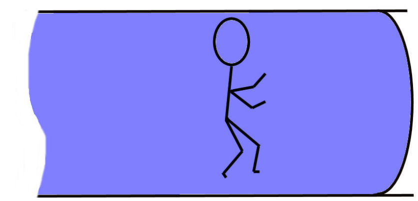
STRUCTURAL • ELASTOMERS • WEAR • COLOR
CONDUCTIVE • FLAME RETARDANT • FILM/SHEET

Plastic Design Principles for Structural Composites

Keith Scales
CAE Analyst

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Live in the Wall Section

Design for Injection Molding

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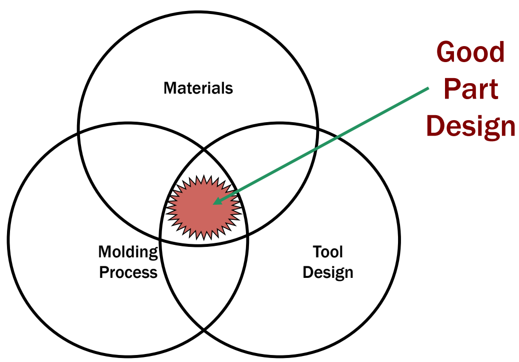

What We Will Cover

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

- Material Issues/Concerns with Structural Composites
- Part Design Guidelines – Common Mistakes
- Warpage
- Structural Failures

Amorphous vs. Semi-Crystalline

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Random Structure	Ordered Structure
Broad Melting Point	Sharp Melting Point
Often Solvent Sensitive	Solvent Resistant
Impact Resistant	Fatigue Resistant
Low Shrink	High Shrink
Better Dimensional Stability	More Difficult Dimensional Control

Amorphous vs. Semi-Crystalline

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ABS	Acetals
PC	Nylons
Polystyrene	Polyesters (PET, PBT)
Thermoplastic Urethanes	PP
PSU	PE
PEI	PEEK

Live in the Wall Section

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

Many plastics are anisotropic

Plastics are non-Newtonian

Isotropic vs. Anisotropic

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

- Isotropic: **Material properties (including shrink) are <u>uniform</u> in flow and cross-flow direction.**
- Anisotropic: **Material properties (including shrink) are <u>not uniform</u> in every direction.**

Filler & Reinforcement Geometry

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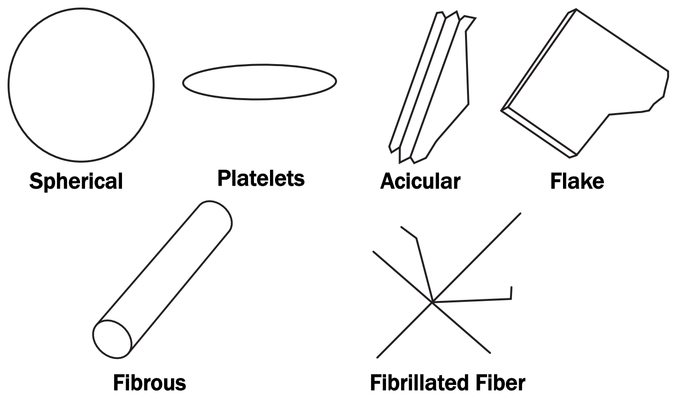

Filler/Reinforcement Classification

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Type	Geometry	Aspect Ratio	Classification
Glass Beads	Spherical	1	Filler
Clay	Platelet	1-3	Filler
Calcium Carbonate	Platelet	1-3	Filler
Talc	Platelet	2-5	Filler
Wollastonite	Acicular	5-20	Transition
Mica	Flake	30-50	Transition
Milled Glass	Fibrous	10-50	Transition
Glass Fiber	Fibrous	50+	Reinforcement
Carbon Fiber	Fibrous	50+	Reinforcement
Nickel Coated Carbon Fibers	Fibrous	50+	Reinforcement
Stainless Steel	Fibrous	50+	?
Aramid	Fibrillated Fiber	50+	Reinforcement

Properties Affected by Additives

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Tensile Strength
Impact Strength

Specific Gravity
Viscosity
Thermal Conductivity
Specific Heat
Shrinkage

Stress-Strain of Polymers

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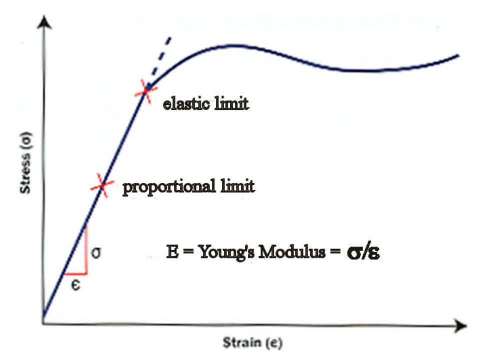

Stress-Strain of Polymers

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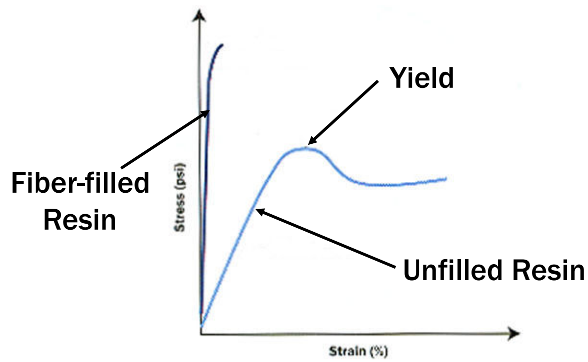

Stress-Strain of Polymers

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Dilemma:

Fiber filled materials are not isotropic

How do we account for this variation in mechanical properties during design?

