A Roundness Study With Moldflow

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AUTODESK.

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Introduction

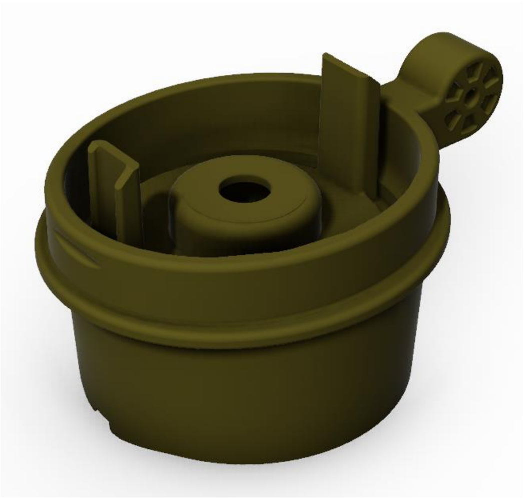
- Aim
  - Demonstrate how to use Moldflow to study warpage and how the process variation affects the correlation between Moldflow and the part
- Why do it
  - Warpage is a complex problem and there are several ways to measure and correlate it
- Overview
  - Model simplification
  - Correlation between Moldflow results and Process results
  - Reducing warpage problem

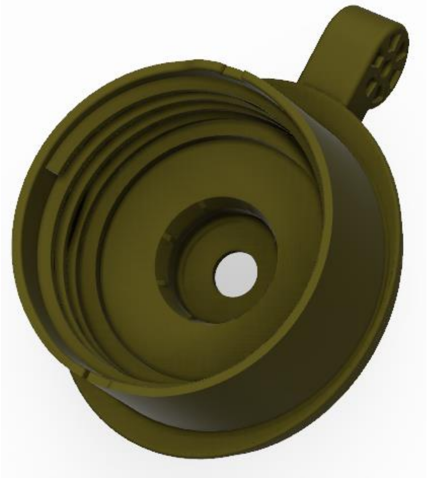
Agenda

- Introduction
- Model Definition and Simplification
- Initial Analysis
- Design of Experiment
- Recommendations
- Final Report
- Final Comments

The Case

- This is a bottle top
- The study focused on:
  - Correlation of real vs simulation
  - Roundness problem
  - Stress Cracking problem





The Problem Chronology

The mold was built

Due to an assembly problem the Geometry was modified

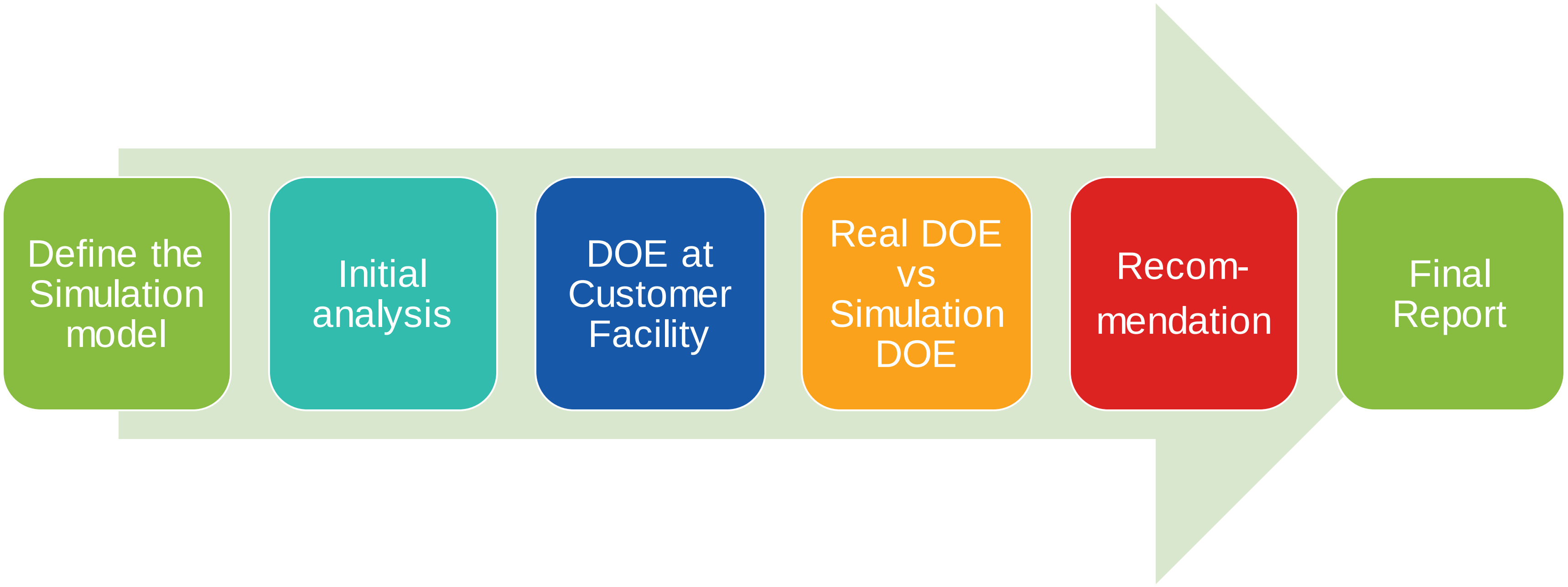
Two problems showed up:
- **Roundness**
- Stress Cracking

Some modifications were done on the mold cavities

After 4 different geometry versions

The moldflow study started here

Moldflow Project Workflow

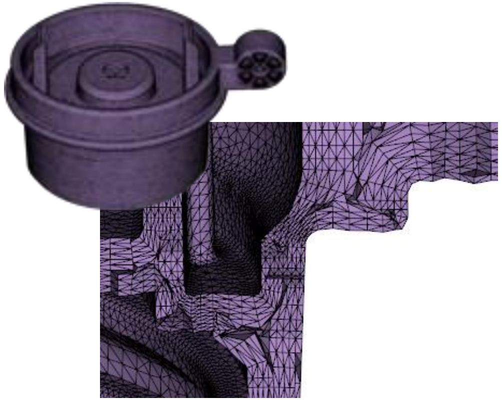


Model definition and simplification

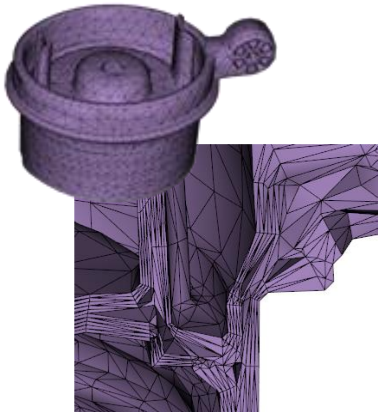
Model Simplification

- Geometry and cad files
  - Native cad format was used
  - Moldflow 2017.3 was used to generate the mesh
- All analyses were made by using Moldflow 2017.3
- 2 Models
  - Different mesh densities
  - Different number of cavities

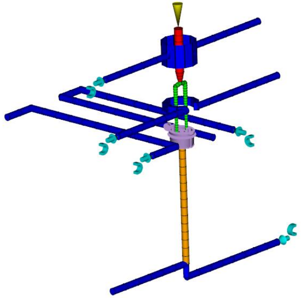
Fine mesh



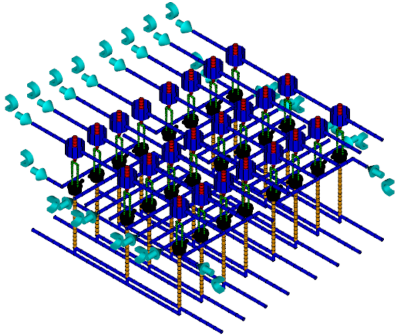
Coarse mesh



One cavity model



24 cavities model



N° of elements per cavity	1,694,997	148,944

Material Data

- The current material was not in the database so, because of that, a gold rated material for warpage was used.

Manufacturer	Trade name	Family abbreviation	Fibers/fillers	Material ID
Confidential	Confidential	HDPE	N/A	Confidential

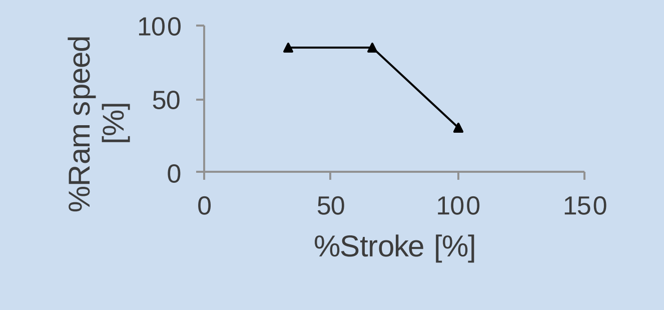
Description	Value	Units
Mold temperature range (recommended)	5:50	C:C
Melt temperature range (recommended)	190:260	C:C
Ejection temperature	106	C
Maximum shear rate	40,000	1/s
Absolute maximum melt temperature	300	C

Process Settings

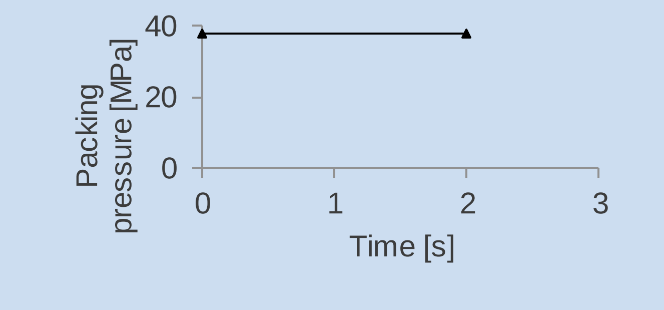
- Process Settings from the real process set-up.

Description	Value	Units
Mold surface temperature	28	C
Melt Temperature	225	C
Filling control	%Stroke - %Ram speed	
Velocity/pressure switch-over % volume filled	100	%
Pack/holding control	Time - Packing pressure	
Cooling time	20	s

Filling control

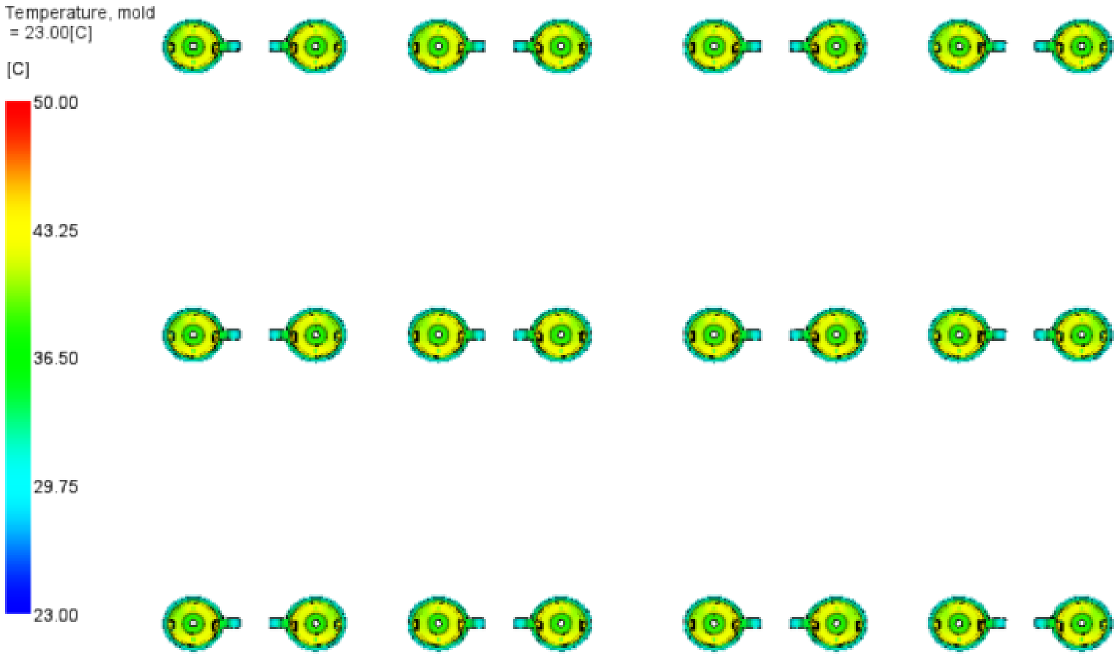


Pack/holding control



24 Cavities Model – Temperate, Mold

- The temperatures are very similar for all cavities

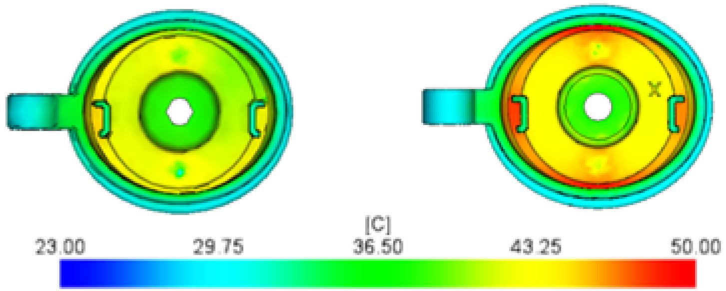


Conclusion

- The one cavity model with fine mesh on the part can be used since the mold temperature is uniform.

