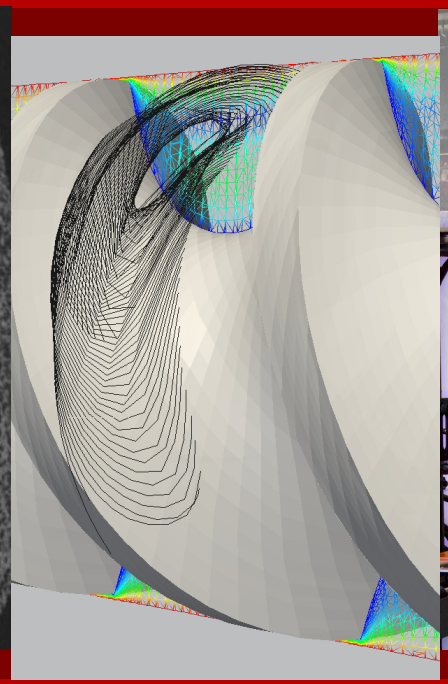
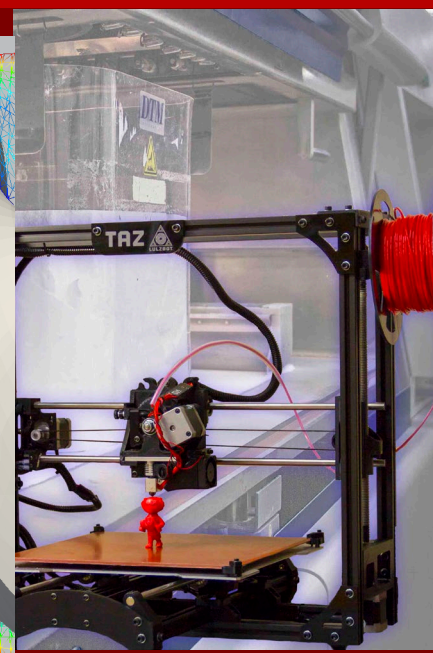
Polymer Engineering Center

University of Wisconsin - Madison





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Processing Behavior of Recycled Thermoplastics: Process-Induced Changes in Microstructure

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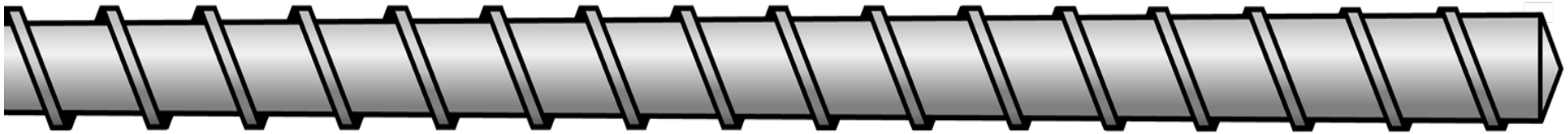
UW - Madison

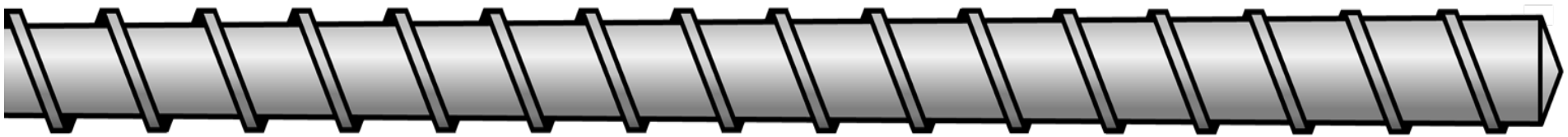
July 29, 2025

Flow for Today



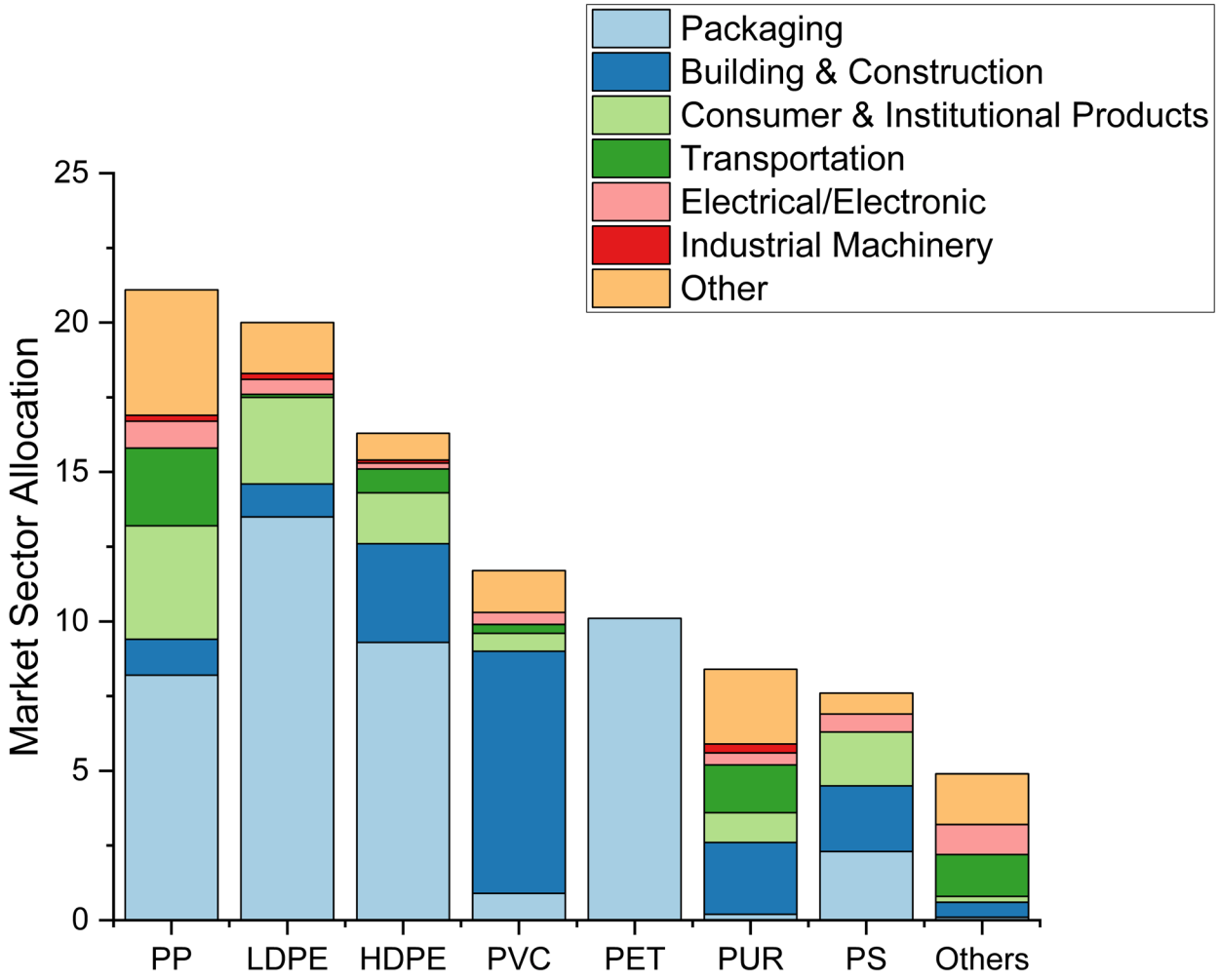
Introduction → Case Study → Results & Learnings → Outlook

