Evaluation of Effects of Wax Additive on Injection Molding

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Penn State Plastic Team

- Penn State Behrend manufacturing lab is one of the best-equipped plastics manufacturing labs in the nation.
- We are specialized for our capability in thermoplastic processing and material characterization related to real-life processing.
- Our machine shop and simulation team also support the tool making and processing simulation.

Speaker biographies

- **Mr. Brian Young**

- Is an associate professor of Engineering and the chair of the Plastics Engineering Technology department at Penn State Behrend
- He received both the B.S. in Plastics Engineering Technology 1995 and the MFGSE, Masters in Manufacturing Systems Engineering, in 2005, from Penn State
- Prior to his employment at Penn State, he worked for
  Omni Plastics as a process and tooling engineer for 16 years

- **Merek Jaworski**

- Is a sophomore Plastics Engineering Technology student at Penn State Behrend
- Intern at Beaumont Technologies for 3 years in the simulation and design department
- Penn State undergraduate research assistant under Dr. Xiaoshi Zhang

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Fischer-Tropsch Processing Aids

- Created with $CO + H_2$
  - Syngas
    - Natural gas
    - Coal
    - Biomass
- Long-chain hydrocarbons
- Narrow molecular weight distribution
- High Purity
- High melting point waxes

Benefits of Fischer-Tropsch Processing Aids

- Act as lubricants (both internal and external)
- Viscosity reduction
- Lower plate-out
- Increased dispersion
- Improved surface appearance
- Potential for lower cycle times
- Potential for lower energy costs

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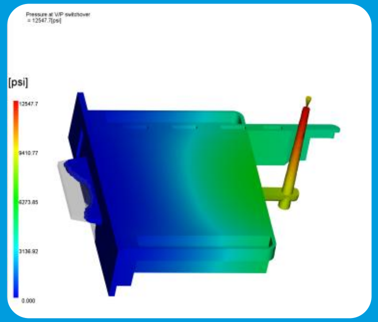
Workflow

Preliminary Quality Examination

Rheology Characterization

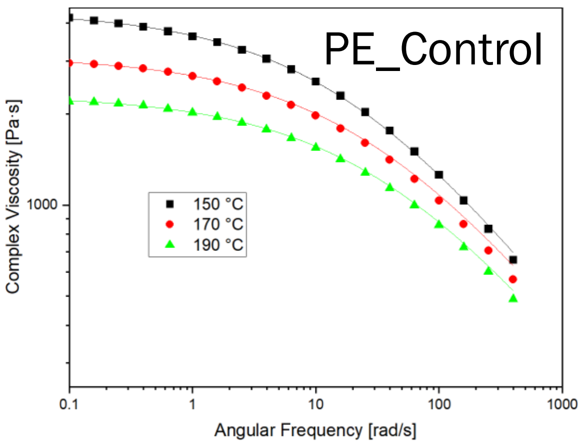
Real Life Validation

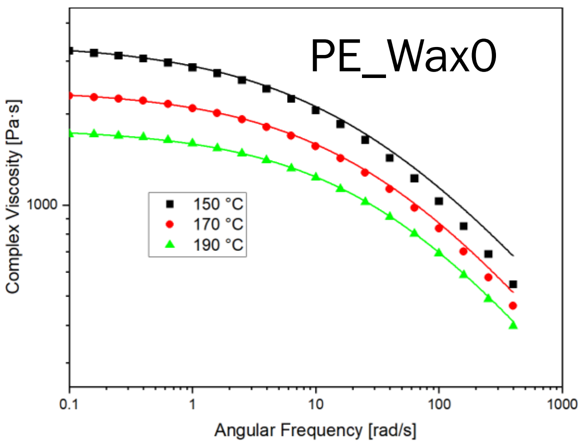


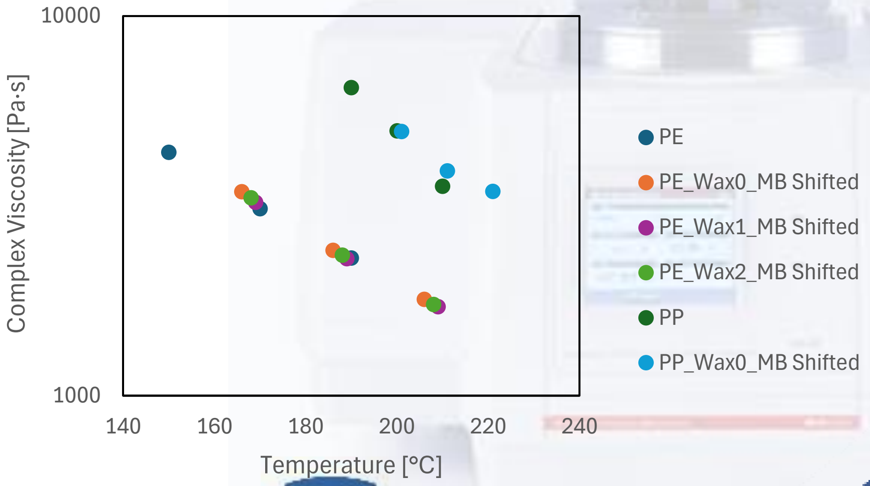
MoldFlow Simulation

Rheometry

- An Anton Paar MCR 702 rotational rheometer equipped with a 25mm parallel plate geometry was used for this characterization. Zero-shear complex viscosities from Cross-WLF model were compared, and it is evident that all waxes reduce viscosity.
- For the PE samples, the near-zero-shear viscosity decreased by 22%, 26%, and 24% for Wax 0, 1, and 2, respectively. To achieve a similar reduction, the PE control would require an increase in barrel temperature of 16 °C, 19 °C, and 18 °C, respectively.
- For the PP samples, the zero-shear viscosity from Cross-WLF model decreased by 23%, 21%, and 3% at 190 °C, 200 °C, and 210 °C, respectively. To achieve this level of reduction, the PP control would require an increase in barrel temperature of at least 11 °C.







