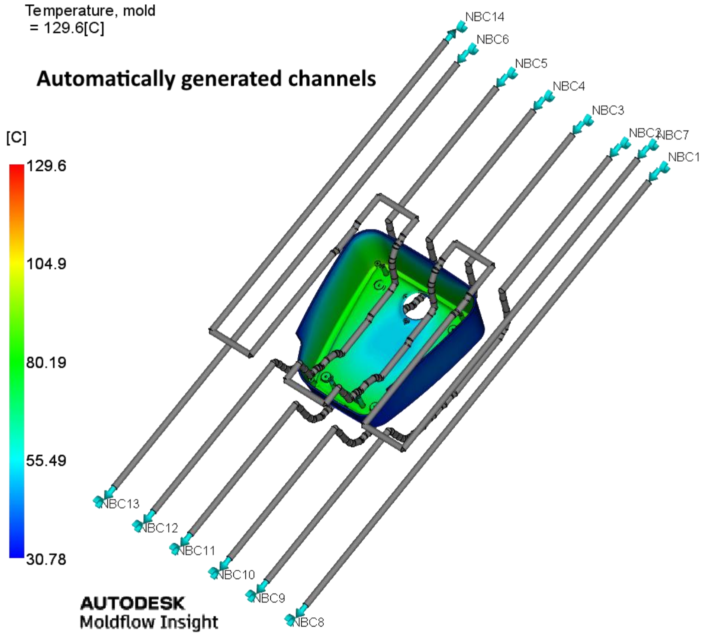
- *We may make statements regarding planned or future development efforts for our existing or new products and services. These statements are not intended to be a promise or guarantee of future delivery of products, services or features but merely reflect our current plans, which may change. Purchasing decisions should not be made based upon reliance on these statements.*

- *The Company assumes no obligation to update these forward-looking statements to reflect events that occur or circumstances that exist or change after the date on which they were made.*

Automatic Conformal Cooling Channels

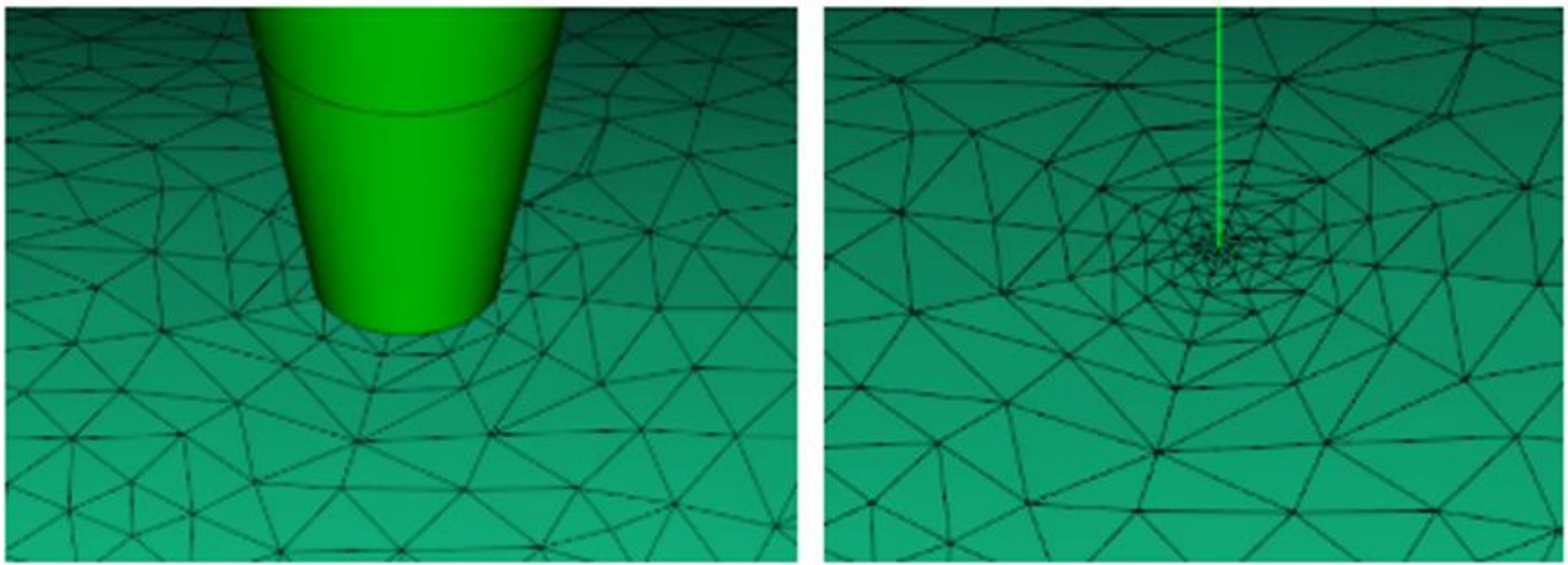
- Channel layout follows part contours
  - Phase 1: For Additive Manufactured channels / mold inserts
  - Phase 2: Restrict to straight (drill & plug) channels





