ON-LINE COMPOUNDING OF TPO BLENDS FOR LARGE PART THERMOFORMING APPLICATIONS

Kurt A. Koppi, Sam L. Crabtree, and Todd A. Hogan

The Dow Chemical Company, Midland, MI

Overview

- What’s a Thermoplastic Olefin (TPO)?
- TPO’s in Cut Sheet Thermoforming
- Resin Design / On-Line Compounding
- Mixing Study Experimental Results
- Sag Rate / Thermoformability
- Summary

What is a TPO?

- Thermoplastic Olefins are polymer alloys typically comprised of:
  - Polypropylene . . . for stiffness, chemical resistance, heat resistance
  - Elastomer . . . impact modifier, for toughness / impact resistance
  - Inorganic filler . . . for stiffness, lower Coefficient of Linear Thermal Expansion (CLTE)

What is a TPO?

- Physical properties can be tailored to the end use application by the type and amount of the components:
  - "Soft / Flexible" TPO's – major phase is elastomer, e.g. automotive interiors (modulus < 1,000 MPa/150,000 psi)
  - "Rigid / Stiff" TPO's – major phase is PP, e.g. automotive exteriors (modulus > 2,000 MPa/300,000 psi)

This project was focused on …

… Rigid TPO (modulus > 2,000 MPa) for sheet extrusion and thermoforming applications

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Cut-Sheet Thermoforming

FormSim software, from Industrial Materials Institute, NRC (Canada)

TPO's in Thermoforming

- TPO's have had limited acceptance in thermoforming, primarily due to *processing* issues:
  - Excessive *sag*
  - *Inconsistent* forming from lot to lot/within a lot
  - Webbing
  - Recycle of high gloss sheet

- Previous work has successfully …

… developed a high melt strength thermoformable TPO with improved *thermoforming performance* while delivering excellent physical properties

Physical Properties

- *Performance requirements* were achieved:
  - Stiffness: Flexural Modulus 2,100 MPa (300,000 psi)
  - Toughness: Instrumented Dart Ductile at -20°C (0°F)
  - Low CLTE: 4.0 X 10^{-5} mm/mm/°C (2.2 X 10^{-5} in/in/°F)
  - Heat Resistance: DTUL @ 0.45 MPa 110°C (230°F)
  - Excellent Weatherability (impact and color retention)
- New *HMS TPO* with excellent *physical* properties and improved *thermoforming* performance

Improved Sag Resistance

HMS-TPO Conventional-TPO

Reduced Sagging = Reduced Webbing

HMS-TPO

Conventional-TPO

Cost Reduction Opportunity

- HMS-TPO prepared via a secondary compounding step
- HMS-TPO typically prepared on a FCM
- Direct compounding on sheet line would reduce cost
- Compounding raw talc on SSE very challenging
- Talc concentrates should be a feasible approach
- On-Line Compounding:

  what type of talc concentrate?
  acceptable properties?
  acceptable processability?

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Resin Design

- HMS-TPO Formulation:
  55% impact copolymer polypropylene (0.5 dg/min)
  15% polyolefin elastomer (0.868 g/cc, 0.5 dg/min)
  30% talc (magnesium silicate)

- Talc Concentrates: CP-250 Farrel Continuous Mixer (FCM) @ 210°C

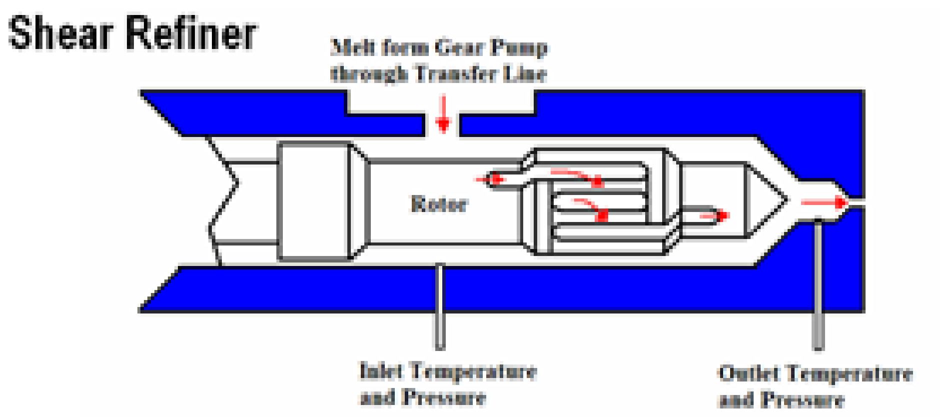
Concentrate #1	Concentrate #2
60% Talc	67% Talc
40% PP	33% POE