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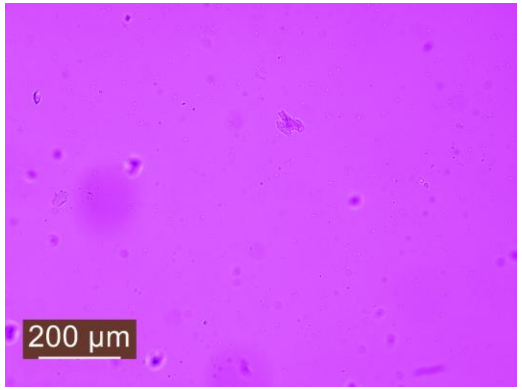
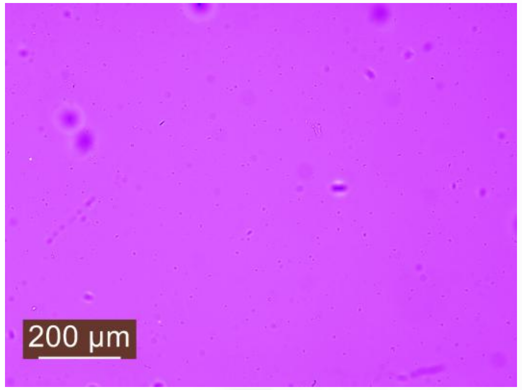
Preliminary Characterization – Stability & Morphology

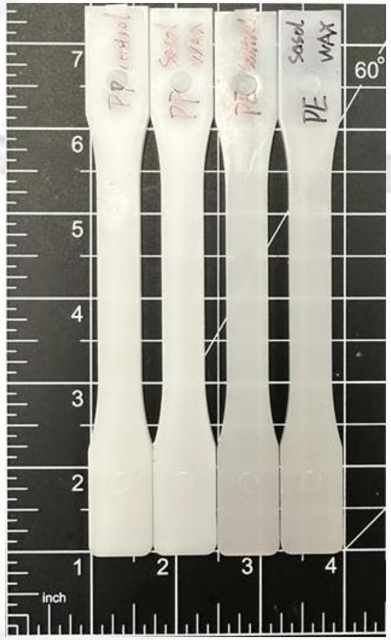
- FTPA was characterized using a Mettler Toledo TGA 2 and DSC 3 to determine its thermal stability and processing window. The results indicate that FTPA wax is thermally stable up to 258 °C and fully degrades by 500 °C.
- PE and PP are fully miscible with the FTPA, with no clear indication of phase separation.
- Wax additives do not alter the surface appearance.

PE_Control 200 °C w/ filter



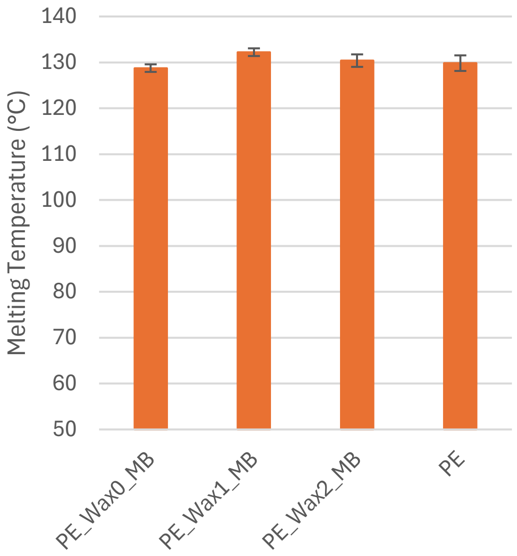
PE_Wax_MB 200 °C w/ filter

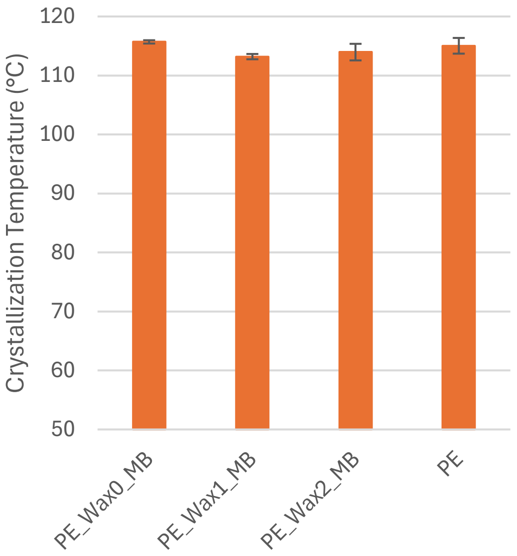




DSC Characterization

- The DSC experiment was conducted by heating the sample from room temperature to 160 °C, cooling it to 50 °C, and then reheating to 160°C.
- Adding wax does not affect the melting temperature and crystallization kinetics of the controls.





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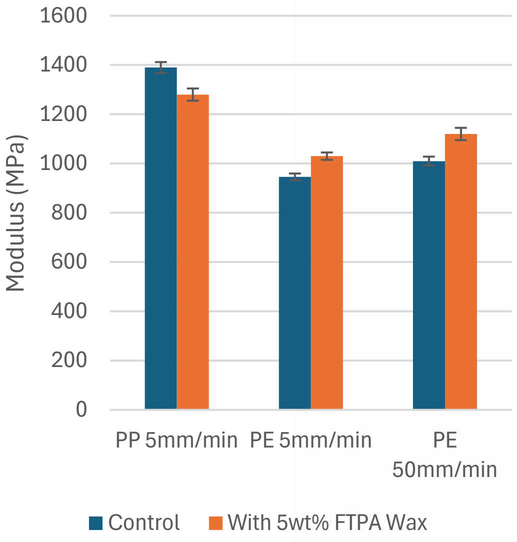
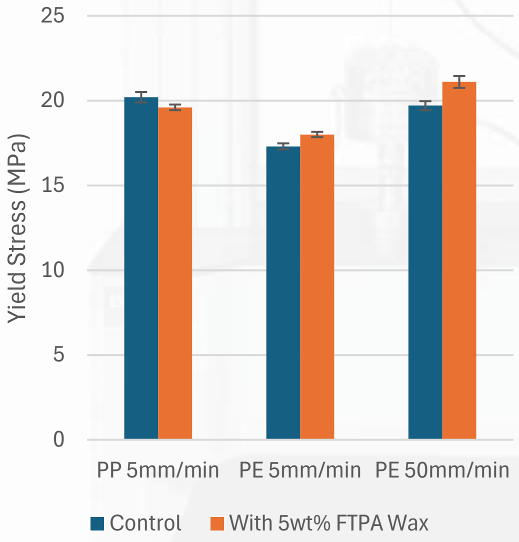
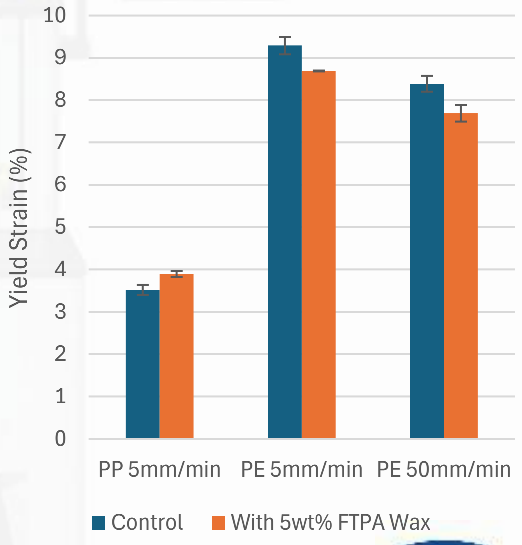
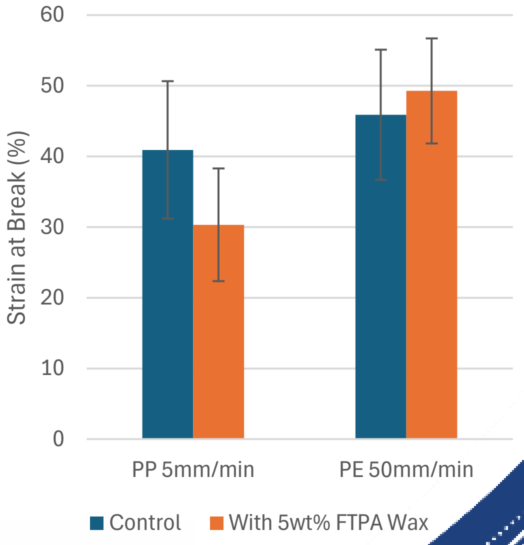
Tensile Testing

