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3M Advanced Materials Division

3M™ Nextel™ 610 Towpreg: A new pathway for oxide ceramic matrix composite fabrication

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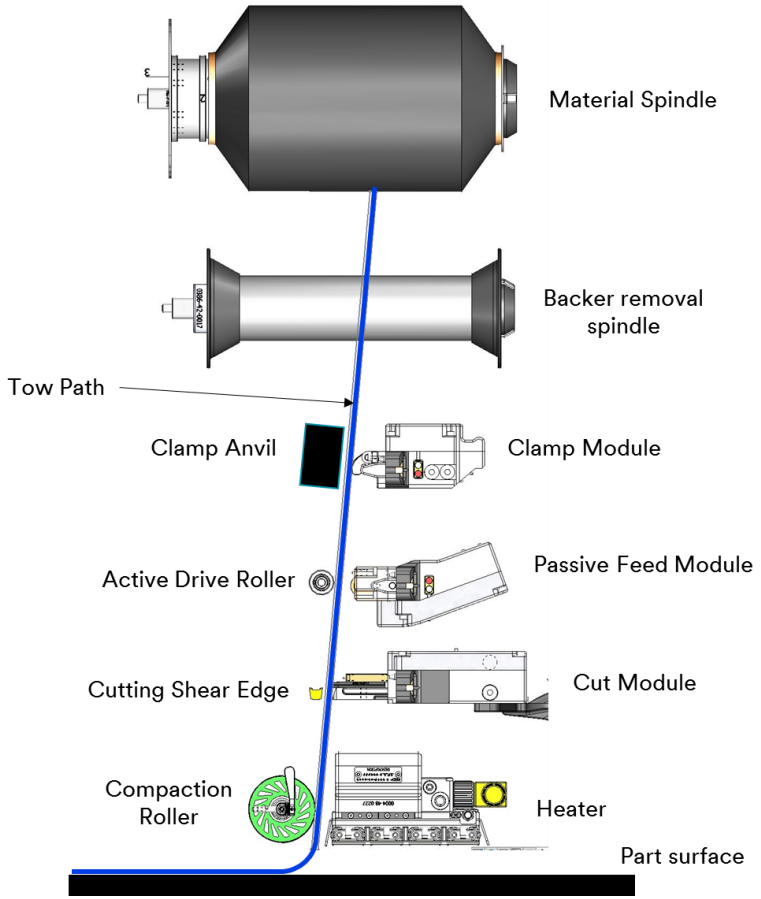
Automated fiber placement

- Automated Fiber Placement (AFP) is a digital additive manufacturing process where multiple tows can be independently added or cut in the fabrication of a composite

- AFP combines the advantages of

  Filament winding + automated tape layup + 3D printing

Technique	Fabrication rates	Geometric constraints
Filament winding	Fast	Requires constant convex curvature
Automated tape layup	Fast	Simple shapes with no compound curvature
3D printing	Slow	Minimal
Automated fiber placement	Fast	Lower contour parts and male tools



Fabrication of composites using AFP

Advantages vs hand layup

- Lower scrap
- Lower material costs
- Automated process
  - More consistent and higher quality parts
  - High layup rates
  - Digital process (inspection, digital twin, etc)
- Process scales and is flexible
  - Many different part geometries and sizes can be produced via the process

Limitations

- Better suited for lower contour parts and male tools
- Minimum feature size
  - Radius ≥500 mm for 180° tool
- Minimum part size
  - Min segment length of 4”

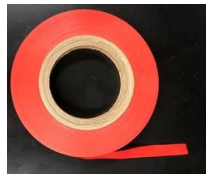
Potential applications for CMC structures

- Thermal shielding
- Exhaust cone
- Combustion liner

3M™ Nextel™ 610 Towpreg – Experimental Product

Nextel 610 Spread tow
- Controlled width and thickness
- Water soluble sizing

Ceramic matrix
- All alumina, water based composition
- Organic additives to provide tack



Release liner
- Polyethylene
- Carrier for tacky towpreg

Coating
- Slurry infused into fiber tow to provide controlled matrix content
- Water soluble sizing removed from fiber surfaces