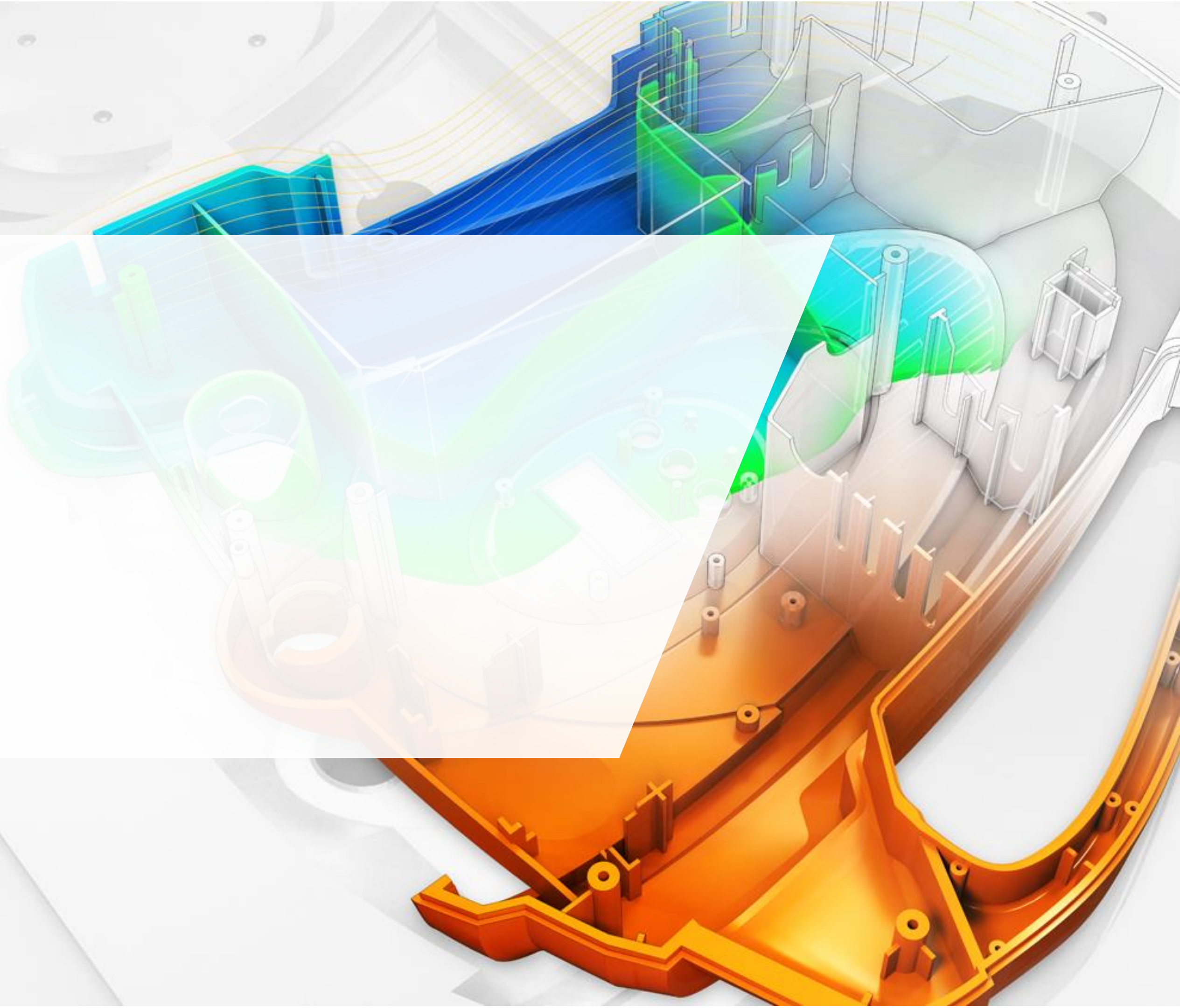
Temperature, Mold

24 cavities model | One cavity model



Cavity surface temp	24 cavities model	One cavity model
Maximum	47.9 C	50.2 C
Minimum	23.0 C	23.0 C
Average	34.8 C	34.9 C

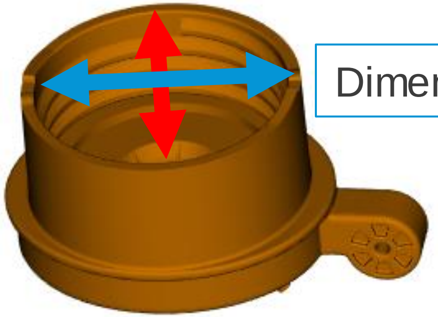
Initial analysis



Problems

- The **stress cracking**
  - The part failed in 8 hours
- The **roundness**
  - The customer reported that it was higher than the 0.2 mm limit.

Dimension B



Dimension A

Roundness should be less than 0.2mm

Roundness = Dimension A – Dimension B

The Problem Chronology

The mold was built

Due to an assembly problem the Geometry was modified

Two problems showed up:
- Roundness
- Stress Cracking

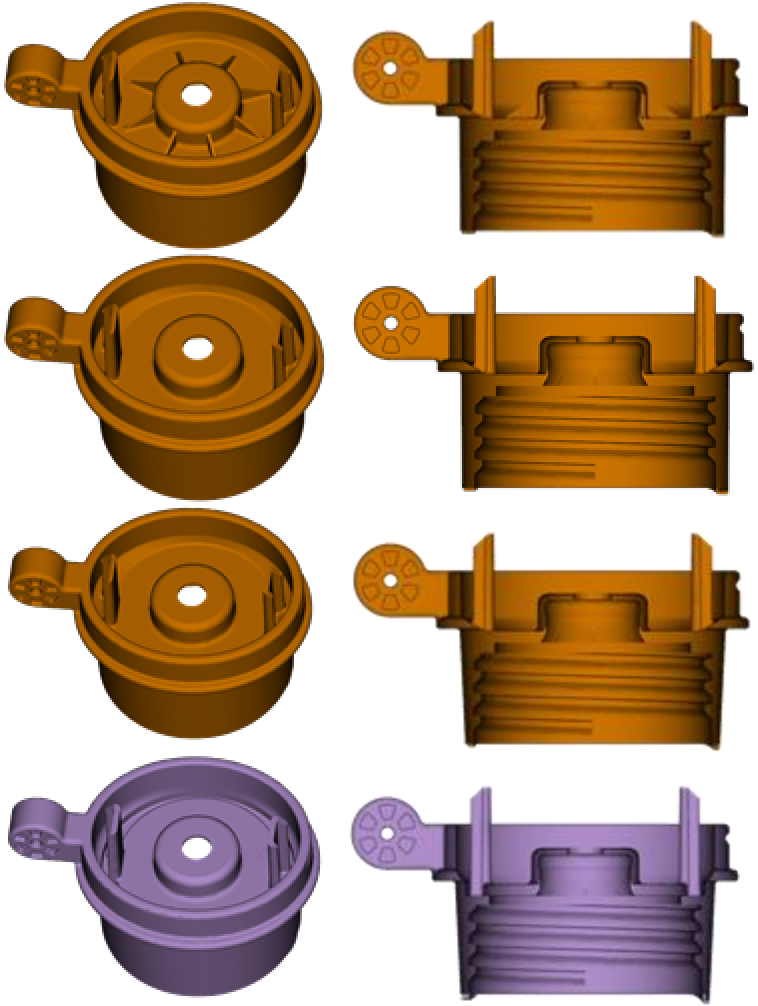
Some modifications were done on the mold cavities

After 4 different geometry versions

The moldflow study started here

Geometries

- V1 was the baseline version
- V2 removed ribs from V1
- V3 reduced thickness from V2
- V4 added a recess from V3

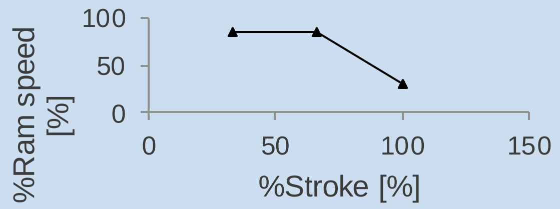


Process Settings

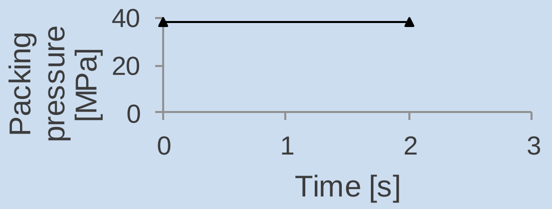
- The same process that was used during the prior phase was replicated

Description	Value	Units
Mold surface temperature	28.00	C
Melt Temperature	225	C
Filling control	%Stroke - %Ram speed	
Velocity/pressure switch-over %Maximum ram speed	100.00	%
Pack/holding control	Time - Packing pressure	
Cooling time	20.00	s