Flow for Today



Introduction → Case Study → Results & Learnings → Outlook

1 The Challenge of Plastics Waste



Data Source: Geyer, R., et. al. 2017. Production, use, and fate of all plastics ever made. DOI: 10.1126/sciadv.1700782

Prevalence

Plastic's versatility and widespread usage have led to its prevalence in various industries and everyday life.

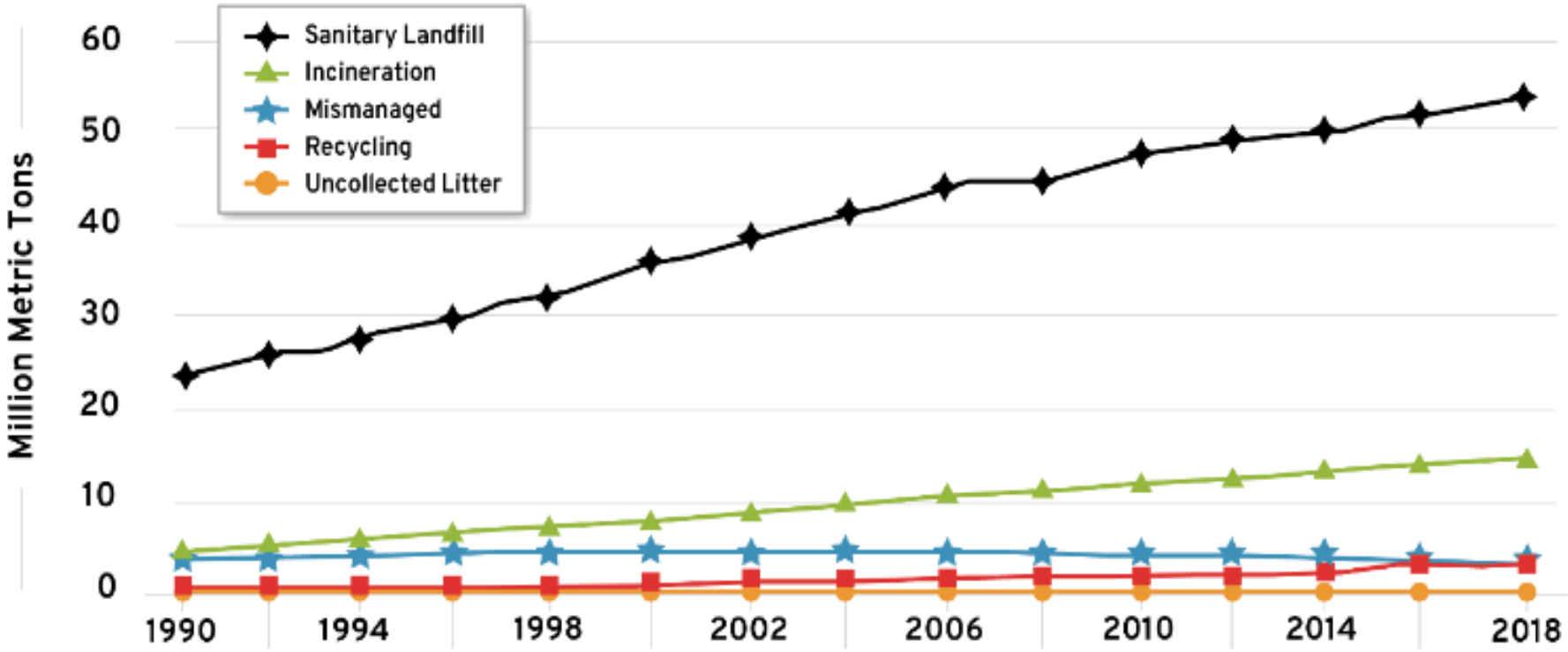
Advantages

- Inexpensive
- Widely available
- Good mechanical properties
- Strong chemical resistance

Future Projections

Plastic use is expected to increase by approximately 90% through 2060, raising concerns about environmental impact.

2 U.S. Plastics Waste Disposal



Low Recycling Rates

Despite demand for recyclable materials, plastic recycling rates remain low.

9%

of plastic waste recycled in the U.S.

Landfill Destination

The vast majority of plastics in the U.S. end up in landfills.