- FTPA slightly reduced the strength of PP but made PE stiffer.
- Both Control and additive modified exhibited similar tensile properties.









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Molding - Tensile

- Arburg 370A Alldrive
  - 22 mm screw diameter
  - 50 ton
- PE
  - 193°C melt/ 40°C mold
  - PE + W0-2 (5%) showed an average 15.2% decrease in transfer pressure vs. PE
- PP
  - 204°C melt/ 40°C mold
  - PP + W0 (5%) showed a 10.6% decrease in transfer pressure vs. PP

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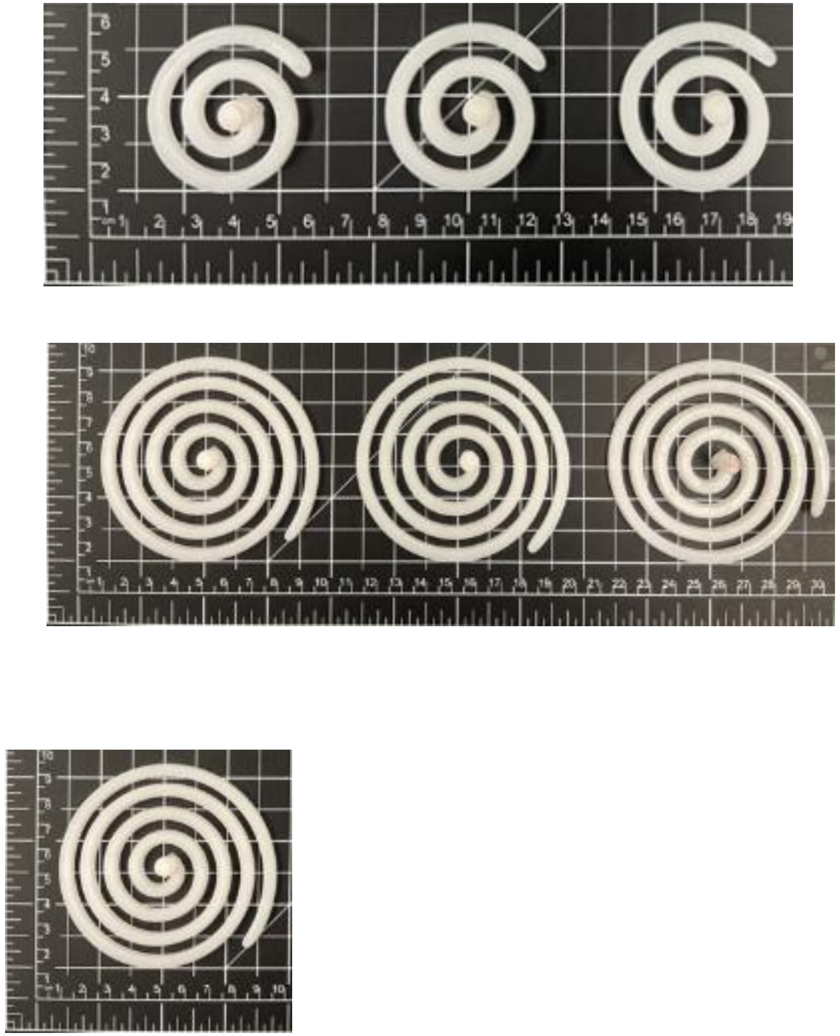
Molding – Spiral Flow

- Arburg 370A Alldrive
  - 22 mm screw diameter
  - 50 ton
  - 25.4 mm/sec injection speed
  - Pressure varied
    - PE - 17.2 MPa, 34.5 MPa, 69 MPa, 103.4 MPa
    - PP - 17.2 MPa, 34.5 MPa, 69 MPa, 86.2 MPa
- PE
  - 193°C melt/ 40°C mold
  - All PA's at 5% loading
- PP
  - 204°C melt/ 40°C mold
  - W0, W1, + W2 at 5% Loading, WC at 1% loading



