Utilizing Recycled Carbon Fiber-Based Composites for Sustainable Manufacturing

Mitchell Rencheck

Vipin Kumar, Halil Tekinalp, Vinit Chaudhary, Samarthya Bhagia, Vlastimil Kunc, Soydan Ozcan, Uday Vaidya, Brian Knouff, and Patrick Blanchard

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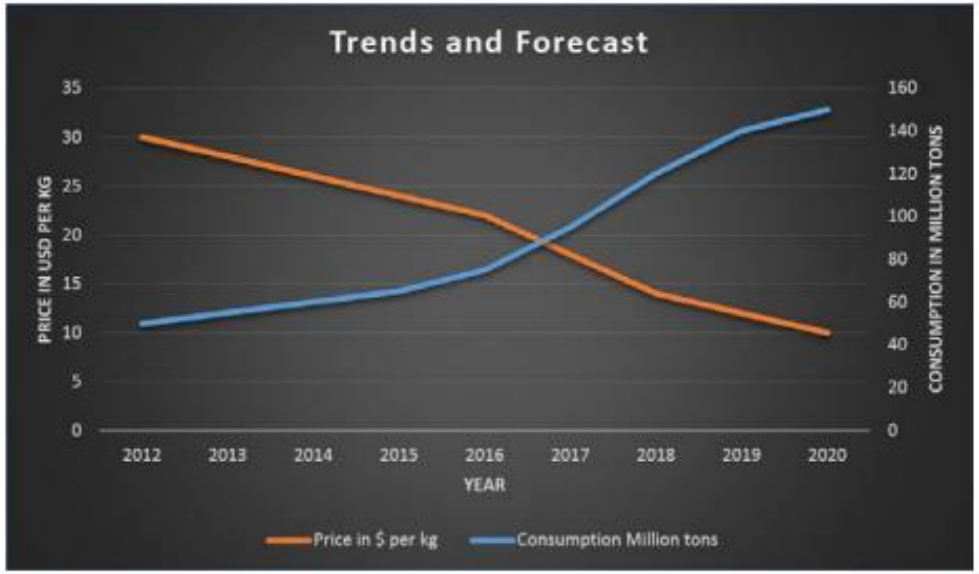
Carbon Fiber Composites are Becoming More Cost Effective

Advanced Software Tools	Affordable Precursors	Production Technology
• Simulation tools • Cost modeling • Design integrated manufacturing simulation	• Textile grade PAN • Lignin based • Polyolefin based • Recycled CF	• Automation • Faster cycle times • Out of autoclave processes



As the price of carbon fiber (CF) decreases, the demand of CF will increase → Can create less stability on CF supply chain

OAK RIDGE National Laboratory

Rao et al. *Carbon Composites are Becoming Competitive and Cost Effective (White Paper). Infosys*

Stabilizing Carbon Fiber Supply Chains for OEMs

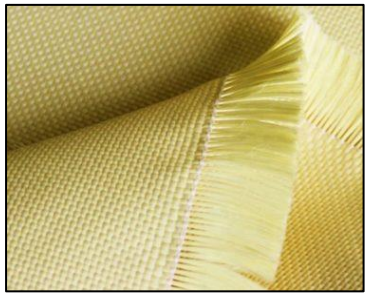
How can OEMs stabilize their own CF supply chains?