75%

of plastic waste goes to landfills

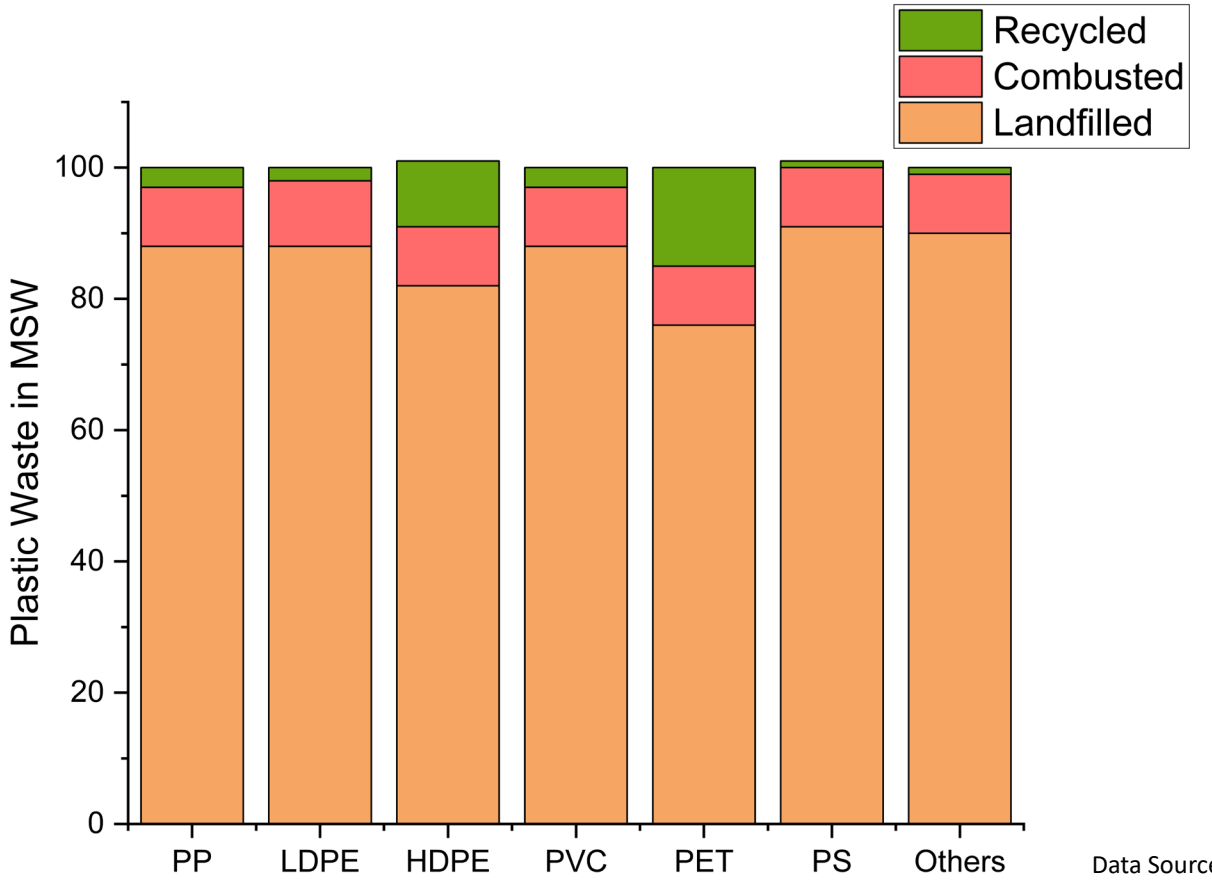
Data Source: OECD, NREL

3 Economics of Landfilled Plastics Waste

Landfilled Plastic Value

Estimated market value of landfilled plastic material:

$7.2 Billion

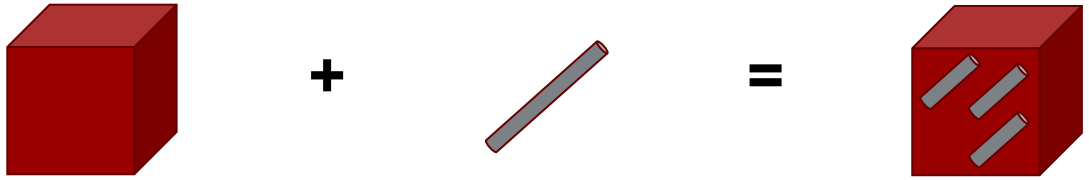


Data Source: OECD, NREL

? How can we enable more recycling?

(Recycled) Long Fiber-Reinforced Thermoplastics (LFT)

