Productivity Advantages of Lightweight Injection Molded Thermoplastics Enabled by 3M Hollow Glass Microspheres

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Outline

- Background
  - Glass bubbles
  - Initial work
- Experimental
  - Tooling
  - Processing
  - Measurements
- Case Studies : Materials
  - 20% talc Polypropylene
  - 20% glass fiber + 10% mineral Polypropylene
  - PA66
- Results
  - Mechanical properties
  - Processing savings
  - Cycle time
  - Warp improvement
- Applications
- Summary
- Acknowledgements

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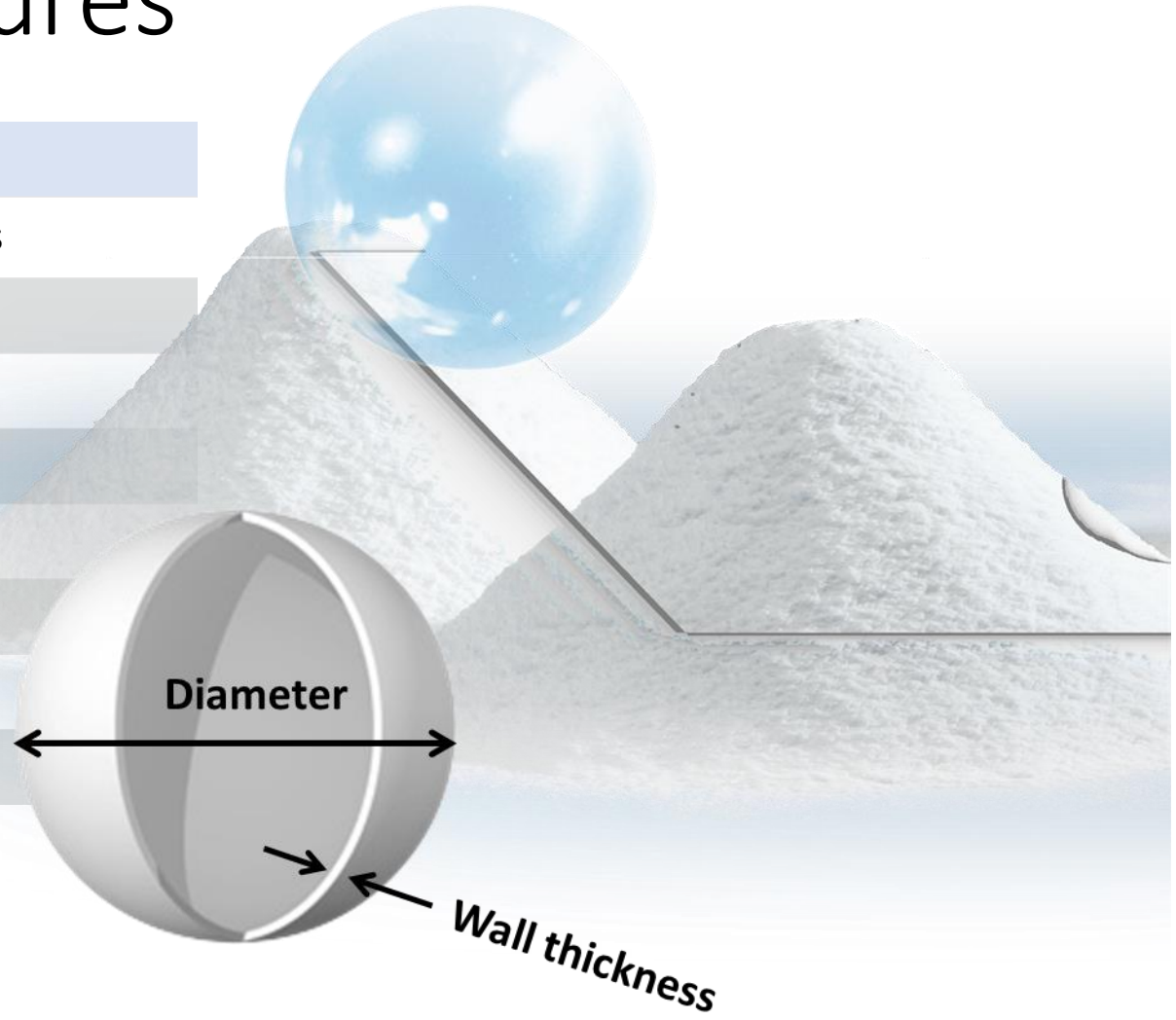
3M™ Glass Bubbles Features

Property	Value
Shape	Hollow, thin walled, unicellular spheres
Composition	Soda-lime borosilicate glass
Color	White
True Density†	0.12 - 0.60 g/cc
Crush Strength*	250 – 28,000 psi
Hardness	Mohs scale 5
Softening Temp	600° C
Average Dia	15 - 65 microns

•3M internal QCM

† Helium Gas Pycnometer



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3M™ Glass Bubbles Key Attributes and Benefits

Glass Bubble Attributes

- Low Density
- Spherical (AR = 1)
- White
- Thermally Stable
- Water Stable
- Micron PS, PSD
- Easy Flowing
- Low K Value
- Wide Strength Range
- Low Surface to Volume Ratio

Benefits

- Light Weight
- Dimensional Stability
- Processing Improvements
- Insulation (Acoustical, Thermal, Electrical)
- Good Composite Properties
- Good Aesthetics
- Low Viscosity Build/Resin Demand

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Cycle time?

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Increased Cooling Rates with Glass Bubbles

The theoretical cooling time for an injection molded plate:

$$\downarrow t_c = \frac{h^2}{\pi^2 \alpha \uparrow} \ln\left(\frac{4}{\pi} \frac{T_{melt} - T_{mold}}{T_{eject} - T_{mold}}\right)$$

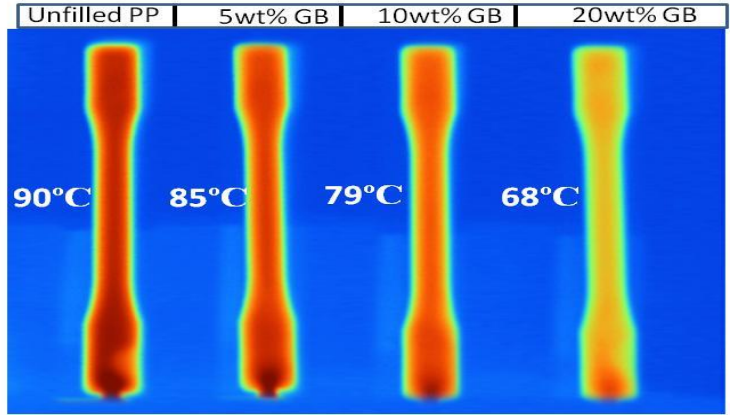
Where
t_c: Cooling time
h: Part thickness
α: Thermal Diffusivity
T: Temperature

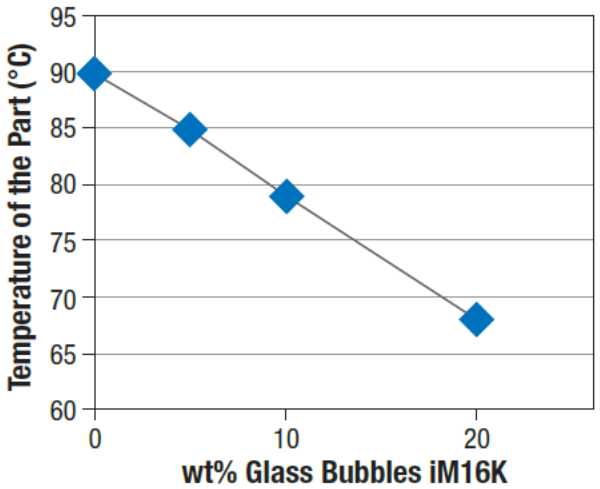
↑ Glass Bubble weight fraction

↓ Density, composite specific heat capacity

↑ Thermal diffusivity (α) and cooling rates

Initial work at 3M on PP tensile bars showed decreased part temperatures with increasing glass bubble content





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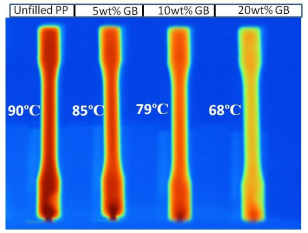
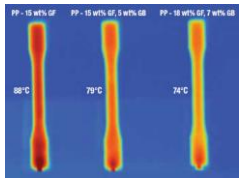
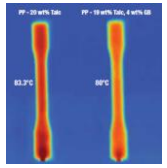
Effect of Glass Bubble Content on Cycle time – Initial Work

- Initial work by 3M and SKZ Institute showed variability in cycle time reduction depending on base resin and additional fillers.
- Further research on larger parts would help further understand the effect of glass bubbles on cycle time and processing improvements







