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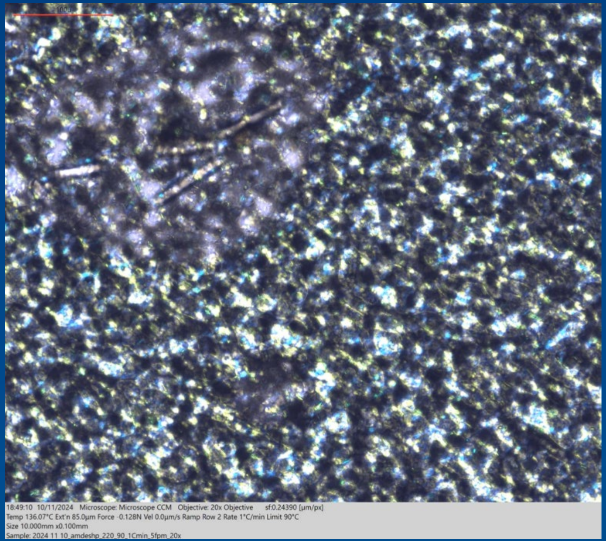
Understanding Material-Process-Microstructure-Property Relationships of Fiber Reinforced TPO Composites



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About the Authors

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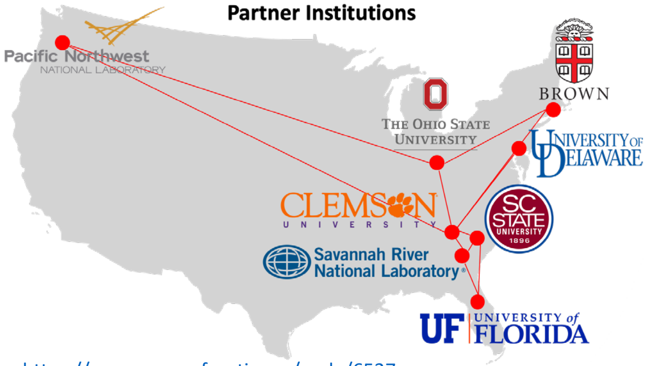
"to build an AI-enabled inverse design approach for fundamental understanding and integrated material-manufacturing design of advanced polymer composites."



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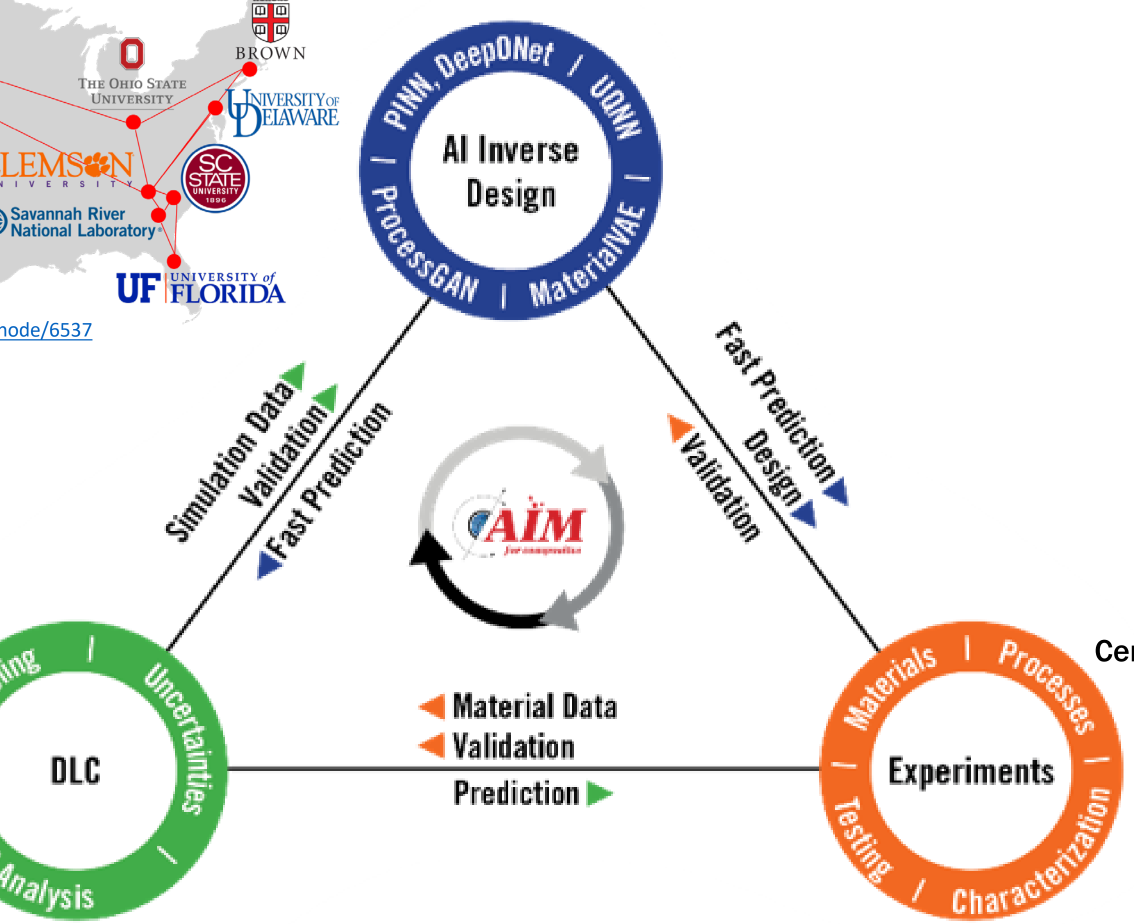