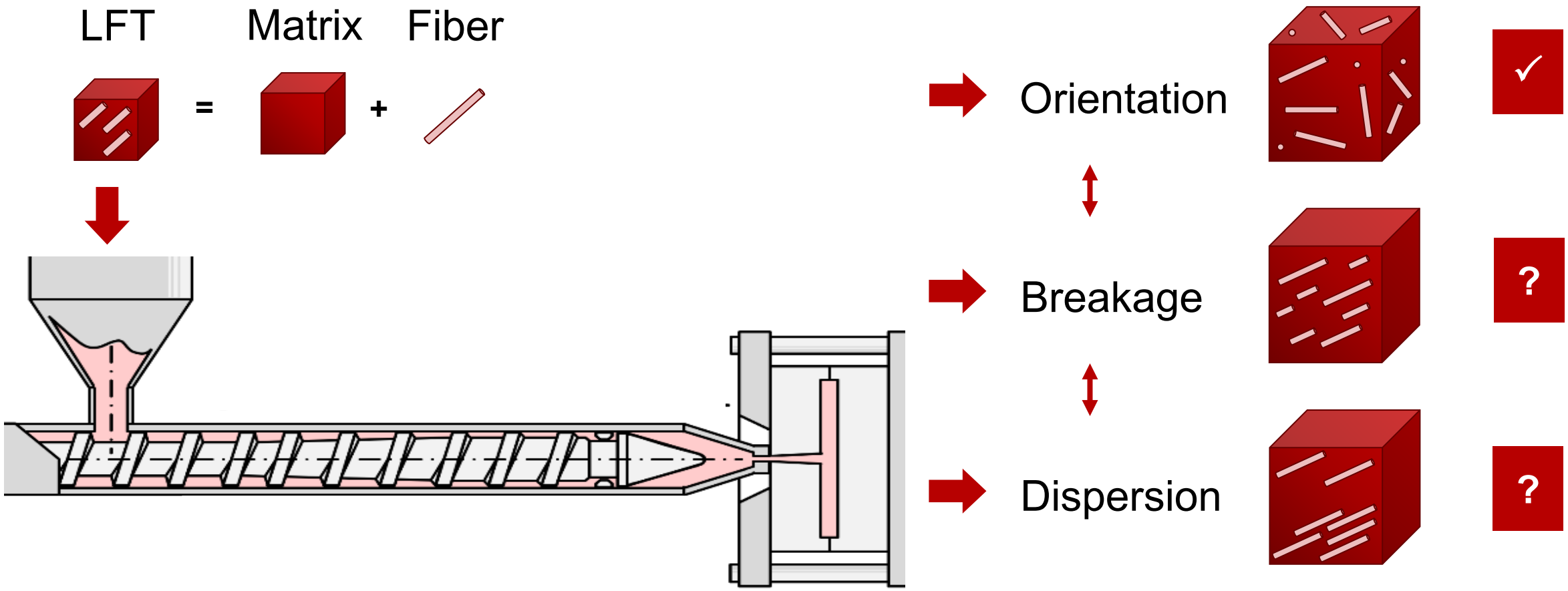
Matrix + **Fiber** = **LFT**



Matrix	Fiber
virgin	virgin
recycled	virgin
virgin	recycled
recycled	recycled

Consider Both:
Changes in Fiber Microstructure
and
Changes in the Polymer Matrix

Fiber Microstructure of LFT

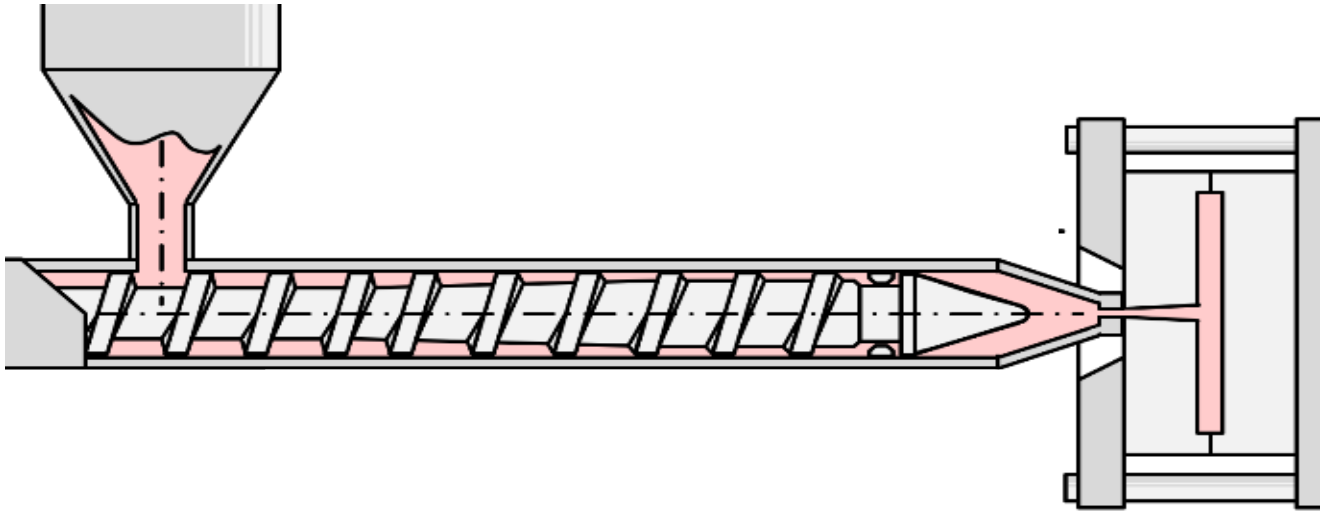


! Understand interdependencies in fiber microstructure!

Process-Induced Changes of Polypropylene (PP)

PP

≠



Viscosity

Thermal Behavior

Crystallization

?

?

?

!

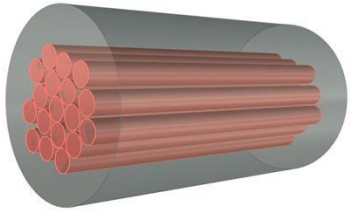
Understand material changes induced during processing!

My PhD Research Summary

Context

How does Polymer Processing impact…

Fiber Microstructure



?

Polymer Degradation

Action

- Fiber length
- Fiber dispersion
- Fiber orientation

Test + Analyze + Model

- Viscosity
- Flow dynamics
- Heat transfer

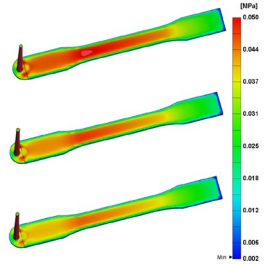
Results

Mathematical Models

$$\frac{d\varepsilon}{dt} = k\dot{\gamma}\left(\frac{\tau}{\sigma_c}\right)^n e^{-k\dot{\gamma}t\left(\frac{\tau}{\sigma_c}\right)^n}$$

$$\frac{dL}{dt} = k_f(L - L_\infty)$$

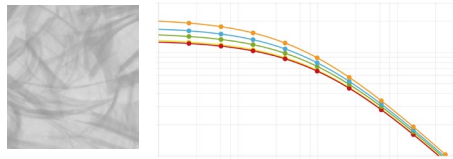
Processing Insights



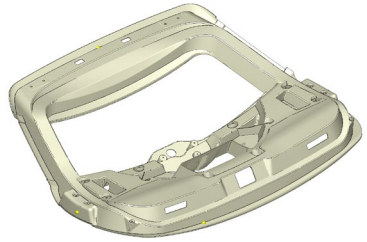
So What?