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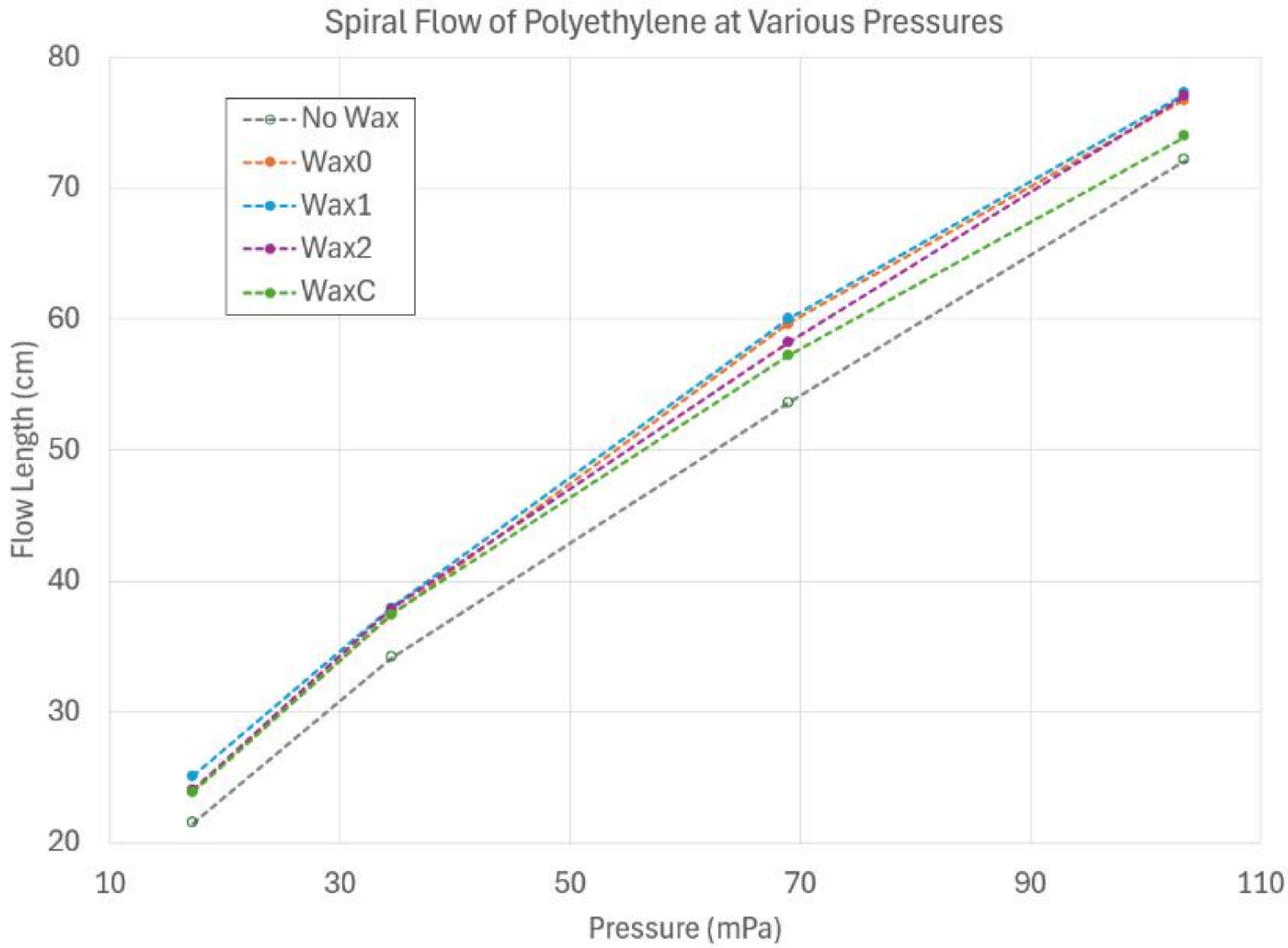
Molding – Spiral Flow - PE



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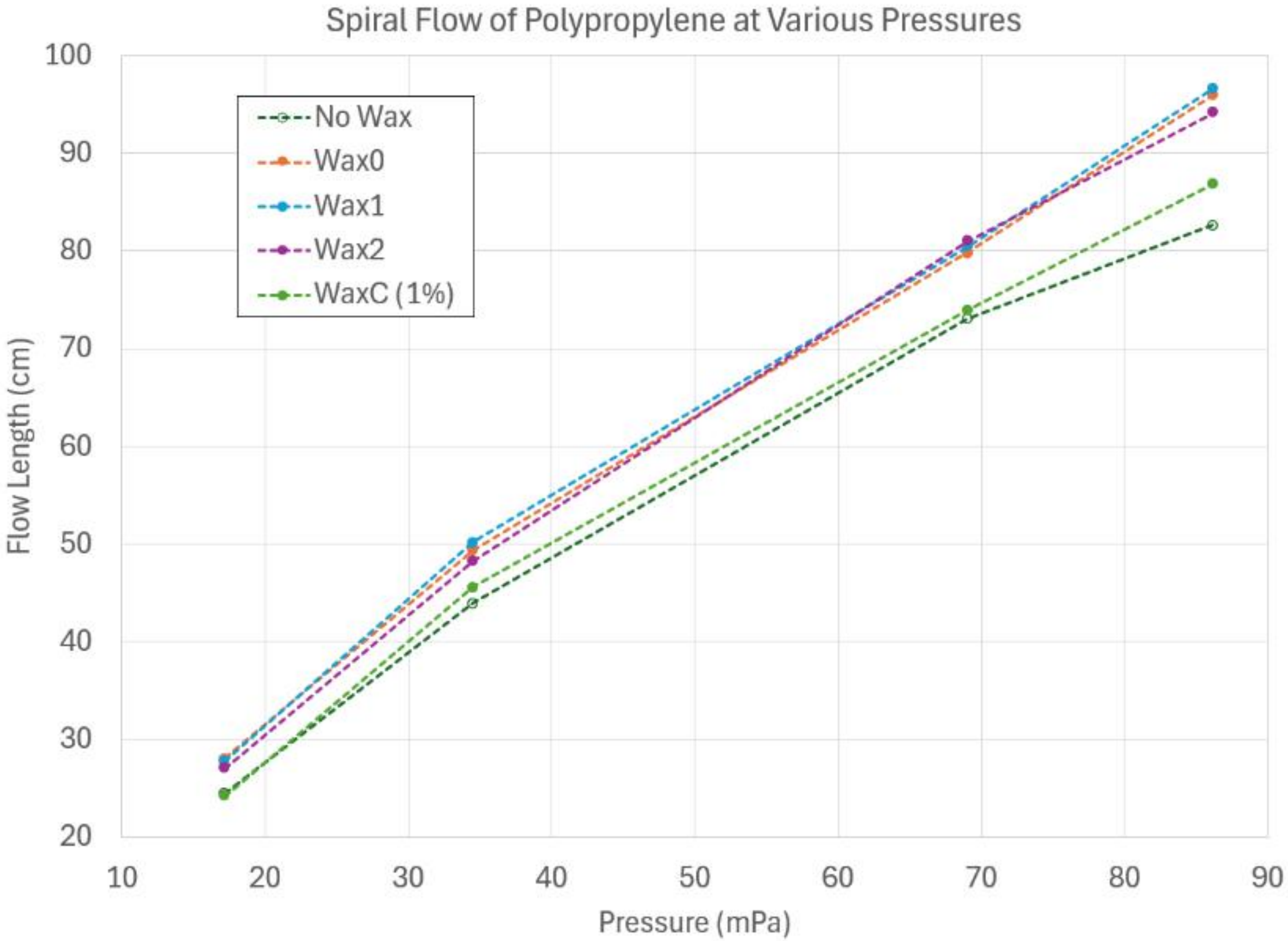
Molding – Spiral Flow - PP