Replace CF with an alternative reinforcing filler

Glass Fibers

Ali et al .Const. Bui. Mat. 2019

Aramid Fibers



cacomposites.com

Natural Fibers

Concreteconstruction.net

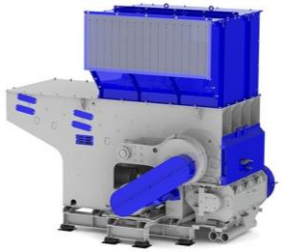
Utilize recycled content

Recycled feedstocks

End of Life part

↓

Mechanical Recycling



recyclingtoday.com

↓

Recycled material

Recycled CF

CF composites

↓

Pyrolysis

Wasteplasticpyrolysisplant.com

↓

Recycled CF

compositesworld.com

Goal: Implement Strategies without Sacrificing Mechanical Performance

Replacing CF Content with Alternative Fiber

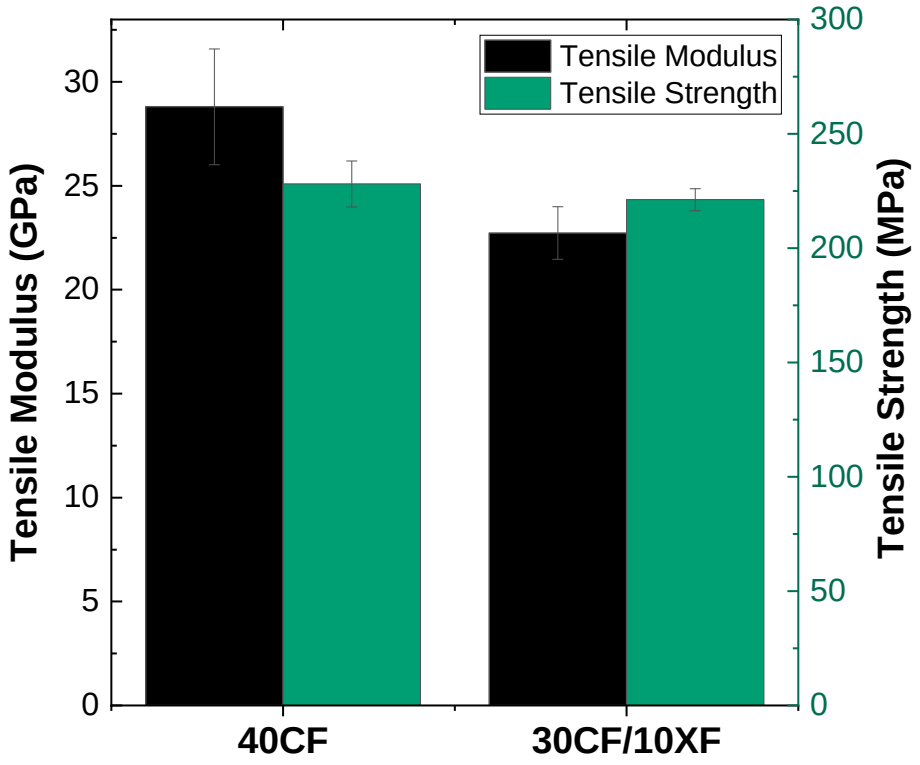
Base CF Composite

Polyamide-6,6' (PA66)
+
40wt% CF

Substitute some portion of CF content with alternative fiber →

Example CF-base Composite

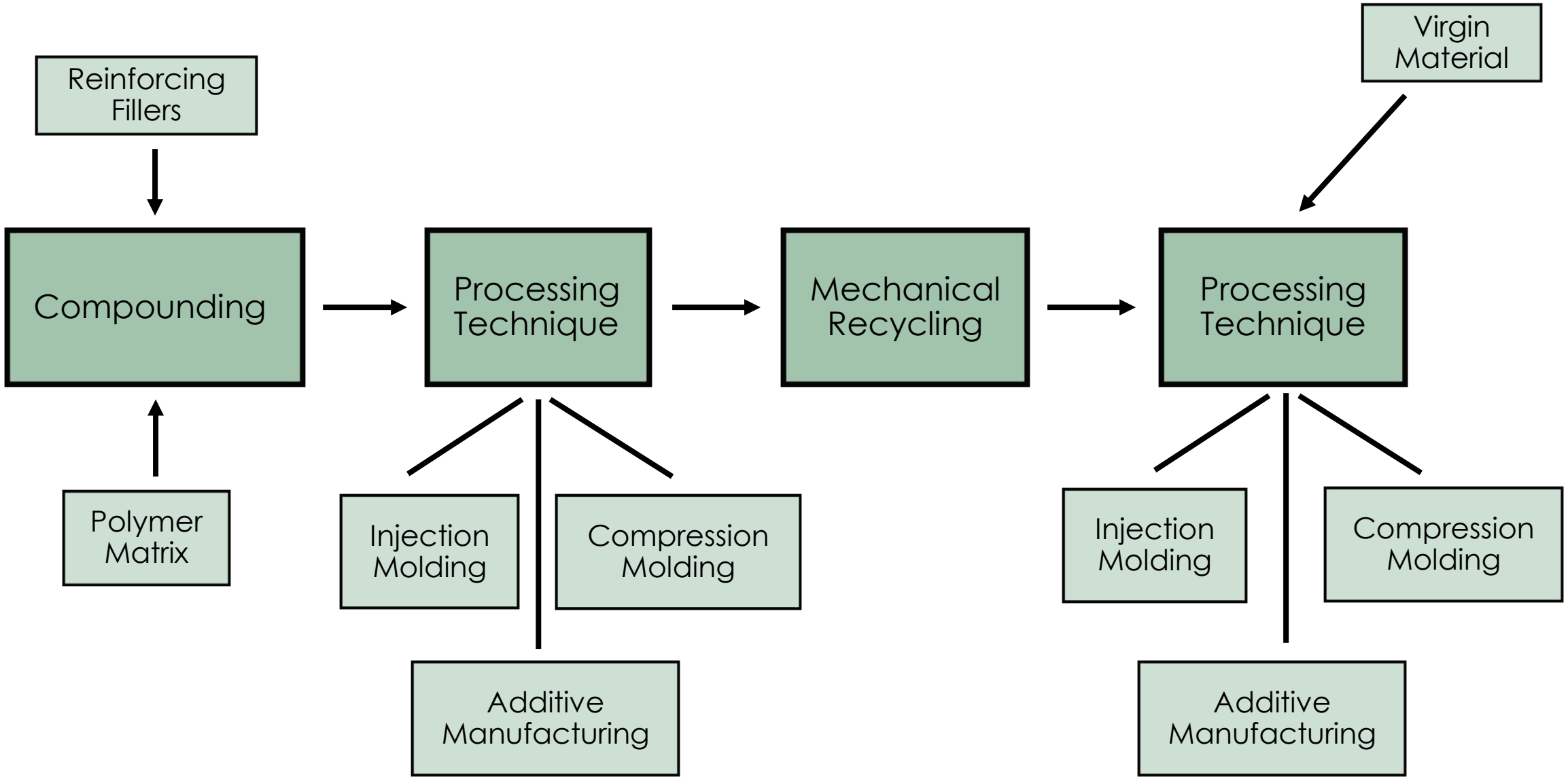
Polyamide-6,6' (PA66)
+
30wt% CF
+
10wt% Alternative Fiber (XF)



Effect of Substituting 10wt% of CF Content

- Decrease in tensile modulus
- Relatively consistent strength
- Substitution ratio depends on application and replacement fiber type

Utilizing Mechanically Recycled Content



Considerations When Determining Mechanical Properties of Recycled Materials

How do mechanical properties change with respect to amount of recycled content?