Improve and Predict Properties of:

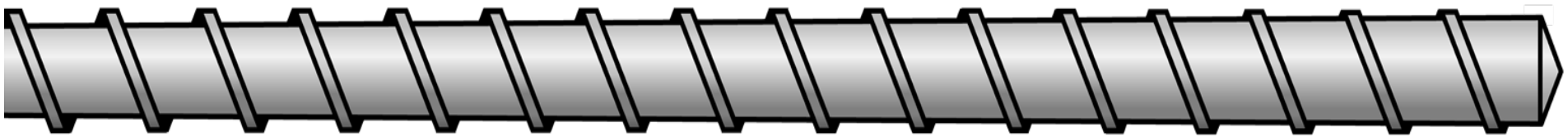
- **Material**



- **Product**



Flow for Today



Introduction → **Case Study** → Results & Learnings → Outlook

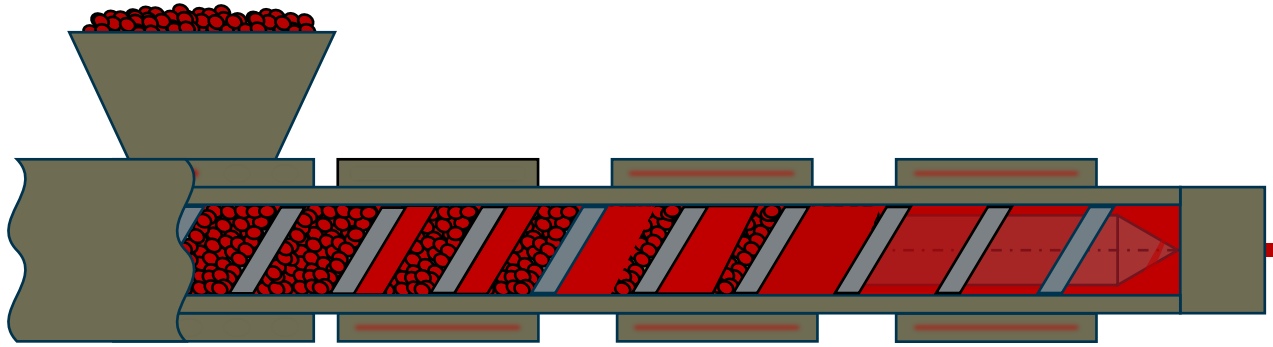
Flow Study of Recycled Polypropylene

Pure Virgin PP

First Extrusion Run

Pure Recycled PP

Extrusion Run 2 - 6



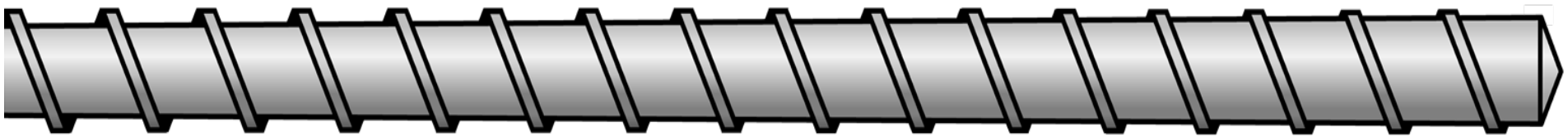
Pelletizing

Condition	T [°C]	RPM
C1	200	30
C2	200	50
C3	250	30
C4	250	50

Material Testing

- Thermal Properties
- Viscosity
- Crystallization

Flow for Today



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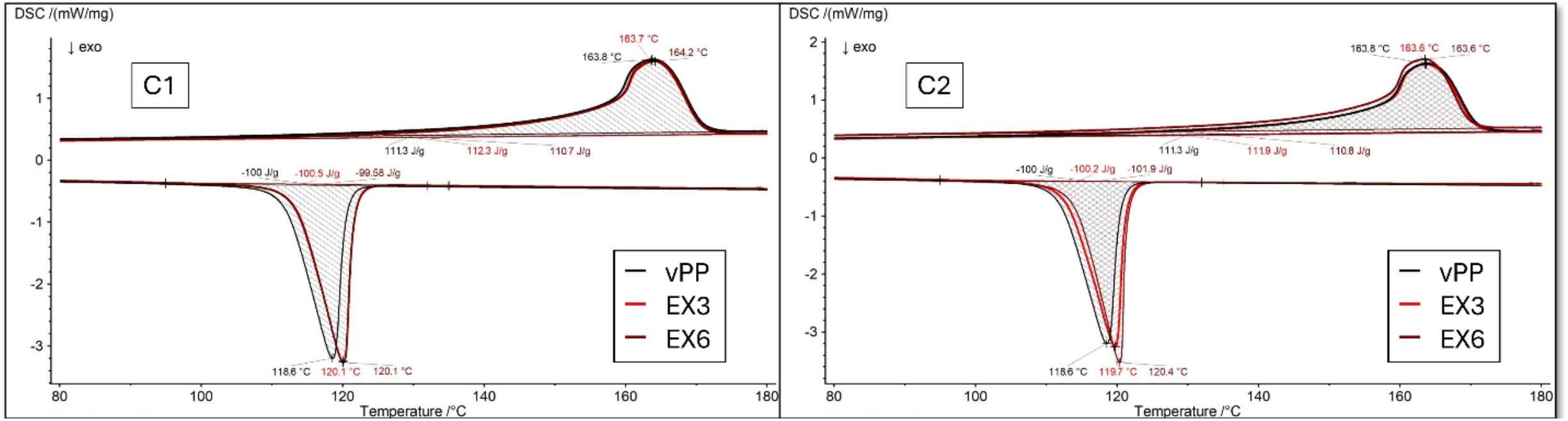
Thermal Properties