Filling control



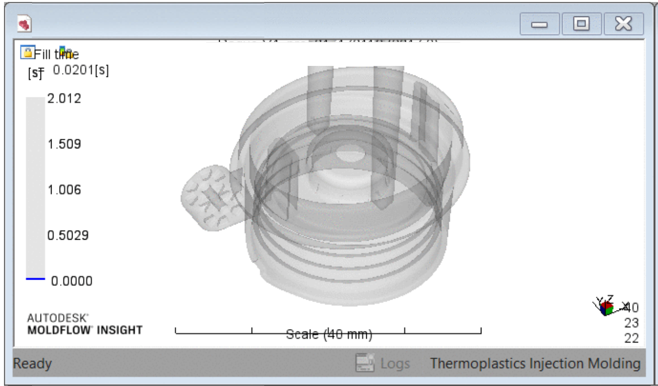
Pack/holding control



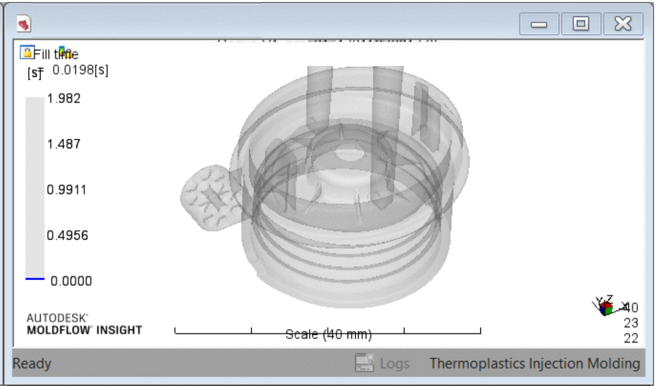
Single Cavity Results – Fill Animation

- It showed a little unbalanced flow due to the geometry

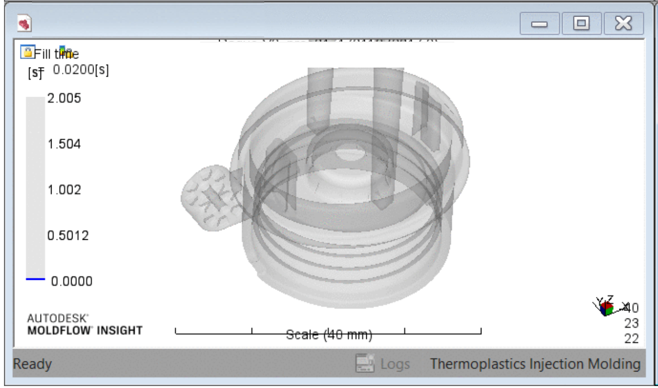
V1



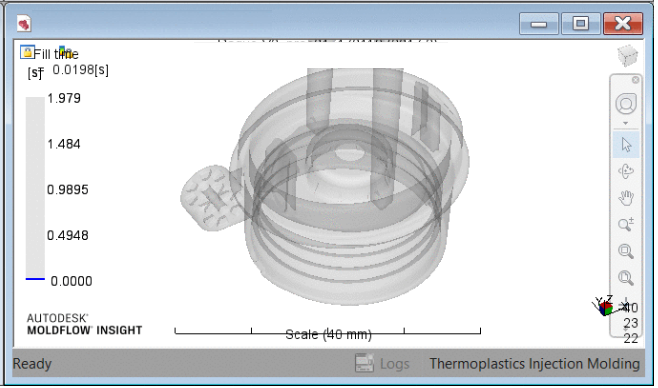
V3



V2



V4

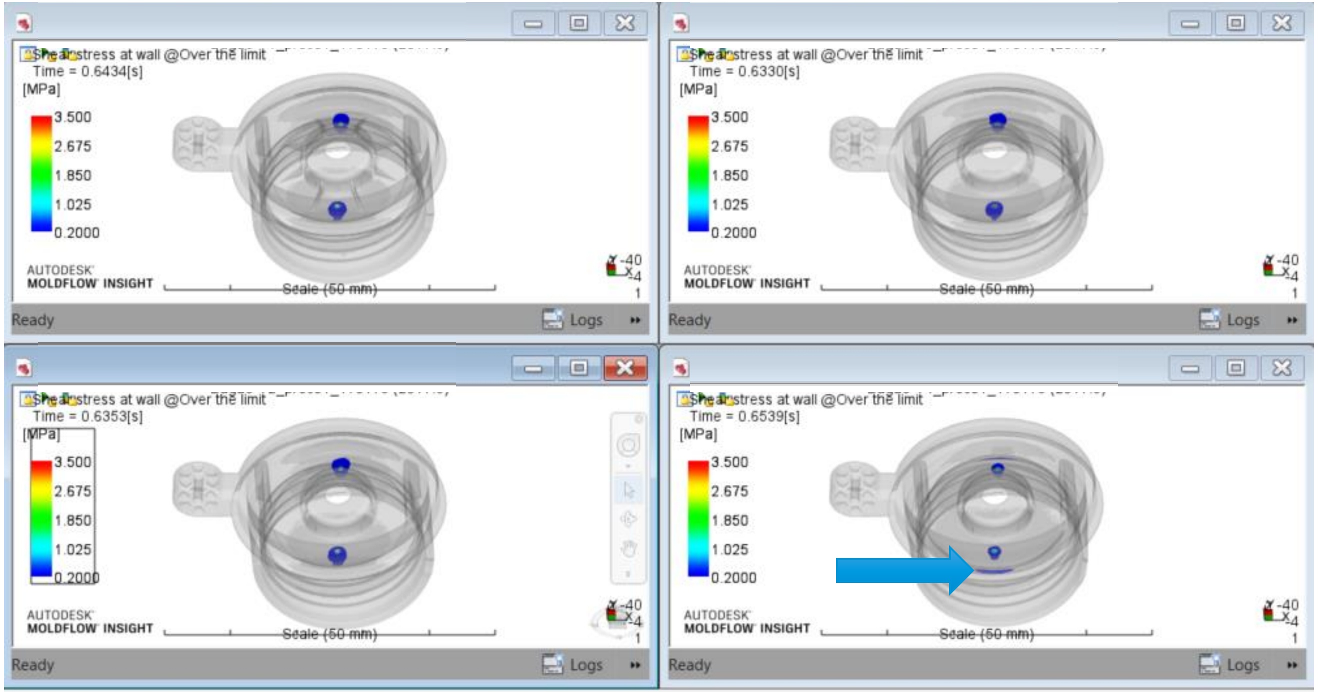


Single Cavity Results – Shear Stress

- The maximum shear stress at wall value is greater than the material limit on the V4 out of the gate region

V1

V3

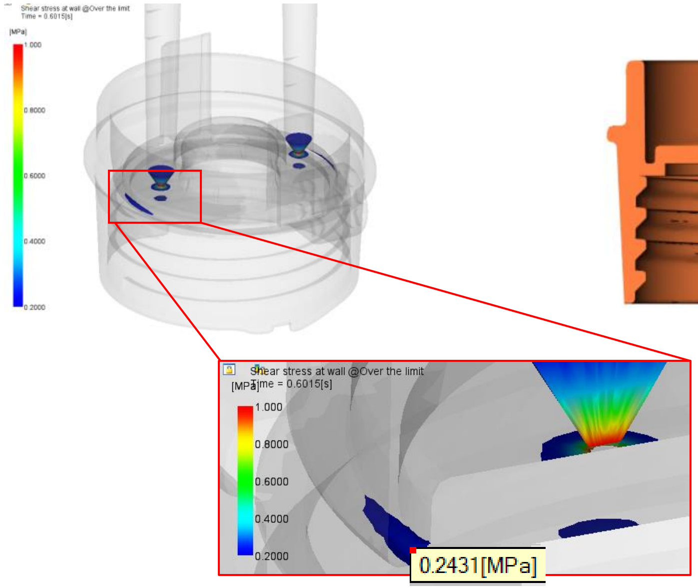


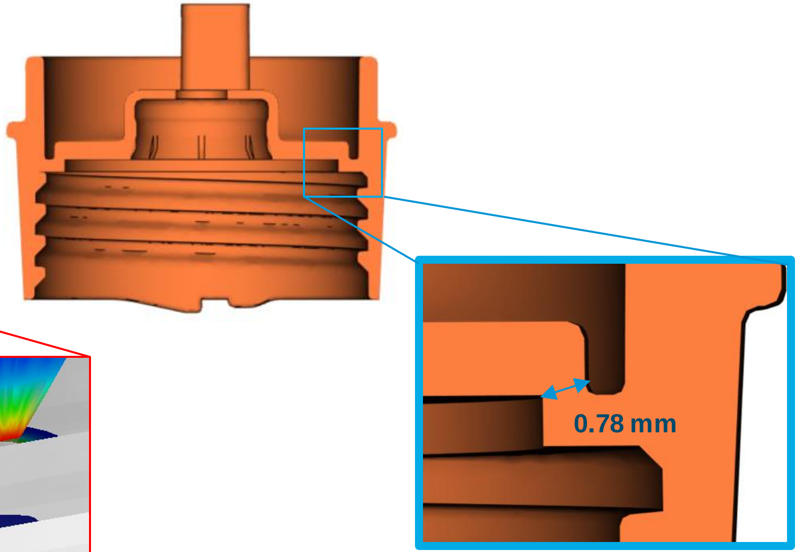
V2

V4

Single Cavity Results – Shear Stress V4

- This thickness variation may lead to a weak mechanical spot on the part. The recommendation is to review this thickness point



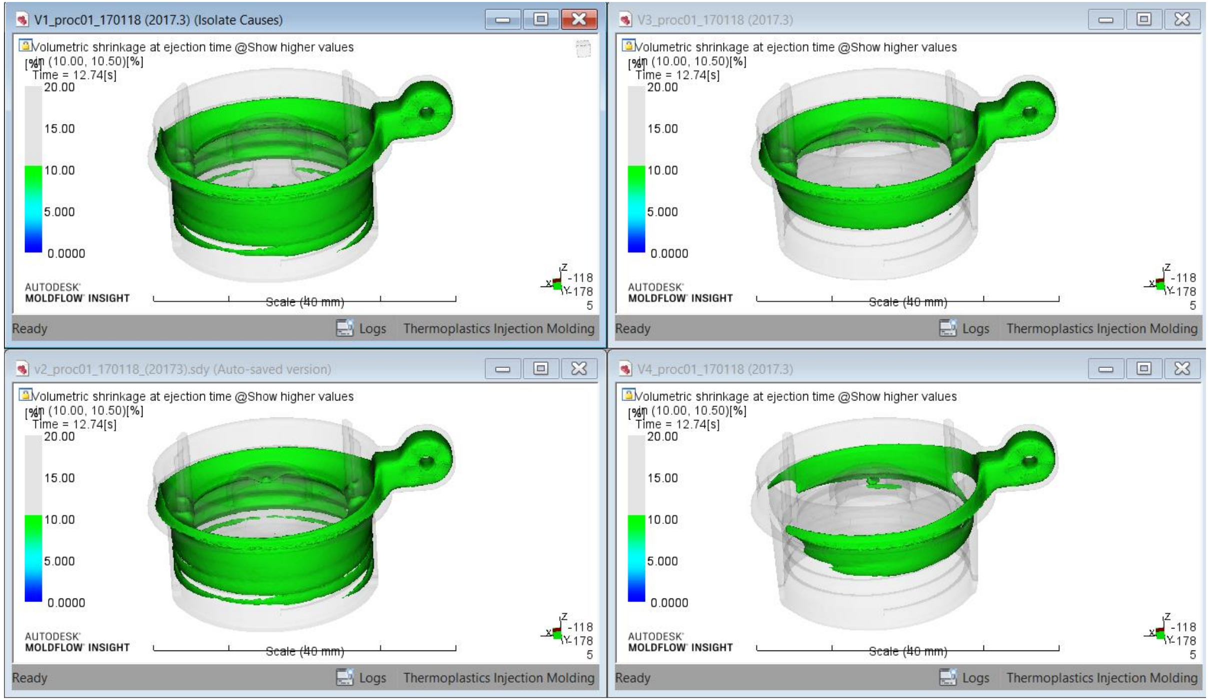


Single Cavity Results – Volumetric Shrinkage

- The part does not show uniform shrinkage values throughout the part. This is important for good packing of the material, ensuring good structural and visual integrity of the part