Recycled Material	Virgin Material
0%	100%
33%	67%
67%	33%
100%	0%

*** Processing/Recycling ***
Pathway Dependent

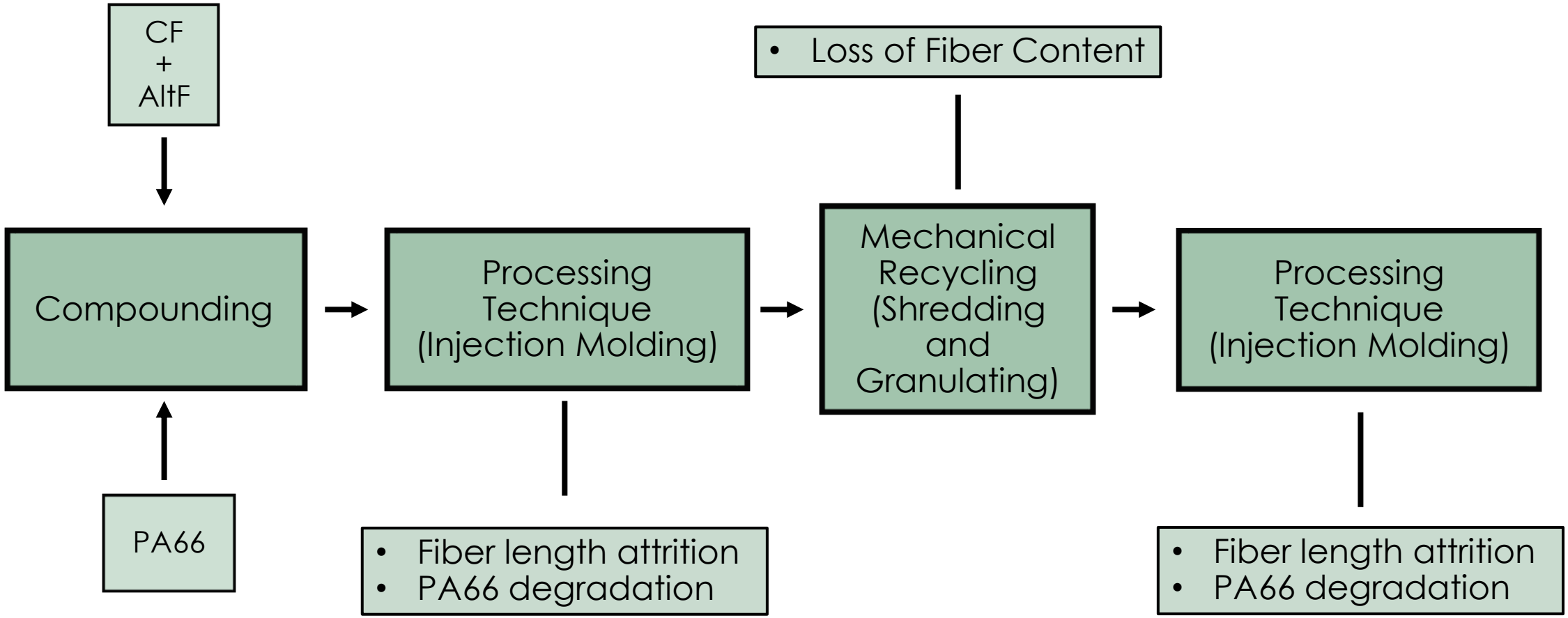
What are the mechanisms that cause mechanical properties to change?

Potential Mechanisms

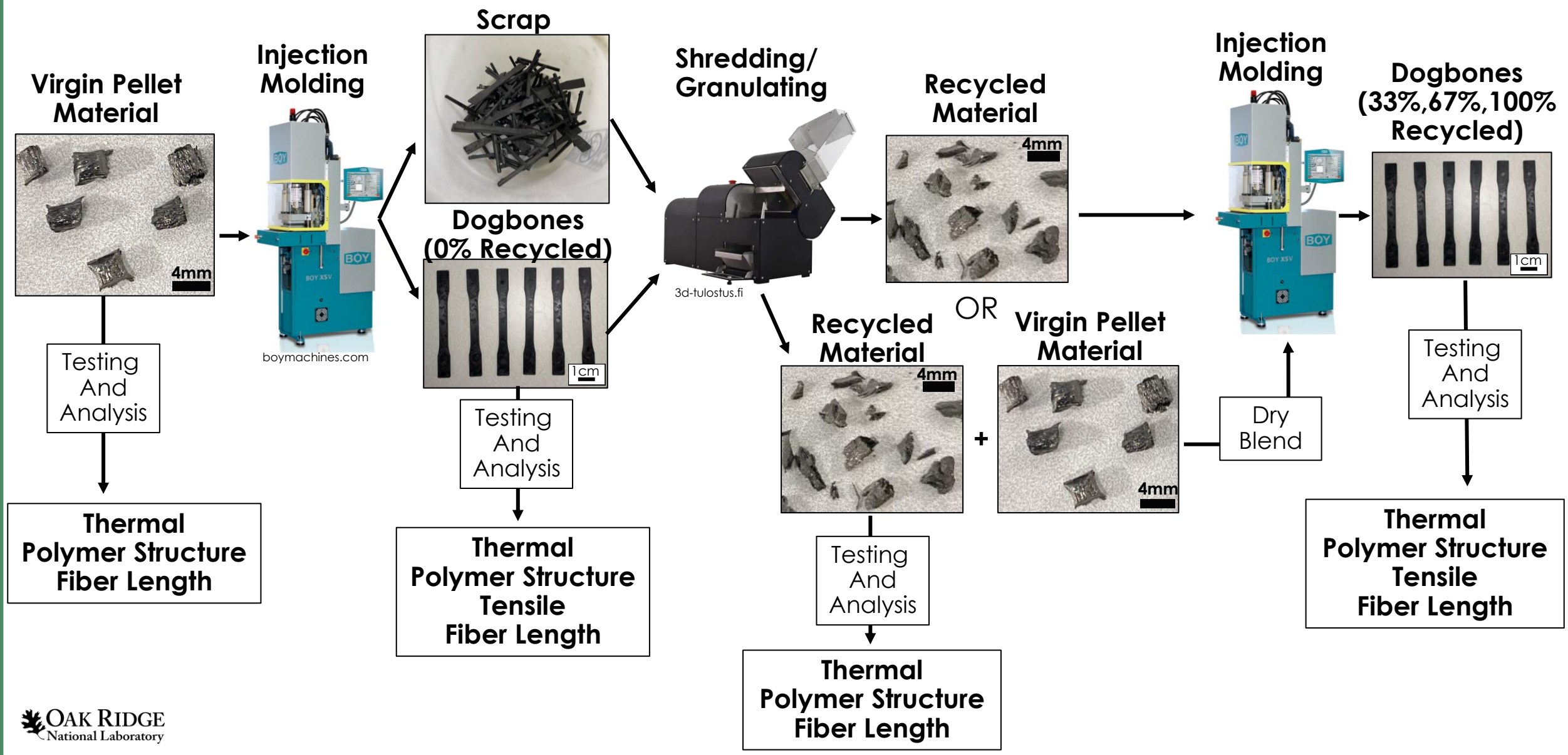
1) **Loss in Fiber Content**
2) **Fiber Length Attrition**
3) **Polymer Degradation**