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Introduction – TPOs

Thermoplastic polyolefins (TPO) typically consist of a polyolefin and elastomer blend, and are widely used for automotive applications. They exhibit:

- Good scratch/ impact resistance
- Low weight, low cost
- Mass production compatibilities
- Compatible with fiber reinforcements

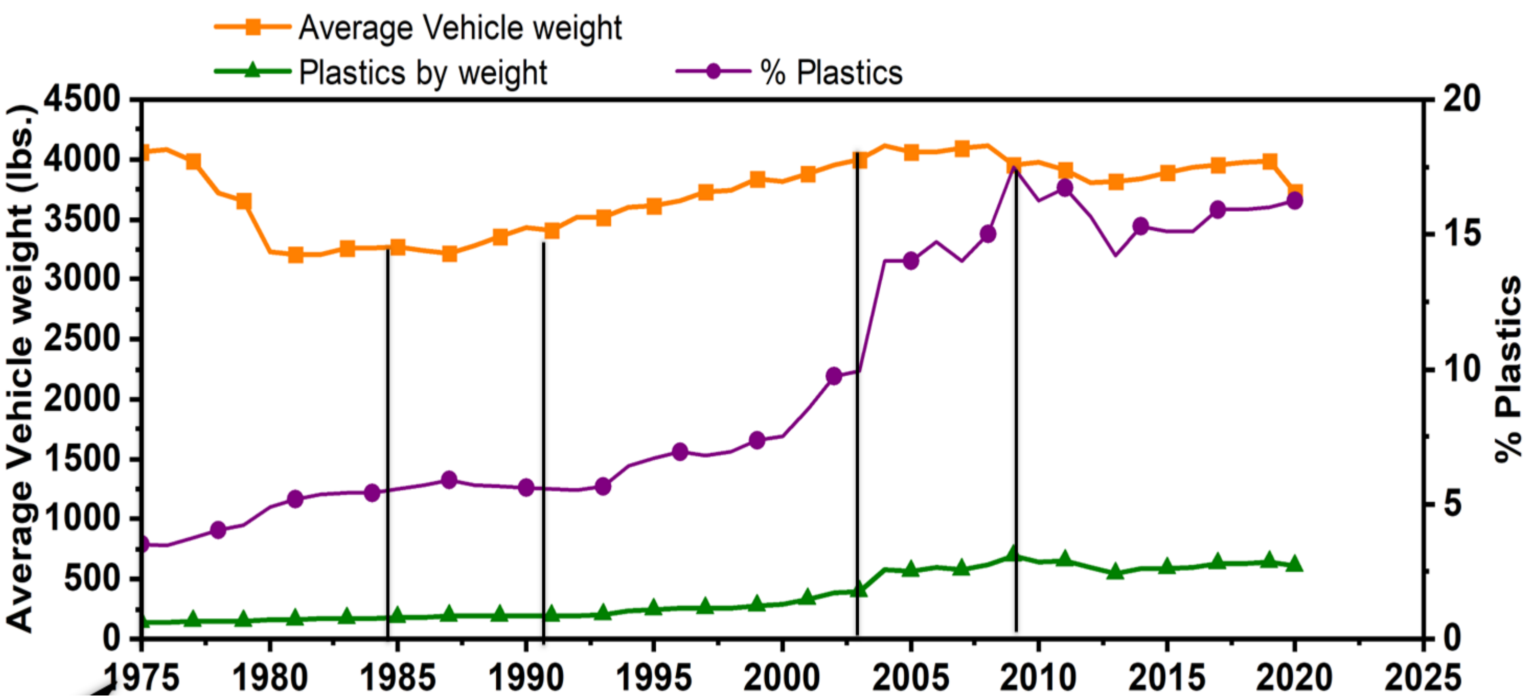

Figure 1: Growth in use of plastics and composites in passenger vehicles [1]

[1] S. A. Pradeep, S. Shukla, N. Brown, and S. Pilla, “Thermoplastics Foams : An Automotive Perspective,” in Lightweight and Sustainable Materials for Automotive Applications, CRC Press, 2017, pp. 369–400. doi: 10.1201/9781315152967-11.

Introduction – TPO Composites

Many parameters influence the properties of TPO parts consisting of fiber reinforcements, such as:

- Matrix blend composition
- Fiber surface morphology
- Fiber sizing
- Cooling rate
- Consolidation pressure
- Matrix viscosity and MFI