- On-Line Compounded Formulations:

Formulation #1	Formulation #2
50% Conc. #1	45% Conc. #2
35% PP	55% PP
15% POE	

Mixing Study

- Shear Refiner: influence of applied shear stress



Shear Stress: $\tau = \eta\dot{\gamma}$ η = polymer viscosity

Shear Rate: $\dot{\gamma} = \dfrac{\pi D N}{60\delta}$

D = barrel diameter (2 inch)
N = screw speed (rpm)
δ = clearance between barrel and rotor shearing flight (0.020 inch)

Pellet samples prepared across a range of rotor speeds which correspond to different applied shear stresses.

Pellet samples then injection molded into tensile bar test specimens.

- Sheet Extrusion Line: influence of screw design & extrusion rate
  - a) simple single-flighted screw
  - b) single-pass mixing blister ring
  - c) high performance double wave screw

Test specimens cut from samples to measure tensile and impact.

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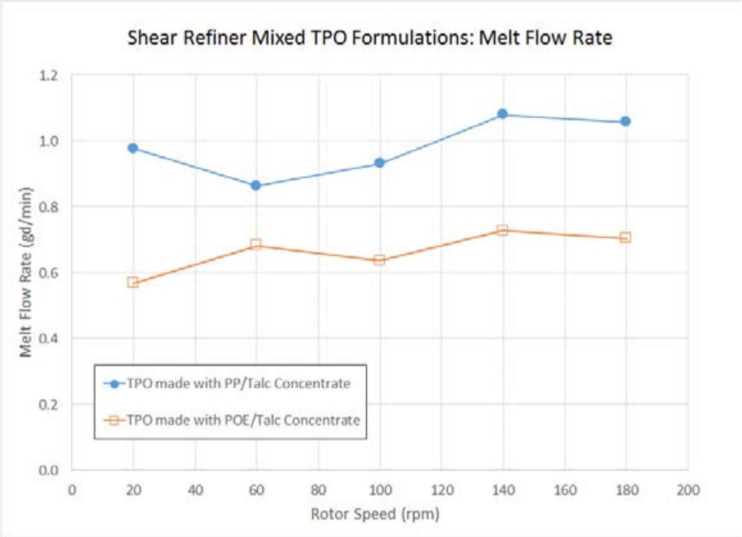
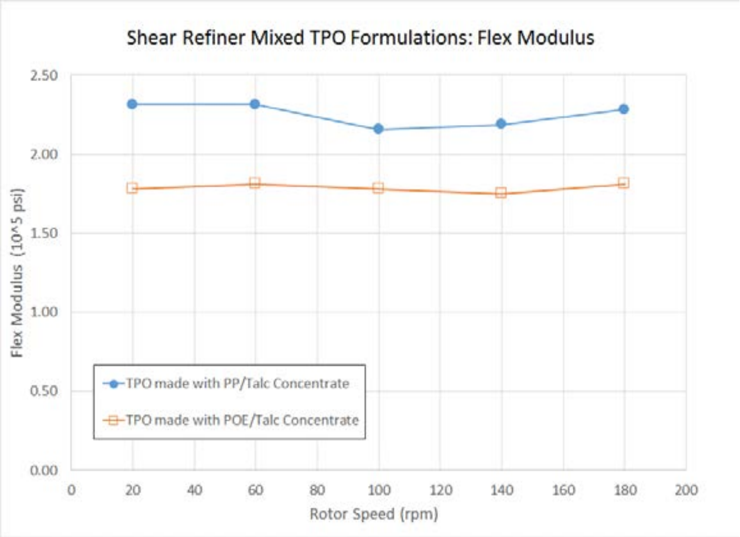
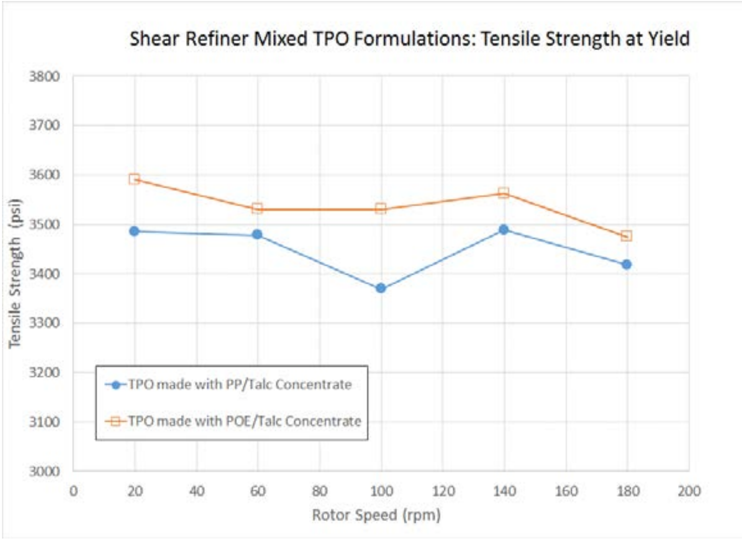
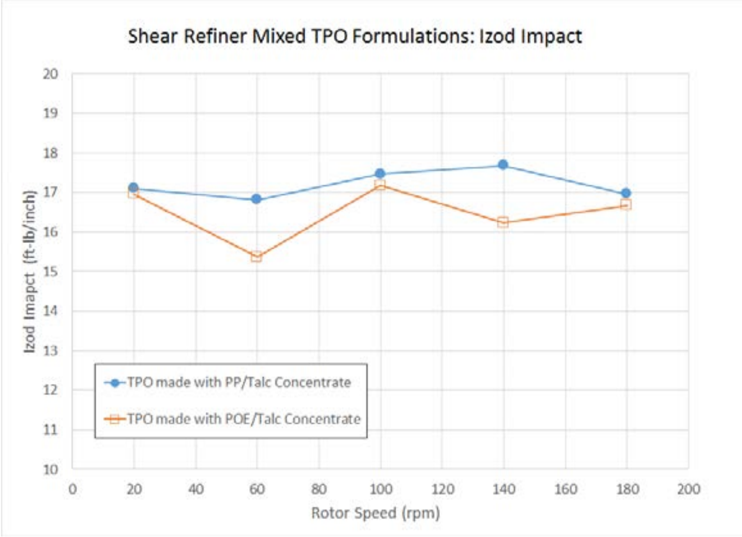
Shear Refiner