*** Processing/Recycling ***
Pathway Independent

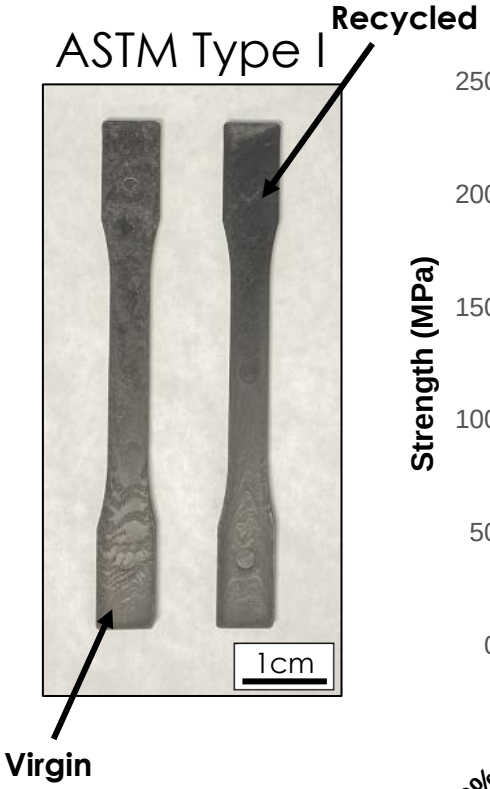
Where Mechanisms Occur During Processing/Recycling

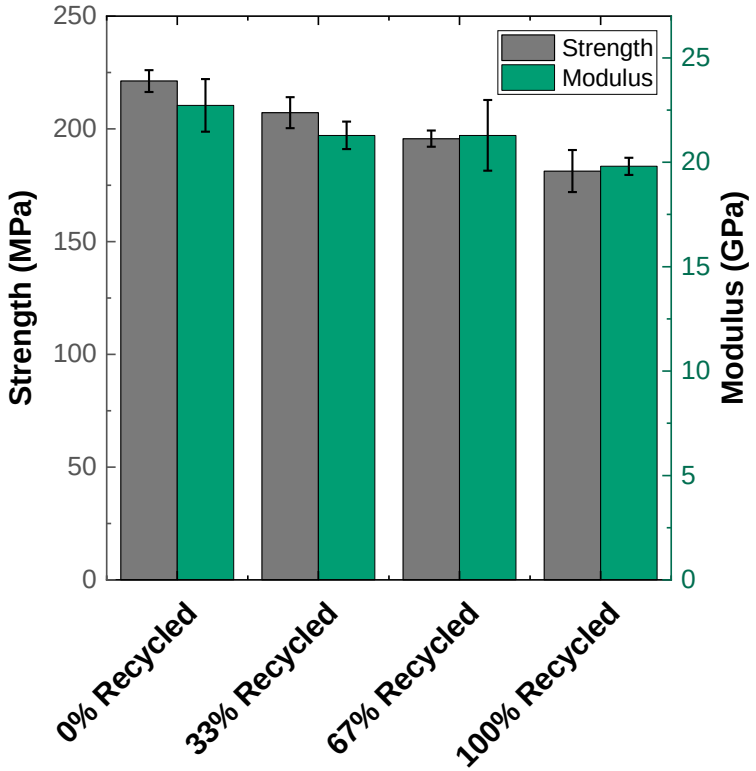


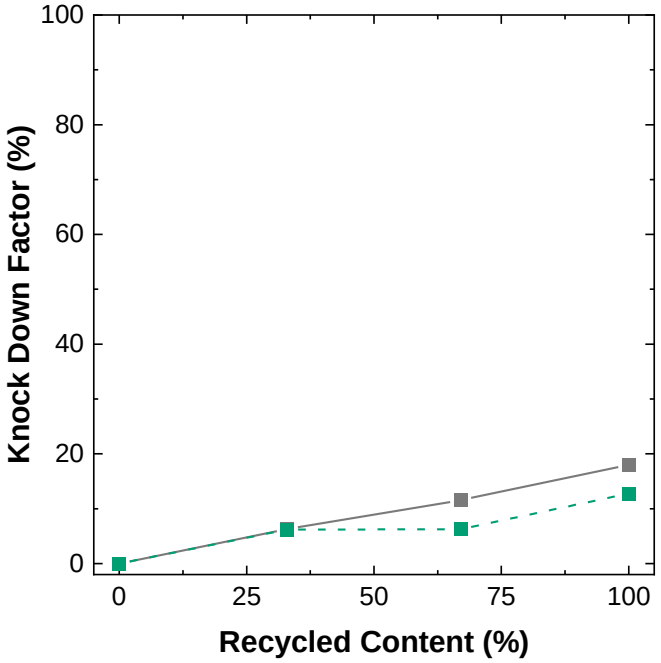
Case Study for Recycling of PA66/30CF/10AltF