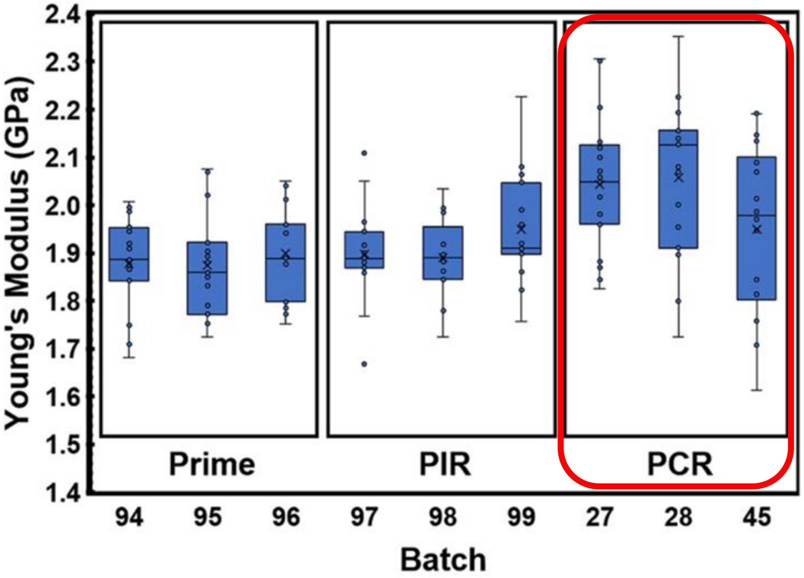
3D Meshing

Increased refinement and improve symmetry at gates connected to beams

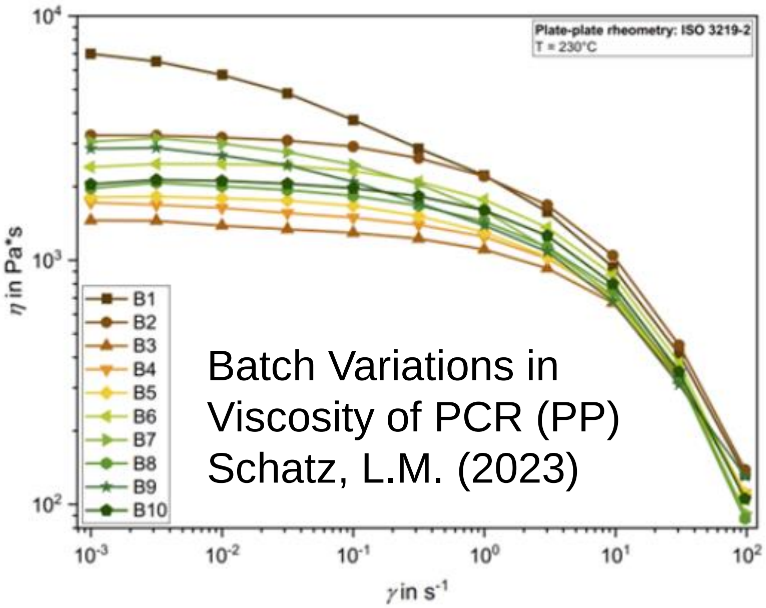


Use of Recycled Content

- Expect variation in properties (especially for Post-Consumer Recycled materials)
  - Density, Viscosity, Solidification Temperature & Thermal Expansion Coefficient