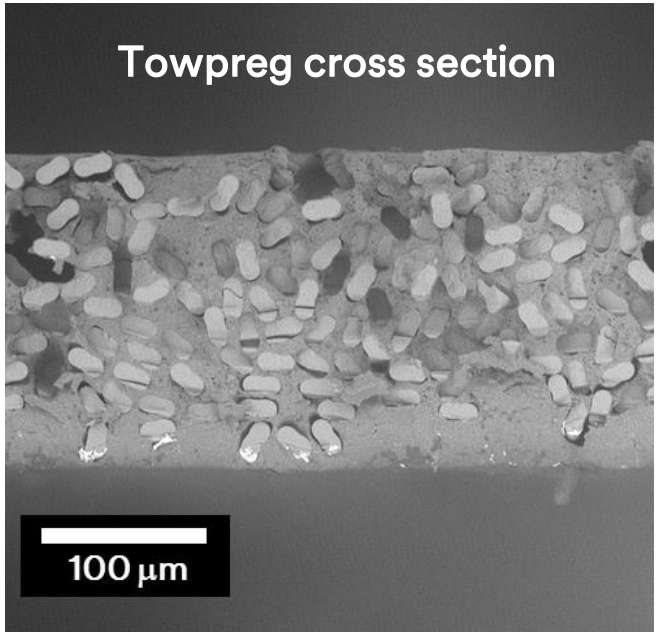
Drying
- Water removed from slurry to produce a dry matrix
  - Target < 1 wt.% water
- Room temperature stable matrix
  - Humidity can result in slightly higher moisture content (1.5 to 2 wt.%)

Winding
- Level wound roll
- Interleaved liner
  - Smooth, stable unwind of dry towpreg

3M™ Nextel™ 610 Towpreg – Experimental Product

Nextel 610 Towpreg

- Controlled width and thickness
- Controlled matrix content
  - Dry, room temperature stable
  - Heat-activated tack

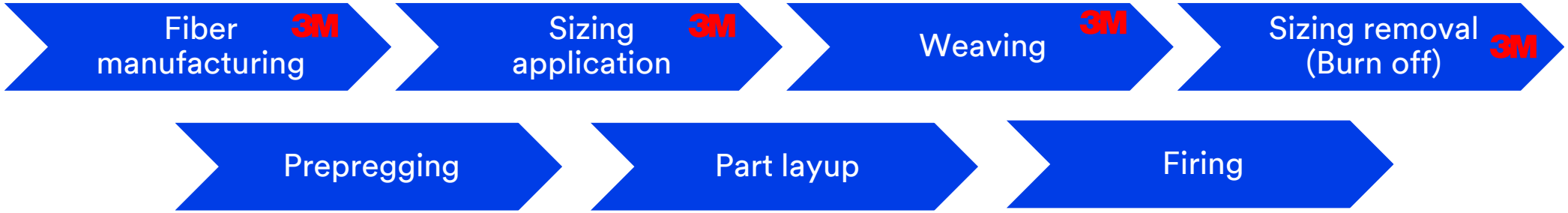


Fiber	Nextel 610
Denier (g/9,000m)	10,000
Nominal width (mm)	6.35
Nominal thickness (um)	200
Ceramic matrix content (wt%)	51
Oxide particle composition	alumina
Liner	polyethylene

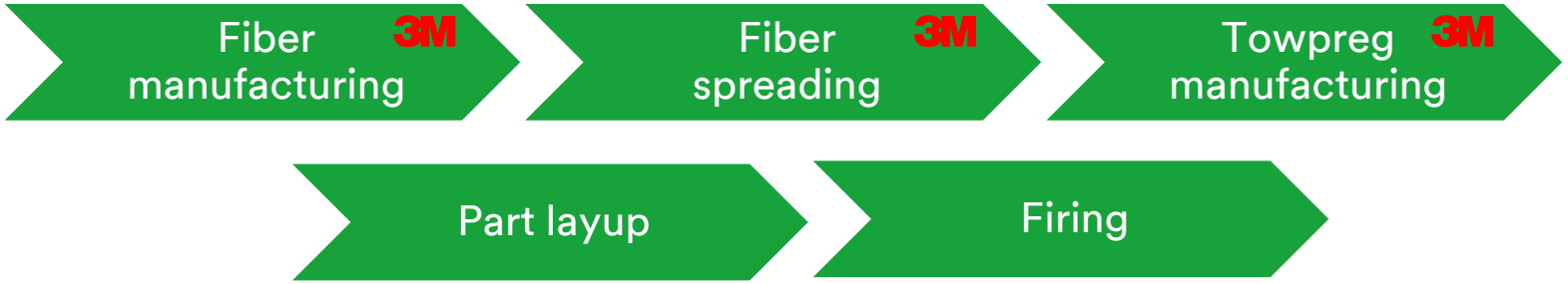
Towpreg properties are representative and not for specification purposes