V1

V3



V2

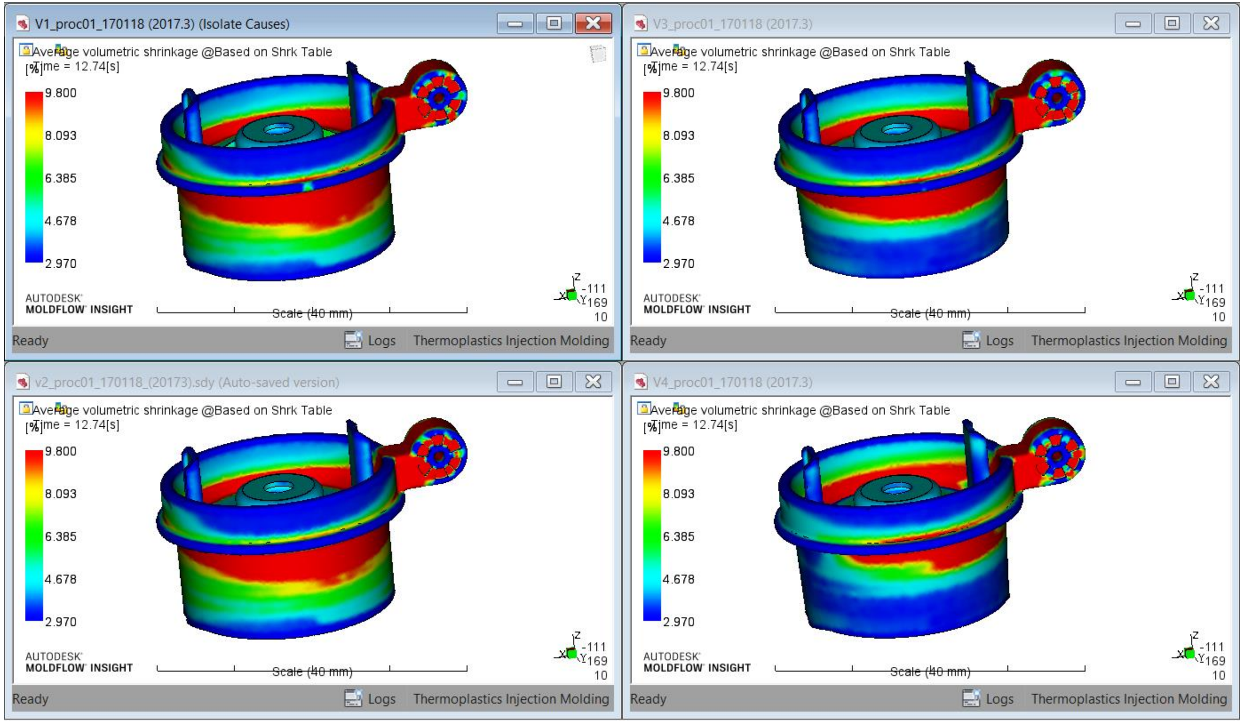
V4

Single Cavity Results – AVG Volumetric Shrinkage

- The average volumetric shrinkage values are not in the expected range for the material

V1

V3

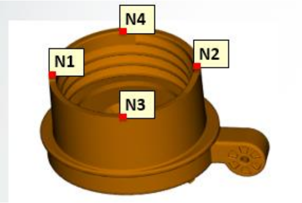


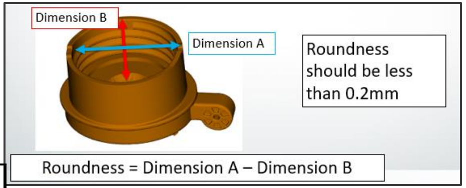
V2

V4

Single Cavity Results – Roundness

- The roundness changed 16% when the geometry was modified
- All results are below the limit of 0.2mm





	Node Deflection [mm]						
	N1	N2	N3	N4	Dimension A	Dimension B	Roundness
V1	0.34	-0.33	-0.28	0.27	0.67	0.55	0.12
V2	0.34	-0.33	-0.27	0.27	0.67	0.54	0.13
V3	0.32	-0.32	-0.25	0.25	0.64	0.5	0.14
V4	0.26	-0.38	-0.26	0.26	0.64	0.52	0.12

	Roundness - Isolate Causes			
	Total	DC	DS	OE
V1	0.12	0.04	0.08	0
V2	0.13	0.04	0.07	0
V3	0.14	0.04	0.08	0
V4	0.12	0.02	0.06	0

The main cause is **differential shrinkage**

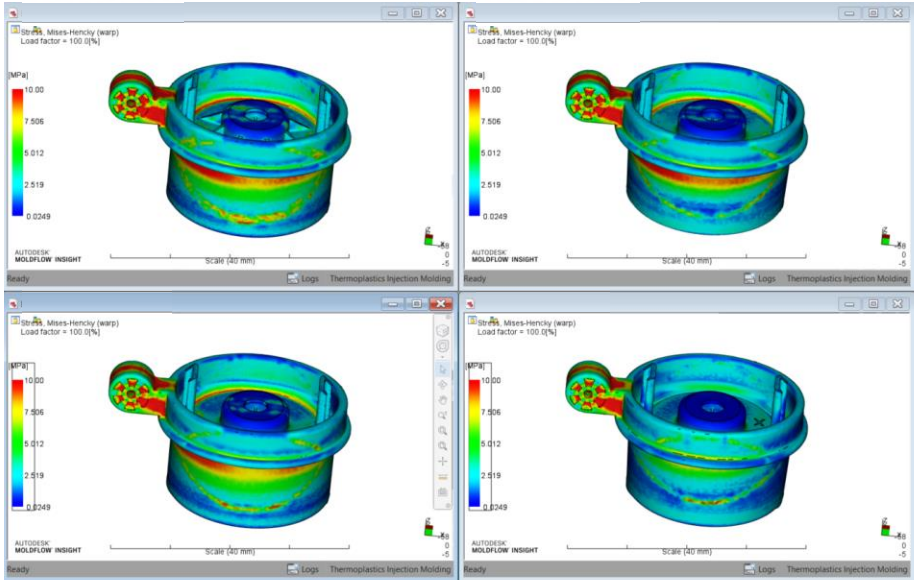
Single Cavity Results – Stress, Misses-Hencky

- The part presents greater stress Misses-Hencky tensor at higher thickness points due the differential volumetric shrinkage

- The recommendation is to normalize the nominal thickness to reduce the differential volumetric shrinkage

V1

V3



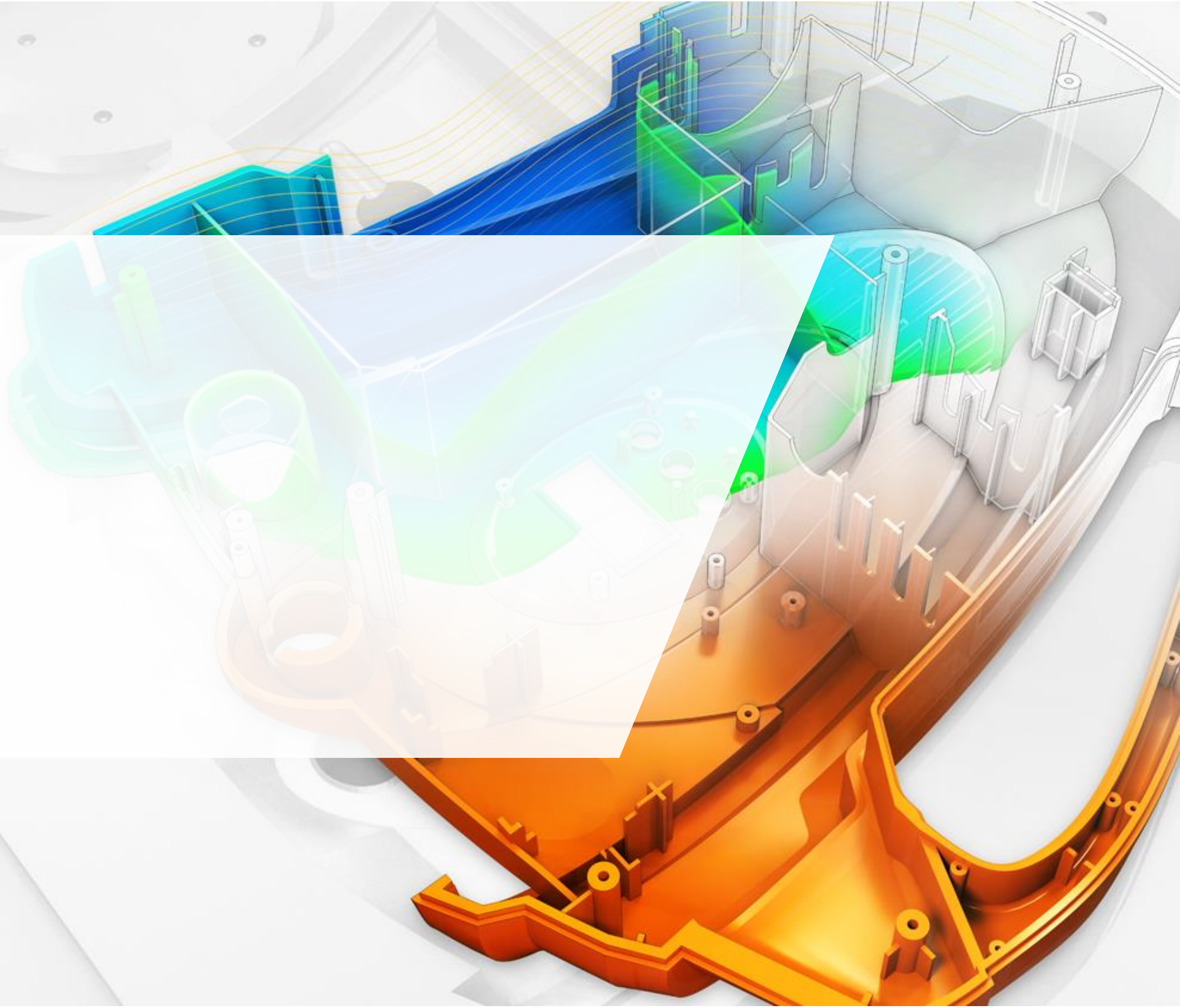
V2

V4

Single Cavity Results – Conclusions

- The previous shop floor information was that the roundness was higher than the limit
- The simulation roundness results were the same for all geometries
- The main warpage cause is the differential shrinkage (DS)
- Only V4 showed a mechanical weakness spot that could explain the stress cracking problem

DOE on shop floor

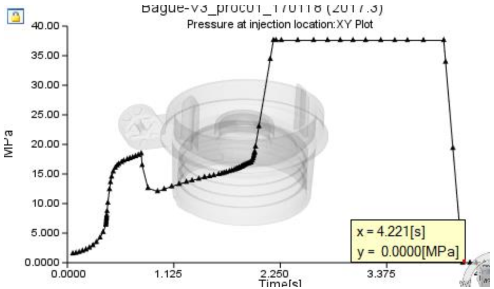


Design of Experiment (DOE)

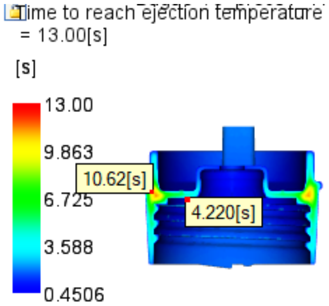
Input Parameters

- Since the main cause was DS
  - All input parameters were chosen, as volumetric shrinkage was shown to be affected by it
- The volumetric shrinkage is higher because:
  - The thinkness where the gate is located froze earlier
  - The pressure pack went to 0 MPa before the gate froze

Pressure at injection location



Time to reach ejection temperature



Regions over Transition Temperature

DOE – Experiments Table

	DOE Inputs				
runs	Mold temperature	Melt Temperature	Packing time	Injection time	Packing Pressure
1	25	225	4	1.88	50
2	25	225	4	1.88	20
3	25	225	4	1.6	20
4	25	225	4	2.5	50
5	25	225	4	2.5	35
6	25	225	2	1.88	35
7	25	225	2	2.5	50
8	25	250	4	1.88	35
9	25	250	4	2.5	50
10	25	250	4	2.3	20
11	25	250	2	1.88	50
12	25	250	2	1.88	20
13	25	250	2	2.3	35
14	30	190	2	2.3	50
15	30	190	2	1.8	50
16	30	190	4	1.8	20

Design of Experiment (DOE)