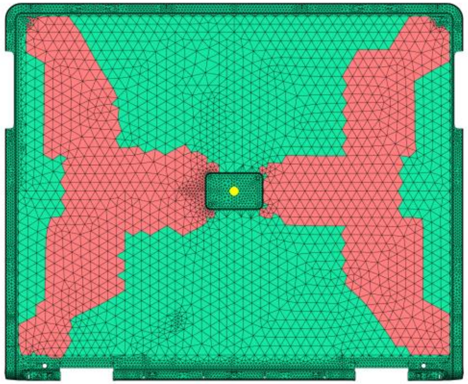


Orzan et al., 2021



Batch Variations in Viscosity of PCR (PP)
Schatz, L.M. (2023)

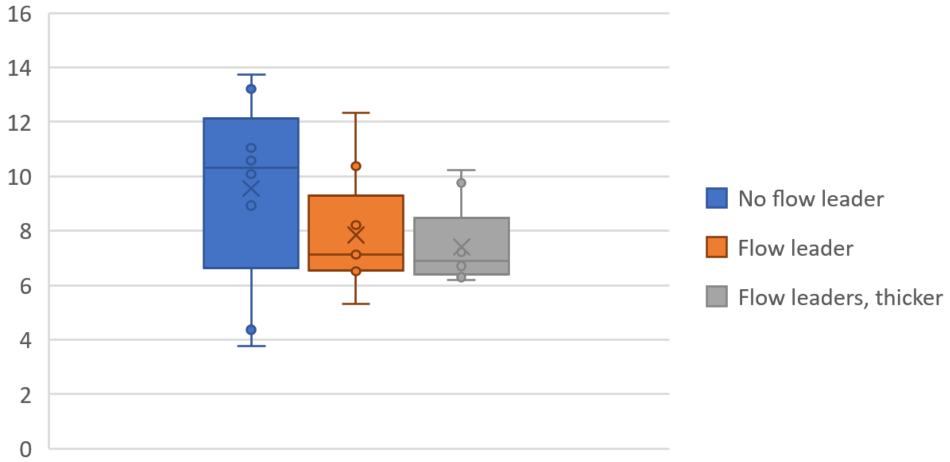
Minimizing sensitivity to Recycled Plastics



Thin-walled cover with Flow Leaders

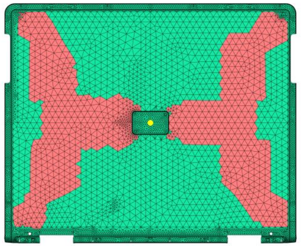
PA with 30% glass fiber

Nominal Wall Thickness: 1.5mm
Flow leader thickness 1.7mm & 2.0mm



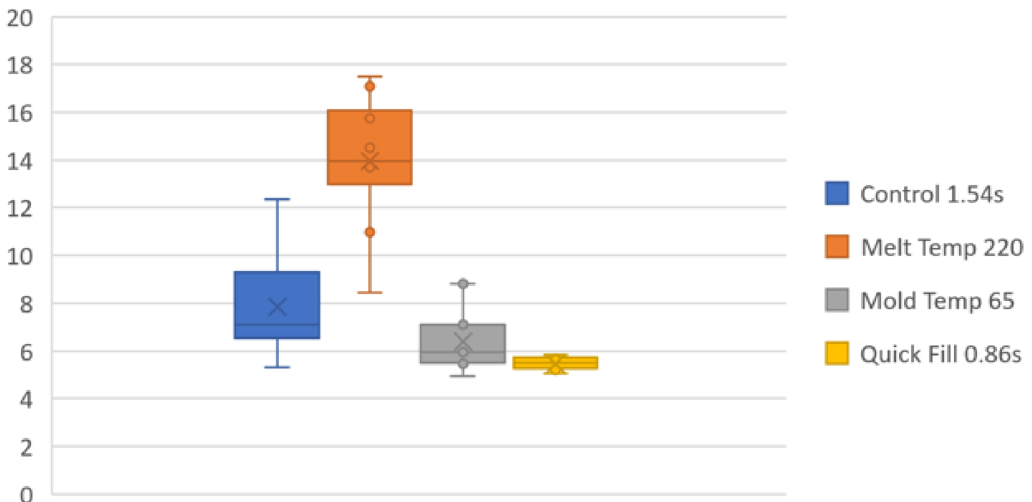
Deflection (mm) with material variation
for various flow leader designs