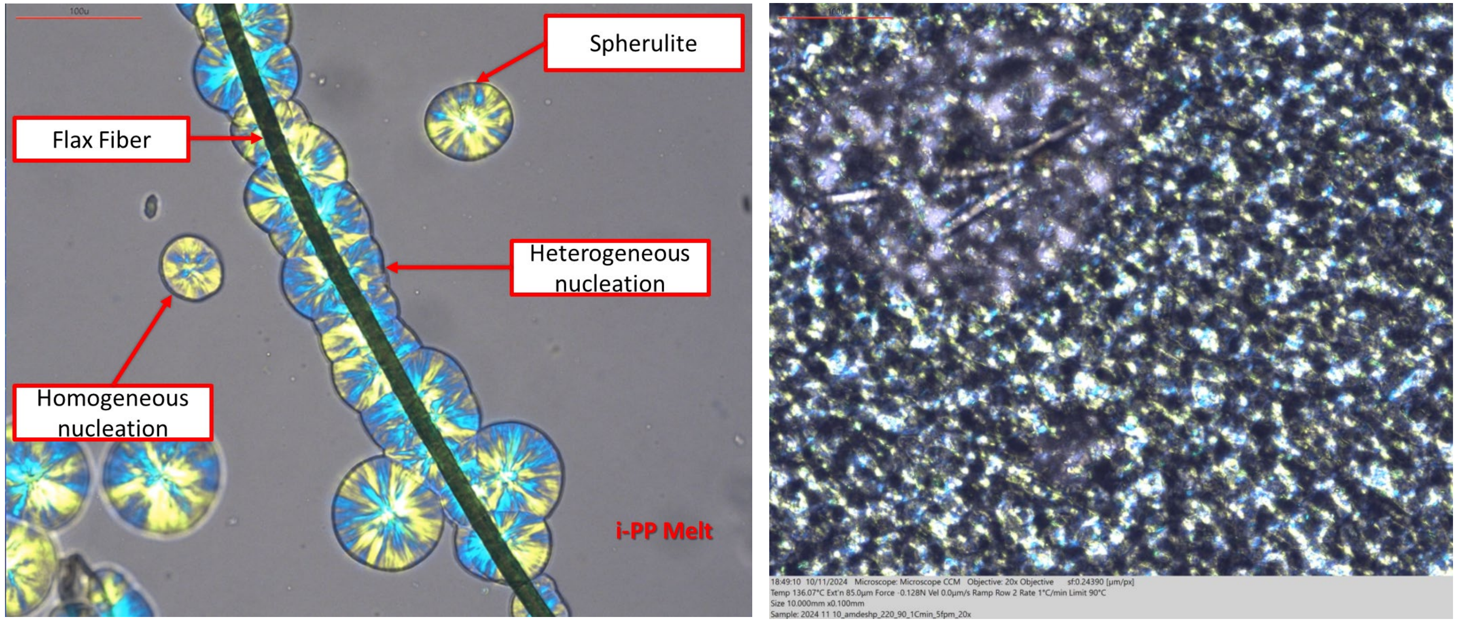

Figure 1. Polarized Light Microscopy Images (20x) showing comparison of crystallinity for PP and TPO

Motivation

- Long or continuous fiber reinforcements offer superior strength and toughness to fillers or short-fibers[1]. But effect of fiber and matrix blend composition on effective properties due to process parameters needs to be quantified.
- Interfacial shear strength (IFSS) was thus, proposed to be characterized for samples fabricated with varying material combinations and cooling rates.

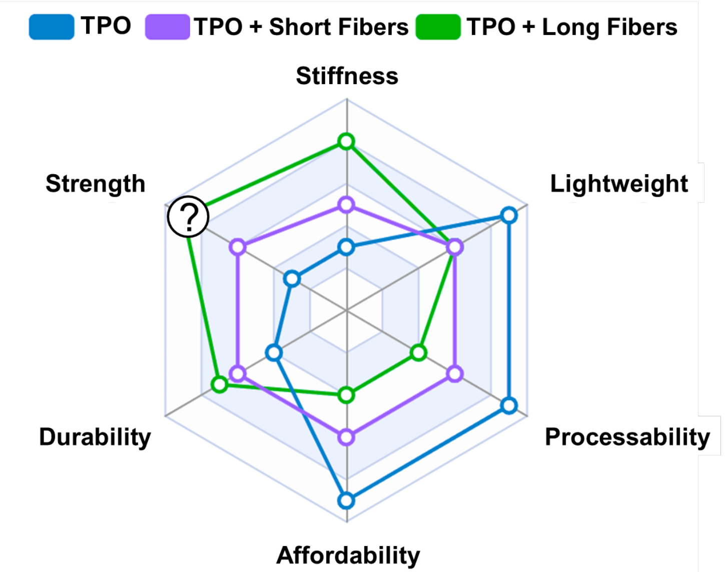

Figure 2. Property comparison between TPO and TPO with various fiber reinforcements[1],[2]

Work	TPOs	Fiber Reinforcement	IFSS	Fiber Surface Morphology	Cooling Rate	TPO Blend
Zhandarov et al (2012)	✗	✓ (Model Development)	✓ (Model Development)	✗	✗	✗
Pradeep (2021)	✓ (Experimental Investigation) ✓ (Model Development)	✗	✗	✗	✗	✗
Leitner et al (2022)	✗	✓ (Experimental Investigation)	✓ (Experimental Investigation)	✗	✓ (Experimental Investigation)	✗
ElKhoury and Berg (2022)	✗	✓ (Experimental Investigation)	✓ (Experimental Investigation)	✓ (Experimental Investigation)	✓ (Experimental Investigation)	✗
Pradeep et al. (2024)	✓ (Experimental Investigation) ✓ (Model Development)	✗	✗	✗	✗	✗