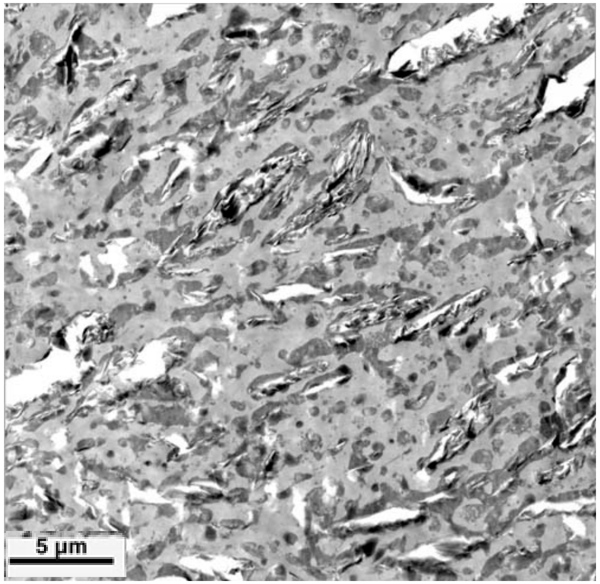




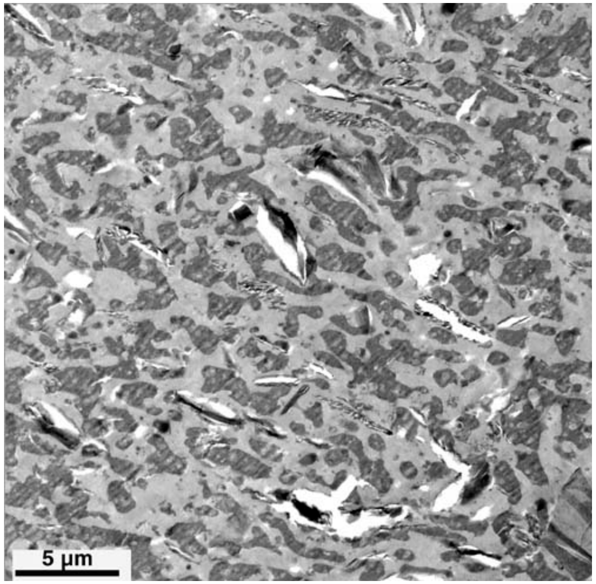




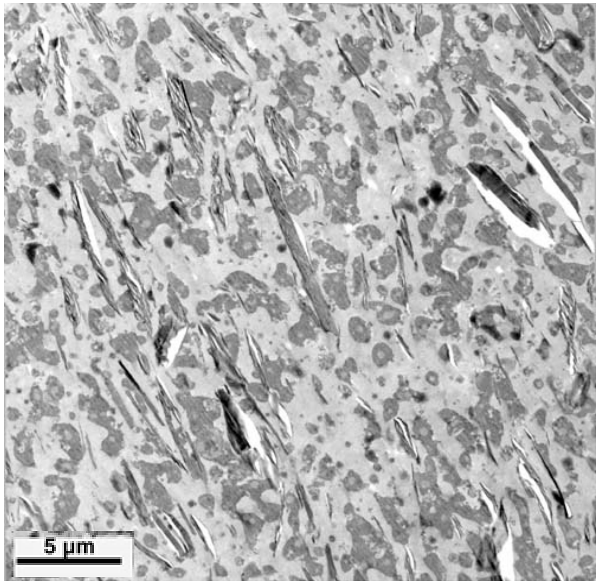
Shear Refiner TPO Morphology via TEM



TPO prepared w/ POE/Talc Conc.
Low Shear Stress Mixing



TPO prepared w/ PPP/Talc Conc.
Low Shear Stress Mixing



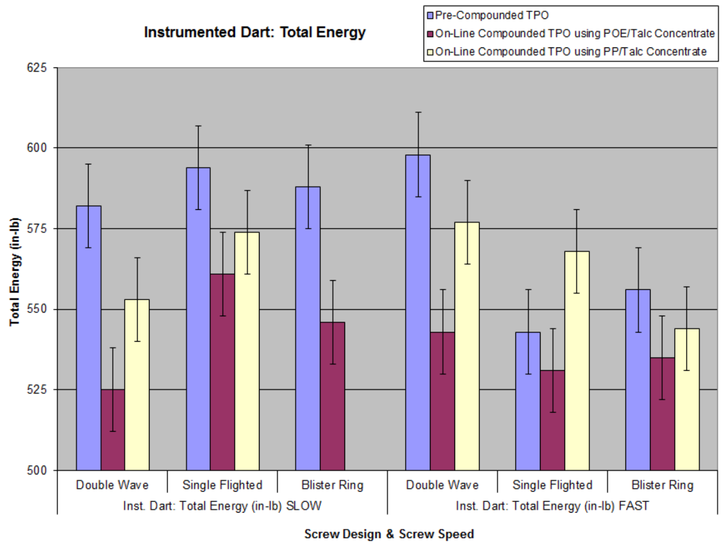
TPO prepared w/ PP/Talc Conc.
High Shear Stress Mixing