Component	GB Loading	Other Fillers	Cycle Time (sec)	Cycle time reduction (%)
Unfilled PP	0	-	16	-
	5 wt.%	-	14.7	8
	10 wt.%	-	13.1	18
	20 wt.%	-	10	38
Glass Fiber - Filled PP	0	15 wt.%	16	-
	5 wt.%	15 wt.%	13.5	16
	7 wt.%	18 wt.%	12.2	24
Talc - Filled PP	0	20 wt.%	16	-
	4 wt.%	10 wt.%	15	6
Glass Fiber - filled PA6*	0	0	40.2	-
	4 wt.%	13 wt.%	38.2	5
	7 wt.%	0	35.2	12

Dimensions: 60 x 60 x 2 mm

*Independent Study by SKZ Institute, Germany

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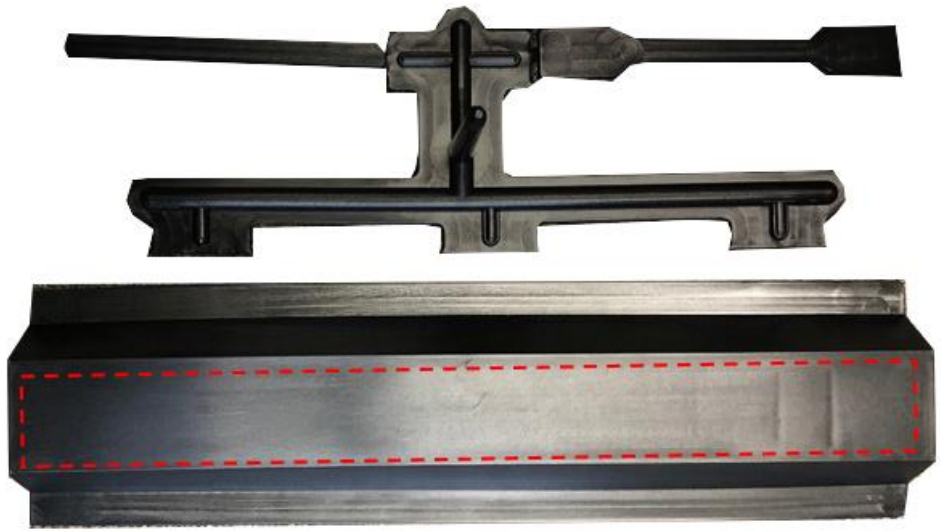
Experimental



1”

- Tooling - Ford Research Beam Tool
  - 14” Beam
  - Tensile Bar
  - Flex Bar
  - 2 Pressure Transducers
  - 5 Thermocouples
- Processing
  - Standard
    - Barrel and Tool temperatures recommended by material supplier
  - Optimized
    - Lower Barrel and Tool temperatures to simulate a condition that might be run at a supplier to maximize output

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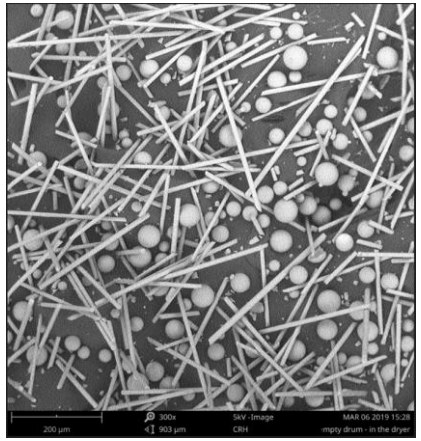
Experimental

- Measurement
  - Thermal – FlirONE camera
    - Measured 18s after ejection
  - Mechanical
    - Tensile
    - Flex
    - Charpy
  - Processing – RJG eDART data collection of temperature and pressure in the mold
  - Warp – DIC of Beam
  - Part Weight
  - Bubble Survivability – Gas Pycnometer

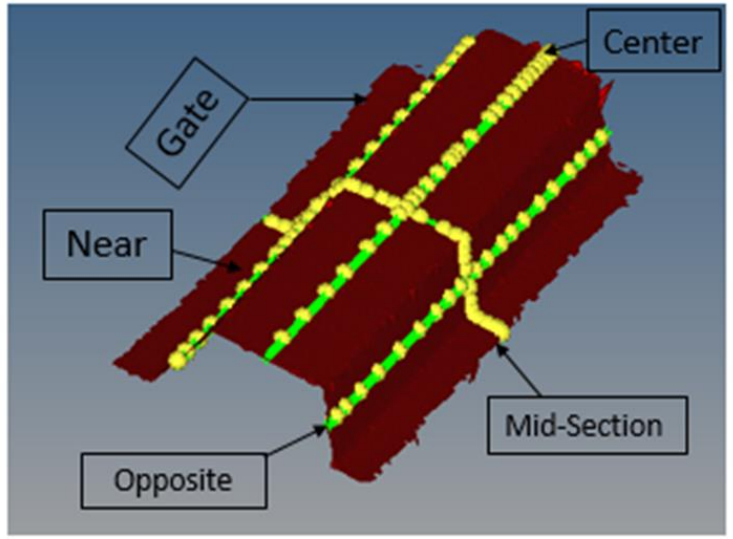
FlirONE Thermal Image of Beam

Bubble Retention



Warp -DIC

Multiple cameras use high contrast random speckle pattern to create a 3D mesh of the object



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Case Study I:

20% Talc + Polypropylene (PP T20)

↓

5% Glass Fiber + 5% Glass Bubbles +Polypropylene (PP GF5/GB5)

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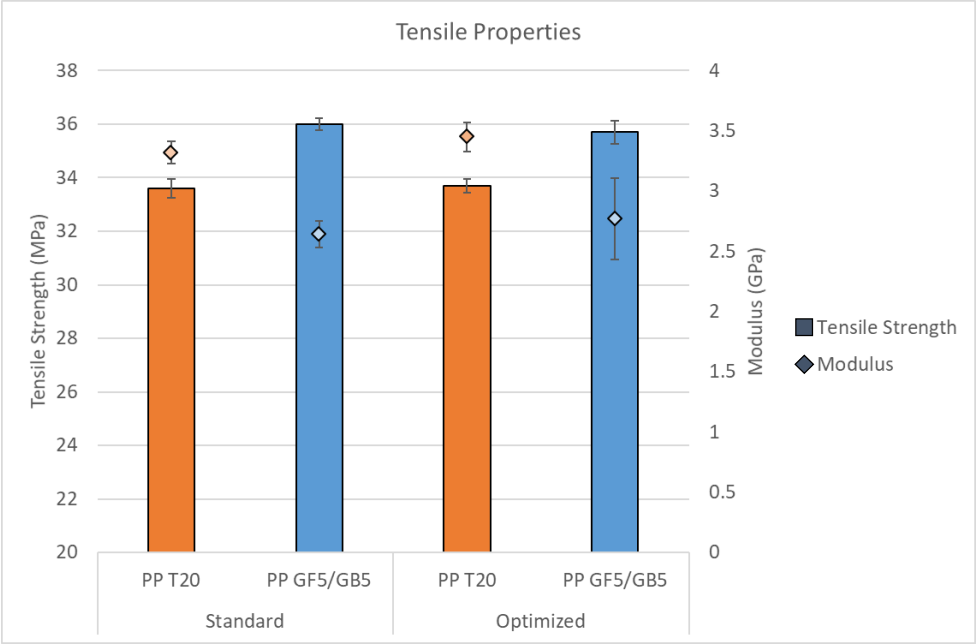
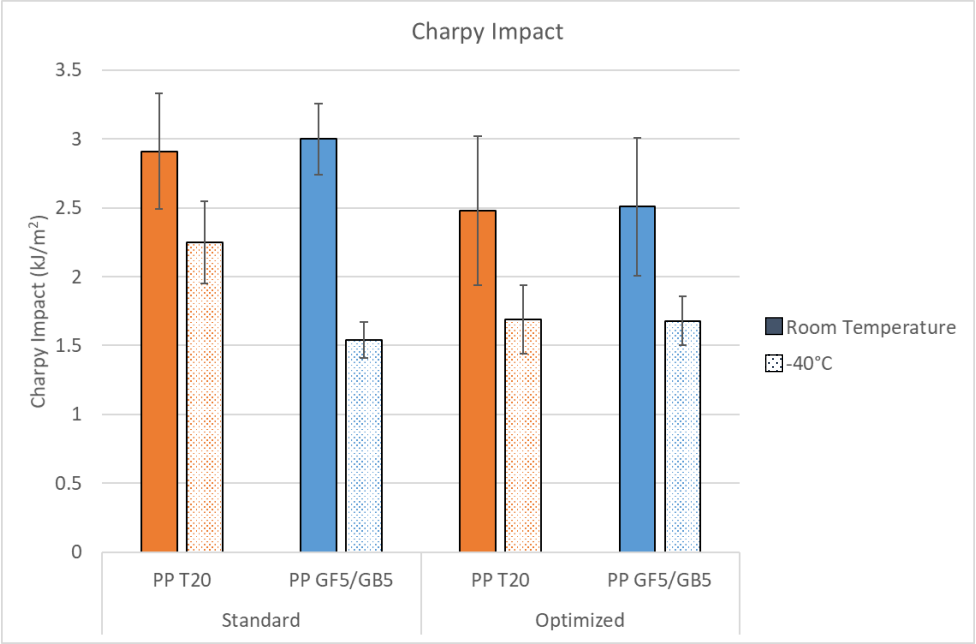
Case Study I:
PP T20 → PP GF5/GB5