A new pathway for simple geometry parts

Fabric prepreg model

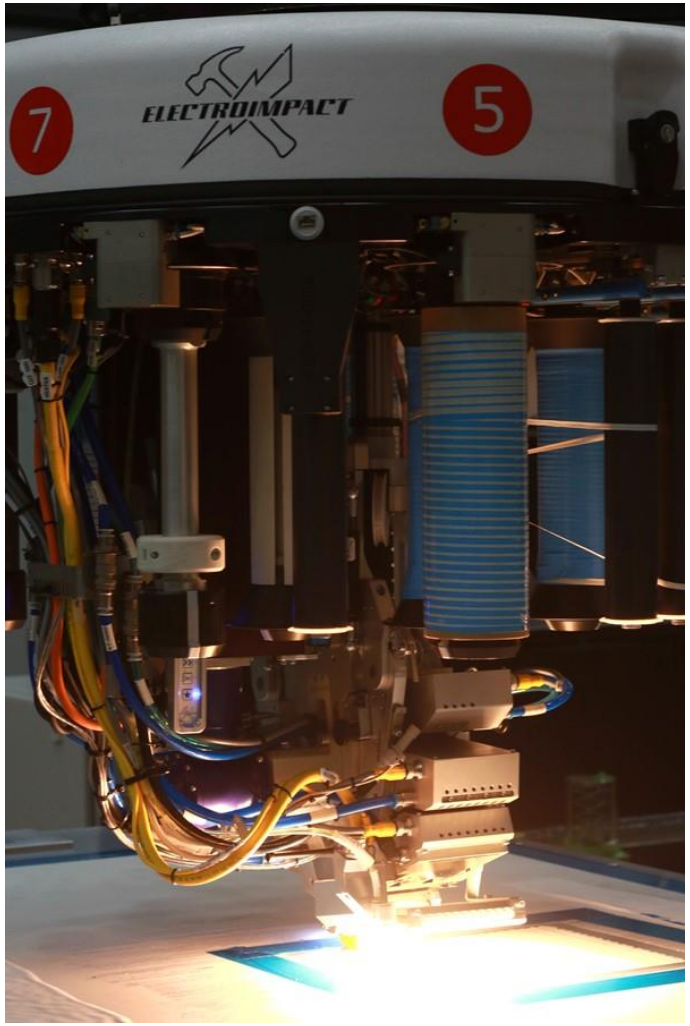


Tow preg enabled model

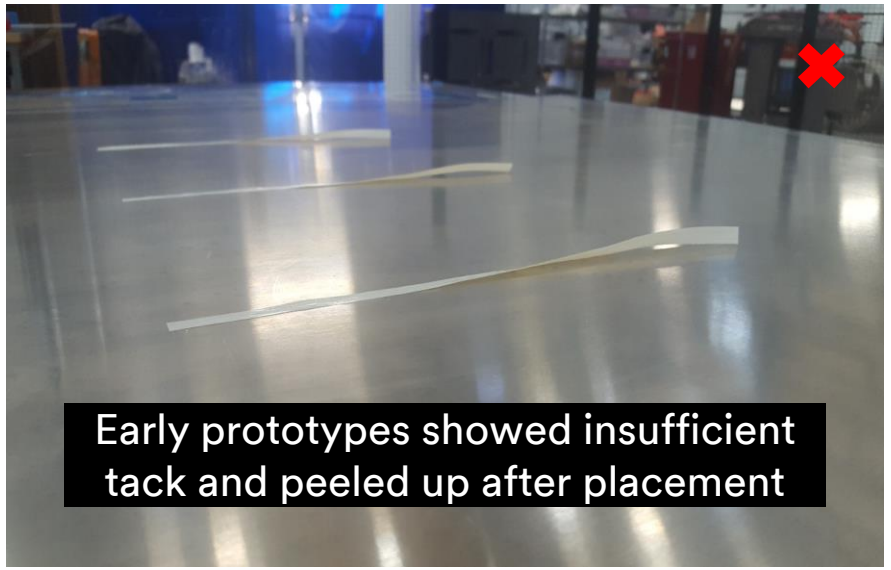


- We are enabling another, more simple supply chain with a potential for the **lowest cost RM for oxide CMCs**
- Enables customers to pursue **lower cost manufacturing**, including AFP, for simple geometries