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Molding – Spiral Flow - PP

Average increase in flow length for PE (all waxes at 5%)

- PE + W0 = 9.7%
- PE + W1 = 16.5%
- PE + W2 = 14.1%
- PE + WC = 12.0%

Average increase in flow length for PP (all waxes at 5% except WC – 1%)

- PP + W0 = 13.0%
- PE + W1 = 13.6%
- PE + W2 = 11.2%
- PE + WC = 2.1%

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Molding – Drawer - PE

- Sumitomo SE100DU
  - 28 mm screw diameter
  - 100 ton
  - 193°C melt/ 40°C mold
  - 63.2 cc/sec injection velocity
- Change in Transfer Pressure vs. Unmodified
  - PE + W0-2 (5%) showed a 12.7% decrease
  - PE + WC (5%) showed an 8.1% decrease

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Molding – Drawer - PP

- Sumitomo SE100DU
  - 28 mm screw diameter
  - 100 ton
  - 204°C melt/ 40°C mold
  - 77.8 cc/sec injection velocity
- Change in Transfer Pressure vs. Unmodified
  - PP + W0-2 (5%) showed a 14.4% decrease
  - PP + W2 (2%) showed a 6.6% decrease
  - PP + W2 (1%) showed a 3.6% decrease
  - PP + WC (1%) showed a 3.7% decrease

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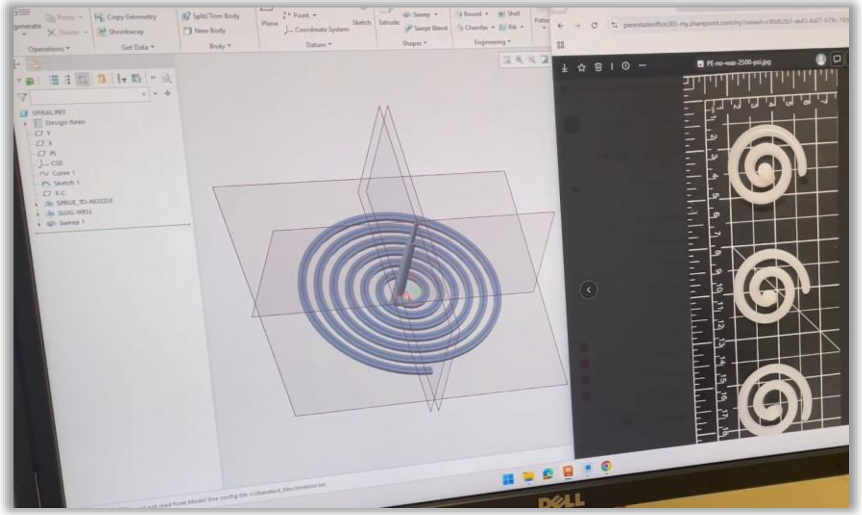
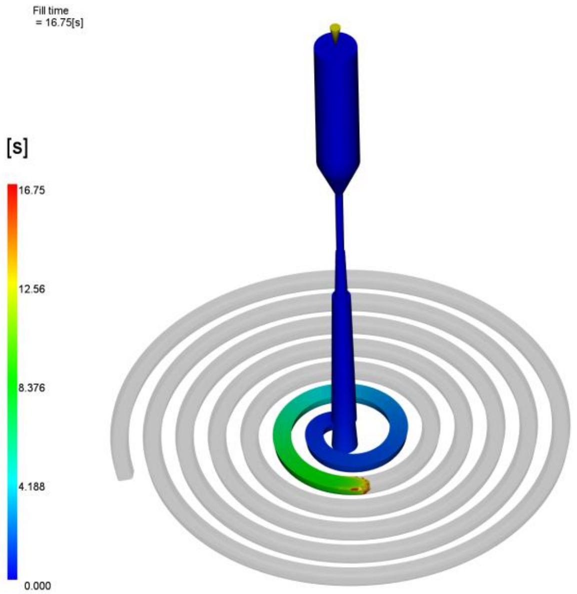
Reduction in required demolding force.

Simulation

- 3D Modeling
  - Creo Parametric
  - Mesh densities
  - Calipers and machine/mold inspection
- Process
  - Unique spiral mold process
  - Recorded processing data
- Improving replication of reality
  - Processing data
  - Machine information
  - Material selection
  - Tradeoff with time and money