Minimizing sensitivity to Recycled Plastics



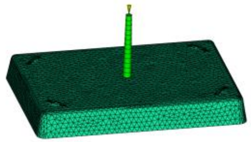
Process condition	Nominal	Alternative
Melt Temperature (°C)	260	220
Mold Temperature (°C)	80	65
Injection Time (sec)	1.54	0.86

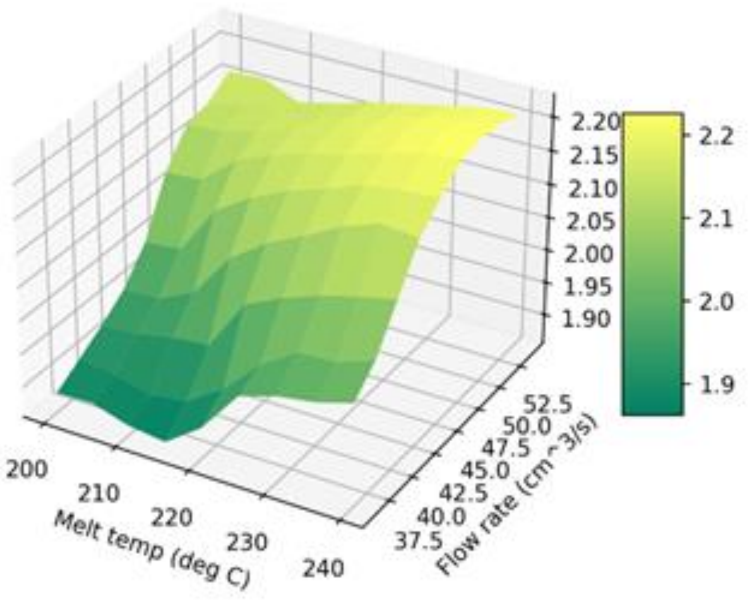
- Using cover design with 1.7mm flow leader
- Try varying melt temperature, mold temperature & Injection Time
- Same material variations ranges for each case



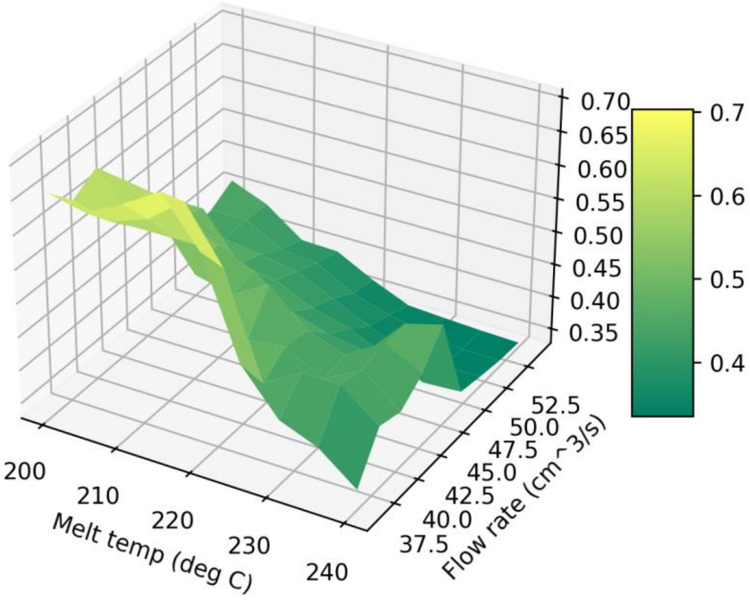
Deflection (mm) with material variation for various process conditions