Panel fabrication

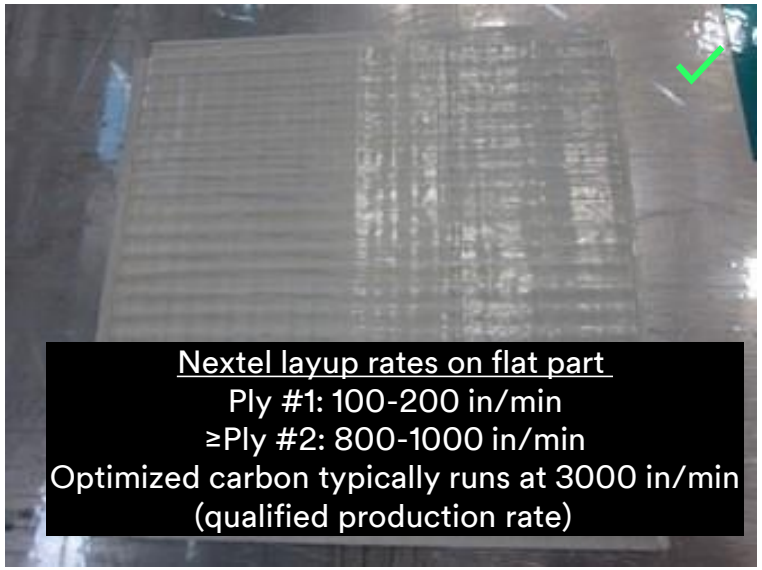


Poor tack

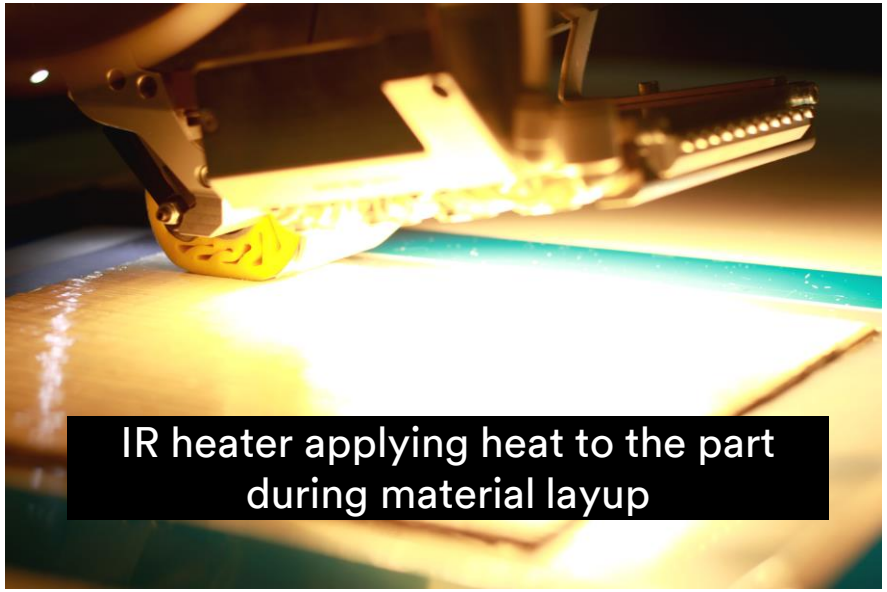


Early prototypes showed insufficient tack and peeled up after placement

Excellent tack



Nextel layup rates on flat part
Ply #1: 100-200 in/min
≥Ply #2: 800-1000 in/min
Optimized carbon typically runs at 3000 in/min (qualified production rate)