	Barrel Temp (°F)	Mold Temp (°F)	Cooling Time (s)	Hold Time (s)
Standard	430	80	15	15
Optimized	390	80	15	10

- Part weight reduced from 133 g to 115 g (↓14%)
  - Confirmed by gas pycnometer to have minimal glass bubble breakage from processing
- Tensile strength increased 6%
- Tensile modulus decreased 20%
- Charpy impact shows negligible effect at both room temperature and -40°C





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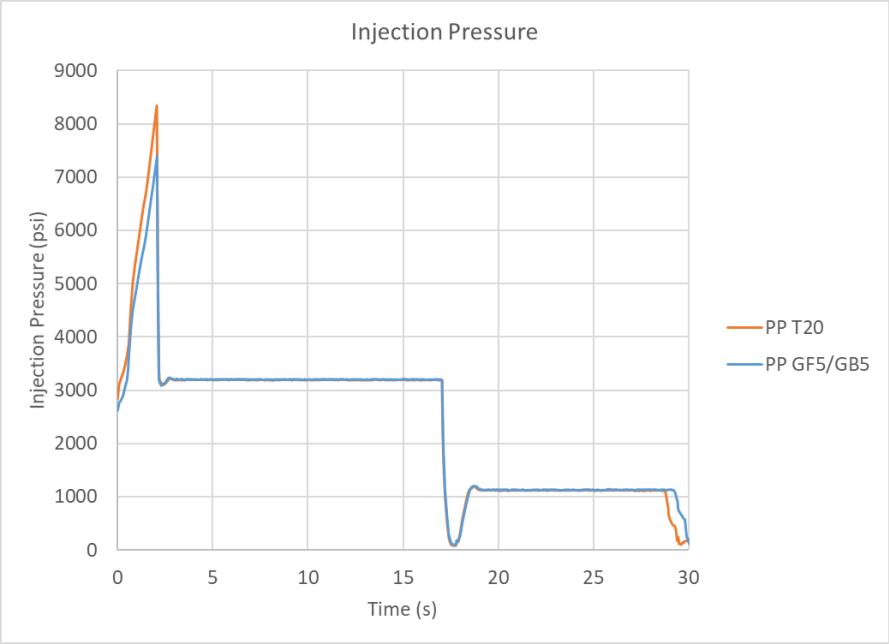
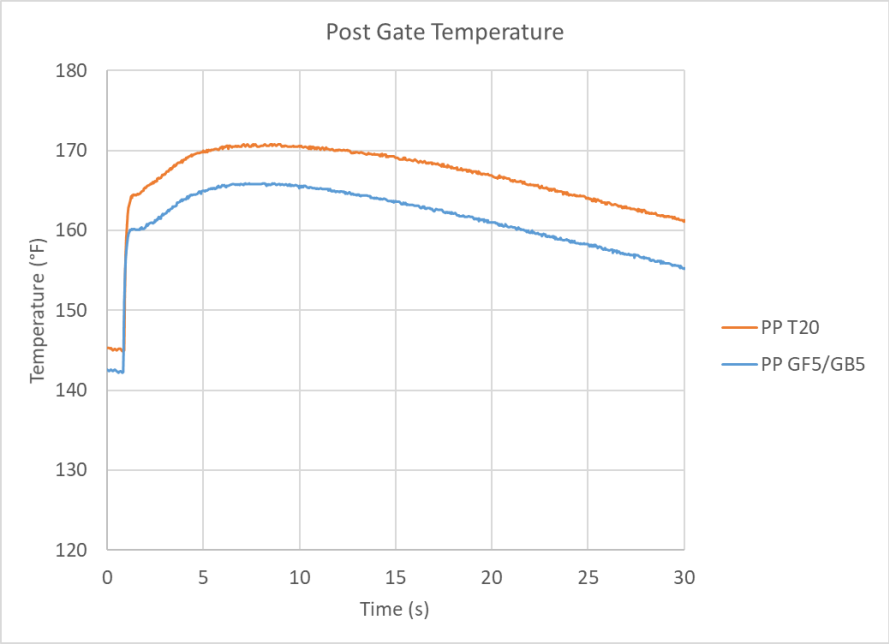
Case Study I:
PP T20 → PP GF5/GB5

- Maximum injection pressures drop up to 18% depending on molding conditions
  - Opportunity to use smaller press
- Maximum post gate temperatures drop ~5°F with glass bubble materials
  - Possibility for faster cycle times.

Material	Molding Condition	Max Injection Pressure (psi)		Maximum Post Gate Temperature (°F)	
PP T20 PP GF5/GB5	Standard	8345 7390	↓11%	171 166	↓3%
PP T20 PP GF5/GB5	Optimized	9862 8099	↓18%	168 162	↓4%





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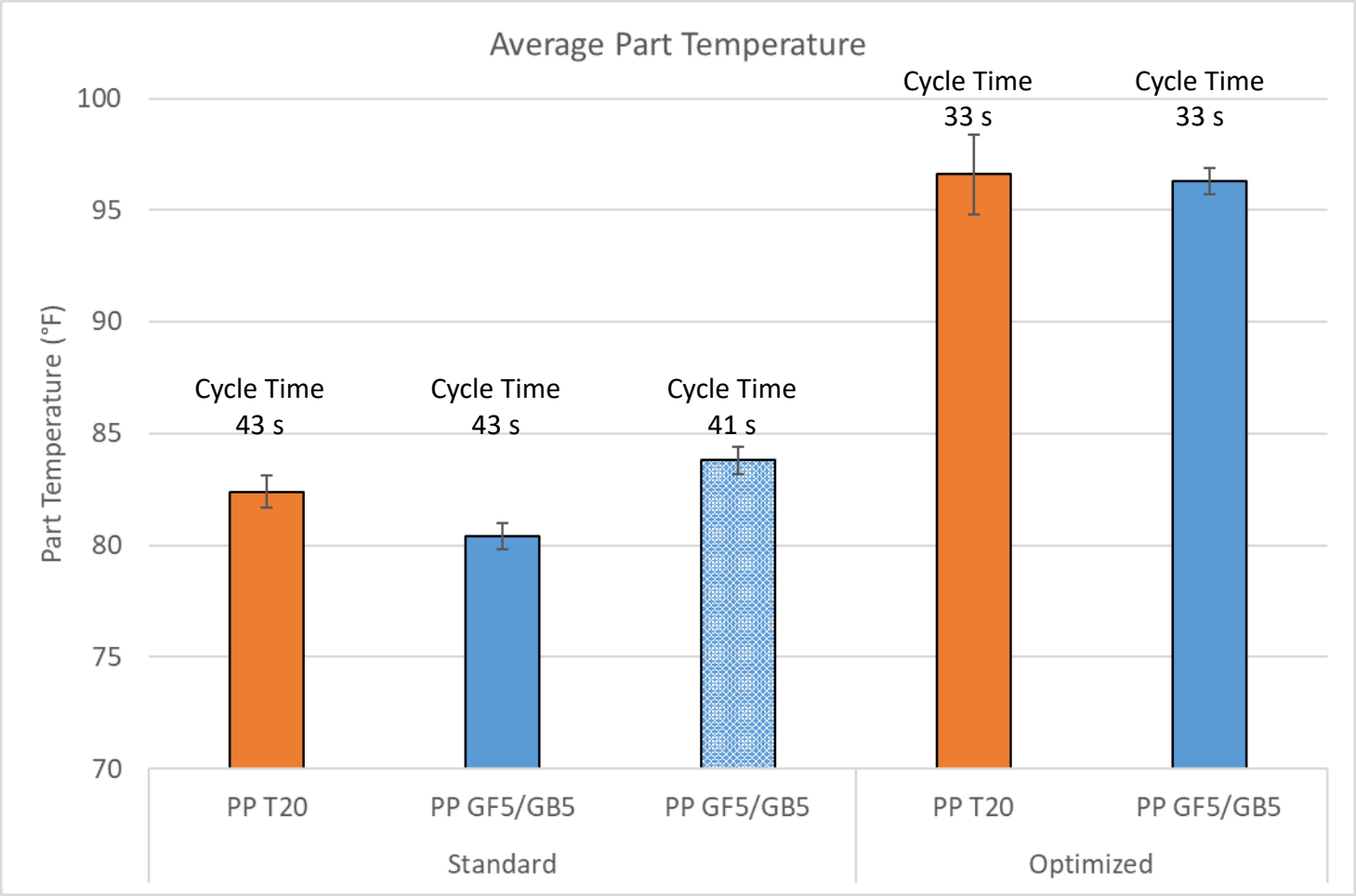
Case Study I: PP T20 → PP GF5/GB5

- Despite the decrease in post gate temperature measured in mold, the average part temperature does not show much difference between the two materials.
- Parts in the PP GF5/GB5 material molded in the standard condition were 2°C cooler out of the mold than the baseline material.
- We were able to reduce the cooling time by 2 seconds for the PP 5GF/5GB material for a 5% reduction in cycle time.
- Faster cycle times have been observed in the molding of larger parts.