Mechanical Characterization of Recycled PA66/30CF/10AltF







Knock Down Factor (KDF)

$$KDF = \left(1 - \frac{P_r}{P_v}\right) * 100$$

P_r - average property value of material with recycled content

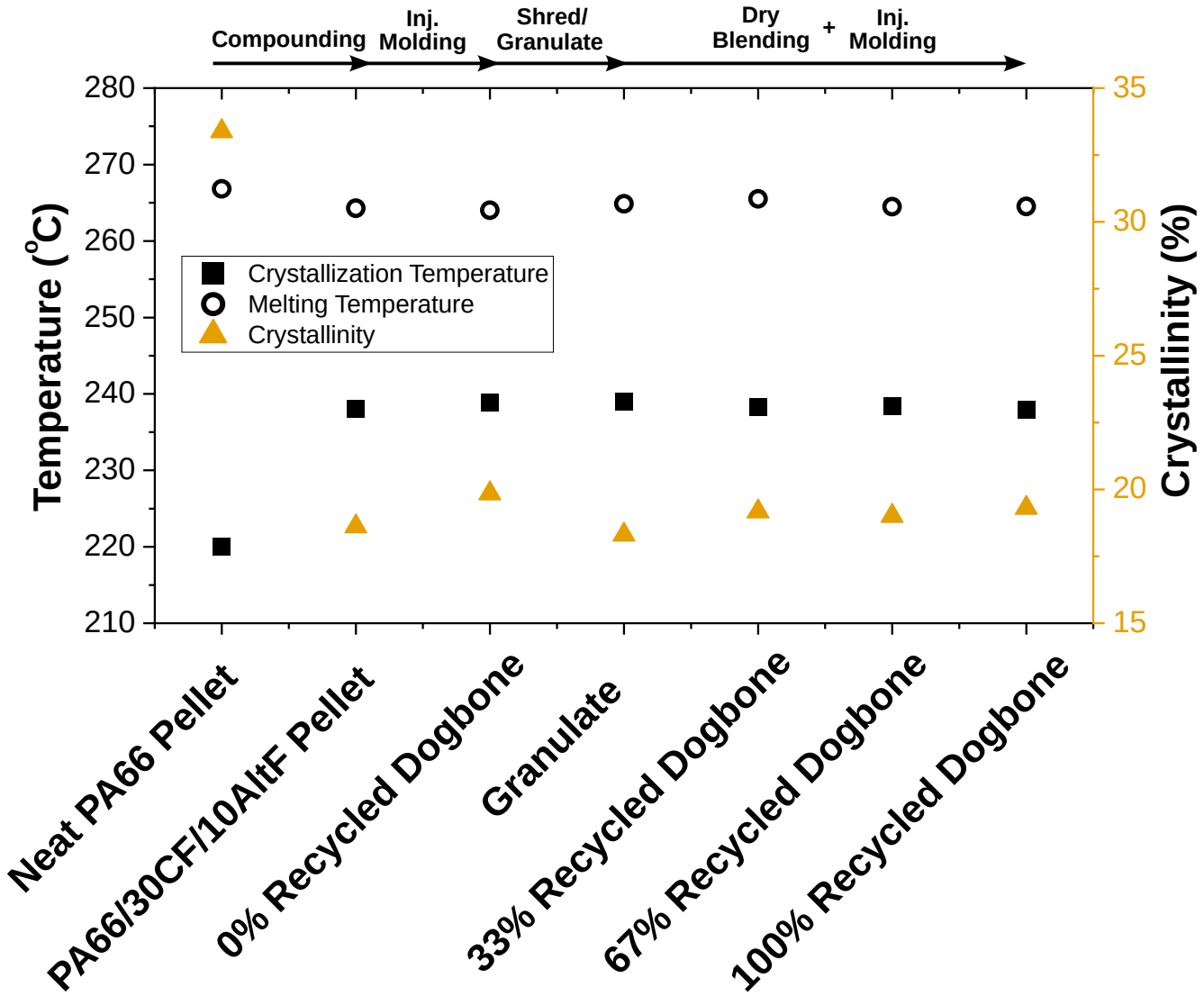
P_v - average property value of material with 0% recycled content

Recycled Content	Strength (MPa)	Strength KDF (%)	Modulus (GPa)	Modulus KDF (%)
0%	221.2 ± 4.82	0	22.7 ± 1.26	0
33%	207.2 ± 6.90	6.3	21.3 ± 0.66	6.2
67%	195.7 ± 3.57	11.6	21.3 ± 1.69	6.2
100%	181.3 ± 9.35	18	19.8 ± 0.41	12.7

- Tensile strength and tensile modulus decreased as recycled content percent increased
- **What Mechanisms are causing a reduction in mechanical properties?**