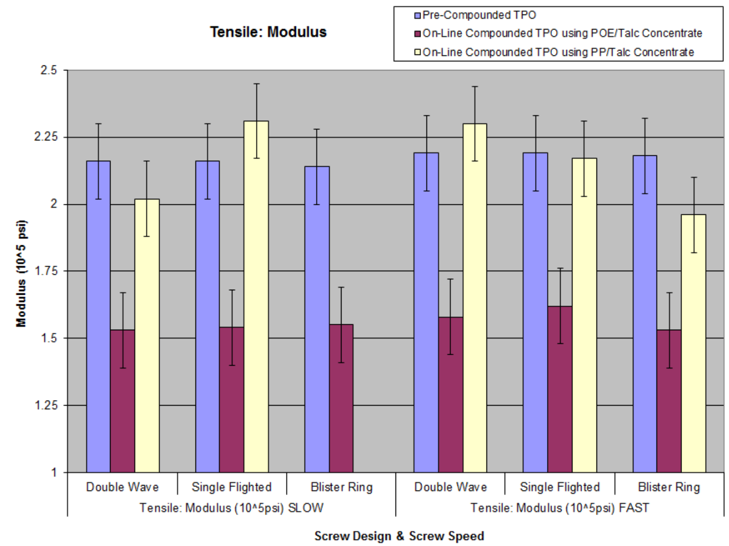
- Talc predominately imbedded in polymer used to make concentrate
- TPO Morphology not influenced by applied shear stress of shear refiner

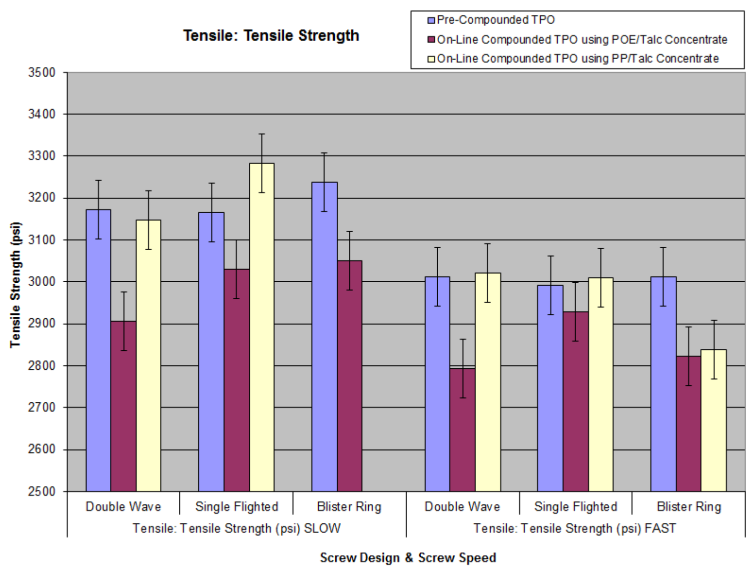
Shear Refiner Observations

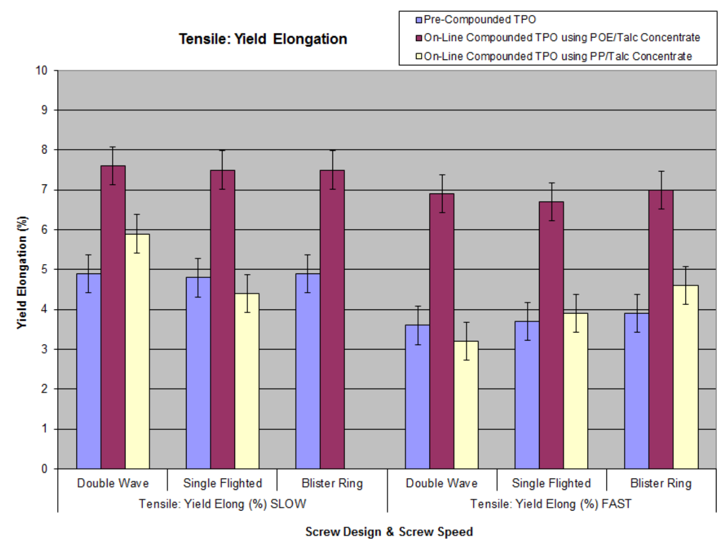
- Increasing level of dispersive mixing did not affect performance properties of HMS-TPO as prepared via on-line compounding with talc concentrate
- Influence of polymer carrier choice in talc concentrate (PP vs. POE):
  - MFR: likely affected by differences in polymer degradation
  - Flex Modulus & Tensile Yield: affected by talc localization
  - Izod Impact: no significant influence observed
- Simple screw design should suffice for adequate dispersive mixing of on-line compounding on a sheet extrusion line