PE Control
2,500 psi Hold

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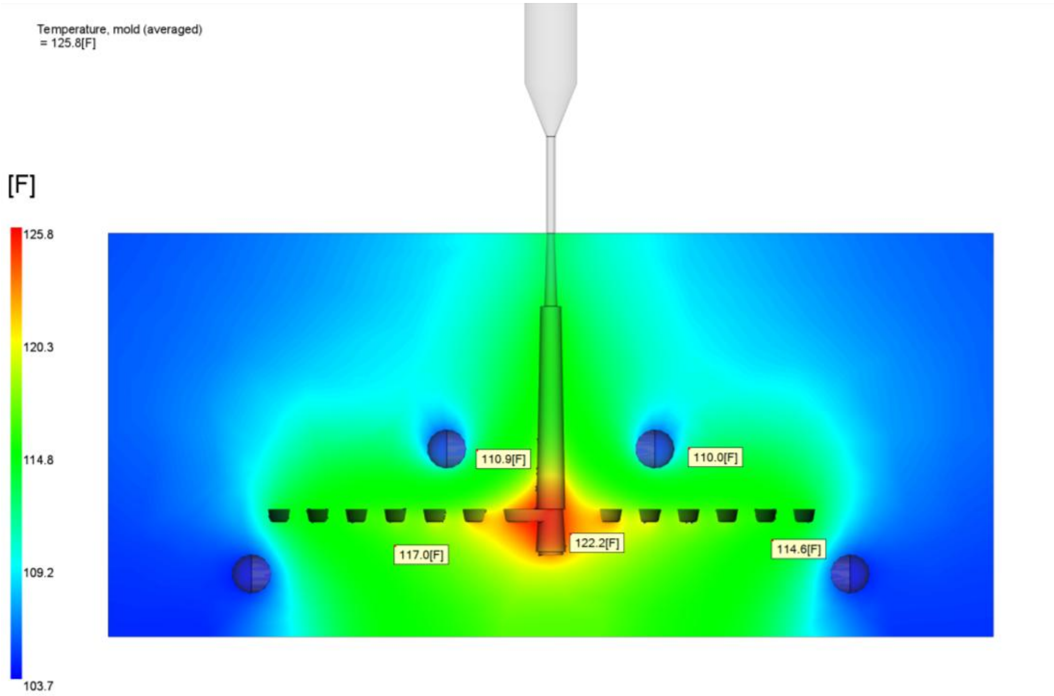
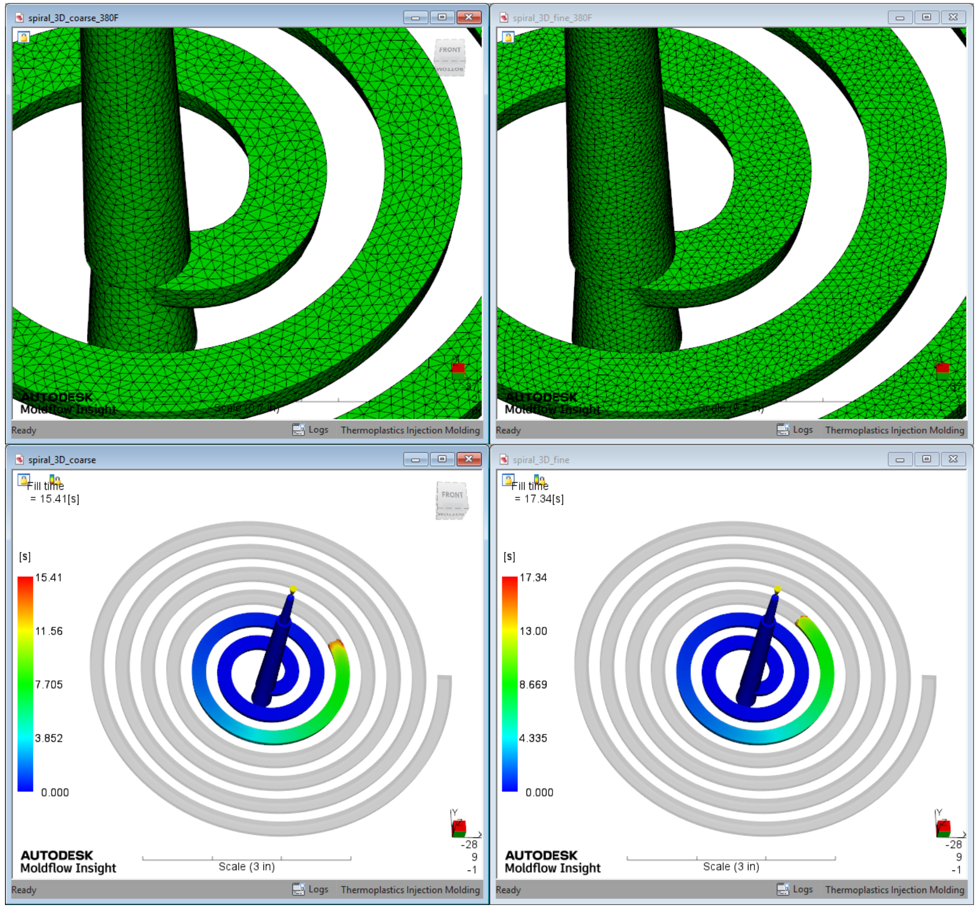
Simulation – Iterative Modeling

- Creo 3D model
- Mesh density
- Sprue to check ring
- Other part design
- Cooling
- FEM Mold