Bi-Directional Stress-Strain

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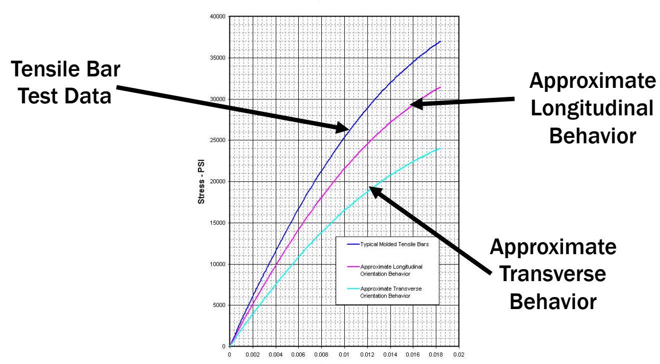

Bi-Directional Stress-Strain

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FEA of Filled Polymers

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Recommendations:

When possible do analysis that considers fiber orientation – Moldflow followed by FEA

For FEA that doesn't use flow simulation inputs, use 60-80% of the modulus/strength to account for property variations

Viscosity of Polymers

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Plastics are non-Newtonian

Viscosity varies not only with temperature but with shear rate

What is Shear Rate?

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Shear: Friction between moving plastic and the mold wall

Shear Rate: Velocity gradient in a flowing material

Injection Molding Process

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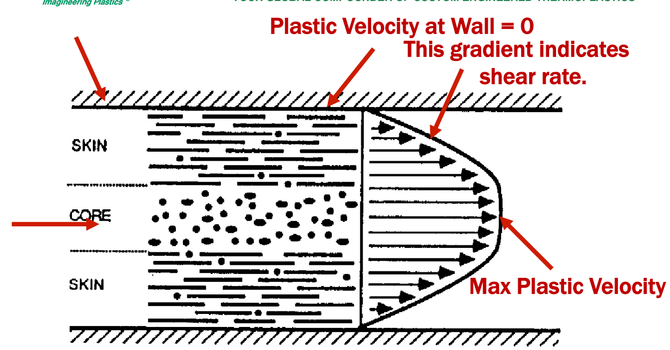

Viscosity of Polymers

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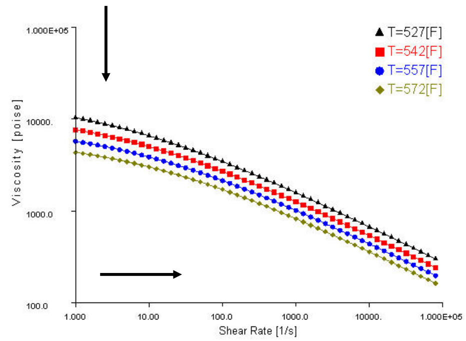

Viscosity of Polymers

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Important things that will affect viscosity:

Wall Thickness
Velocity
Temperature

Live in the Wall Section

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

Many plastics are anisotropic

Plastics are non-Newtonian

What We Will Cover

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

- Material Issues/Concerns with Structural Composites
- Part Design Guidelines – Common Mistakes
- Warpage
- Structural Failures

Common Part Defects

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

- Hesitation/Partialling
- Air/Gas Traps
- Weld Lines
- Warpage
- Sinks and Voids
- Structural Weakness or Failure

Common Part Defects

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- Hesitation/Partialling
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Related to Fill Pattern

Common Part Defects

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

- Hesitation/Partialling
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- Warpage
- Sinks and Voids
- Structural Weakness or Failure

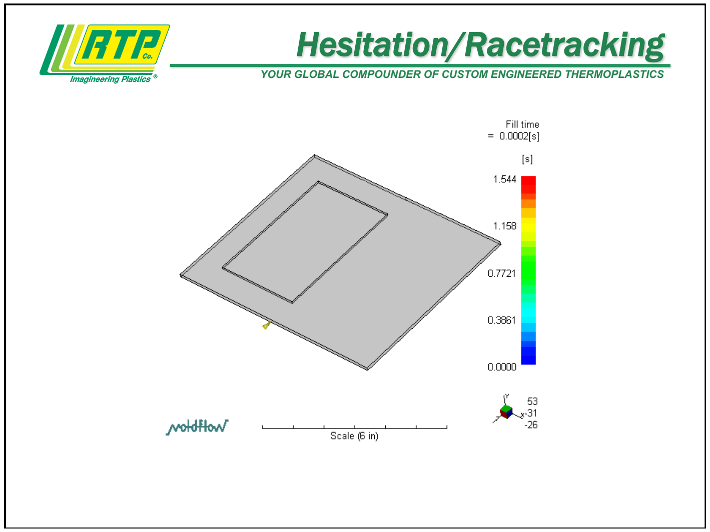
Related to Fill Pattern, Cooling, and Packing

Common Part Defects

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

- Hesitation/Partialling
- Air/Gas Traps
- Weld Lines
- Warpage
- Sinks and Voids
- Structural Weakness or Failure

Related to Cooling and Wall Thickness


Hesitation/Racetracking
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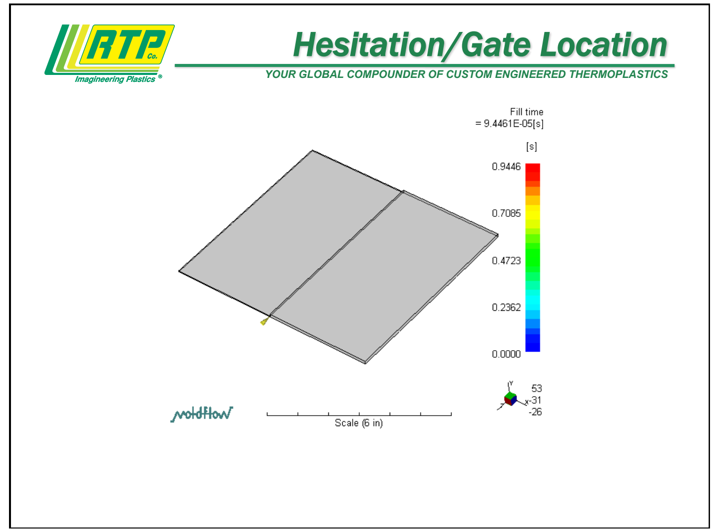
0.3861
0.0000
Scale (6 in)
moldflow