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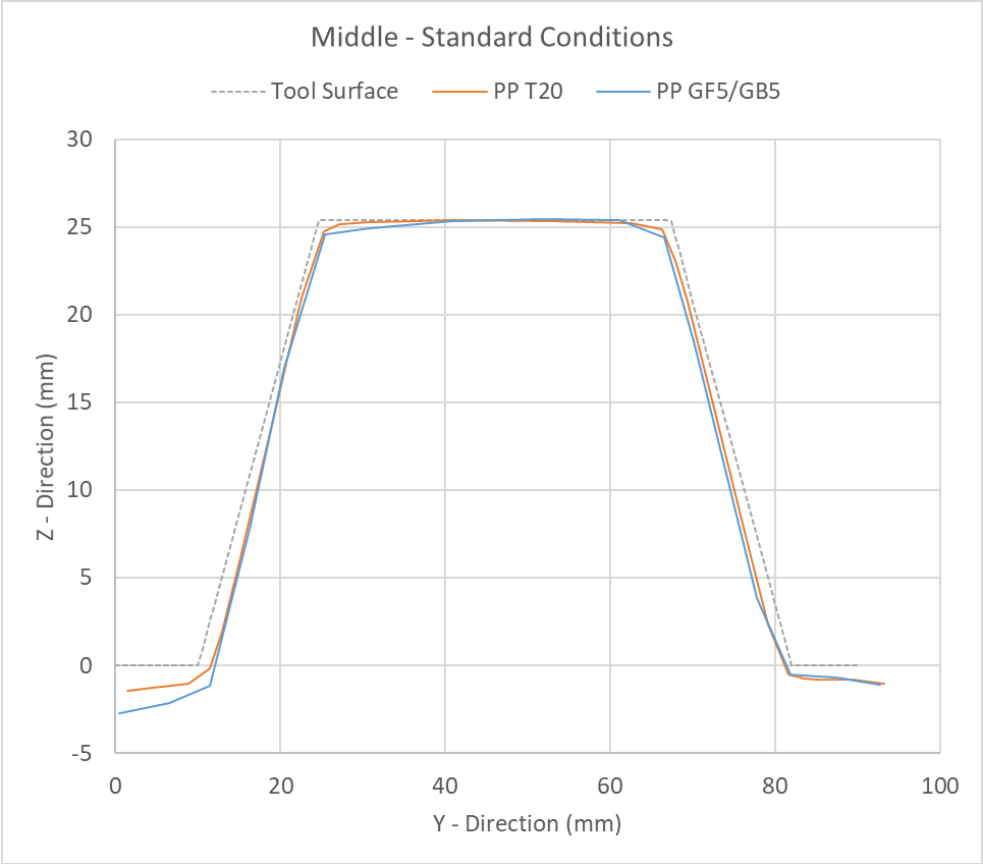
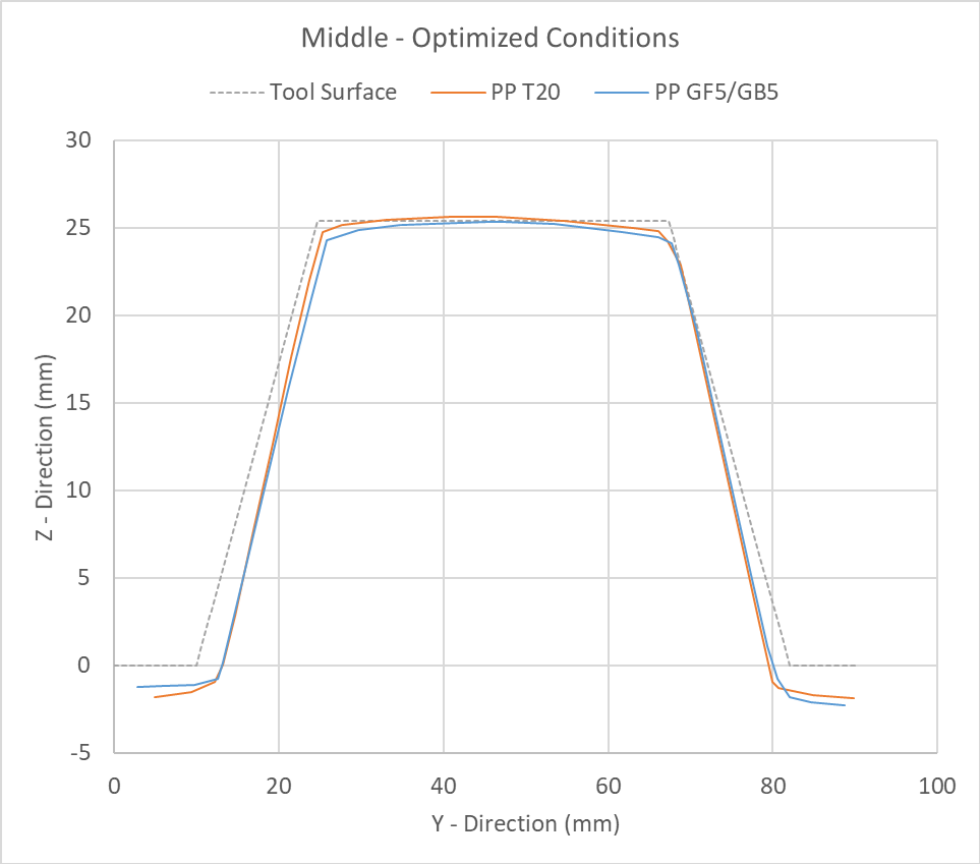
Case Study I: PP T20 → PP GF5/GB5





- Cross-sections through the middle of the beam show similar behavior between the two materials
- As expected, optimized conditions show more warp than the standard conditions

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Case Study II:

20% Glass Fiber + 10% Mineral + Polypropylene (PP GF20/M10)

↓

20% Glass Fiber + 10% Glass Bubbles +Polypropylene (PP GF20/GB10)

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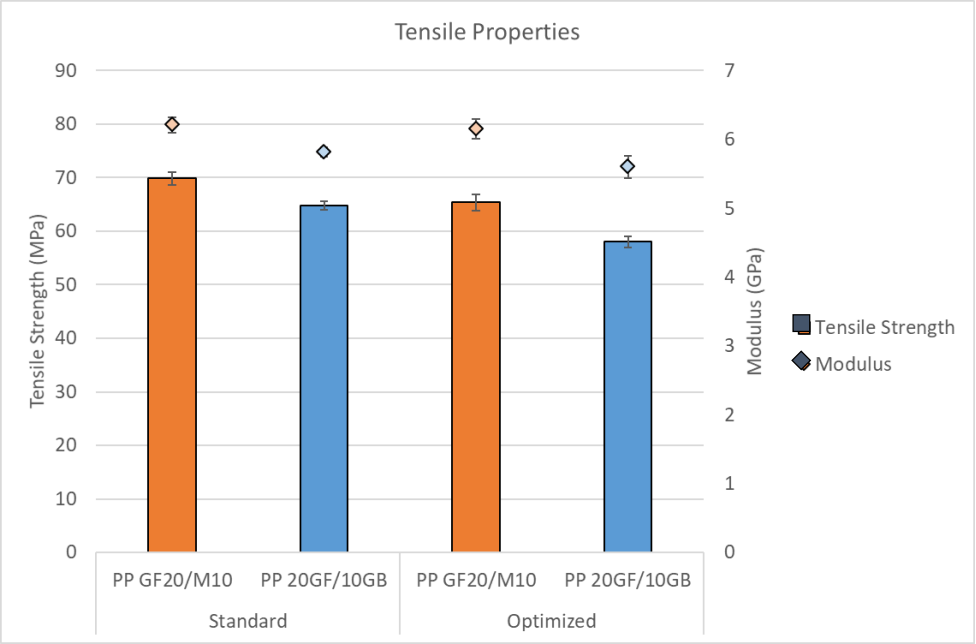
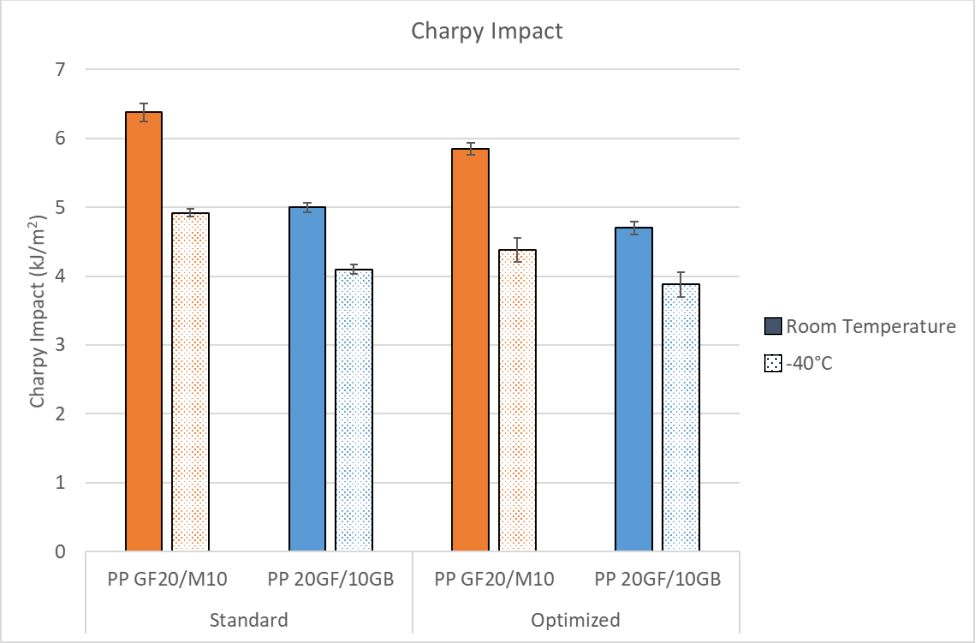
Case Study II:
PP GF20/M10 → PP GF20/GB10