Detailed study of process optimization





Average deflection magnitude (mm)



Deflection variation (mm)

Conflicting optimization objectives: magnitude v.s. variation

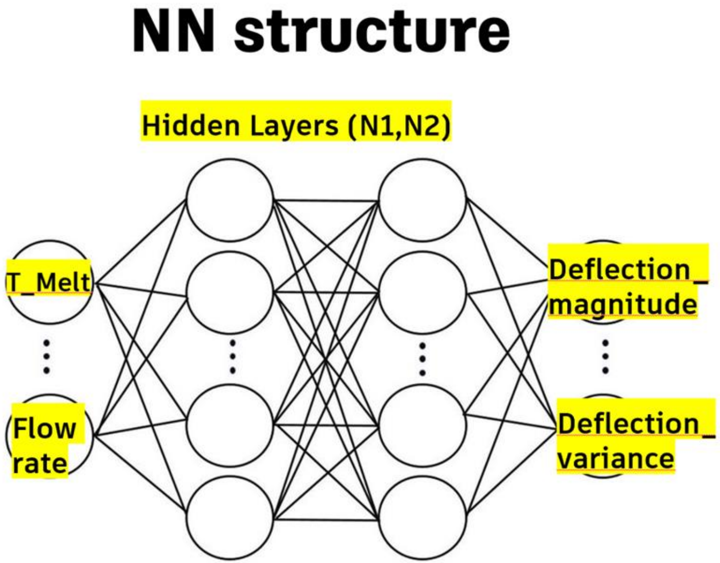
Neural Network Surrogate Model

- Training data should be closely related to the problem to be solved

- In this study: Same geometry, Same material, Same level of material variation

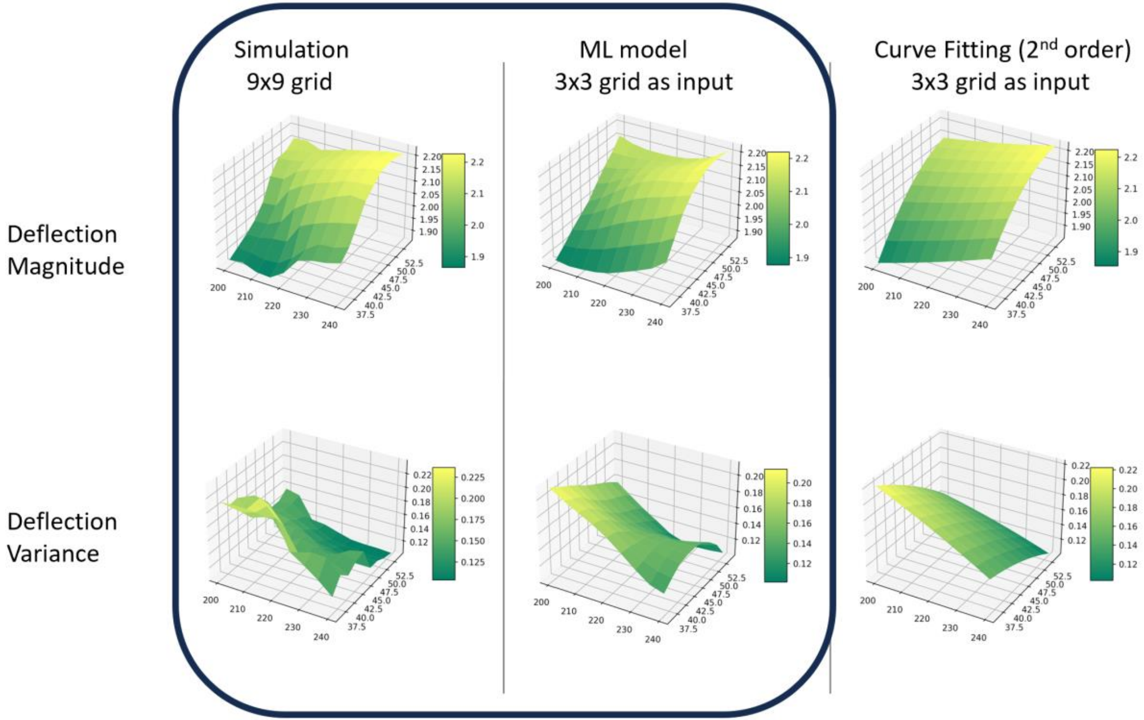
- Train Neural Network using a subset of the 9x9 response surface
  - Remaining points are used for testing