Hesitation/Gate Location
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
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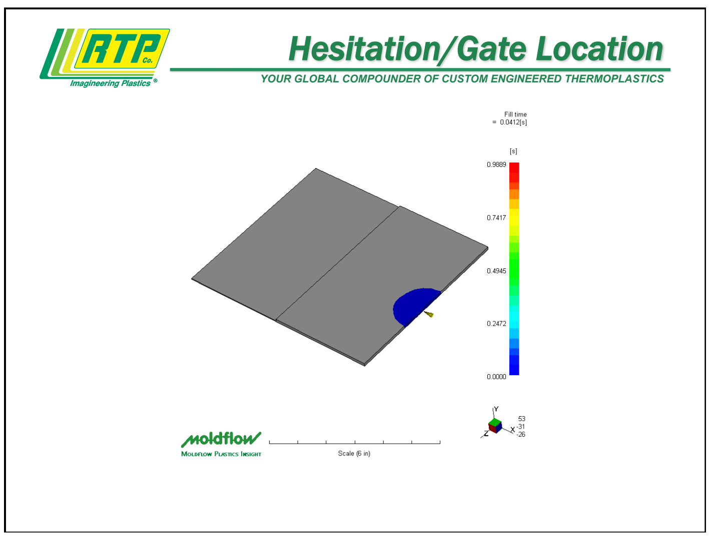
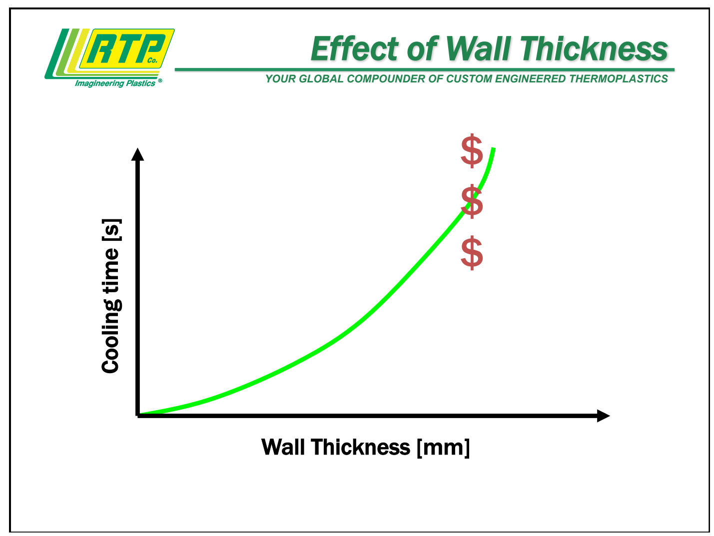
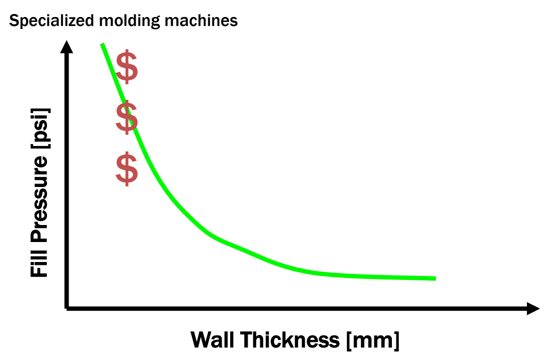
Scale (6 in)
moldflow


Hesitation/Gate Location
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
moldflow


Effect of Wall Thickness
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
$
$
$
Cooling time [s]
Wall Thickness [mm]

Effect of Wall Thickness

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Coring Out

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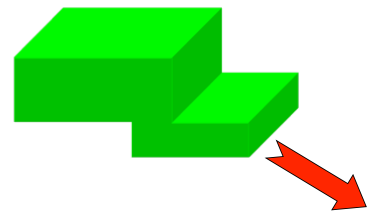

Core out thick sections to eliminate thick masses in the part.

"Core Out" - Examples

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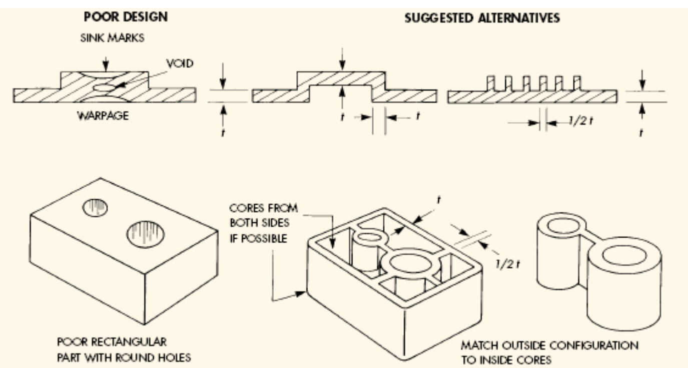

Part Design Guidelines

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- Keep nominal wall less than 5mm (0.200")
- Avoid large variations in thickness
- Avoid abrupt changes in thickness
- Make thickness transitions gradual to avoid stress concentrations

Part Design Guidelines

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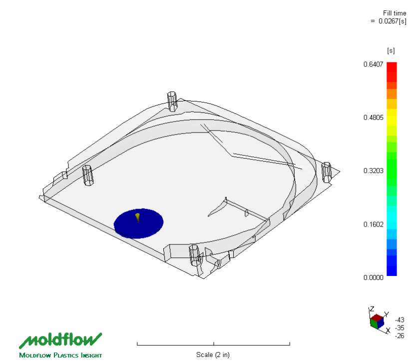
- Constant nominal wall simplifies fill pattern
- Constant nominal wall minimizes stresses and warp
- Avoid gating near areas with large variation

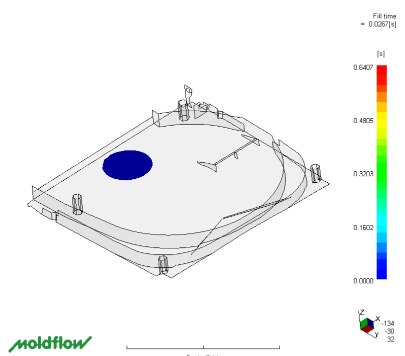
Example

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Example

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Sinks and Voids

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Sinks and voids are both caused by wall sections that are too thick