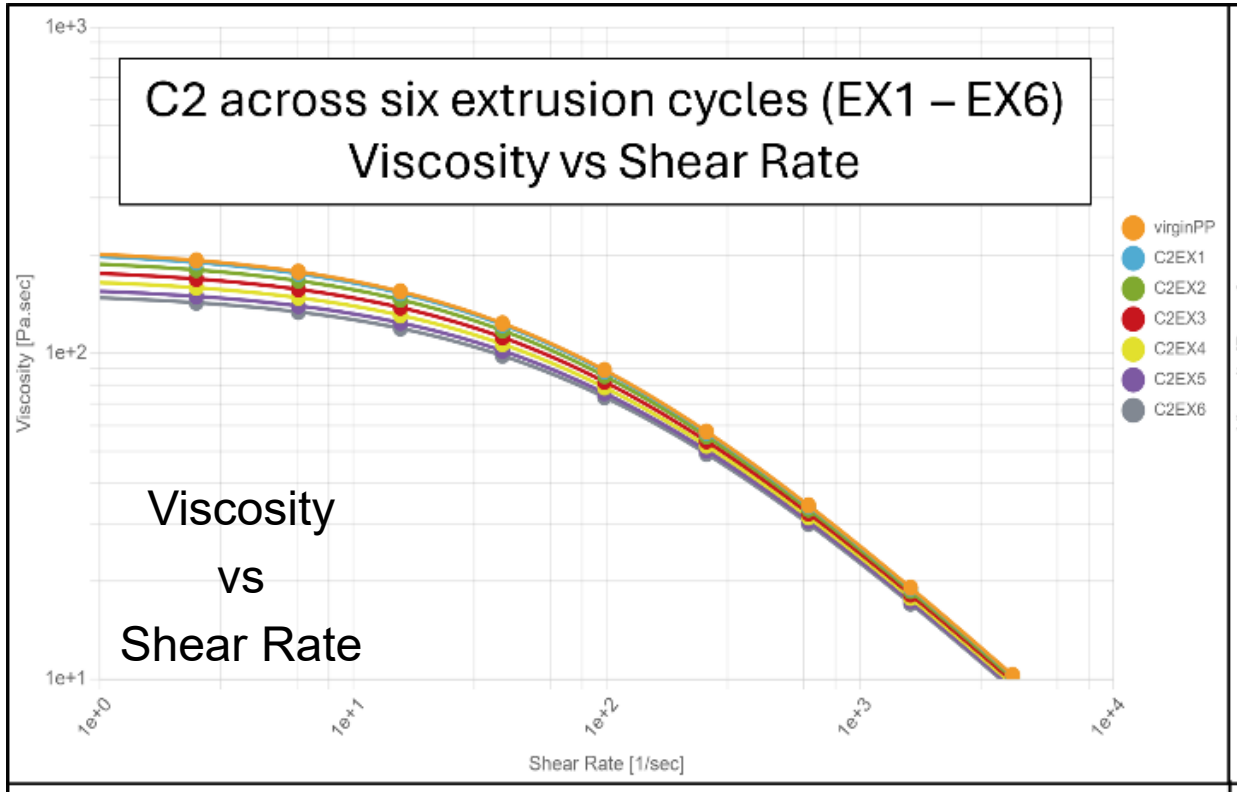


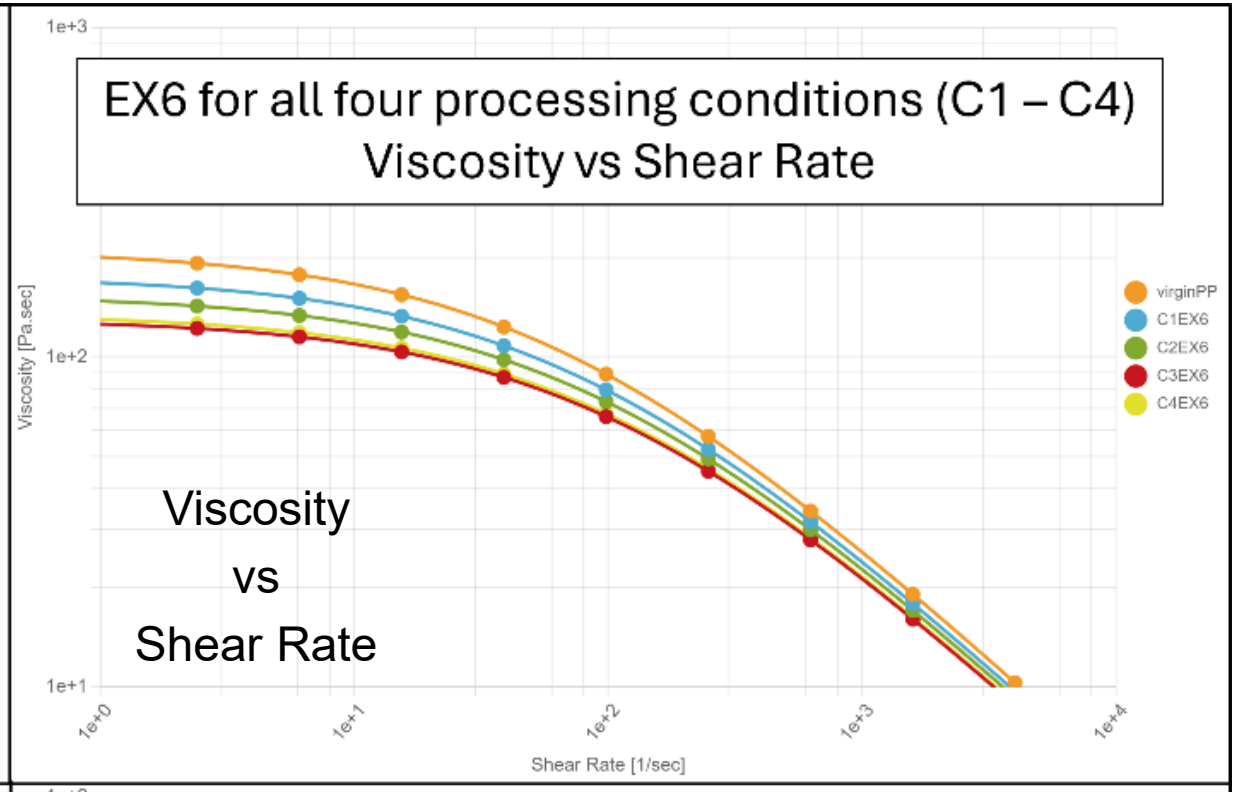
Non-isothermal DSC thermograms showing heating (top) and cooling (bottom) cycles at 10 K/min for virgin PP and EX3 and EX6.