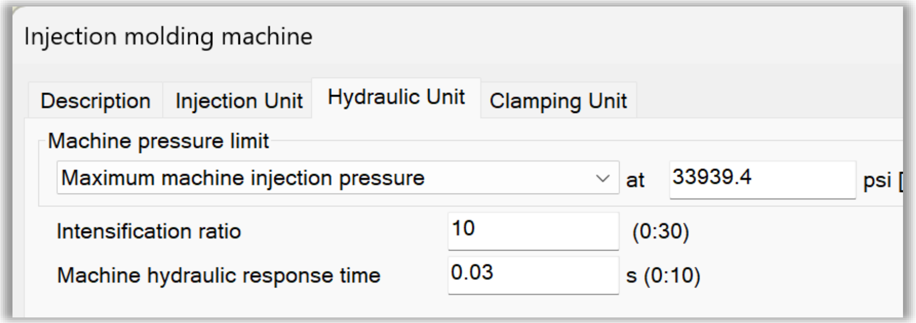
Coarse mesh

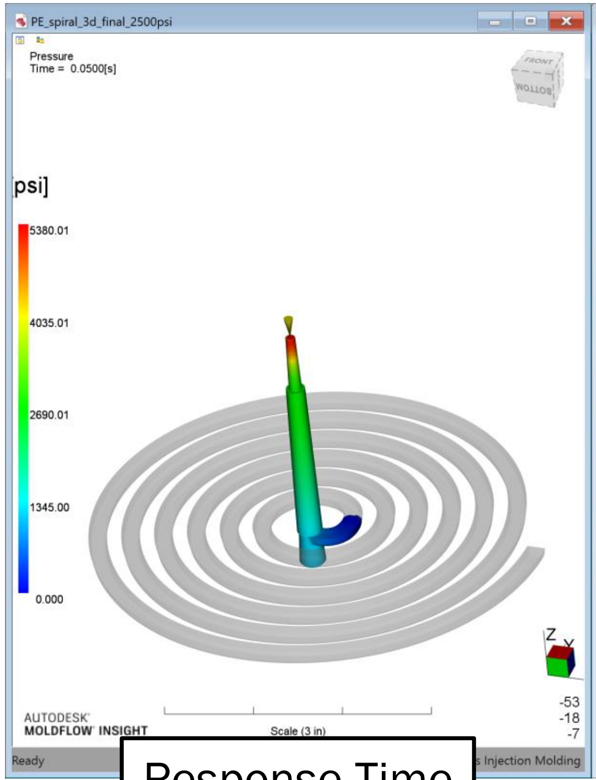
Fine mesh



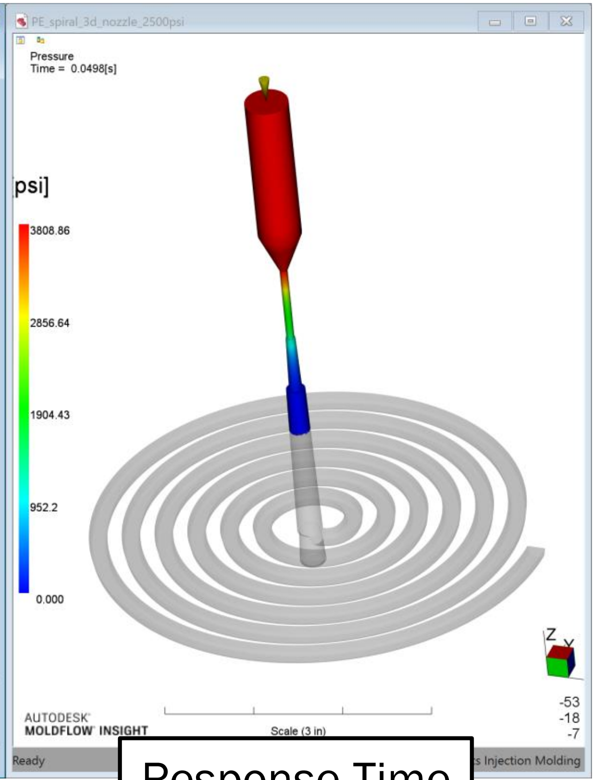
Simulation – Process

- Unique spiral mold process
  - Transfer to pressure-based filling immediately
  - Troubleshooting with Pressure animation plot
- Processing sheet
- Machine info
  - Hydraulic response time most significant
  - Max pressure/clamp force and barrel size





Response Time
0.10s
2,500 psi hold
>**10,000 psi**



Response Time
0.03s
2,500 psi hold
~4,000 psi

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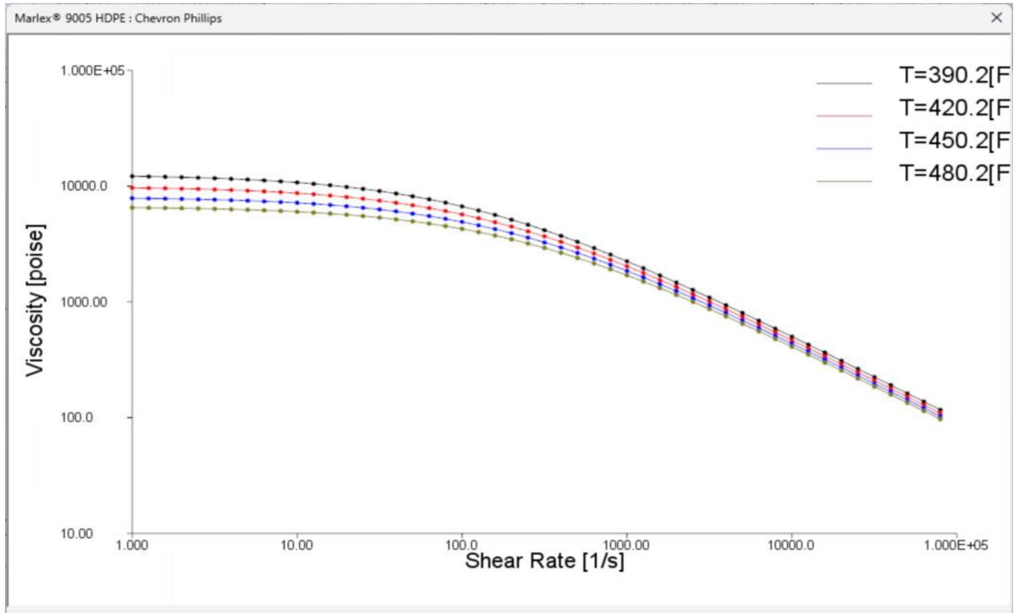
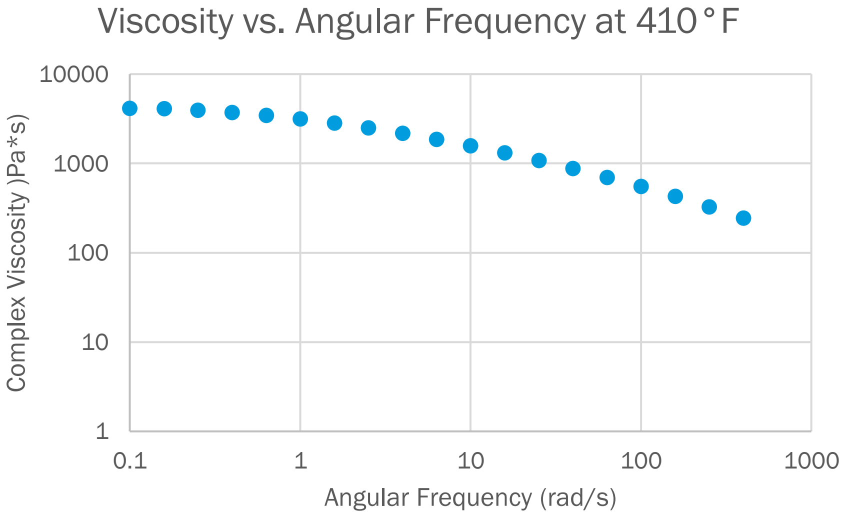
Simulation – Material Selection

- Material Substitution
  - Expensive testing
  - Compare MFR?
  - Compare viscosity curves?
  - D3?
- Processing aids
- Other considerations