Sinks are cosmetic flaws and voids can be structural weak points

Sinks and Voids

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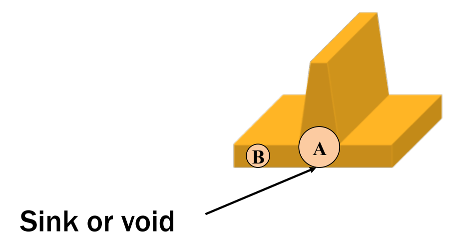

Recommended Rib Design

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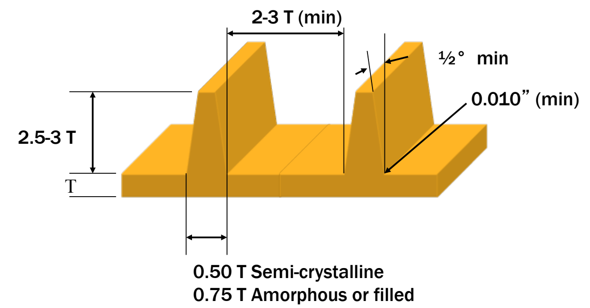

Recommended Gusset Design

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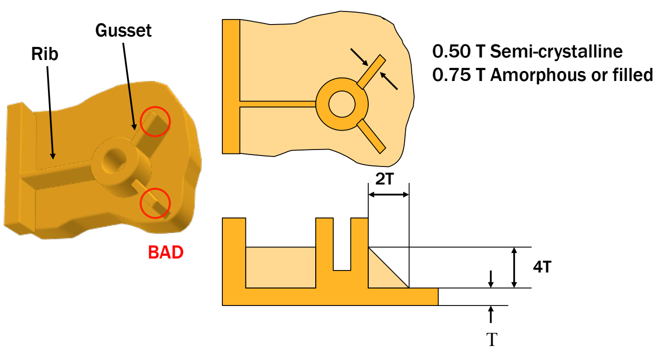

Recommended Boss Design

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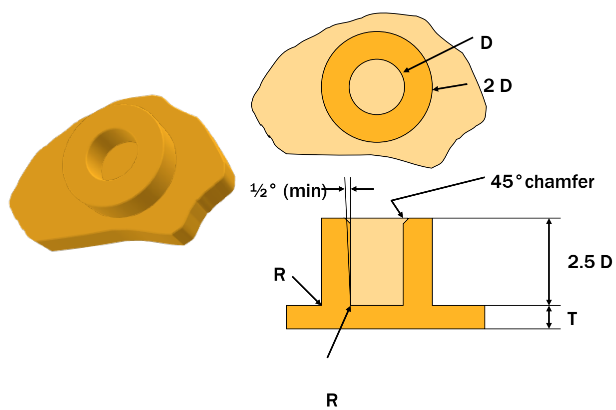

What We Will Cover

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Warpage

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Shrinkage itself doesn't cause warp

Warp is caused by variations in shrinkage

Warpage

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

Three Primary Causes

1. Non-uniform Cooling
2. Orientation Effects
3. Differential Area Shrinkage

Non-Uniform Cooling

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When the mold is hotter on one side than on the other side, the hotter side will take longer to cool so it will shrink more

Non-Uniform Cooling

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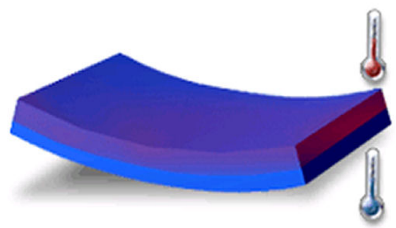

Orientation Effects

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Some plastics shrink differently in the direction of flow than across flow

Orientation Effects

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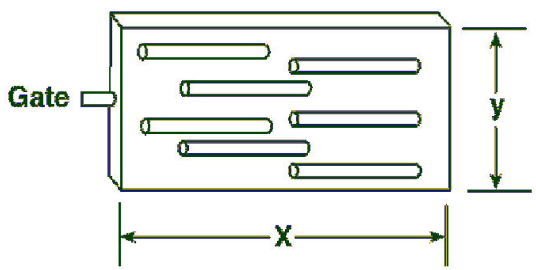

Shrink Rate x ≠ Shrink Rate y ⟶ Warp

Orientation Effects

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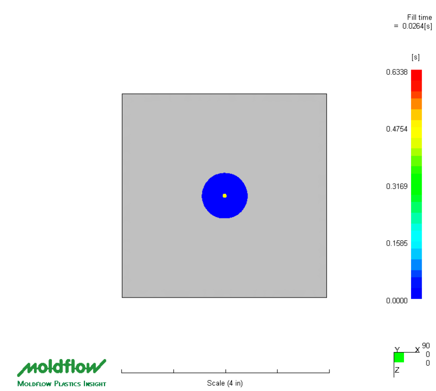

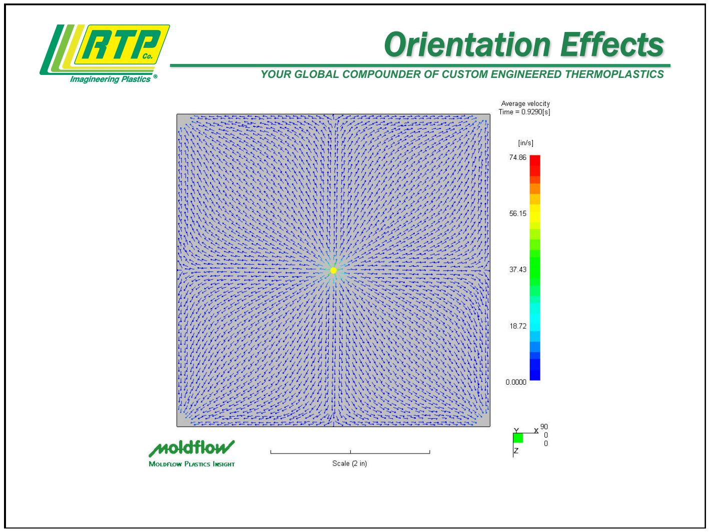
Orientation Effects
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
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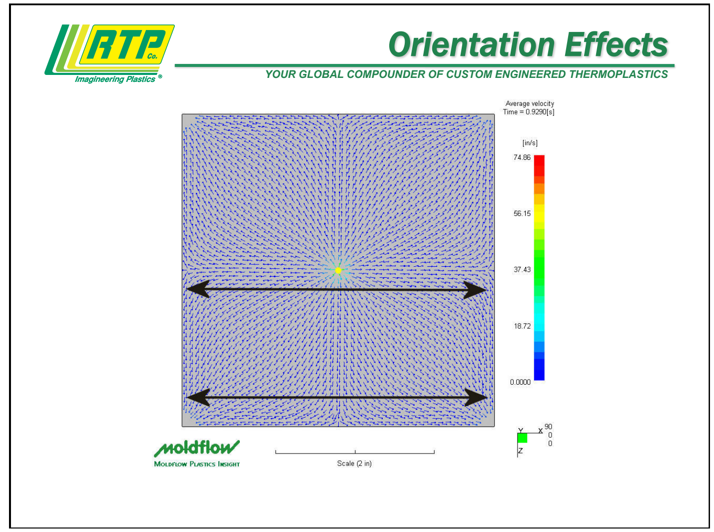
[in/s]
74.86
56.15
37.43
18.72
0.0000
Scale (2 in)