✓: Experimental Investigation | ✓: Model Development | ✗: Not Investigated

Table 1. Relevant prior studies in literature

[1] https://electronics.polyone.com/products/long-fiber-technology/benefits-long-fiber-reinforced-thermoplastic-composites
[2] https://en.wikipedia.org/wiki/Short_fiber_thermoplastics

Materials and Methods

- Single fiber pull-out (SFPO) testing is an effective way to measure IFSS.
- Samples made using Textechno FimaBond.
- Material selected for the study:
  - PP (Scientific Polymer Products LLC) and TPO1 (30% rubber/70% PP) matrix
  - E-glass (HexForce^{TM} 7781) fiber selected
- Material Characterization to determine:
  - SFPO sample fabrication temperature
  - rate of fiber insertion into TPO matrix
- TGA performed to determine matrix degradation onset temperature
  - TA Instruments TGA2500 (New Castle, Delaware, USA)
  - 10 °C/min ramp from 25 °C to 600 °C, inert N_2 environment
- Rheometry performed to determine fiber insertion rate to ensure final geometry is close to ideal hemisphere, and embedded length is consistent.
  - TA Instrument Parallel Plate Hybrid Rheometer (New Castle, Delaware, USA)
  - Isothermal frequency sweeps
  - Temperature sweeps with constant frequency and shear rate.

Material Characterization Results

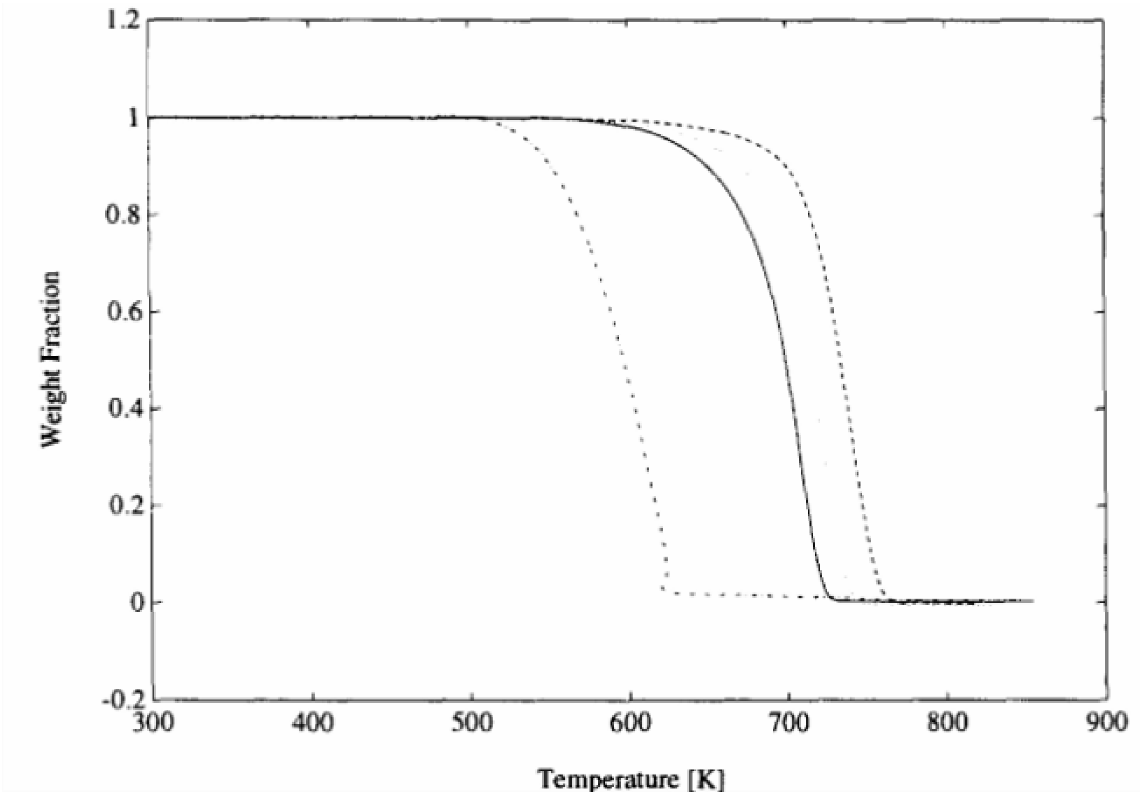

Figure 5. TGA plot for PP, ramp rate of 10°C/min, 5°C/min, 20°C/min (left to right)[3]