Output Parameters

- Only the roundness was measured
- The stress cracking was not possible to study due to the high test duration and cost

Input

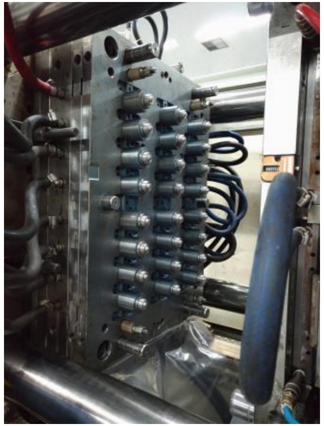
Mold temperature →
Melt temperatue →
Packing time →
Injection time →
Packing Pressure →

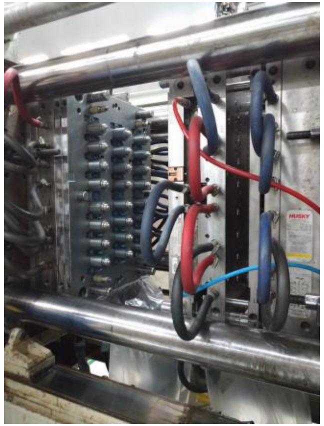
→ Roundness

Output

The Mold

- The mold has 24 cavities:
  - One Baseline V1 cavity
  - Eleven Version 3 V3 Cavities
  - Twelve Version 4 V4 Cavities
    - The difference between cavities could cause unbalanced flow and unexpected results



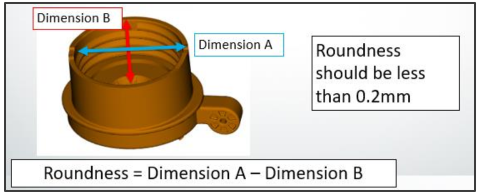


Short Shot Result

- A small difference between cavities was expected, since the cavities were different

- However, the filling pattern was almost the same for all cavities

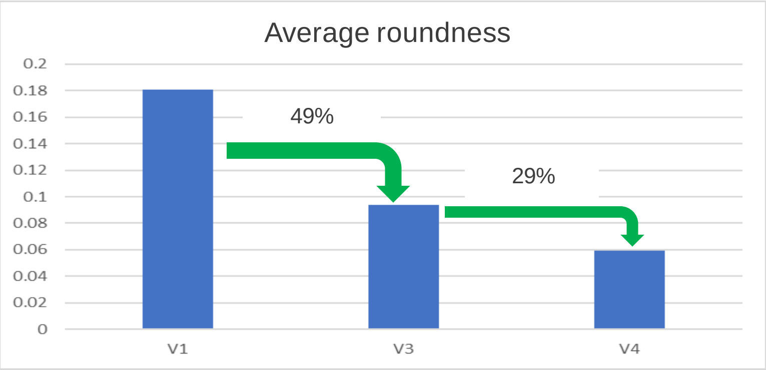
DOE Results - Roundness



Outputs - Roundness

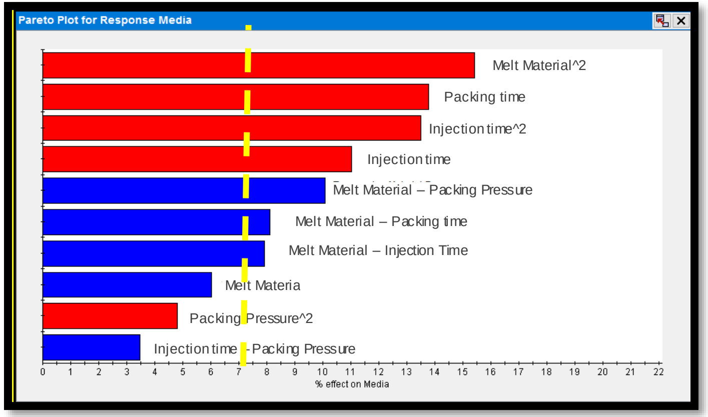
Runs o	V1	V3	V4
1	0.17	0.09	0.05
2	0.09	0.08	0.05
3	0.22	0.10	0.05
4	0.06	0.04	0.02
5	0.04	0.01	-0.01
6	0.20	0.19	0.20
7	0.23	0.14	0.16
8	0.23	0.13	0.10
9	0.09	0.00	0.03
10	0.22	0.07	0.03
11	0.30	0.16	0.09
12	0.20	0.12	0.03
13	0.23	0.09	0.05
14	0.14	0.04	0.01
15	0.17	0.12	0.09
16	0.24	0.14	0.01
Average	0.18	0.09	0.06
standard deviation	0.08	0.05	0.06

The roundness decreased with the geometry modifications



The top 3 parameters:

1. Melt temperature
2. Packing time
3. Injection time



DOE Results - Roundness

Outputs - Roundness

Runs o	V1	V3	V4
1	0.17	0.09	0.05
2	0.09	0.08	0.05
3	0.22	0.10	0.05
4	0.06	0.04	0.02
5	0.04	0.01	-0.01
6	**0.20**	**0.19**	**0.20**
7	0.23	0.14	0.16
8	0.23	0.13	0.10
9	0.09	0.00	0.03
10	0.22	0.07	0.03
11	0.30	0.16	0.09
12	0.20	0.12	0.03
13	0.23	0.09	0.05
14	0.14	0.04	0.01
15	0.17	0.12	0.09
16	0.24	0.14	0.01
Average	0.18	0.09	0.06
standard deviation	0.08	0.05	0.06

Run number 6 is the closest process parameter to the process parameter used at initial analysis.
The roundness for all geometries is the same as the initial analysis result but the real value is higher than simulation value

	Initial Analysis results		
Plot	**V1**	**V3**	**V4**
Roundness	0.12 mm	0.14 mm	0.12 mm

Conclusion

- The DOE results confirm a misunderstanding from the previous information.
- Since the process parameters effect the results, the previous information could be affected by a lack of process parameter information
- The results confirm a similar roundness trend that was obtained at the initial analysis

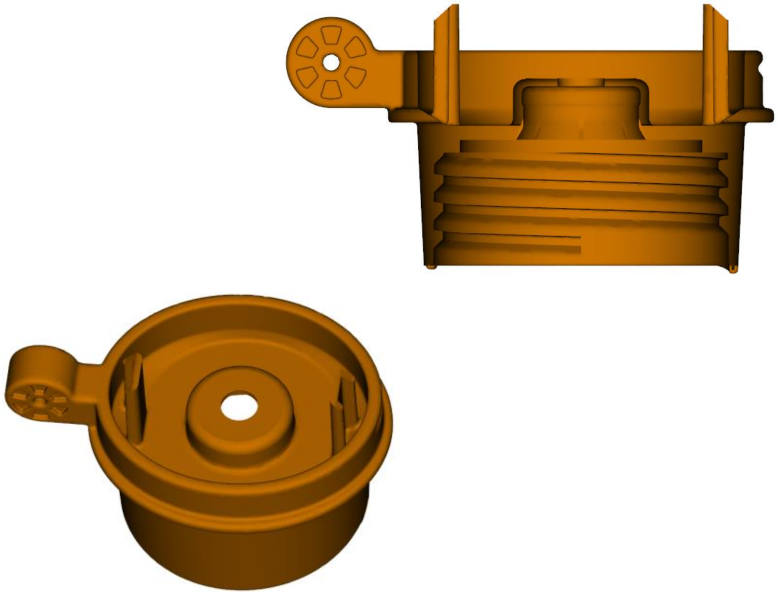
Real DOE vs Virtual DOE

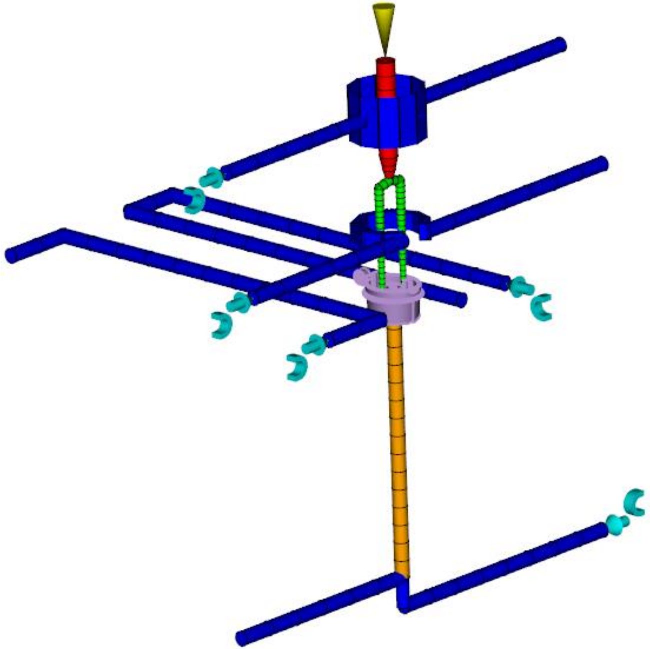
Virtual DOE

- Due to the high computational cost, only the V3 model was used
  - V3 model was used instead of V4 model due to a weak mechanical spot
- The Moldflow command line was used to obtain study files and results

Virtual DOE – Baseline Model

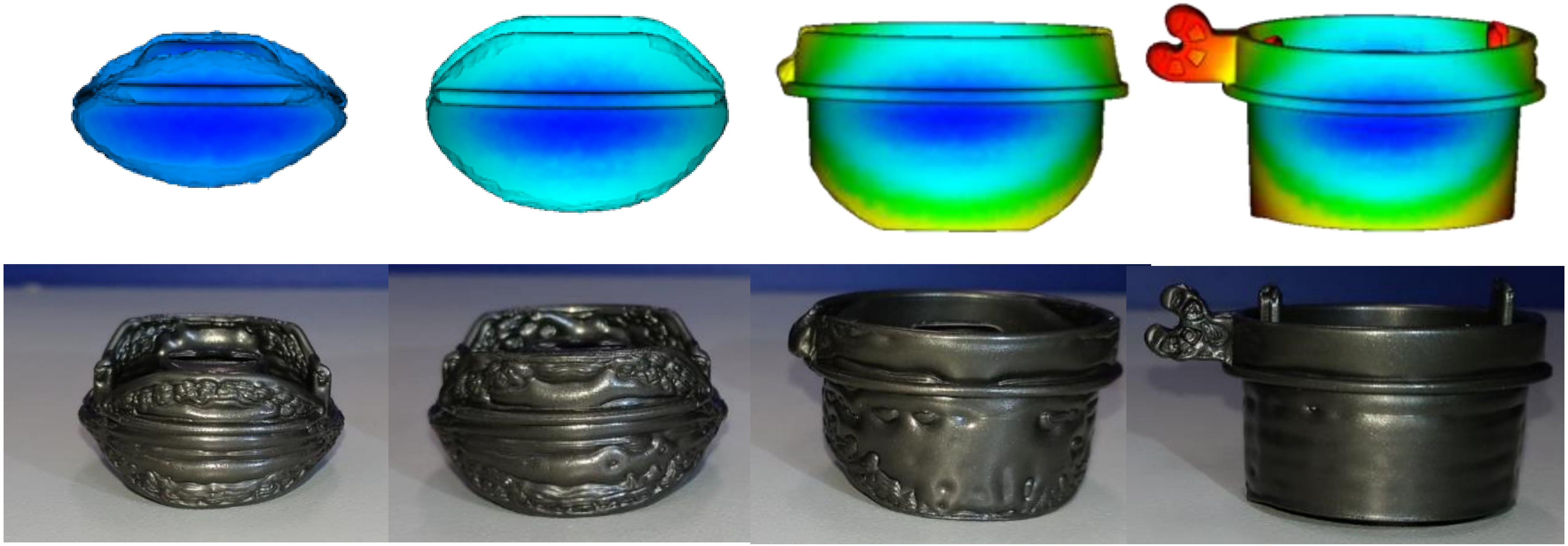
- The baseline model was the V3 used during the initial analysis