Orientation Effects
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
Average velocity
Time = 0.9290[s]
[in/s]
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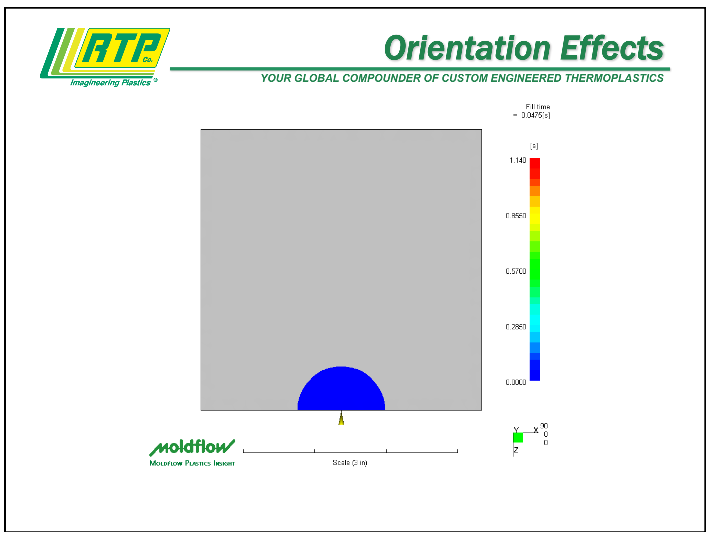
56.15
37.43
18.72
0.0000
Scale (2 in)


Orientation Effects
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
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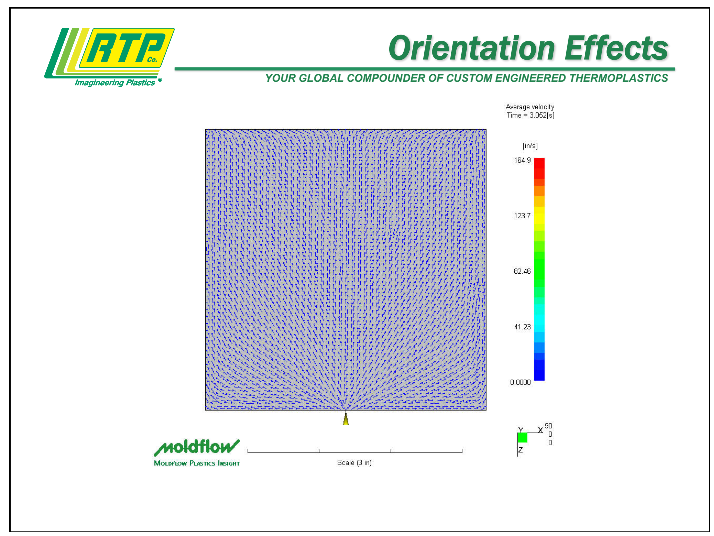
0.0000
Scale (3 in)


Orientation Effects
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
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[in/s]
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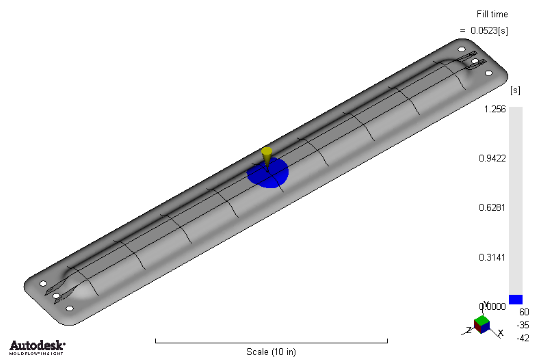
123.7
82.46
41.23
0.0000
Scale (3 in)

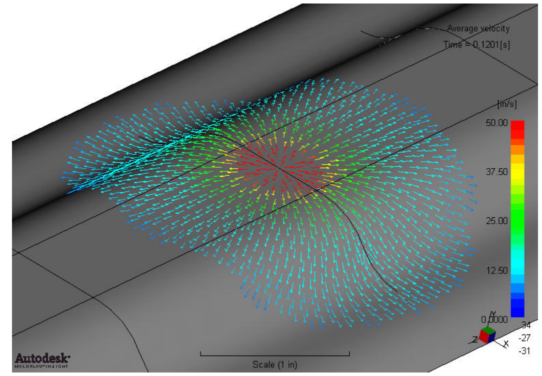
Orientation Effects

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Orientation Effects

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Orientation Effects

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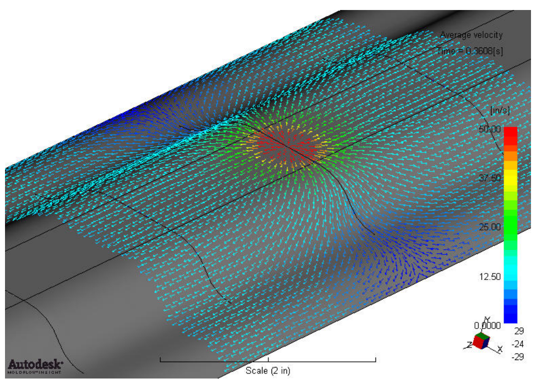