IR heater applying heat to the part during material layup

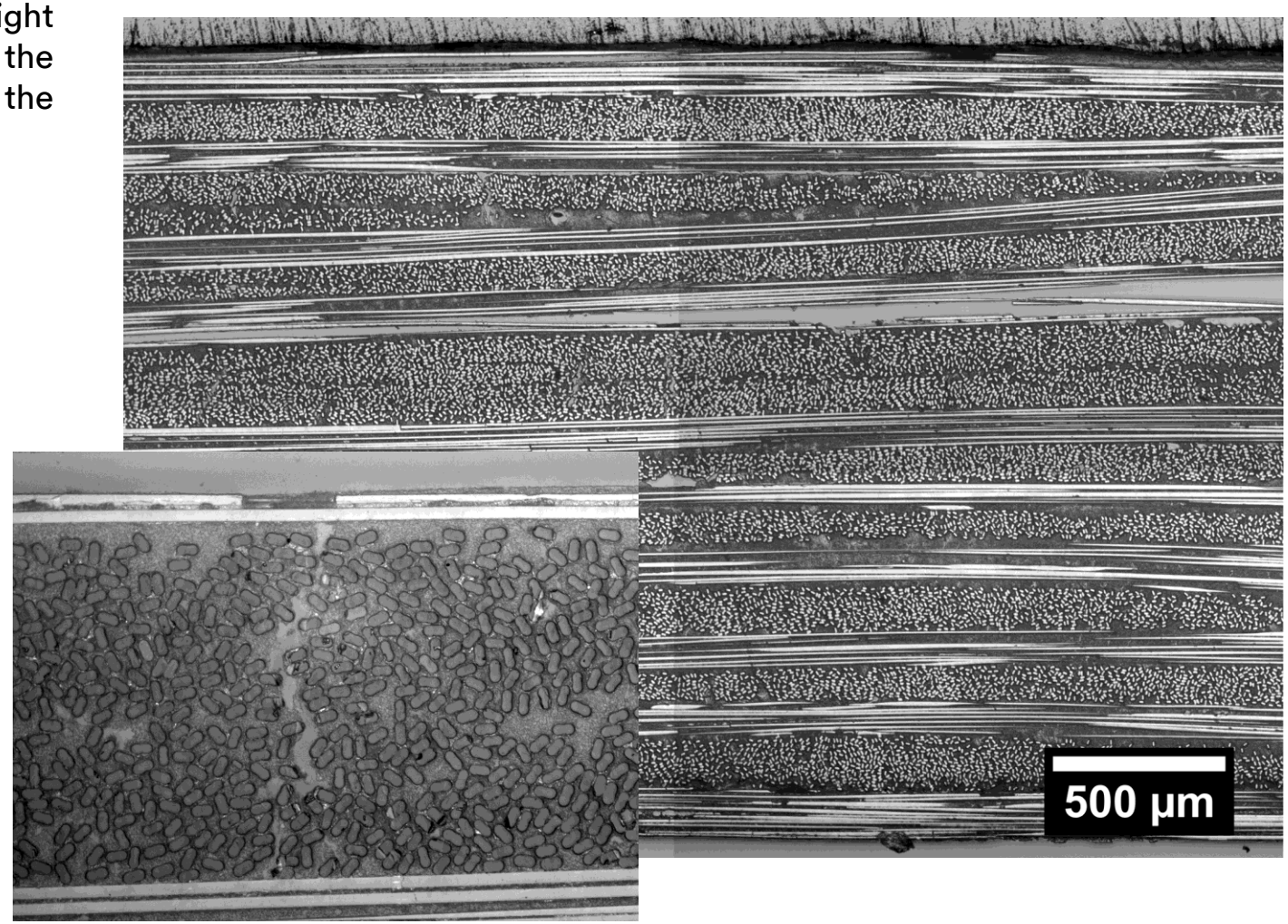
Physical and mechanical properties

Test panels were fabricated with Nextel Towpreg using AFP. Measured properties are given below. The image to the right shows the cross section of the composite, highlighting the consistent distribution of fiber and matrix throughout the composite.

Fiber orientation	0/90 cross-ply
Ply count	20
Per ply thickness (mm)	0.11
Fiber content (vol%)	41.3
Areal density (gsm)	303
Tensile strength (MPa)	290
Tensile modulus (GPa)	108
Flex strength (MPa)	382
Flex modulus (GPa)	122
Interlaminar shear strength (MPa)	20

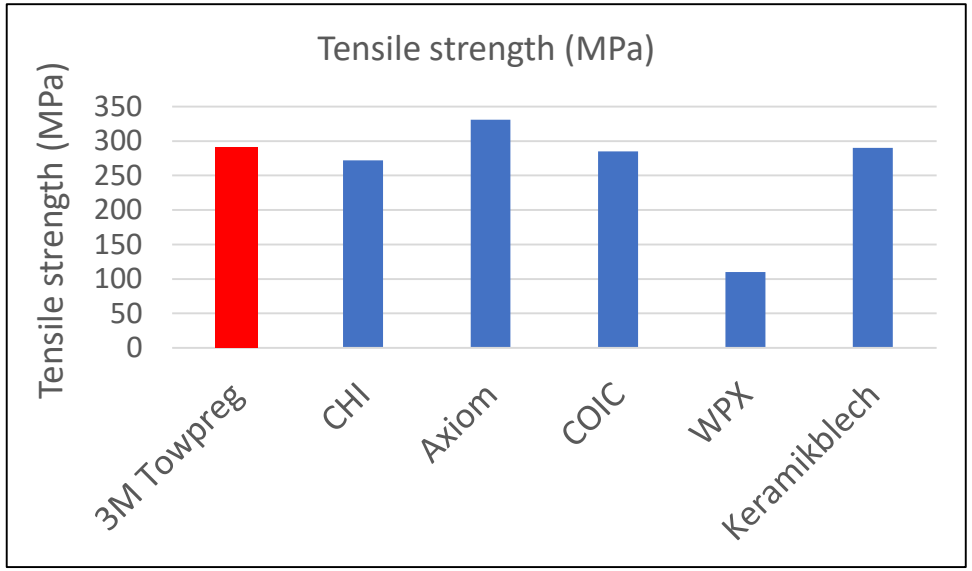
Towpreg composite properties are representative and not for specification purposes