	Barrel Temp (°F)	Mold Temp (°F)	Cooling Time (s)	Hold Time (s)
Standard	430	140	15	15
Optimized	430	105	15	8

- Part weight reduced from 143 g to 124 g (↓13%)
  - Confirmed by gas pycnometer to have minimal glass bubble breakage from processing
- Tensile strength decreased ~10%
- Tensile Modulus decreased ~8%
- Charpy impact shows ~20% decrease at room temperature and ~15% decrease at -40°C.





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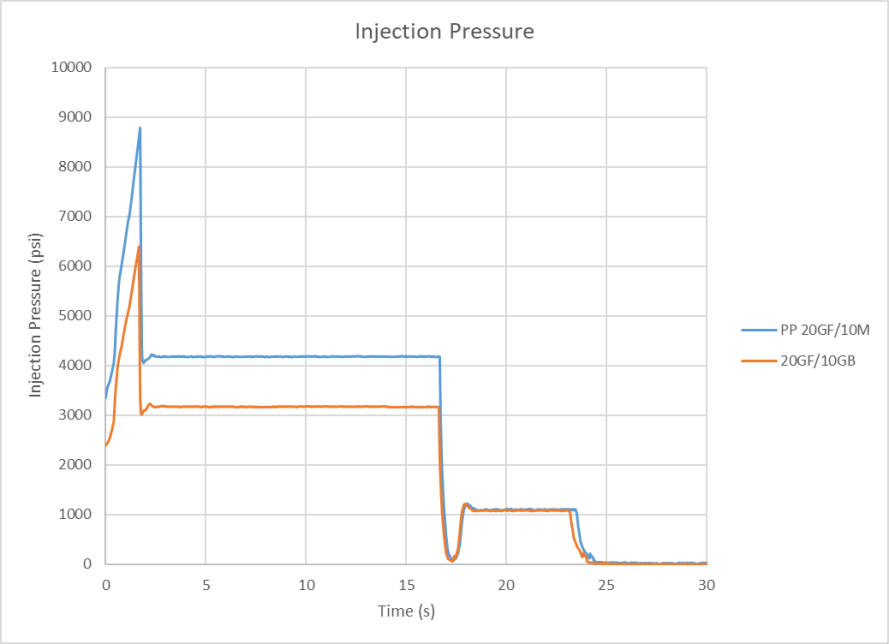
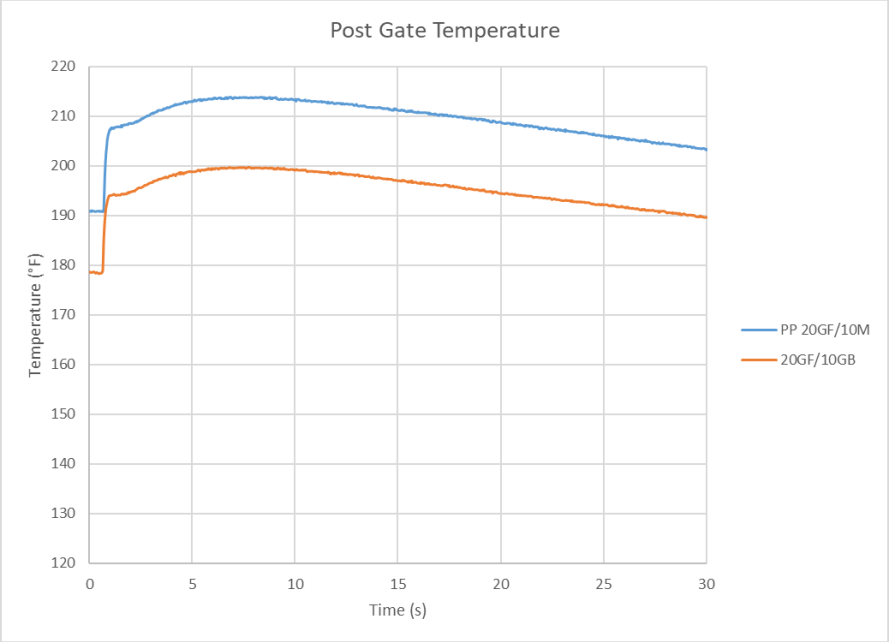
Case Study II:
PP GF20/M10 → PP GF20/GB10

- Maximum injection pressures drop 27%
  - Opportunity to use smaller press
- Maximum post gate temperatures drop up to 14°F with glass bubble materials
  - Possibility for faster cycle times.
- Hold pressures were also able to be reduced from 400 psi to 300 psi for glass bubble materials (25% reduction)

Material	Molding Condition	Max Injection Pressure (psi)		Maximum Post Gate Temperature (°F)	
PP GF20/M10 PP GF20/GB10	Standard	8783 6392	↓27%	214 200	↓7%
PP GF20/M10 PP GF20/GB10	Optimized	8429 6170	↓27%	187 184	↓2%





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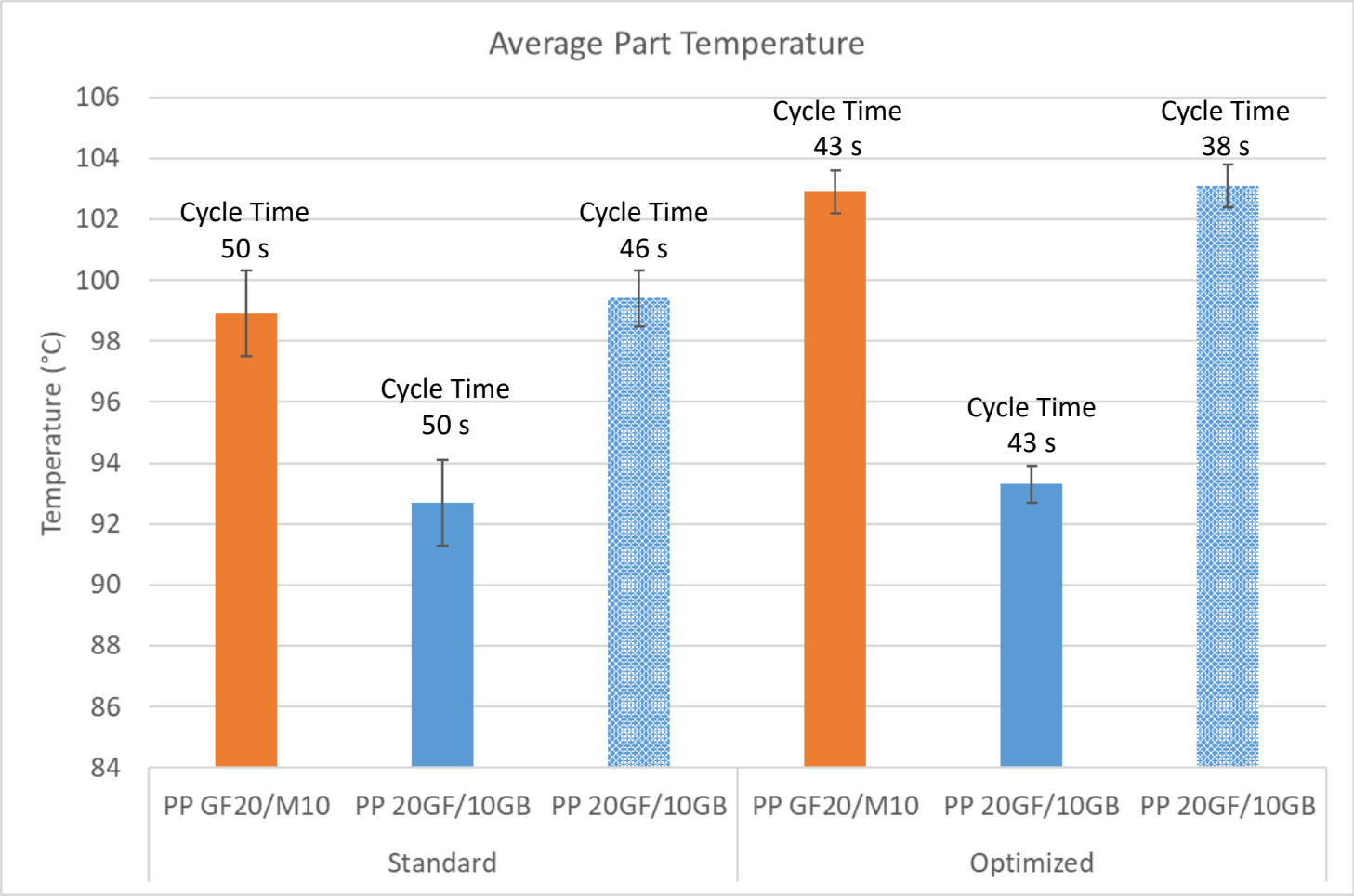
Case Study II: PP GF20/M10 → PP GF20/GB10