Orientation Effects

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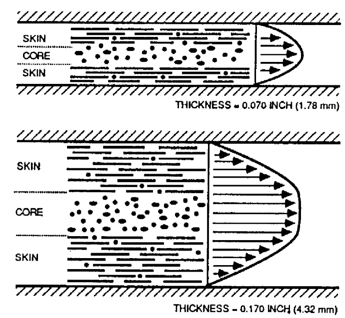

FIGURE 1 VELOCITY PROFILES AND THE RESULTING FIBER ORIENTATION

Orientation Effects Example

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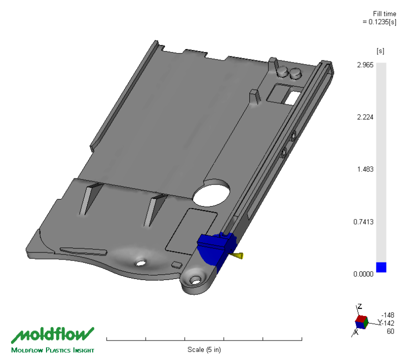
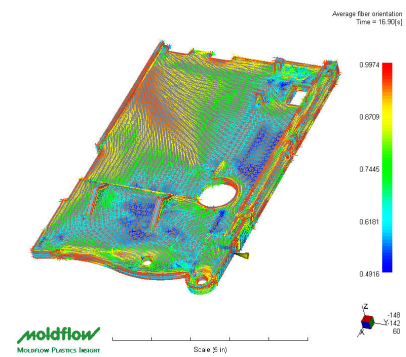


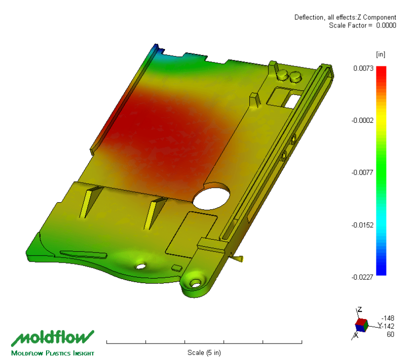
Orientation Effects Example

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Orientation Effects Example

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Example Conclusions

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- The primary cause of the warp is orientation due to a non-uniform fill pattern
- A different gate location will not improve the fill pattern or improve orientation warp
- Reducing the warp will require either major part design changes or a material change

Design to Avoid Orientation Effects

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

- Uniform wall thickness to allow simple fill pattern
- No major thin sections that could result in hesitation or racetracking

Reducing Orientation Effects

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- Gate for the most uniform flow
- Adjust molding conditions (often higher temps and faster injections will help)
- Adjust wall thickness
- Use more uniformly shrinking material (or sometimes a lower viscosity material)

Differential Area Shrinkage

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- Variations in cooling rate result in variations in shrinkage
- Slower cooling results in higher crystallinity and more shrink
- Faster cooling results in less crystallinity and less shrink

Differential Area Shrinkage

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- Thick walls take longer to cool than thin walls resulting in non-uniform shrink
- More densely packed areas take longer to cool resulting in non-uniform shrink

Differential Area Shrinkage

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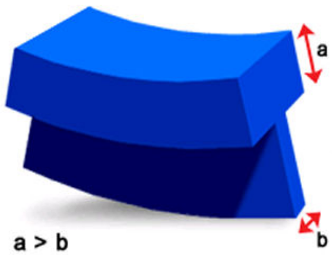
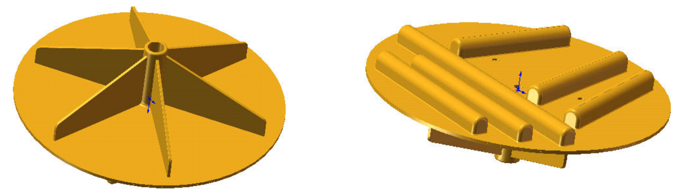


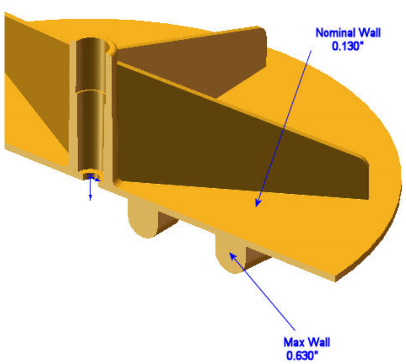
Differential Area Shrinkage Example

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



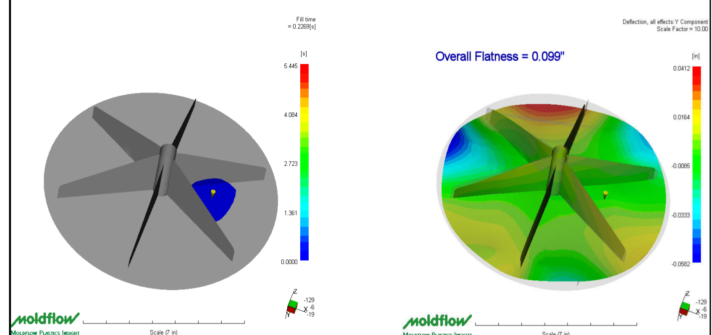
Differential Area Shrinkage Example

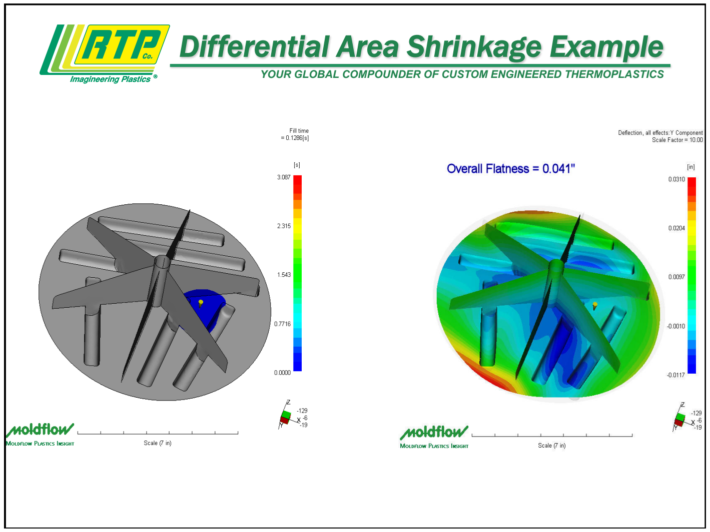
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