- Use multi-layer perception model from Python scikit-learn library (v1.5.0)
  - 2 layers of neurons. Optimization process selected N1 = 470, N2 = 255



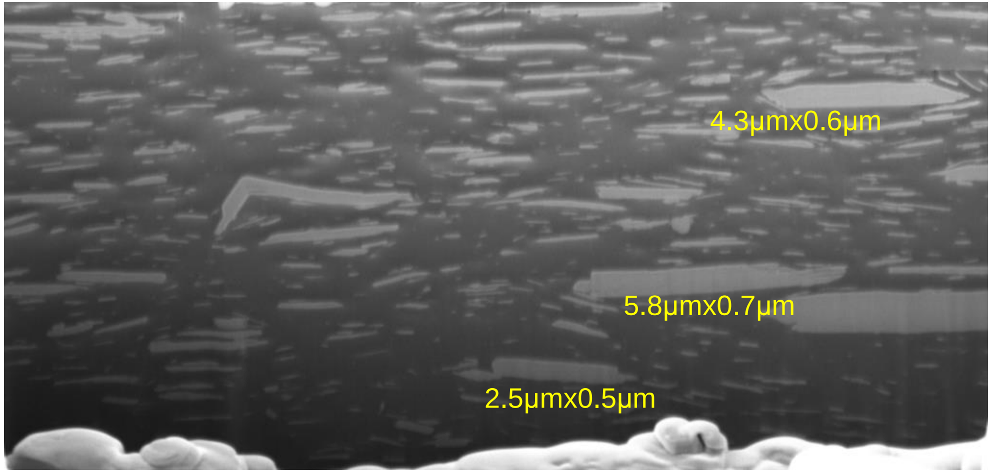
Use Neural Network to decrease compute time

- Use a 3x3 Simulation grid of process conditions to train Neural Network model:
  - Better response characteristic than a 2nd order polymer fit to the same 3x3 grid



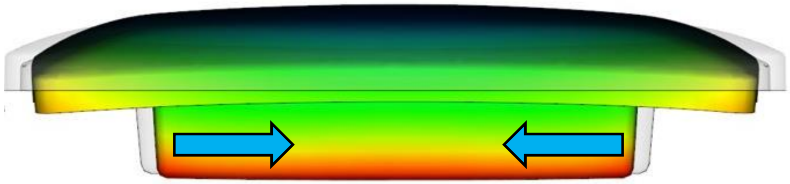
Talc filler

- Common filler in material database (make up ~11% of all materials)
- Assumed to be spherical particles as they have no fixed aspect ratio like fibers
- Imaging shows size distribution which can impact fill/pack/warp
- Potential for using custom aspect ratio for better warp results



Overmolding Improvements

- Improve 3D Warp with Part Inserts by considering
  - Thermal expansion of insert before contact
  - Thermal contraction after contact
  - Achieve consistent application of pre-contact time which heats the insert



- Improve 2-component overmolding by considering relaxation of first shot before overmolding

Other Solver Improvements

- Cool analysis: Reduce computation time and mold meshing time for large complex molds
- Flow analysis: Allow increased flexibility for valve gate controls
- Warp analysis: Improve consistency for ribbed parts (DD vs 3D)