Sheet Extrusion









Sheet Extrusion Observations

- Screw design did not affect performance properties of TPO as prepared via on-line compounding with a talc concentrate
- Influence of polymer carrier choice in talc concentrate (PP vs. POE):
  - Dart Impact: influence observed (unlike Izod of shear refiner samples)
  - Modulus & Elongation & Tensile Strength: affected by talc localization
- Extrusion rate only seemed to influence ultimate tensile strength and this is believed to be due orientation developed in the sheets
- TPO prepared via on-line compounding with a PP/Talc concentrate exhibited very similar performance properties as pre-compounded TPO
- Based on these results, thermoforming experiments only performed on sheet samples extruded using the simple single-flighted screw

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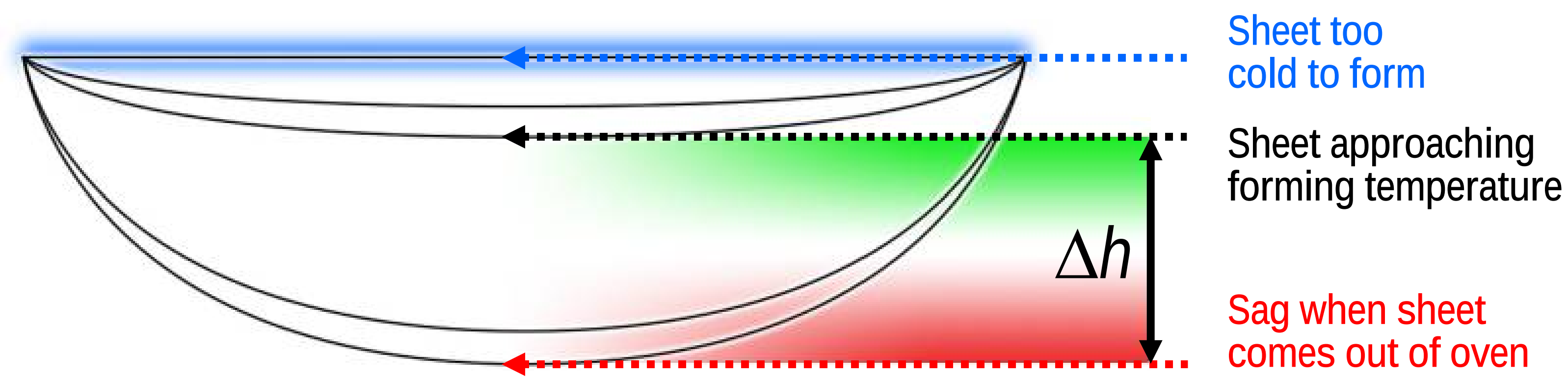
What is “Sag” or “Drape”?