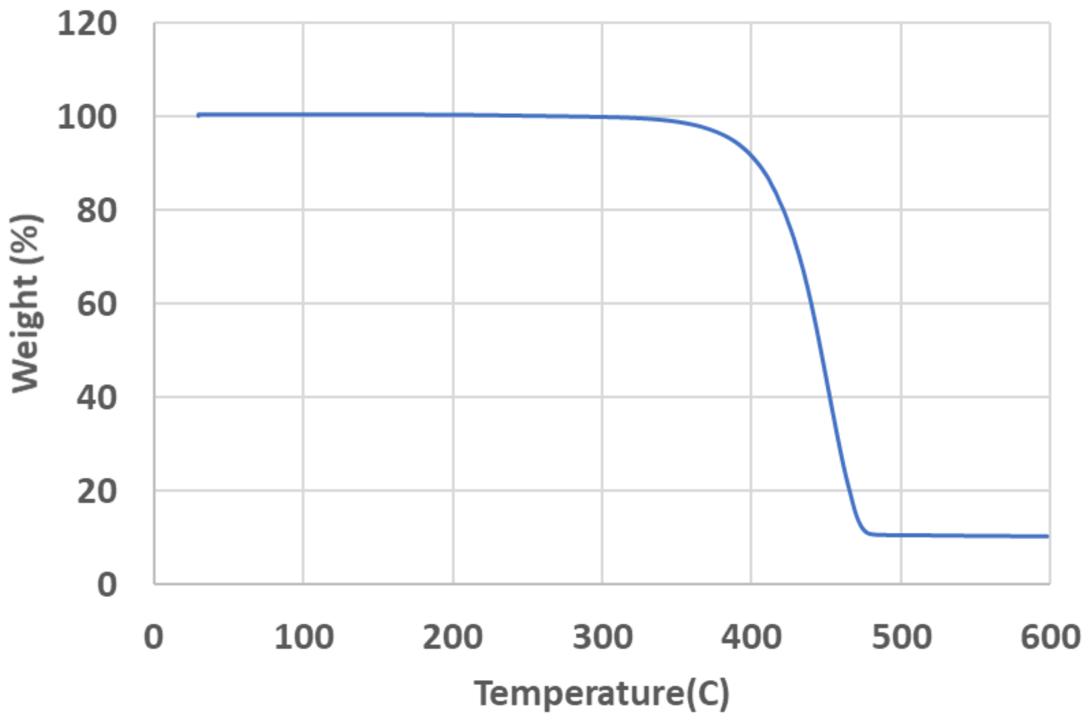

Figure 6. TGA plot for TPO1, ramp rate of 10°C/min, up to 600 °C.

- From TGA and rheometer trials, the ideal temperature minimizing viscosity without degrading material is 240°C (PP), 260°C (TPO1).

[3] https://doi.org/10.1016/S0141-3910(96)00160-7.