Eriksson et al. Poly. Engr. Sci. 1998

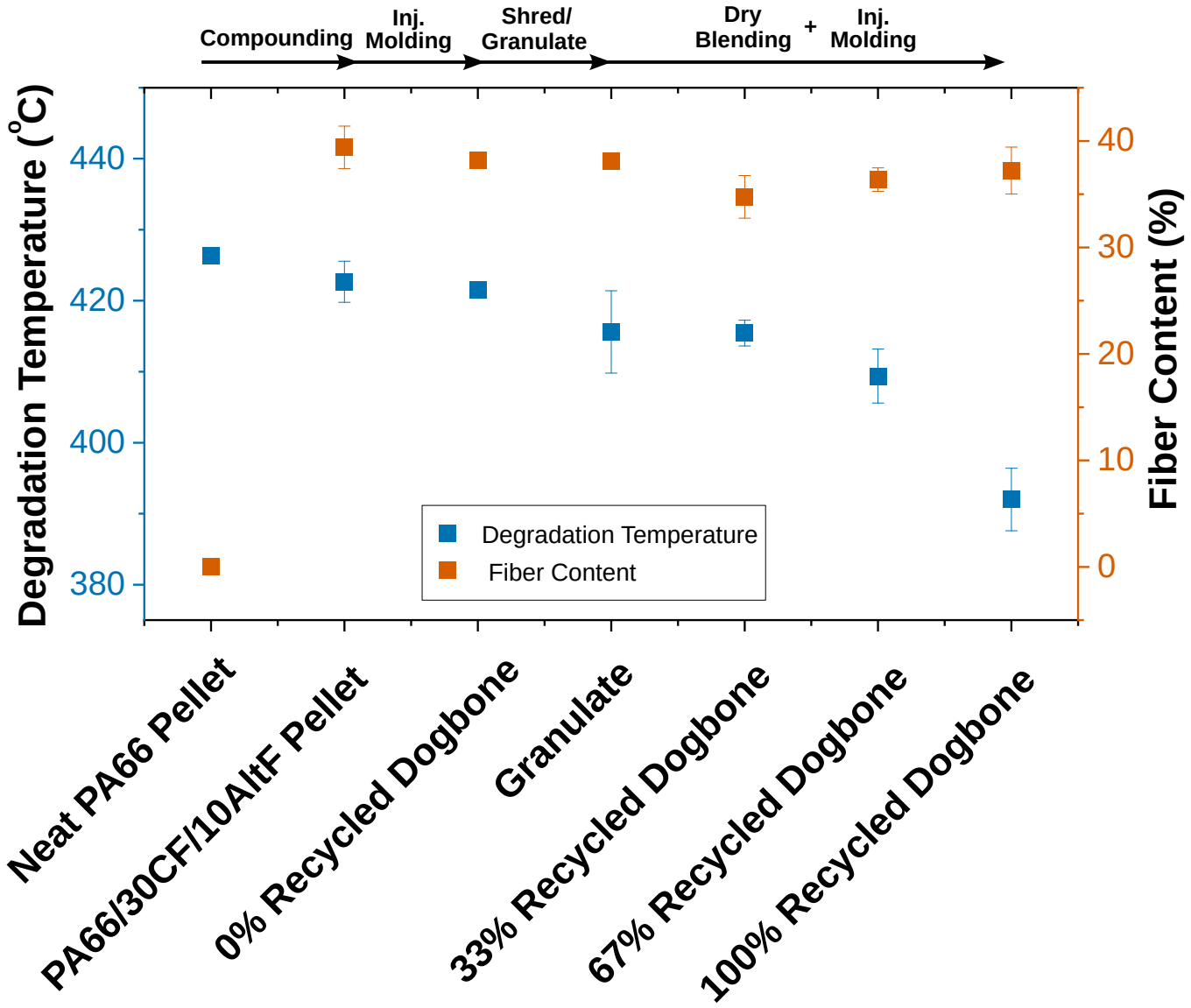
Thermal Characterization of Recycled PA66/30CF/10AltF



Differential Scanning Calorimetry:
1) Heat to 300°C at 10 °C/min
2) Cool to 30°C at 5 °C/min

- Adding fibers (compounding) reduces crystallinity and increased crystallization temperature
- Processing pathway has no effect on melting temperature
- **PA66 crystallinity not a factor in reduction of mechanical properties**

Assessing Loss in Fiber Content Along Processing Pathway



Thermogravimetric Analysis:

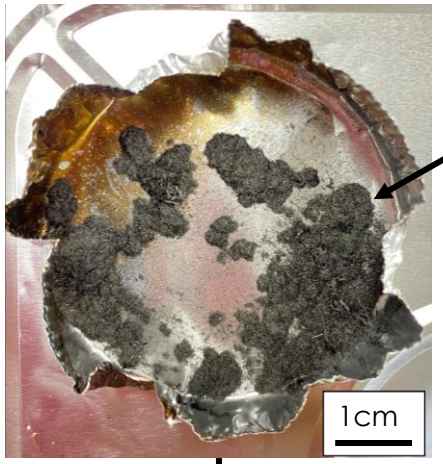
- Heat to 600°C at 10 °C/min in argon

- Processing pathway reduces degradation temperature
- Fiber content remains relatively consistent
- **Loss of fiber content not likely a mechanism for reduction in mechanical properties**