Sintered panel polished cross section

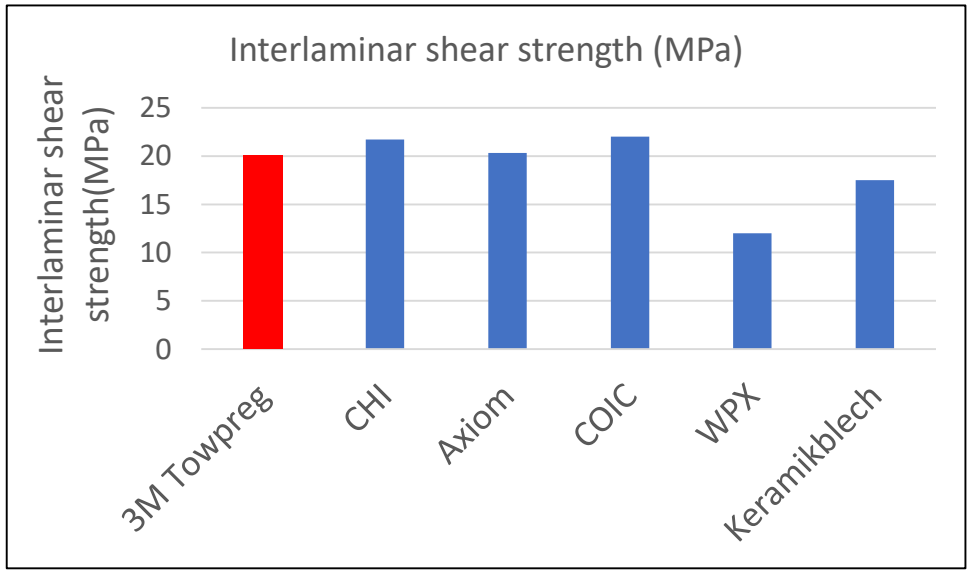


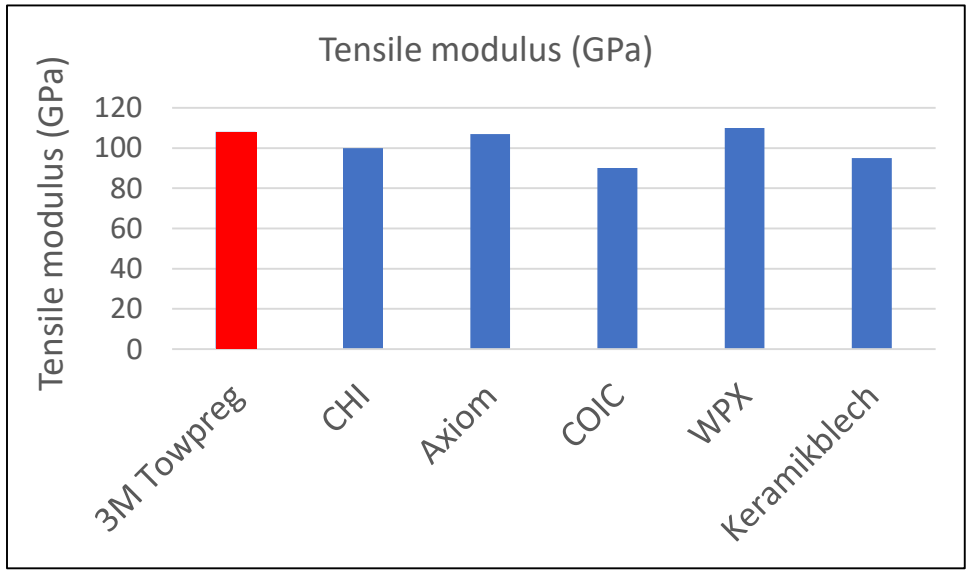
Room temp performance comparison

Material	3M	CHI	Axiom	COIC	WPX	Keramikblech
Fiber	N610	N610	N610	N610	N610	N610
Matrix	alumina	alumina-silica	alumina-silica	alumina-silica	alumina	alumina-zirconia
Fiber content (vol%)	41	41	46	40	39	42
Porosity (vol%)	27	23	21		26	28
Source	USACA 2020	USACA 2017	NSMMS 2019	HTCMC 2019	whipox.com	HTCMC 2019