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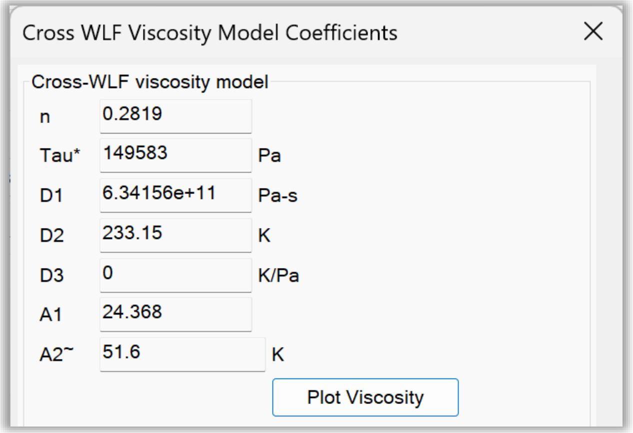
Simulation – Processing Aid

- Shear rate and temperature dependence
- Modifying Viscosity for Cross-WLF Model
  - Changing D_1 value
  - Excel Regression Analysis

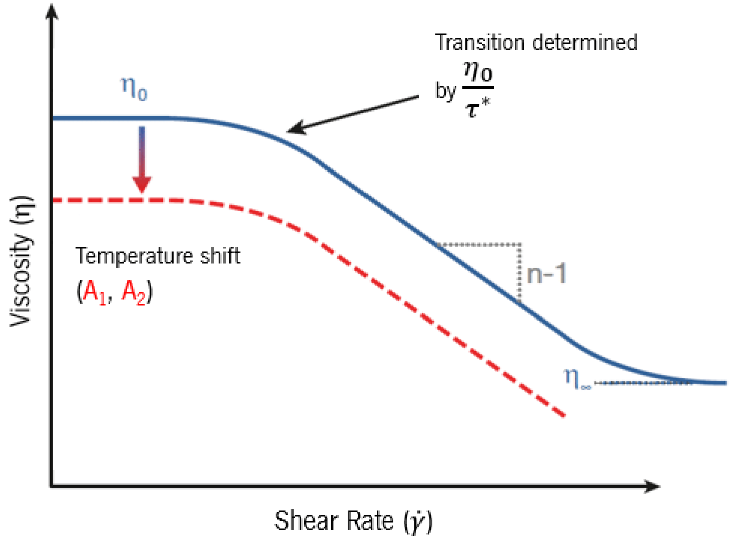


$$\eta_0 = D_1 exp\left[-\frac{A_1(T-T^*)}{A_2+(T-T^*)}\right]$$

$$\eta = \frac{\eta_0}{1+\left(\frac{\eta_0\dot{\gamma}}{\tau^*}\right)^{1-n}}$$

Zero-Shear Viscosity = D_1•f(Temperature)

Molten Viscosity = $\frac{\text{Zero-Shear Viscosity}}{1+(\text{Shear})^{\text{Slope}}}$



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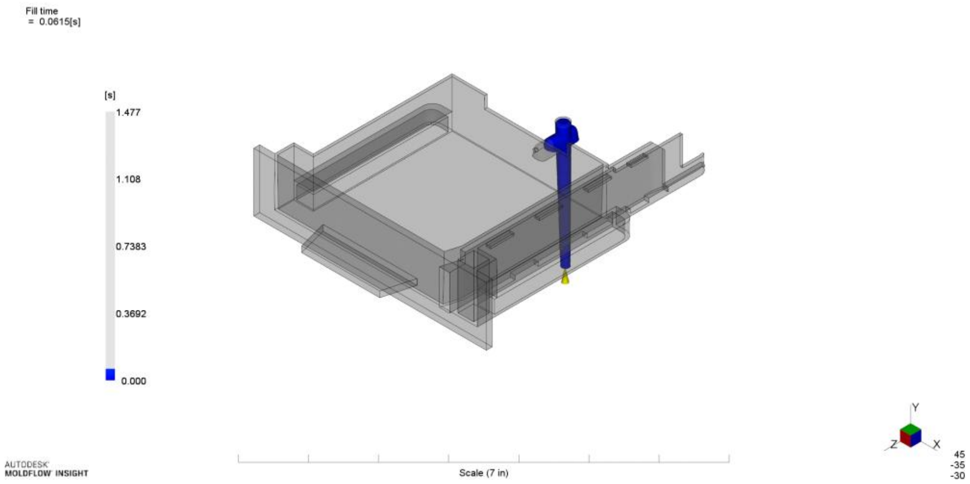
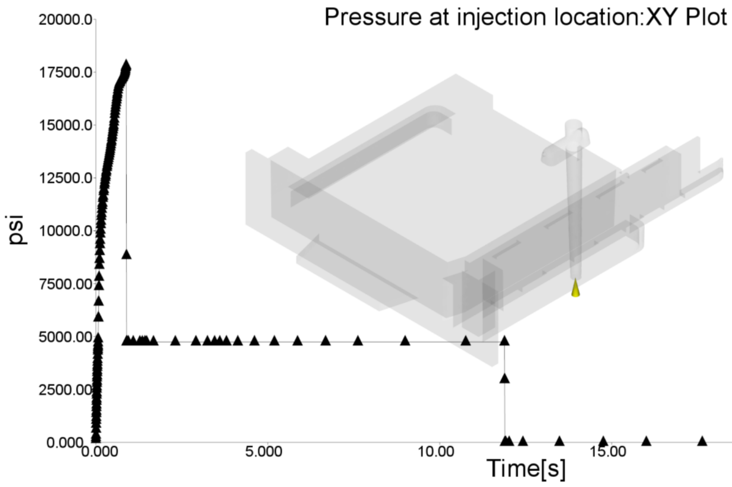
Simulation – Results

- Spiral Mold
  - Spiral length increase
    - PE simulated a 18.3% increase compared to 11.0%
    - PP simulated a 14.5% increase compared to 13.2%
- Drawer Mold
  - Transfer pressure accuracy
    - PE simulated at 15,895 psi compared to 17,350 psi
    - PP simulated at 13,668 psi compared to 13,410 psi
  - Change in transfer pressure with wax
    - PE + WO (5%) showed a 7.4% decrease (Reality – 14.0%)
    - PP + WO (5%) showed a 7.6% decrease (Reality – 14.9%)





Conclusions

- Moldflow indicates processing aid benefits
  - Viscosity reduction
- Mold release effect
- Potential cost savings
  - Lower processing temperatures
  - Faster cycle times

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