Material Characterization Results

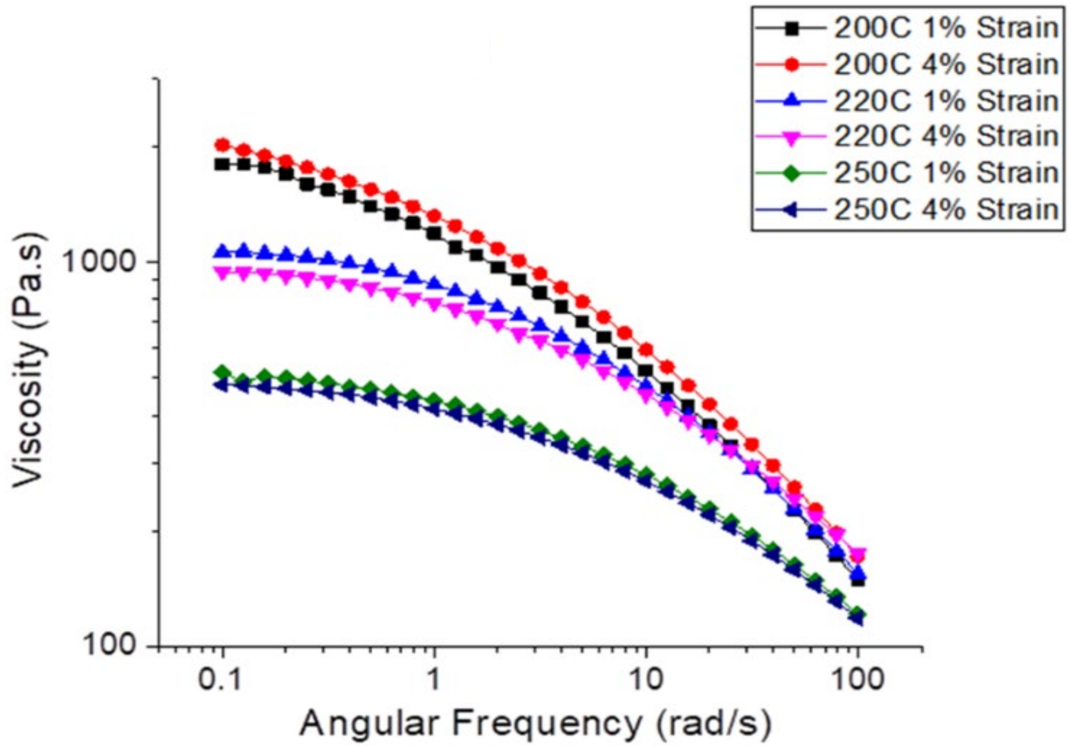

Figure 3. Isothermal rheometer frequency sweeps on PP at 200°C, 220°C, 250°C

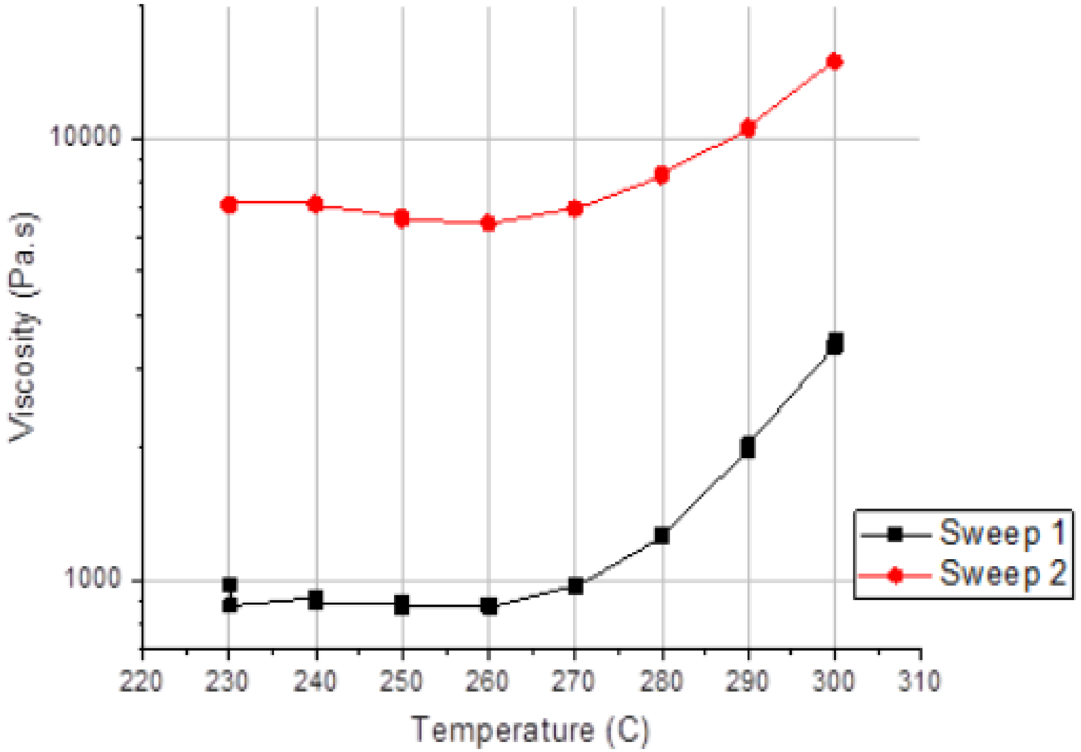

Figure 4. Repeated rheometer temperature sweeps on TPO1 from 230-300°C

SFPO Sample Fabrication

- E-glass fibers were inserted to 300 µm at those ideal temperatures.
- 5 Samples fabricated with 10°C/min and 50°C/min cooling rates for PP and TPO1.