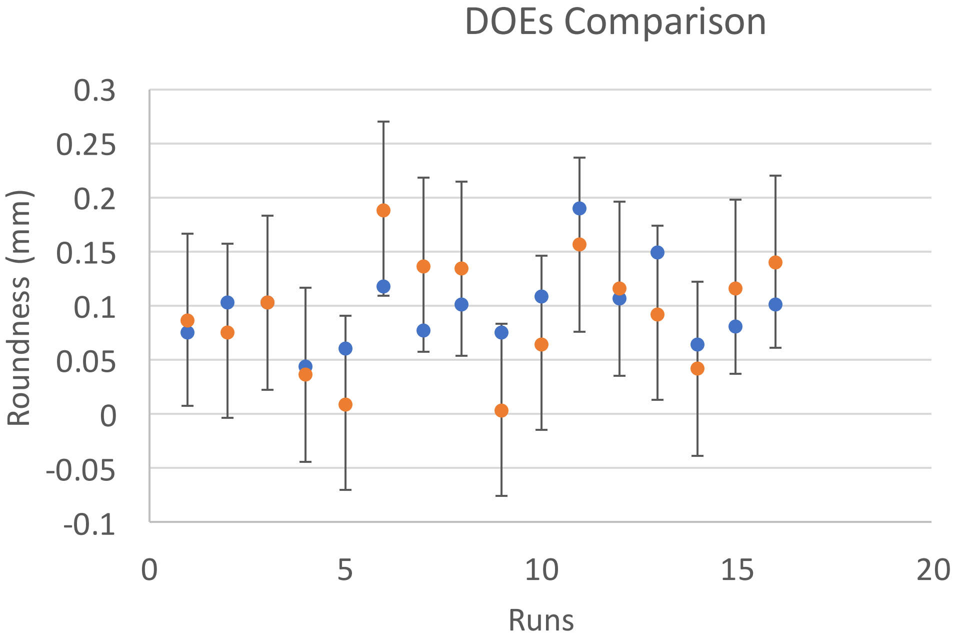
DOE Comparison – Short Shot

- The fill time result is very similar to short shot samples



Comparing of DOEs

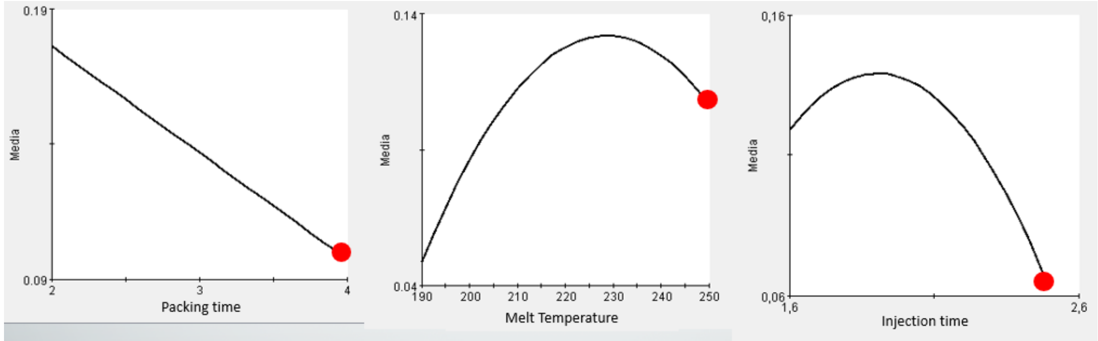
- The simulation results (Blue points) are similar to real measures (Orange points) by considering the standard deviation (The vertical lines)



	Moldflow DOE (mm)	Real DOE (mm)
Average	0.10	0.09
standard deviation	0.04	0.05

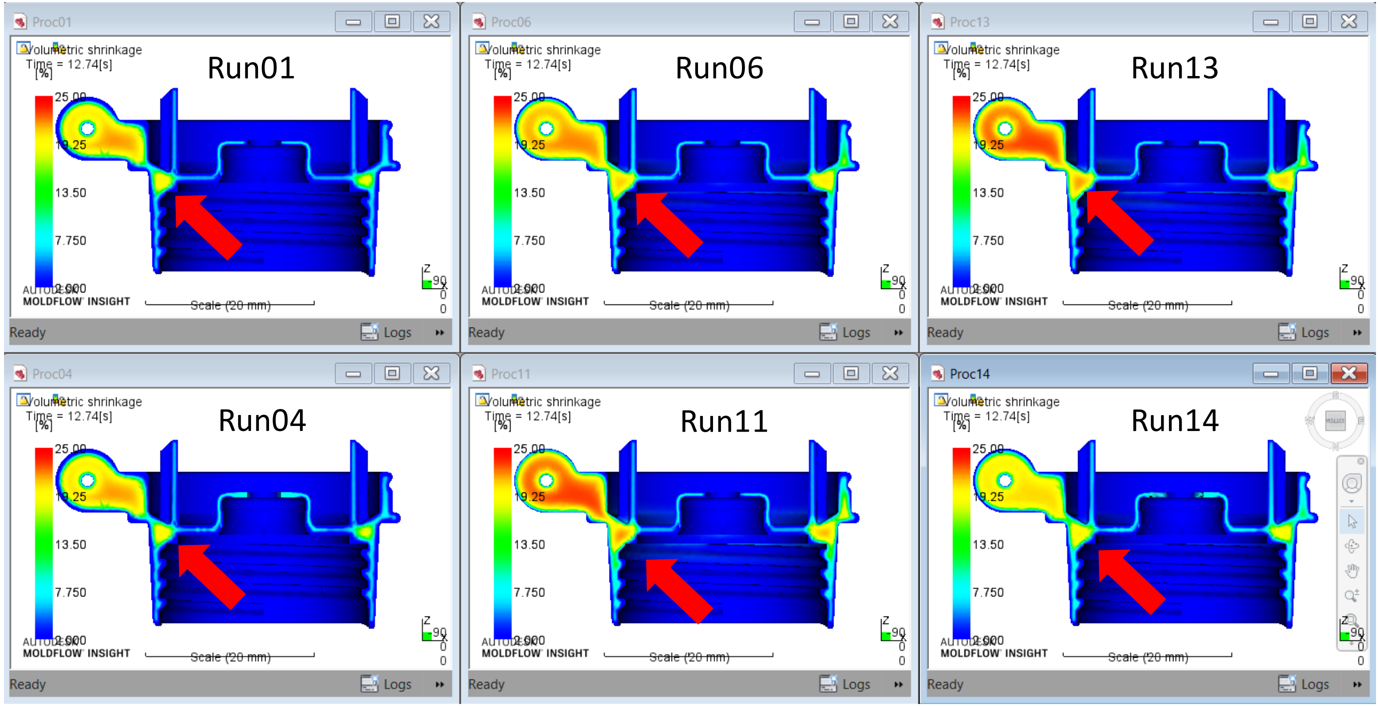
DOE – Process Parameters Optimized

- The process parameters optimized are:
  - Packing time – 4s
  - Temperature – 250°C | The temperature could be 210 or lower but it could increase the risk of stress cracking
  - Injection time- 2.5s | Without any mold changing | The higher injection time could increase residual stress and the risk of stress cracking, however the small injection time increases the shear rate.



DOE – Volumetric Shrinkage

- The part is more out of round when the volumetric shrinkage is higher.



run	Roundness Moldflow DOE (mm)
1	0.08
4	0.04
6	0.12
11	0.19
13	0.15
14	0.06

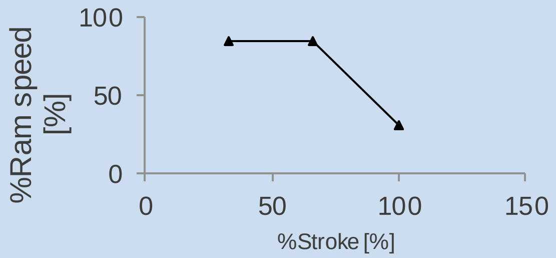
Conclusions

- The virtual DOE results was close to real DOE if the process variation is considered
- Improving the packing on the chunk thickness point, reducing the volumetric shrinkage variation and then reducing the roundness
- There are two potential roots for stress cracking problem:
  - The high stress tensor due to the volumetric shrinkage variation
  - Low stiffness due to the low thickness point (A structural software is recommended to simulate the assembly)

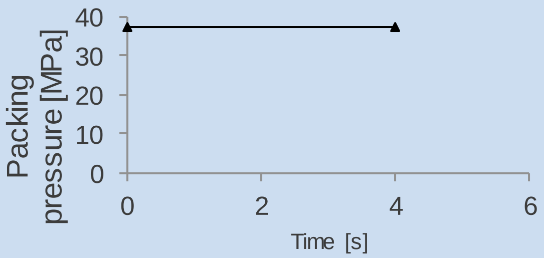
Conclusions – New Proc. Param. Recommendation

Description	Value	Units
Coolant temperature	25	C
Melt Temperature	250	C
Filling control	%Stroke - %Ram speed	
Injection time	2.5	s
Velocity/pressure switch-over % volume filled	99	%
Pack/holding control	Time - Packing pressure	
Cooling time	20	s