Assessing Fiber Length Attrition Along Processing/Recycling Pathway

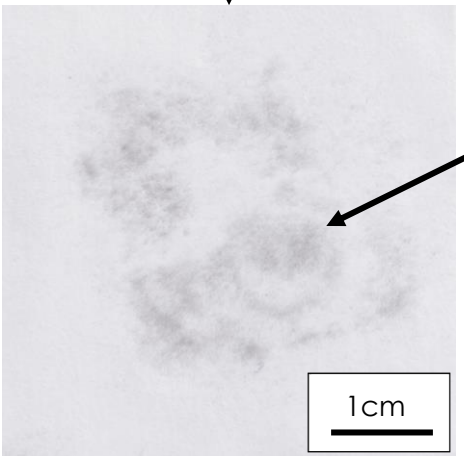
450°C

4 hours



CF and AltF

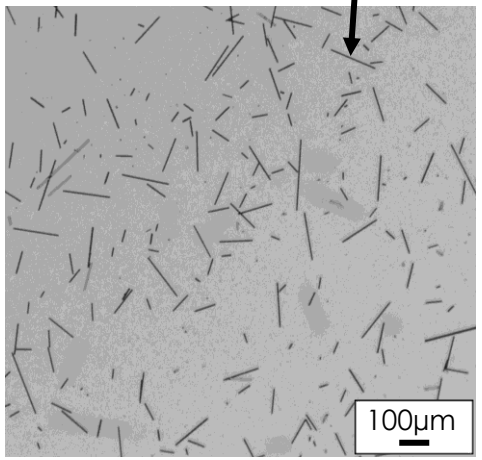
Dispersion



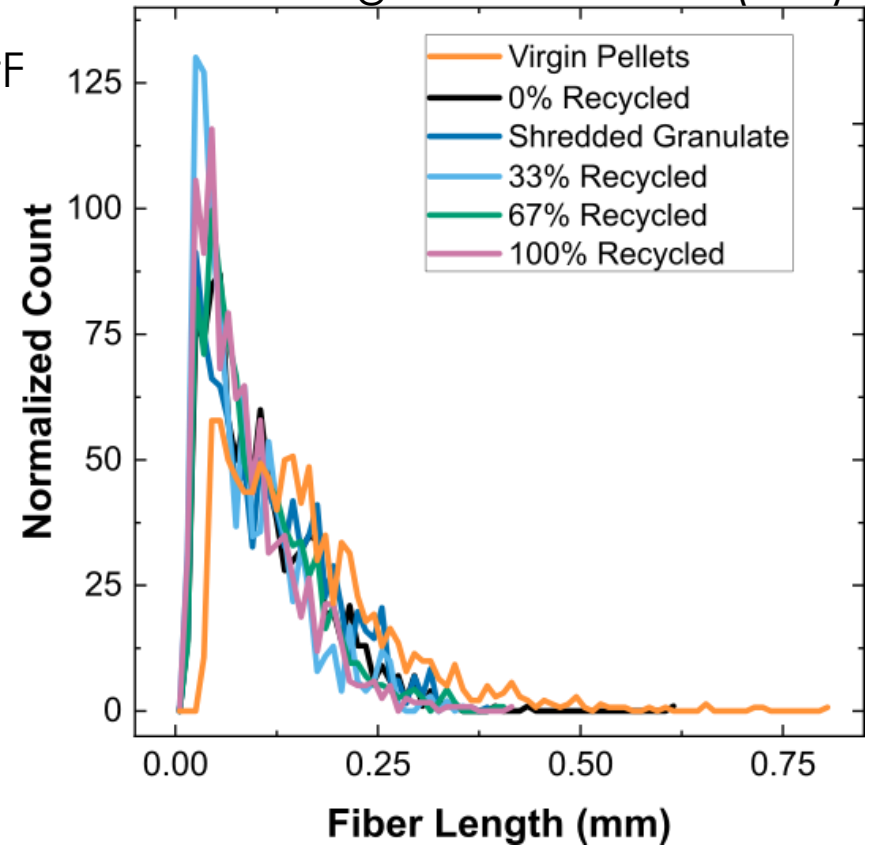
CF and AltF

Imaging

CF or AltF



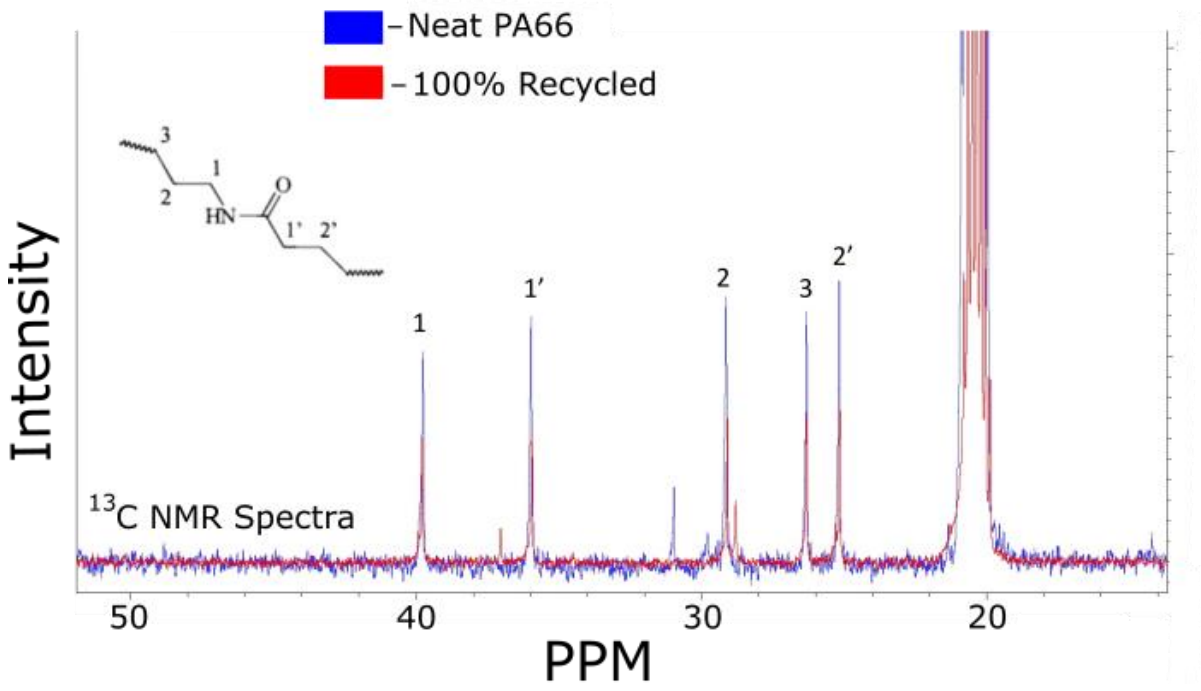
Fiber Length Distributions (FLD)