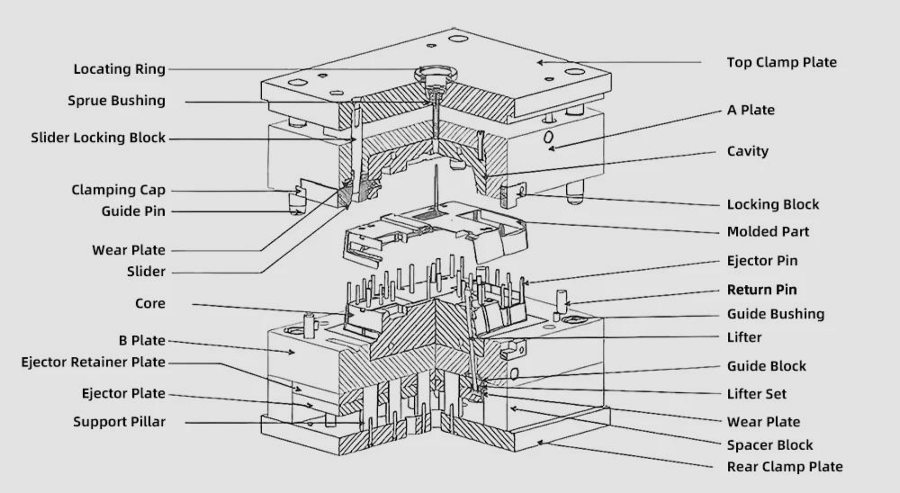
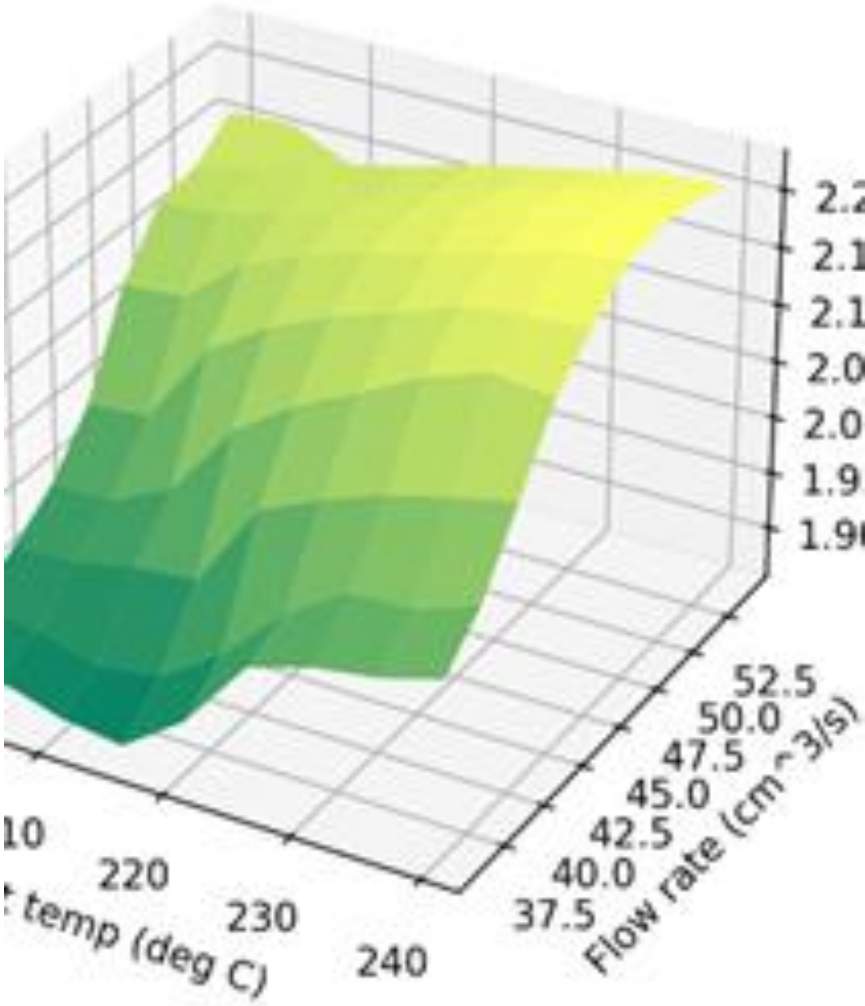


Image source: FirstMold.com

Summary

1. Moldflow 2025 Release
2. Moldflow 2026 Release
3. Current Research Work



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