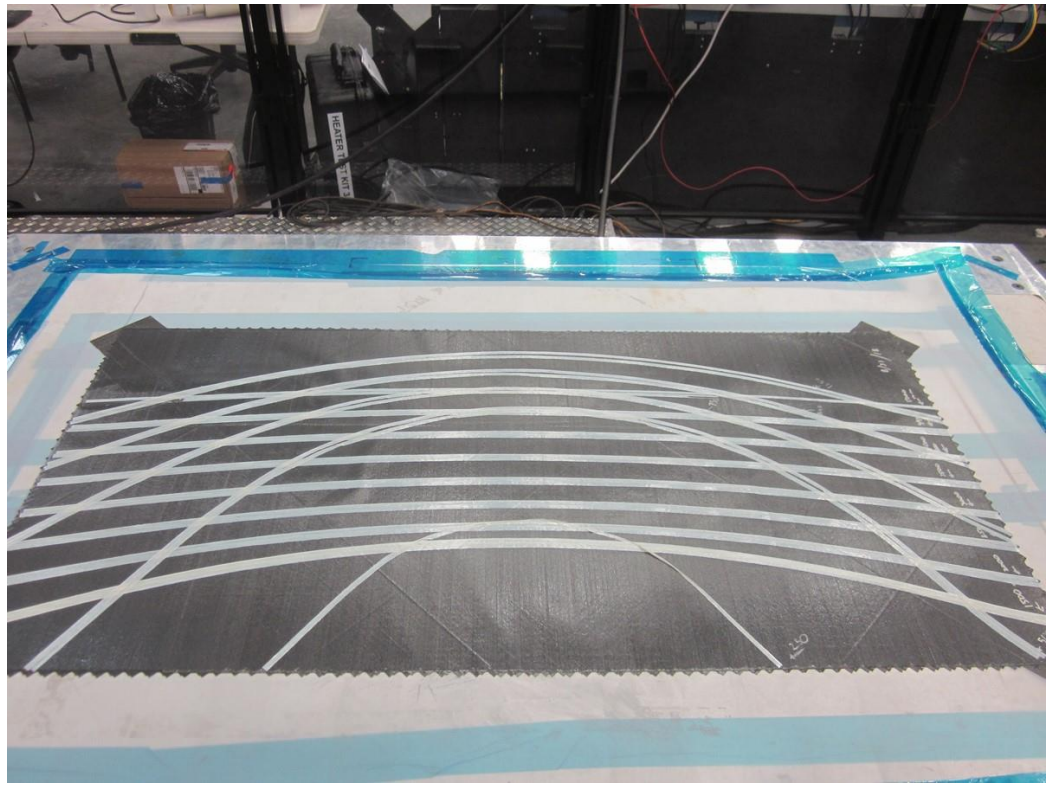
Compared to other commercial CMCs, composites generated with Nextel Towpreg using AFP show in family performance at room temperature.