- Significant cycle time savings were realized for both the standard and optimized processes.
- Parts in the PP GF20/GB10 material were 6°C cooler out of the mold than the baseline material.
- Standard molding conditions achieved a 4 second cycle time saving (8%)
- Optimized molding conditions achieved a 5 second cycle time saving (11%)



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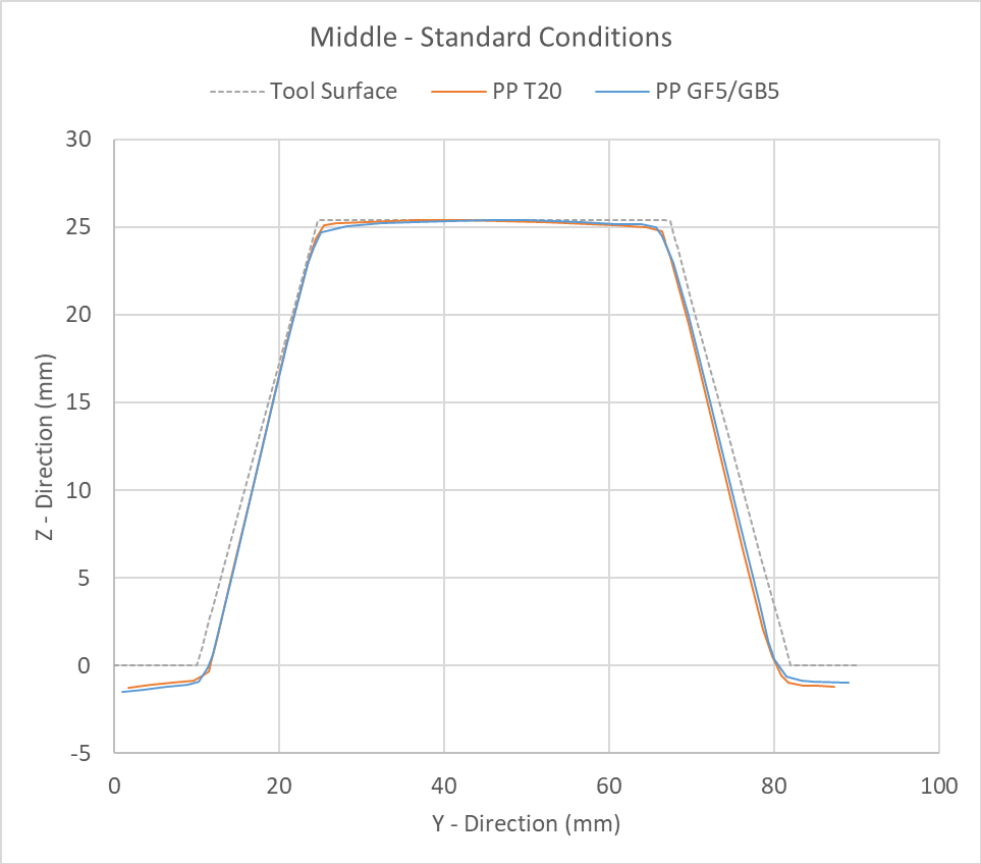
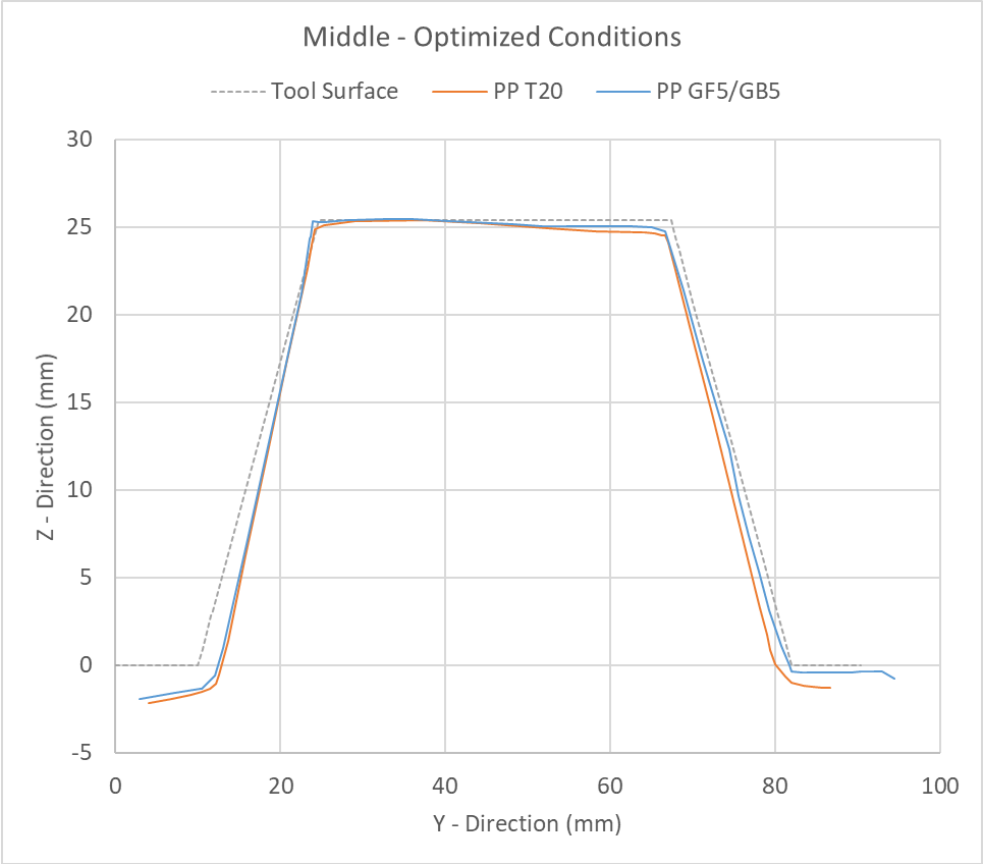
Case Study II: PP GF20/M10 → PP GF20/GB10





- Cross-sections through the middle of the beam show similar behavior between the two materials
- As expected, optimized conditions show more warp than the standard conditions

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Case Study III:

8% Glass Fiber + 10% Mineral + PA66
(PA66 GF8/M10)

↓

7% Glass Fiber + 3% Mineral + 10% Glass Bubbles + PA66
(PA66 GF7/M3/GB10)

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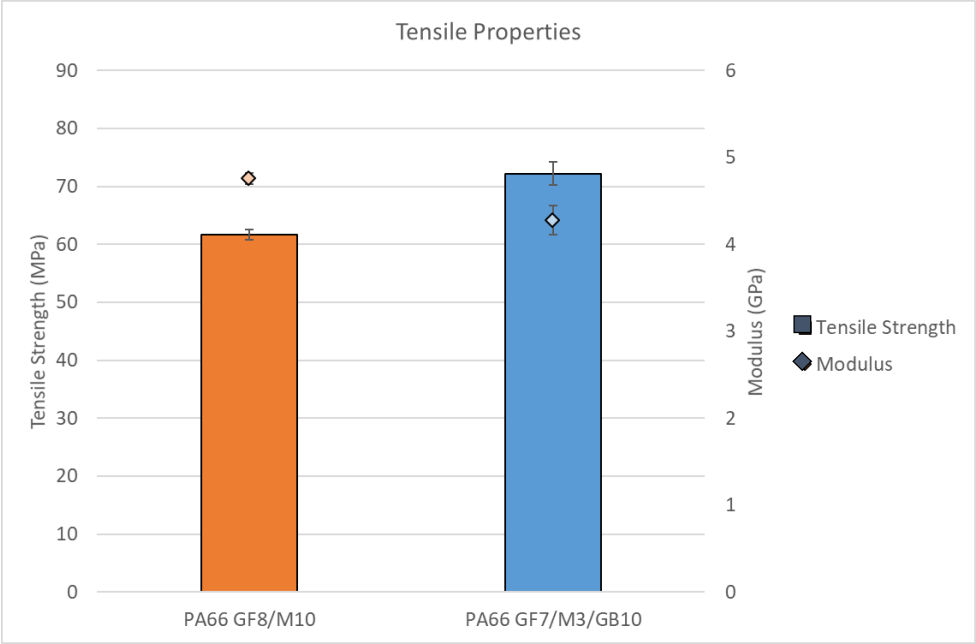
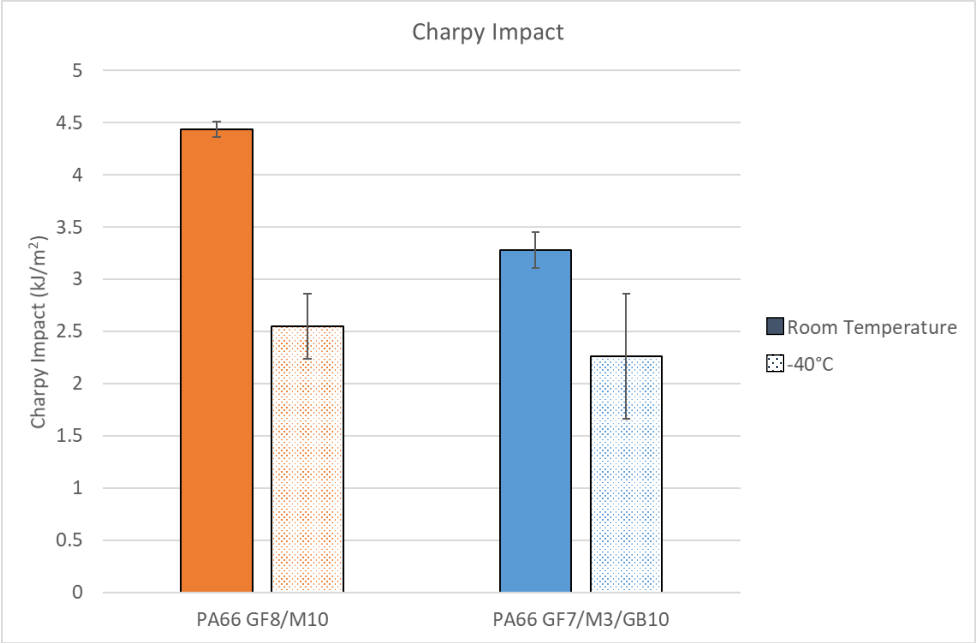
Case Study III: PA66 GF8/M10 → PA66 GF7/M3/GB10