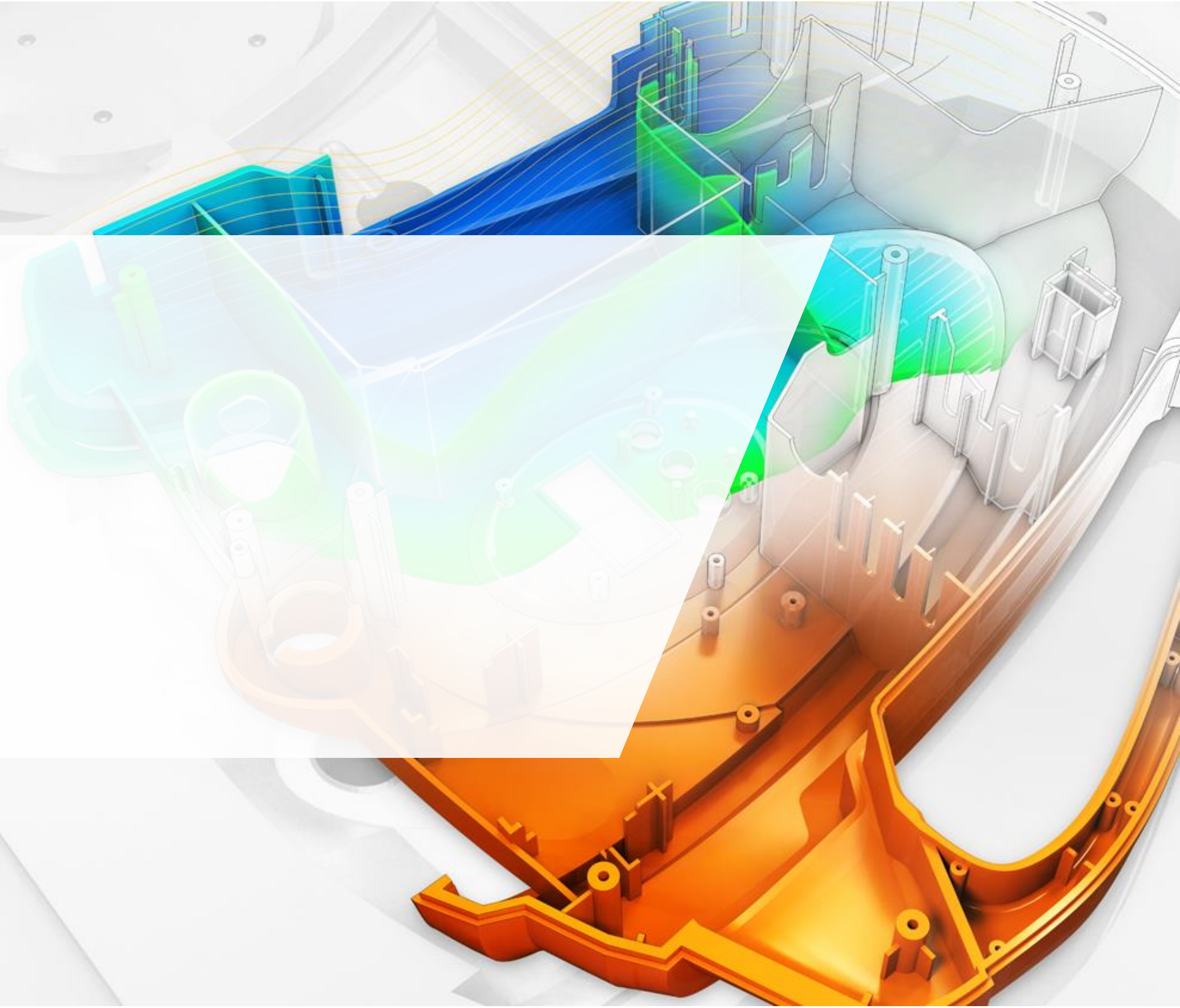
Filling control



Pack/holding control

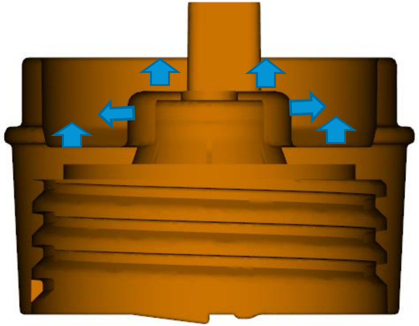


Recommendations

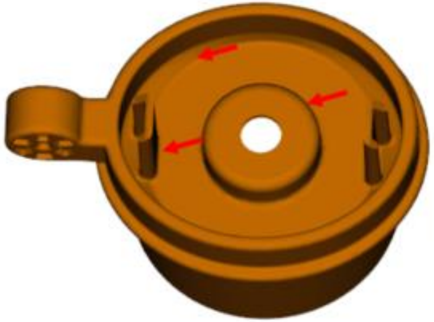


Recommendation

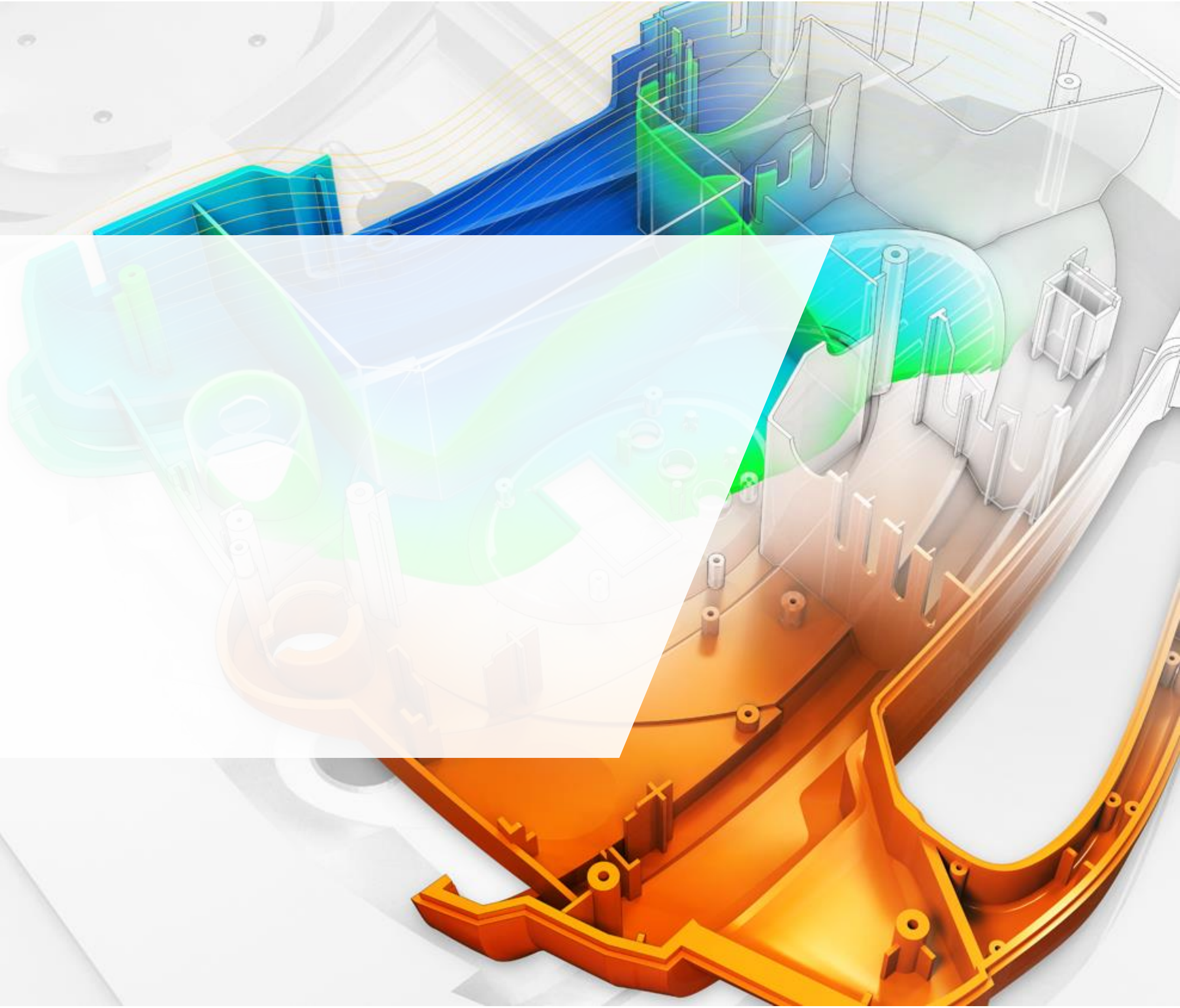
- To increase the part thickness by 0.1 or 0.2mm at the gate location



- Increase the radius to reduce potential stress points during assembly



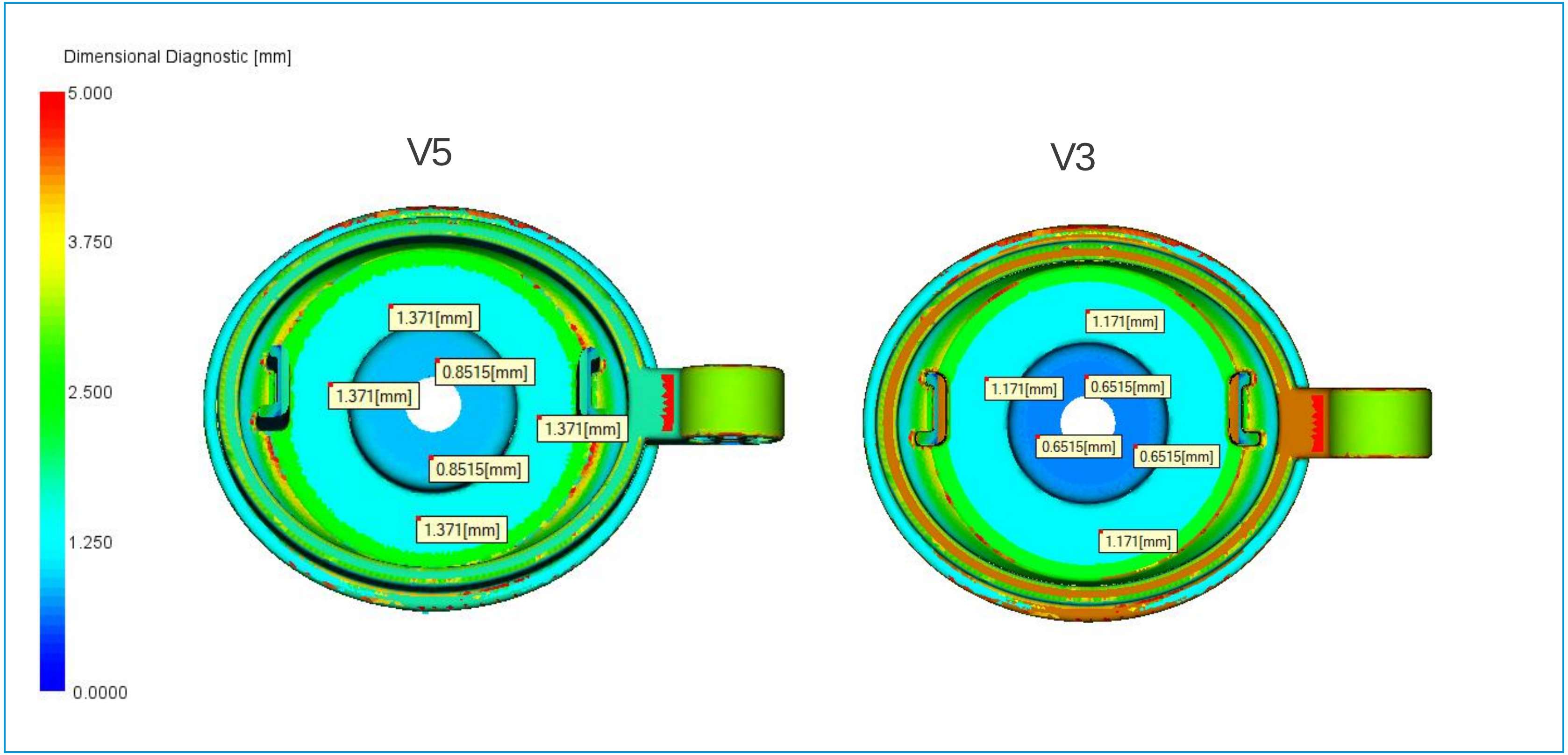
Final Report



Customer Modification Decision

- The 0.2mm thickness increase at the gate surface location was approved
- The DOE process recommendation was used

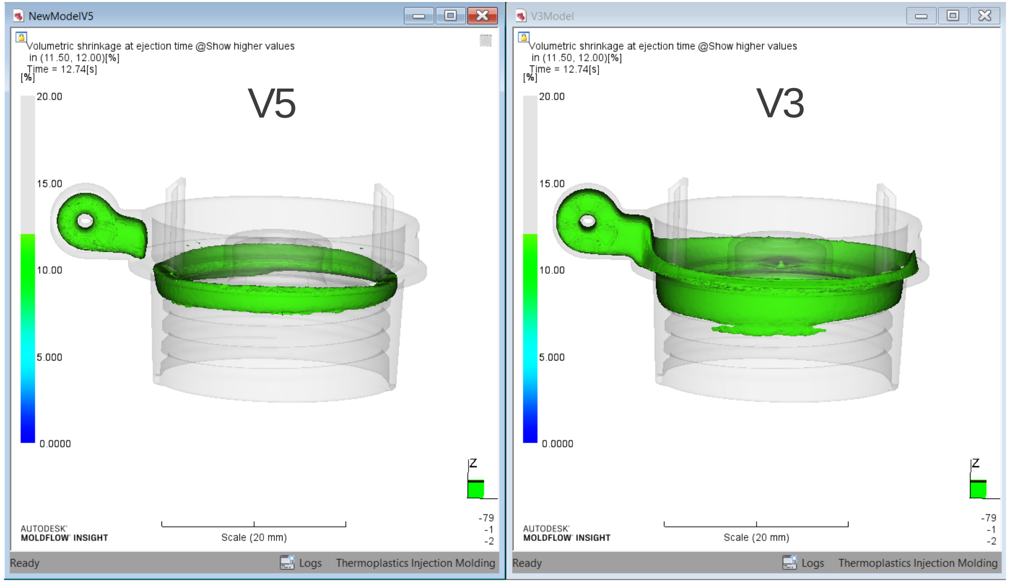
New Model – V5


Dimensional Diagnostic [mm]
5.000
3.750
2.500
1.250
0.0000
V5
1.371[mm]
0.8515[mm]
1.371[mm]
1.371[mm]
0.8515[mm]
1.371[mm]
V3
1.171[mm]
1.171[mm]
0.6515[mm]
0.6515[mm]
0.6515[mm]
1.171[mm]