Estela-García, Hohoff, Osswald (2025)

! Consistent melting but variations in crystallization exotherms during cooling

Viscosity



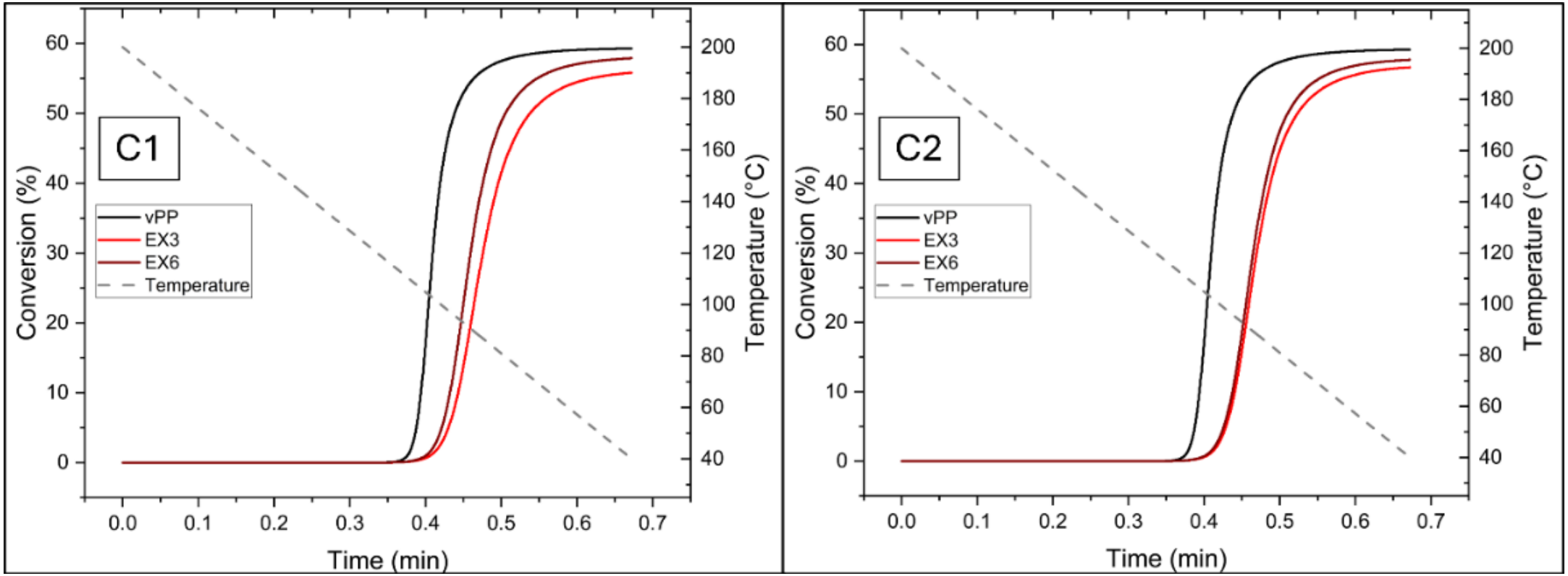


Evolution of PP viscosity profiles at 210°C

Estela-García, Hohoff, Osswald (2025)

! Decrease in viscosity driven by temperature during processing

Crystallization



Simulated crystallization conversion profiles (200°C to 40°C in 40s)

Estela-García, Hohoff, Osswald (2025)