	Barrel Temp (°F)	Mold Temp (°F)	Cooling Time (s)	Hold Time (s)
Standard	518	160	15	10

- Due to lack of material only standard conditions were run
- Part weight reduced from 160 g to 134 g (↓16%)
  - Confirmed by gas pycnometer to have minimal glass bubble breakage from processing
- Tensile strength increased ~17%
- Tensile Modulus decreased ~10%
- Charpy impact shows ~25% decrease at room temperature and ~10% decrease at -40°C.





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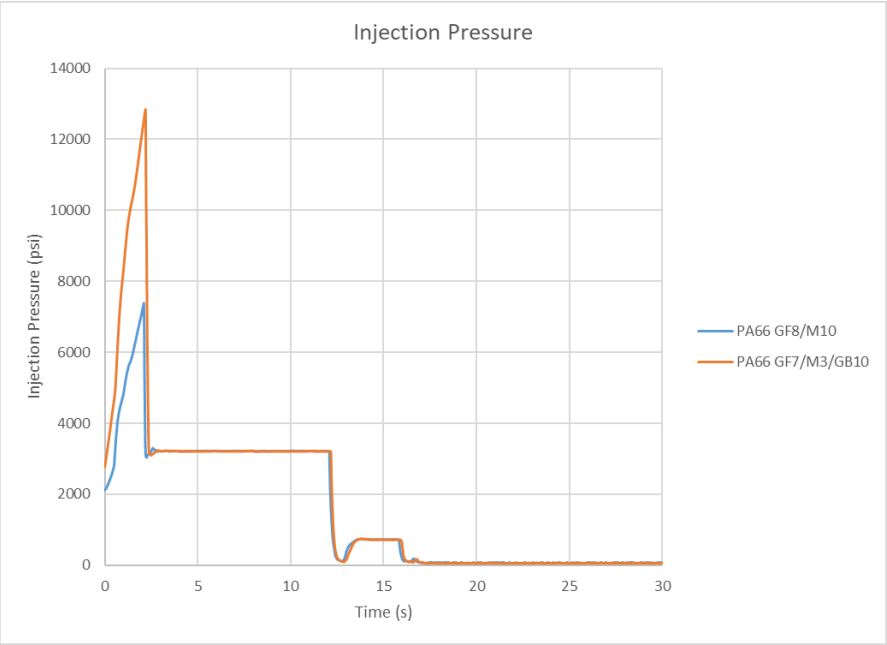
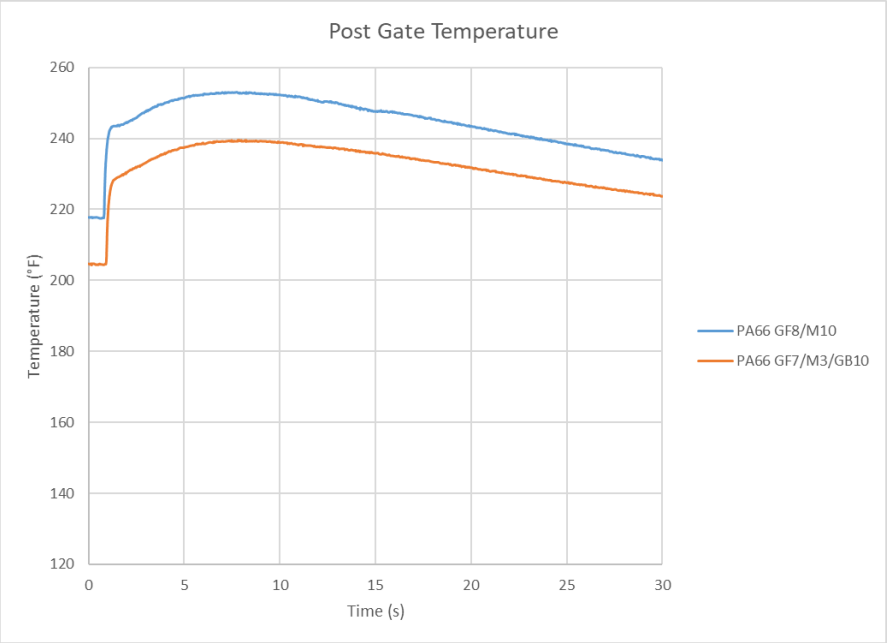
Case Study III: PA66 GF8/M10 → PA66 GF7/M3/GB10

- Maximum injection pressures increased 74%
  - Initial part trial concerns about flash due to addition of glass bubbles prompted a reformulation to increase resin viscosity.
- Maximum post gate temperatures drop up to 14°F (7%)with glass bubble materials
  - Possibility for faster cycle times.

Material	Molding Condition	Max Injection Pressure (psi)		Maximum Post Gate Temperature (°F)	
PP GF20/M10 PP GF20/GB10	Standard	7386 12847	↑74%	214 200	↓7%





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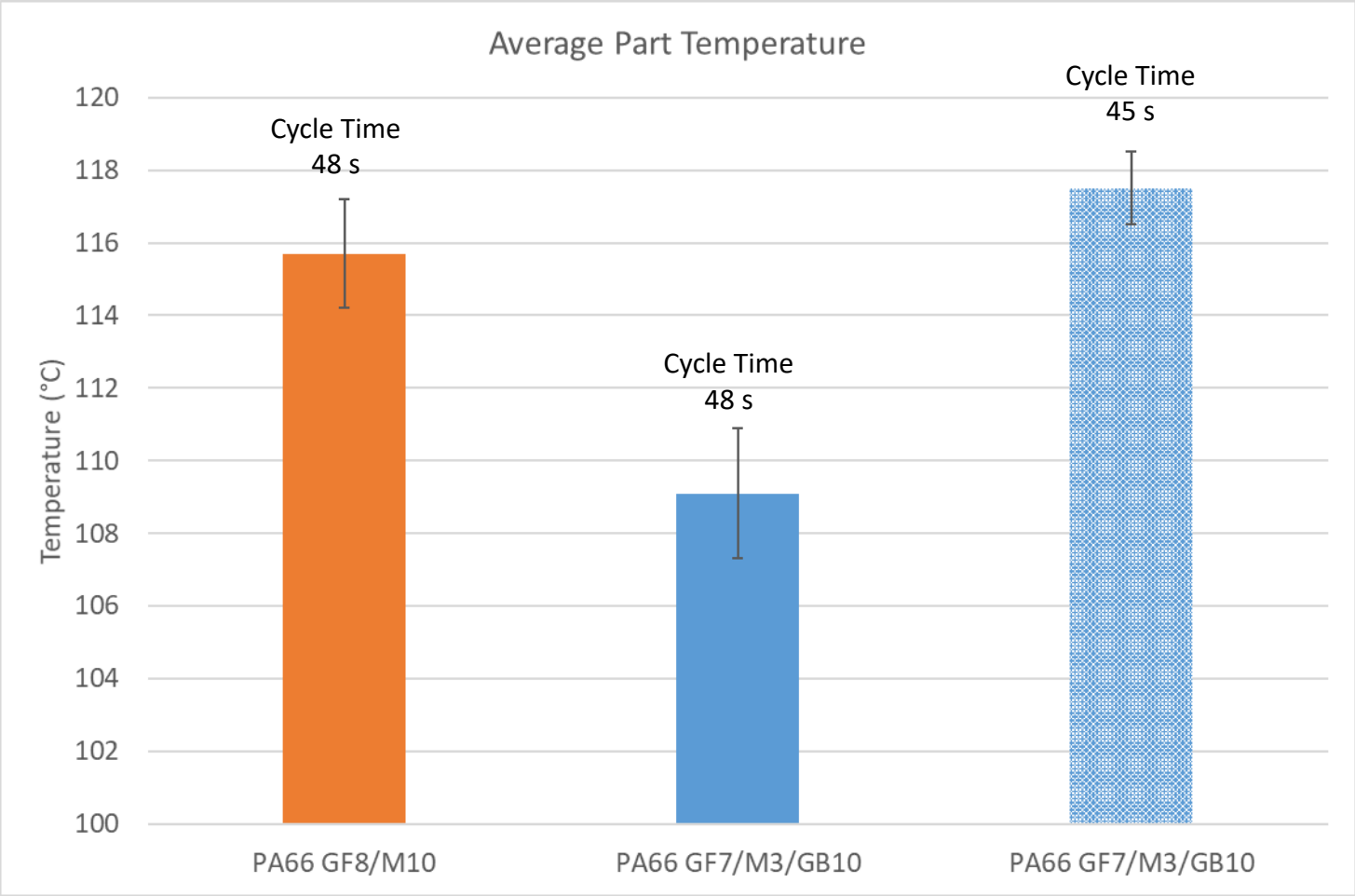
Case Study III: PA66 GF8/M10 → PA66 GF7/M3/GB10