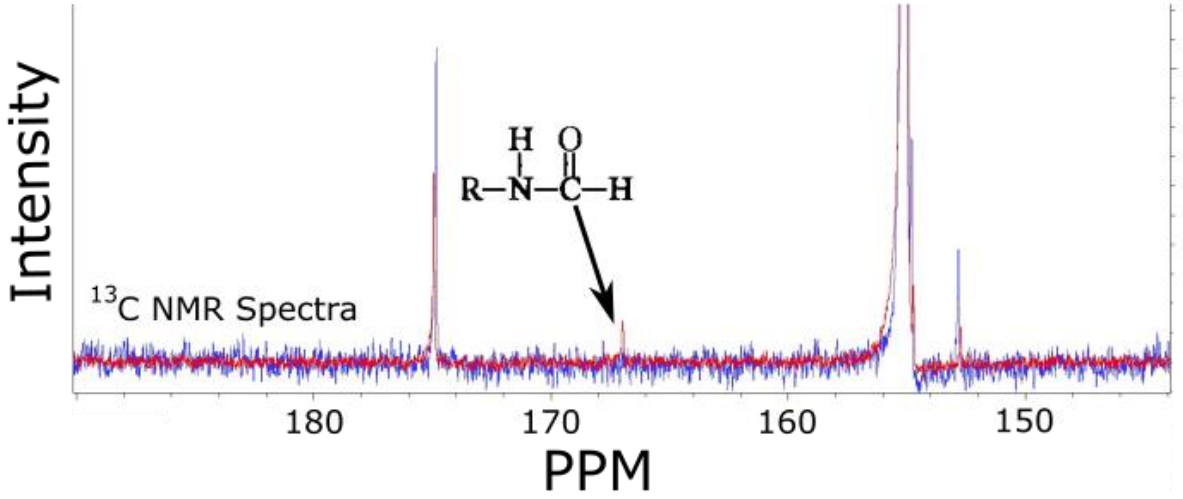


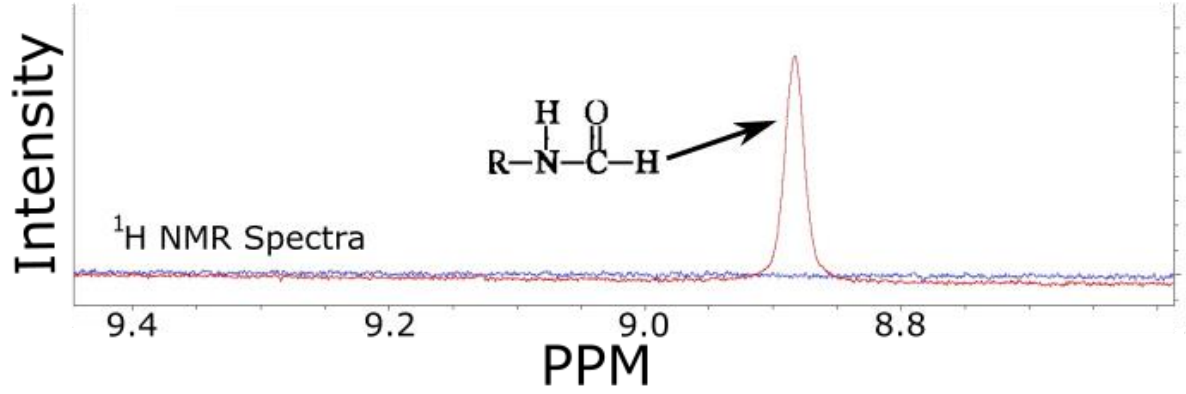
- Virgin Pellets have broader distribution
- Fiber length stabilizes after recycling
- **Fiber length attrition not likely a mechanism for reduction in mechanical properties**

Assessing Polymer Degradation Along Processing/Recycling Pathway

Nuclear magnetic resonance (NMR) used to determine any PA66 degradation

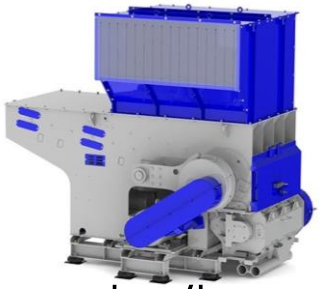
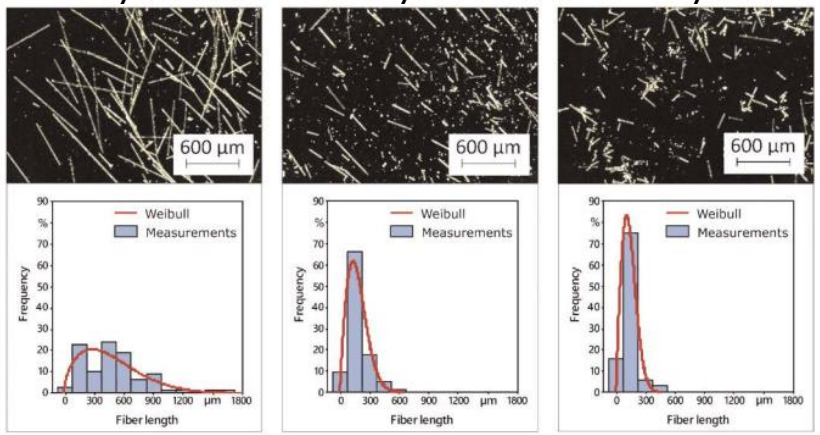






Peaks at 169 ppm in ^{13}C spectra and 8.88 ppm in ^{1}H for 100% recycled sample indicates degradation

Processing/Recycling Steps That Affect Mechanical Properties

	Loss in Fiber Content	Fiber Length Attrition	Polymer Degradation
Processing/ Recycling Steps	None	Injection Molding	Injection Molding
Potential Causes	N/A	High Shear Forces	High Shear Forces High Temperatures
Consider-ations	• Dust generation in scale-up  Vs.  g/hr kg/hr	• Initial fiber lengths • Processing method and parameter selection 1cycle 5 cycles 10 cycles  Evens et al. Intern. Poly. Proc. 2019	• Processing method and parameter selection  Inj. Mold.  indiamart.com Comp. Mold  compositesworld.com Add. Manuf.

Conclusions and Future Work

Conclusions:

- Although recycling reduced the tensile strength and modulus, the decrease was not dramatic
- Loss of fiber content and fiber length attrition did not cause mechanical property reduction
- Polymer degradation is likely the cause for the decrease in mechanical properties
- The selected processing/recycling pathway directly affects mechanical properties when utilizing recycled material

Future Work:

- Determine which processing step(s) is causing polymer degradation
- What impact does the 10wt% AltF have on the mechanical performance when utilizing recycled material?

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Halil Tekinalp

Vipin Kumar

Brian Knouff

Soydan Ozcan

Vlastimil Kunc

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