! Recycled material shows 3 sec delay in crystallization onset

Flow Study of Recycled Polypropylene

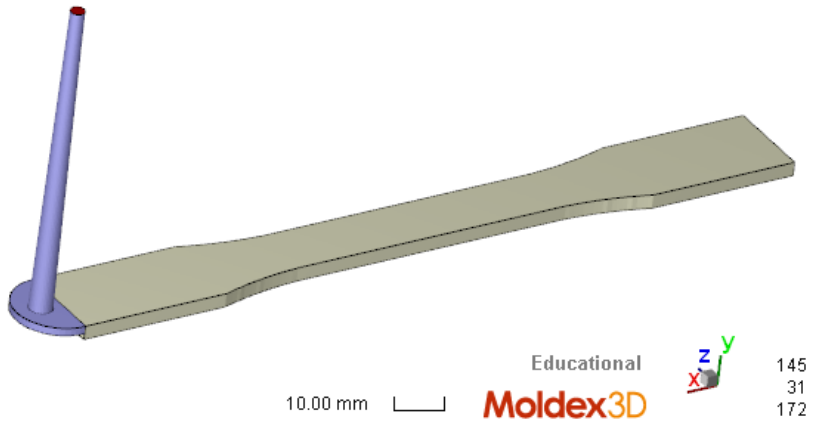
Material Testing

- Thermal Properties
- Viscosity

Material Cards Moldex3D

- 4 Different Conditions
- 1 - 6 Extrusions

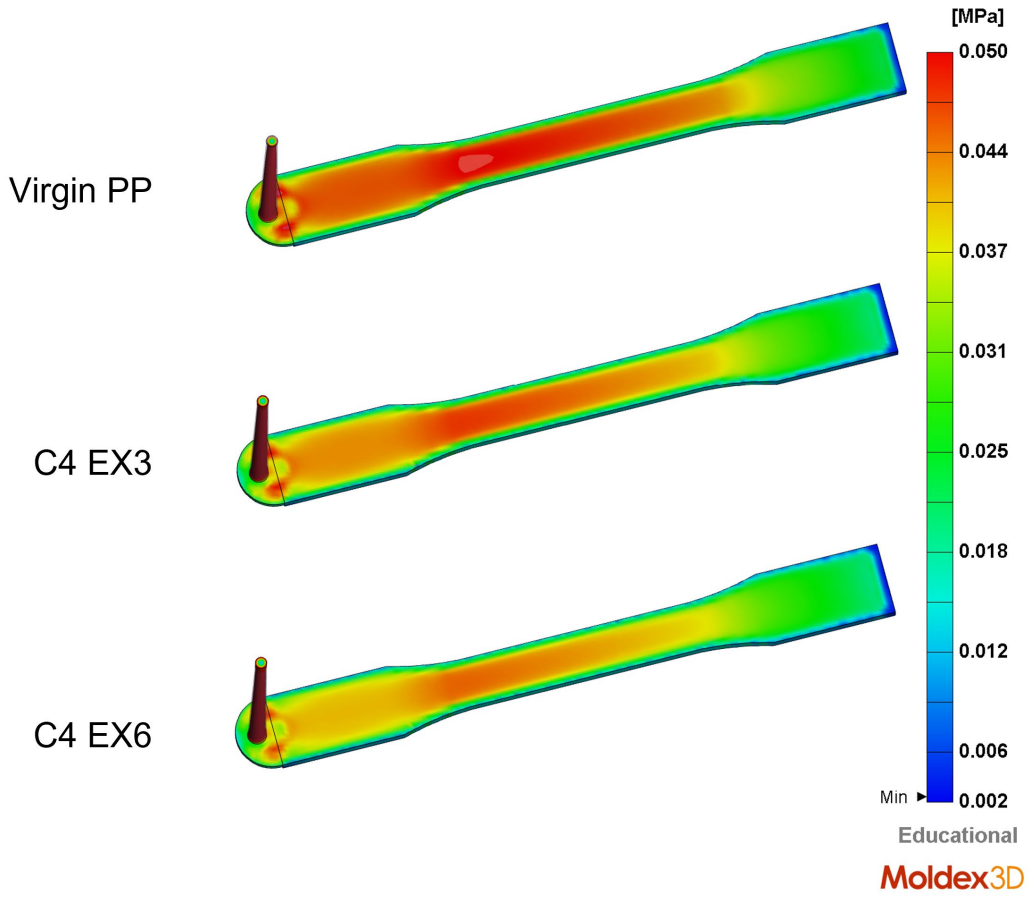
Flow Analysis



? How does the mechanical recycling impact the flow behavior?

Maximum Shear Stress during Injection Molding

Injection molding simulation results for maximum shear stress

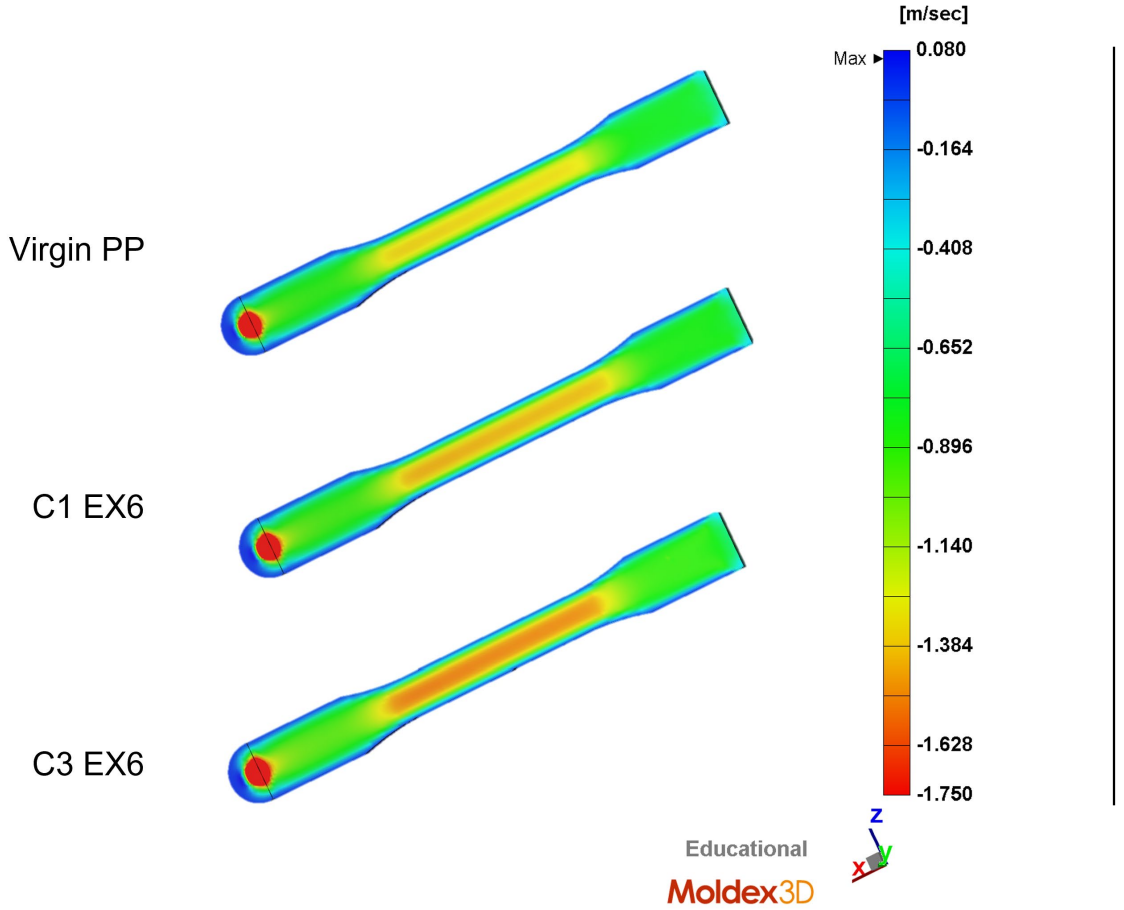


Estela-García, Hohoff, Osswald (2025)

! Decrease in high-stress regions with increased re-extrusion

Velocity (in flow direction) during Injection Molding

Injection molding simulation results for the velocity in the flow direction after varying re-extrusion conditions



Higher flow velocities

⇩

Increased alignment of polymer chains

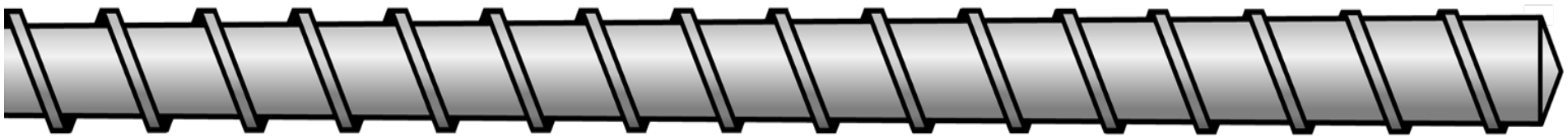
⇩

Increased yield stress

Estela-García, Hohoff, Osswald (2025)

! Increased thermal degradation leads to higher flow velocities

Flow for Today



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Observations & Future Work

Connect knowledge of process-induced changes in fiber and matrix microstructure

Predict changes in flow of recycled materials

Optimize processing conditions

Acknowledgments

NETZSCH
Proven Excellence.

Moldex3D

CUWP
Chemical Upcycling of Waste Plastics

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