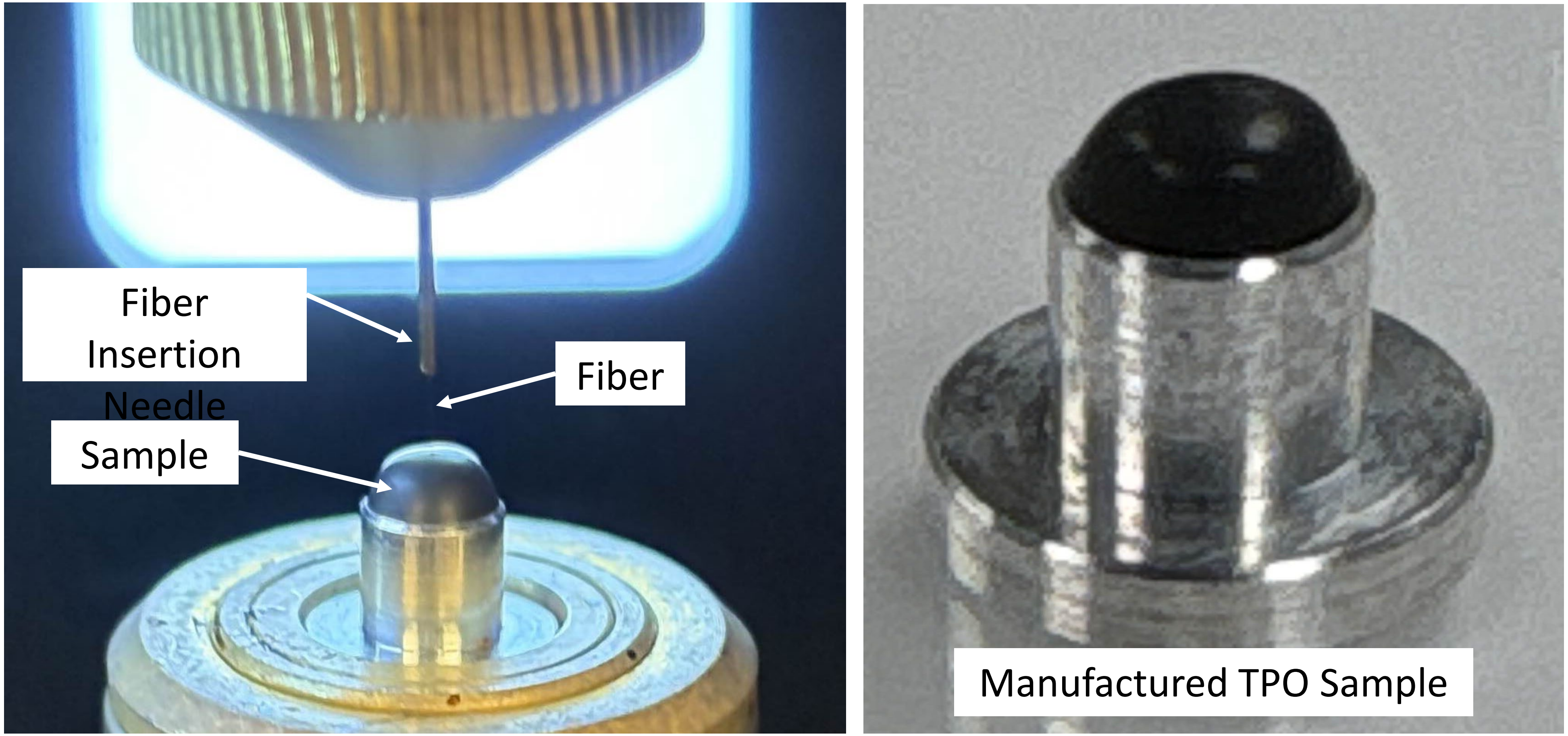

Figure 7. Sample fabrication setup and resulting sample

SFPO Sample Testing

- Testing was done at 0.1 mm/min on a Textechno Favimat+
- Fiber embedded lengths and diameters were measured using SEM.