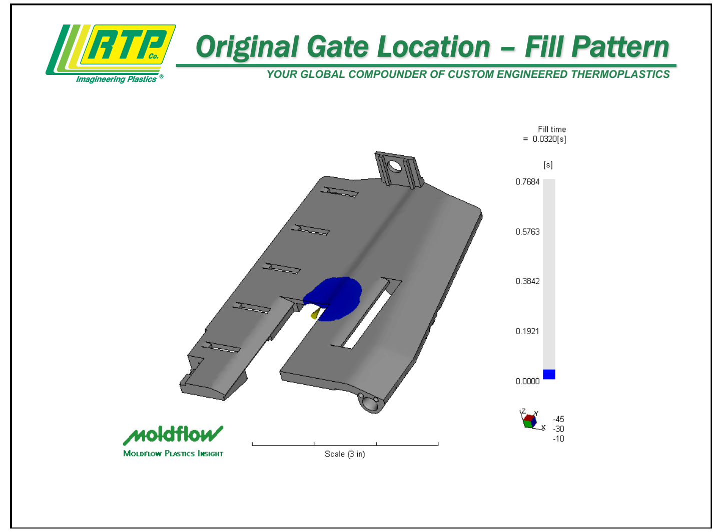


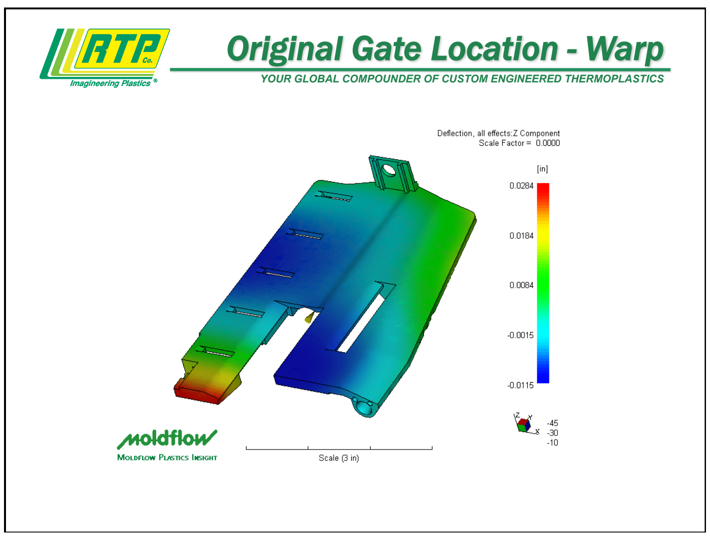
Differential Area Shrinkage Example

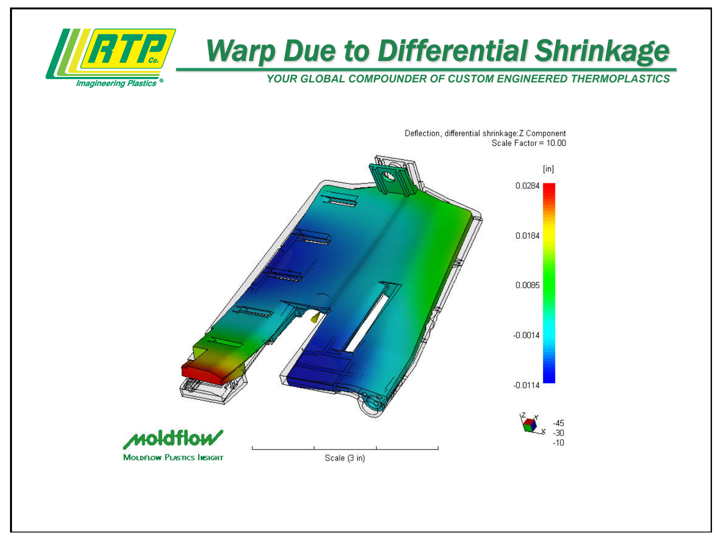
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS




RTP Co.
Imagineering Plastics
Differential Area Shrinkage Example
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
Overall Flatness = 0.041"
moldflow

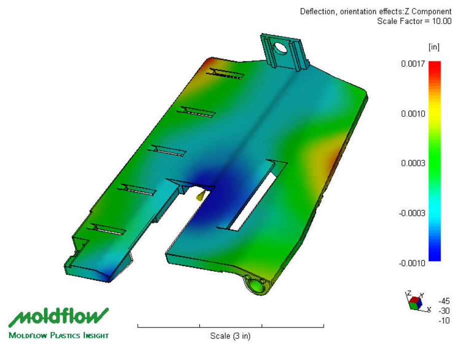

RTP Co.
Imagineering Plastics
Original Gate Location – Fill Pattern
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
Fill time
= 0.0320[s]
[s]
0.7684
0.5763
0.3842
0.1921
0.0000
moldflow
Moldflow Plastics Insight
Scale (3 in)


RTP Co.
Imagineering Plastics
Original Gate Location - Warp
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
Deflection, all effects:Z Component
Scale Factor = 0.0000
[in]
0.0284
0.0184
0.0084
-0.0015
-0.0115
moldflow
Moldflow Plastics Insight
Scale (3 in)


RTP Co.
Imagineering Plastics
Warp Due to Differential Shrinkage
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
Deflection, differential shrinkage:Z Component
Scale Factor = 10.00
[in]
0.0284
0.0184
0.0085
-0.0014
-0.0114
moldflow
Moldflow Plastics Insight
Scale (3 in)