Sag and Sag Rate

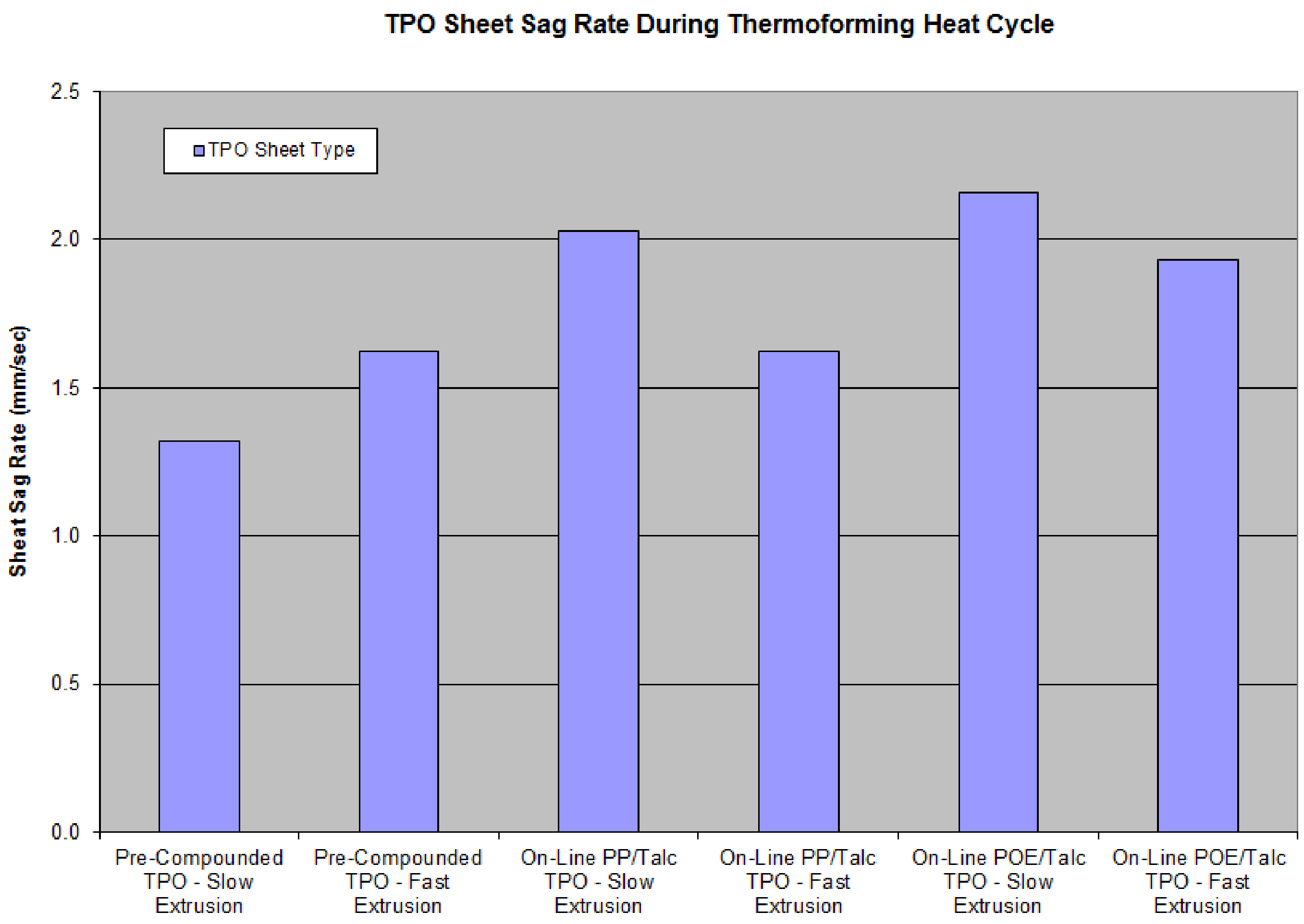
- The amount and consistency of sag is the #1 barrier to the broad use of TPO in cut sheet thermoforming
- Rate of sag once the sheet is ready to form is also an issue:



$$SagRate = \frac{\Delta h}{\Delta t}$$

Sag Rate

ZMD International Model V223 Shuttle Thermoformer
T = 145°C, measure time for sheet to sag 115 mm.



Thermoformability Observations

- Sag rate influenced by sheet extrusion rate:
  - Pre-Compounded TPO: sag rate increases with sheet extrusion rate
  - On-Line Compounded TPO: opposite trend observed
- Sag rate influence by polymer carrier in talc concentrate (PP vs. POE):
  - TPO made with POE/Talc concentrate sags faster
  - TPO made with PP/Talc concentrate sags slower
- For large part thermoforming, slow sheet sag rate is desirable
- TPO sheet prepared via on-line compounding with a PP/Talc concentrate exhibited very similar sag rate as pre-compounded TPO when sheet was extruded at a fast rate
- Likewise, such on-line compounded TPO sheets exhibited less thinning in the corners as compared to those made with POE/Talc concentrate

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Summary

- On-line compounded TPO sheet matches the mechanical performance of pre-compounded TPO sheet when a talc concentrate is used in the formulation
- PP/Talc concentrate is preferred over POE/Talc concentrate
- A simple single-flighted screw works as well as a high performance screw for on-line compounding
- The sag rate and thermoformability of an on-line compounded TPO sheet prepared with a PP/Talc concentrate matches that of a pre-compounded TPO sheet
- On-line compounding of TPO sheet offers the potential to reduce manufacturing cost be eliminating a separate compounding step of the full formulation