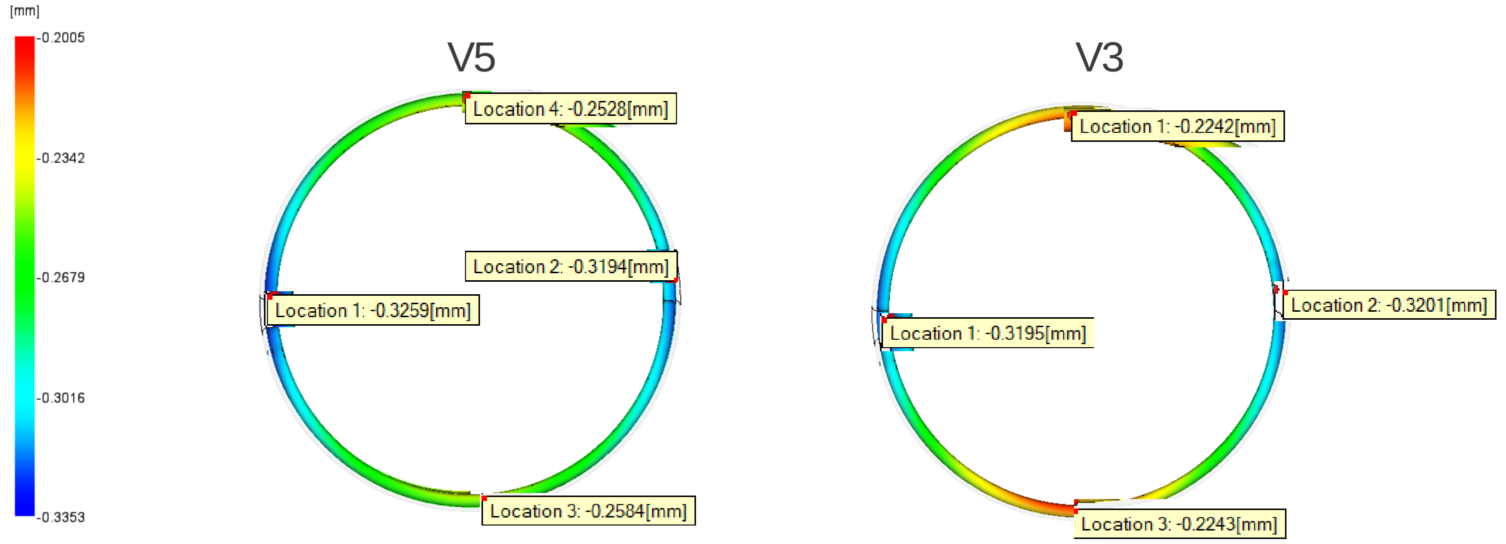
New Model – Volumetric Shrinkage at Ejection Time

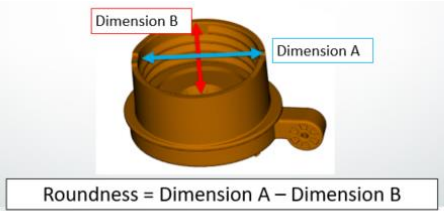
- As seen in the image below, the new model and process setting (DOE Recommendation) reduce the volumetric shrinkage and, as expected, the roundness

- Besides that, the values are not in the expected range for the material yet



New Model - Roundness





Roundness

New Model

0.13mm

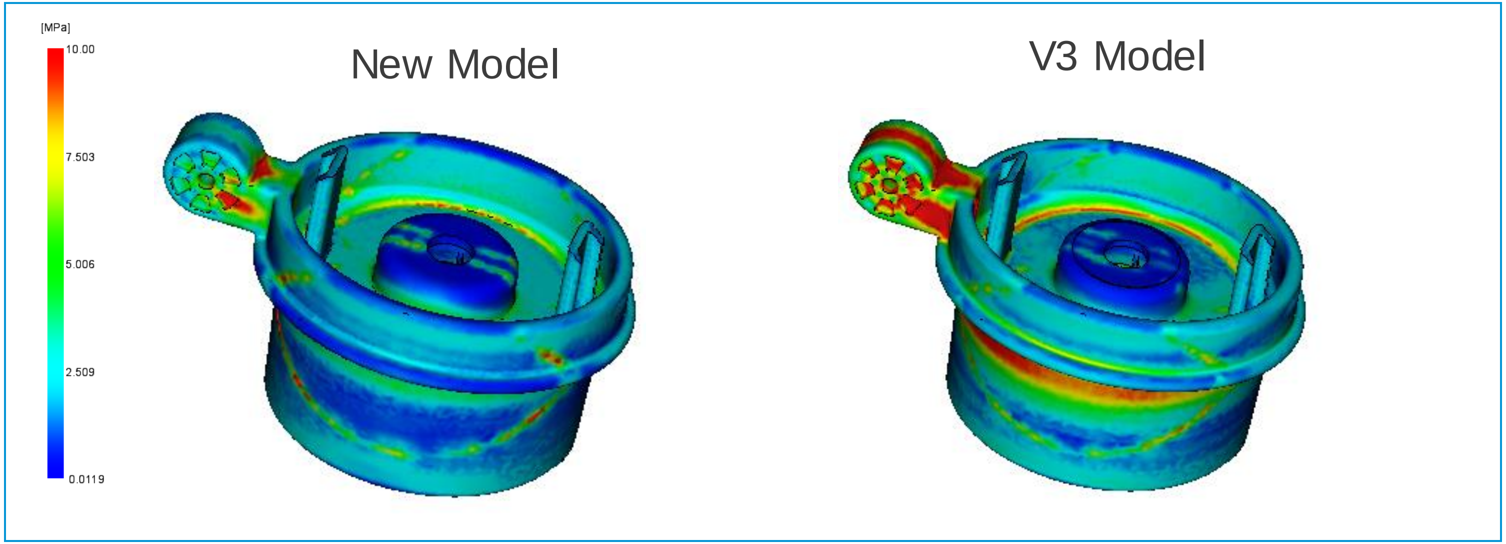
V3 Model

0.19mm

New Model – Stress, Misses-Hencky

- The new model presents lower Misses-Hencky stress variation and less high stress points at surface

- It occurs because the new model has more uniform volumetric shrinkage



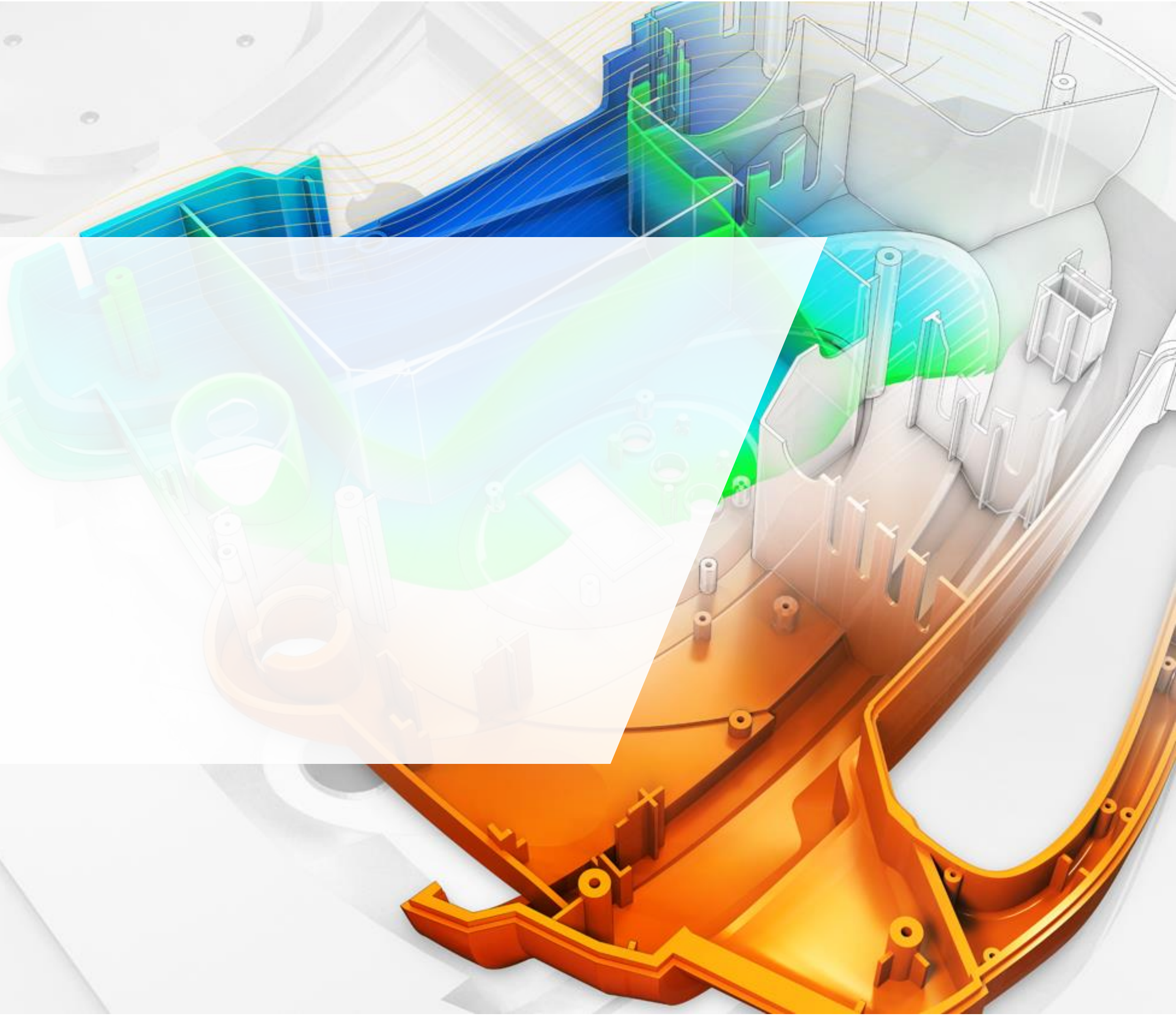
Final Conclusions

- The geometry modification reduces the roundness by reducing the volumetric shrinkage variation

- It also helps to reduce the stress tensor, which may lead to a better performance during the stress cracking test

- Besides that, the part still presents some point outside of the criteria where it did not present a problem in the current production

Final Comments



Customer Feedback

- The new geometry did not present a roundness problem
- After 48 hours of stress cracking testing, the part did not present any cracks
- The production was approved
- The customer did not provide material for new correlation between simulation and final production

Simulation compared to molded parts

- The filling pattern was quite similar to the Moldflow results
- The roundness measure matched with the Moldflow prediction if the standard deviation is considered
- Considering the material used in the simulation was a similar one, the simulation results were close to molded parts and were enough to work on the problem and fix it

What Would I Do Differently Next Time?

- Try an injection molding machine and tooling with more features such as pressure and temperature sensors
- Use all cavities with the same geometry
- Start the simulations before the tooling production
- Ask for the material characterization
- Run a new DOE to define the final process setting for the new model

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