Warp Due to Orientation Effects

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Conclusion

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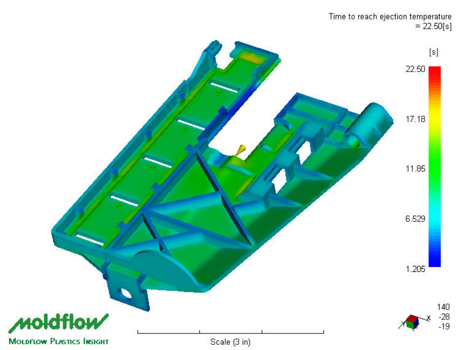
The primary cause of the warp is differential shrinkage

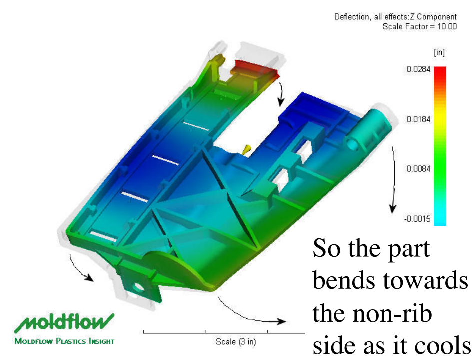
Explanation of Differential Shrinkage

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Explanation of Differential Shrinkage

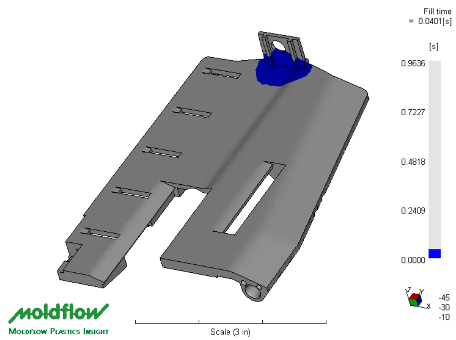
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



So the part bends towards the non-rib side as it cools.

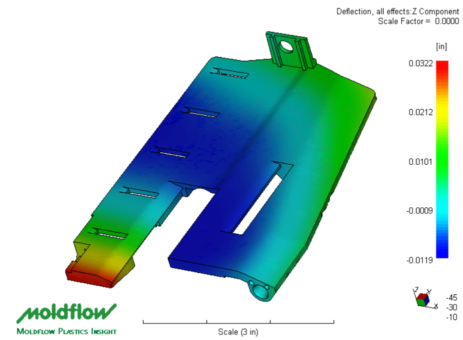
Opposite Gate Location – Fill Pattern

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Opposite Gate Location - Warp

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS



Conclusions

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- The primary cause of the warp is differential shrinkage due to wall thickness variations
- A different gate location will improve the fill pattern but it will not improve differential shrinkage warp
- Wall thickness changes and packing pressure profiles may reduce warp

Part Design to Avoid Differential Shrinkage

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- Uniform wall thickness to allow uniform cooling rate
- Balance thin ribs onto both sides of nominal wall

Reducing Differential Area Shrinkage

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- Uniform wall thickness
- Lower shrink materials
- Adjust the wall thickness/rib structure
- Packing profile during molding
- Tooling inserts such as beryllium copper
- Move gate to allow packing of thick areas

What We Will Cover

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- Material Issues/Concerns with Structural Composites
- Part Design Guidelines – Common Mistakes
- Warpage
- Structural Failures

Structural Weakness or Failures

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Mechanical failures happen when the loading of the part exceeds the capability of the material in a specific area

Common Structural Failures

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- Stress concentrators (such a sharp edges or corners)
- Weld lines
- Poor fiber orientation
- Poor properties due to voids
- Wrong material

Common Structural Failures

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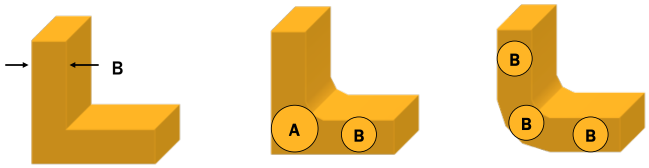
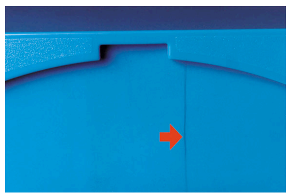
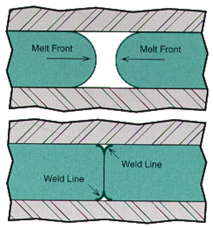


High stresses/ warpage potential — Better… but — Best





Design to Avoid Structural Failures

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- Work with material supplier
- Radius corners and edges
- Thicker is not always better
- Gate to allow flow that orients fiber in the principal direction of the structural load

Other Structural Considerations

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- Fatigue
- Creep
- Moisture, UV, temperature and other environmental concerns

Other Tooling Considerations

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- Draft
- Surface Finish
- Undercuts
- Venting

Summary

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- Understand your material needs and understand the material
- Design parts with relatively uniform wall thickness
- Keep the fill pattern simple

Design for Injection Molding

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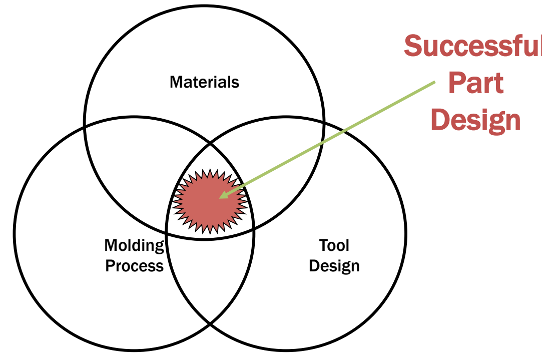

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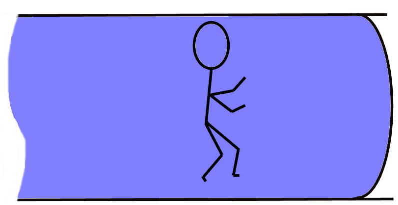
Live in the Wall Section!



STRUCTURAL • ELASTOMERS • WEAR • COLOR
CONDUCTIVE • FLAME RETARDANT • FILM/SHEET

Questions?

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(317) 473-2229