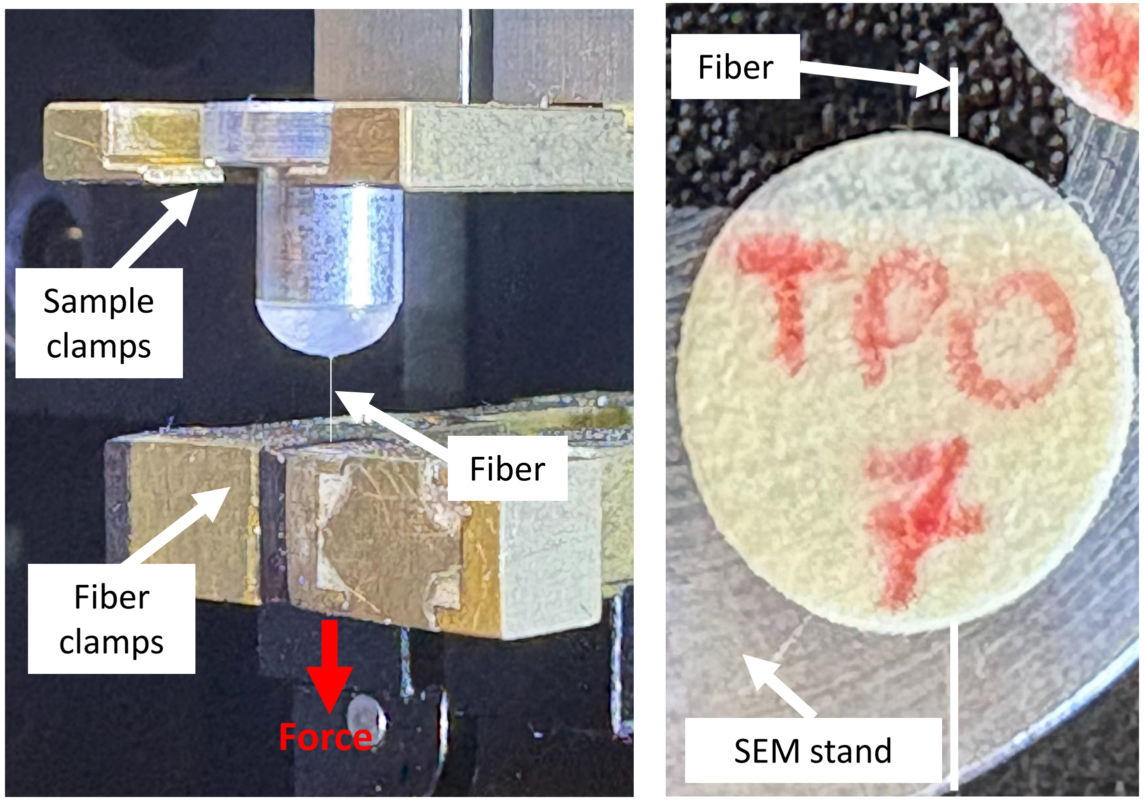

Figure 8. Testing setup and tested fiber for SEM analysis

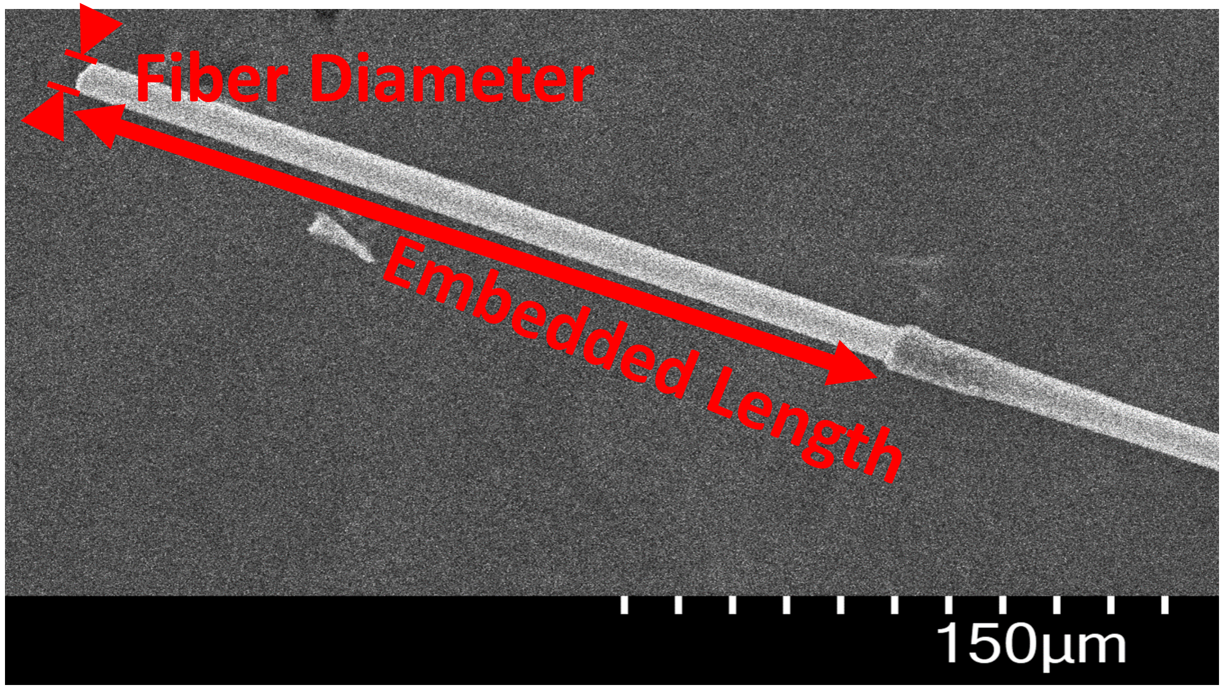

Figure 9. Annotated SEM image of a tested fiber for embedded length and fiber diameter measurements

Results and Discussion

- Samples cooled at 10°C/min tended to have more variation than 50°C/min.
- Most samples experienced primarily adhesive failure, seen on SEM.
- More testing is required to determine if there are any statistically significant relationships between cooling rates and IFSS.
- ***Key Takeaway:***
- Process parameters are critical when manufacturing parts utilizing TPO composites as interfacial strength and subsequent mechanical behavior of the component is influenced.

$$IFSS = \frac{F}{\pi d l_e}$$

F = peak axial force

d = fiber diameter

l_e = embedded length

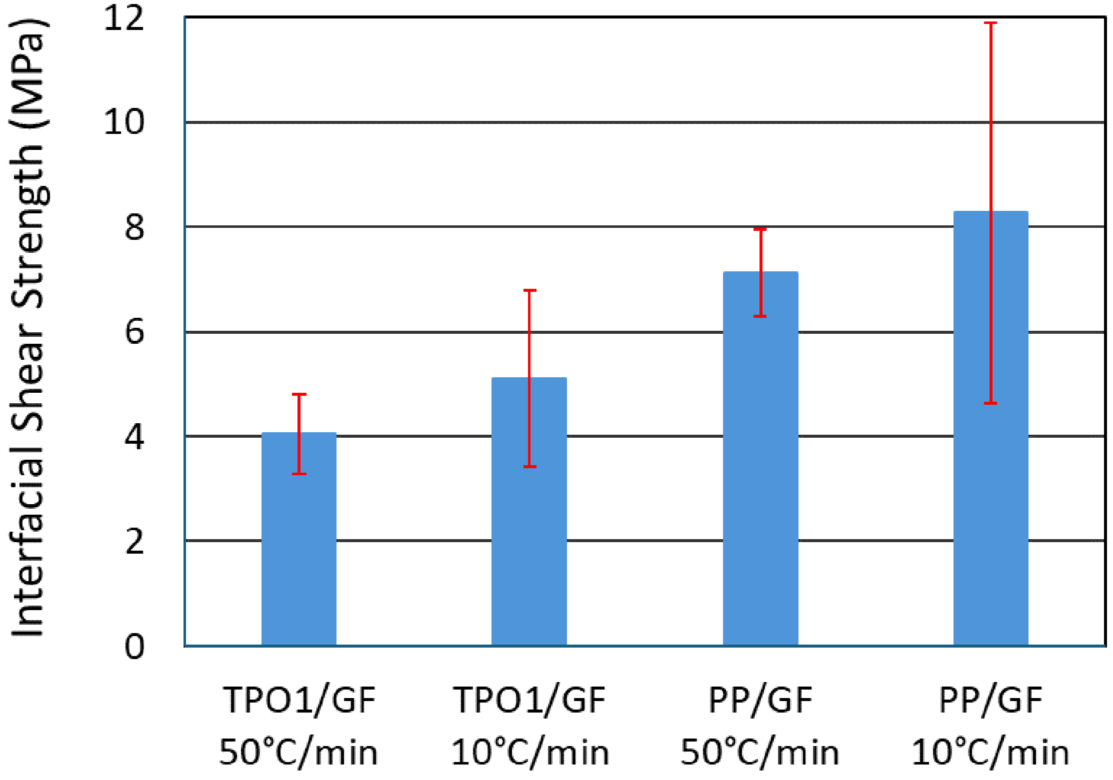

Figure 10. IFSS vs Cooling rate

Future Work

- Test intermediate cooling rates between 10°C/min and 50°C/min to confirm any trends relating cooling rate and IFSS.
- Expand investigation to other fibers, such as carbon fibers.
- Fiber roughness should be characterized when fabricating additional samples

Acknowledgements

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AIM for composites

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