- Parts in the PA66 GF7/M3/GB10 material were 7°C cooler out of the mold than the baseline material.
- Standard molding conditions achieved a 3 second cycle time saving (6%)
- Further savings may possibly be realized with more process optimization



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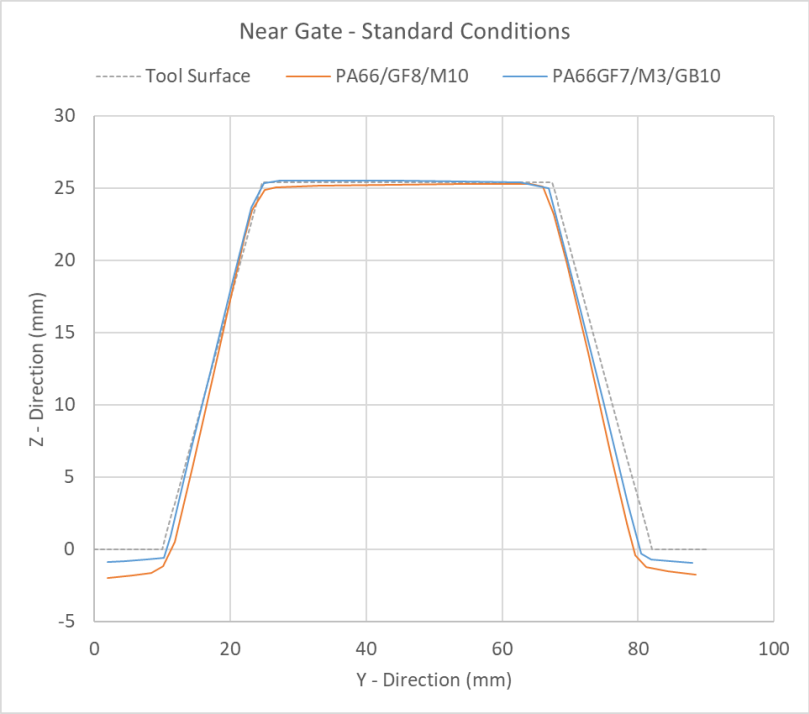
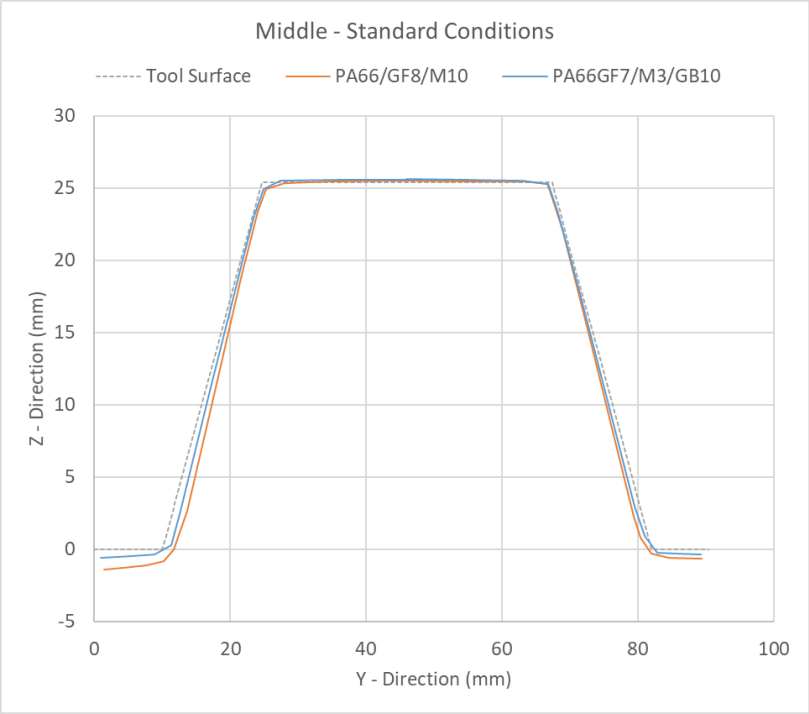
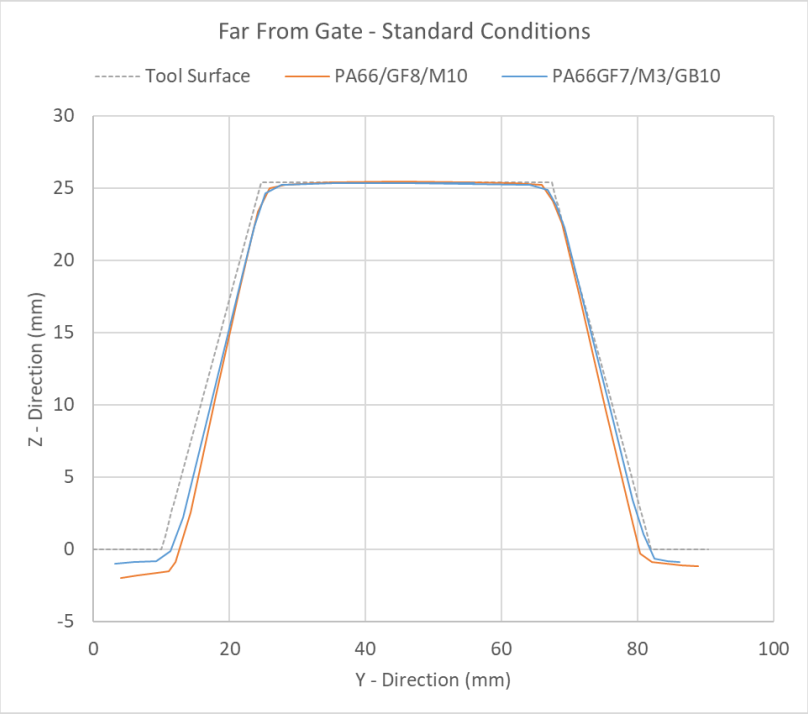
Case Study III: PA66 GF8/M10 → PA66 GF7/M3/GB10







- Cross-sections through the middle of the beam show similar behavior between the two materials.
- Distance from the gate had no effect.

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Case Study III: PA66 GF8/M10 → PA66 GF7/M3/GB10

- Part trials show parts were significantly cooler coming off the tool with the PA66 GF7/M3/GB10 material
- The average overall temperature was 8.5°C cooler on parts molded with the glass bubble material (PA66 GF7/M3/GB10)
- This confirms there may be the opportunity for more cycle time savings with larger parts

PA66 GF8/M10

PA66 GF7/M3/GB10

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Applications

- First target for application is air cleaner boxes
  - Realized at least 15% weight savings depending on formulation
  - Materials specification in progress
  - Will be rolling out to other air induction applications and is scheduled for new programs.

Vehicle Line: B-car
Material: PP 5GF/5GB
Timing: 4Q2019

Vehicle Line: F150
Material: PP 20GF/10GB
Timing: 1Q2020

Vehicle Line: Explorer
Material: PA66/GF7/M3/GB10
Timing: TBD

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Summary

- Glass bubbles offered weight savings of ~15% depending on formulation.
- The addition of glass bubbles to material formulations resulted in cooler parts out of the mold, resulting in cycle time savings up to 11%.
  - Increasing glass bubble volume increased the cycle time savings
  - Cycle time savings could be dependent on the processing conditions
  - This savings could possibly increase with larger parts/more material volume.
- Materials developed are drop-in (same shrink) for incumbent materials.
- Depending on formulation, Charpy impact properties may be reduced with glass bubbles.
  - Future work includes formulation development for improved impact properties.

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