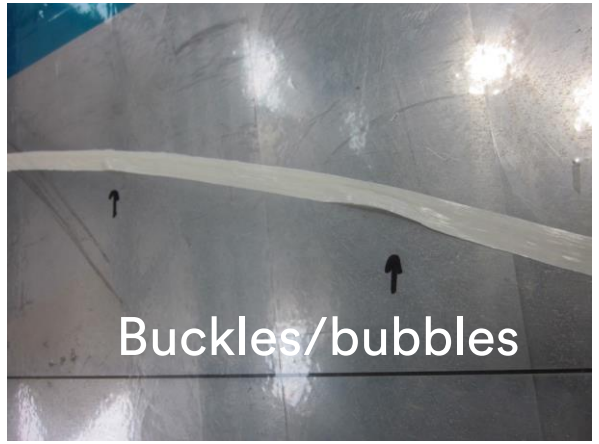


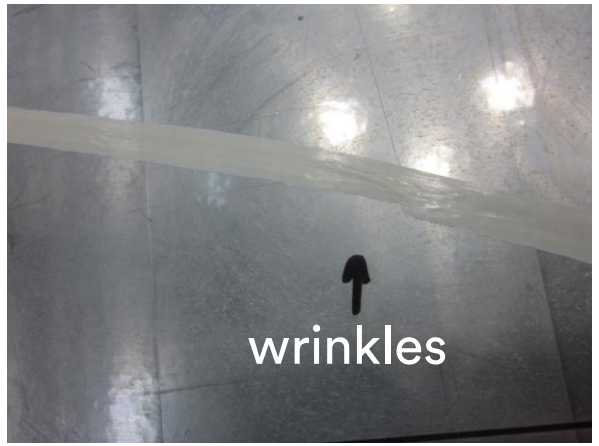
Steering trials

- Steering evaluated with arcs of Nextel Towpreg on carbon and PET substrates
- Evaluation of radius from 500-2500 mm
- No defects for radius greater or equal to 1000 mm
  - As a comparison, optimized carbon typically runs at 2000 mm for ¼”



Examples of steering defects



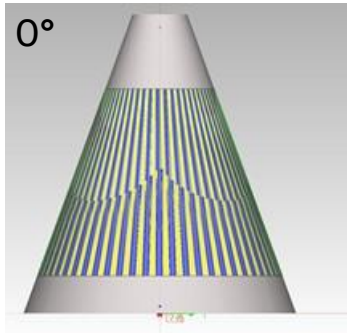


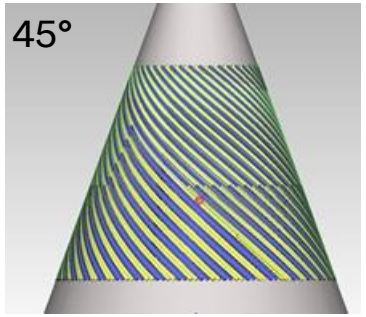
Complex geometries

A variety of tooling has been explored to identify capabilities and limitations of the Nextel Towpreg with AFP

Cone

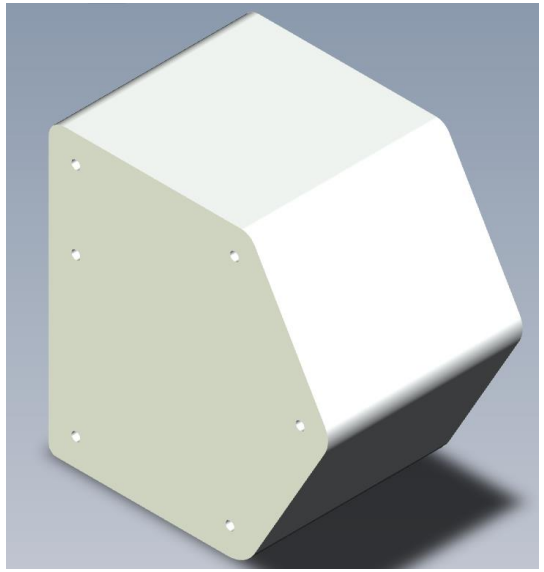
- 20” diameter, 22” height demo cone
- Multiple layup configurations evaluated (0°, 90°, 45°, 30°, etc)

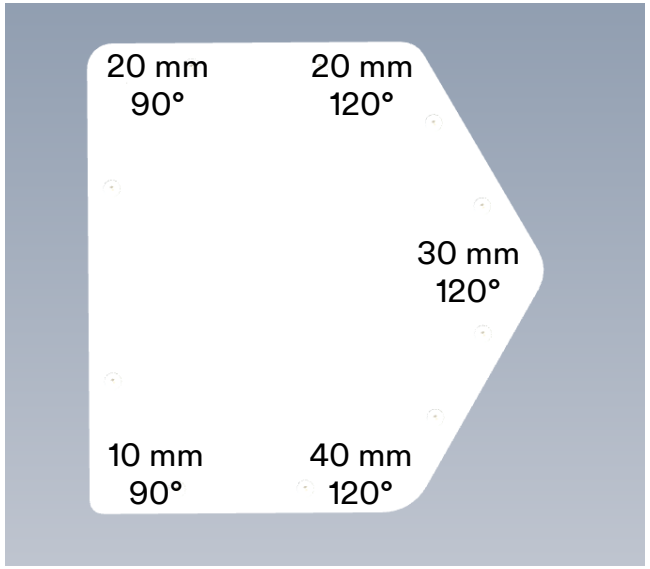




Angled radius

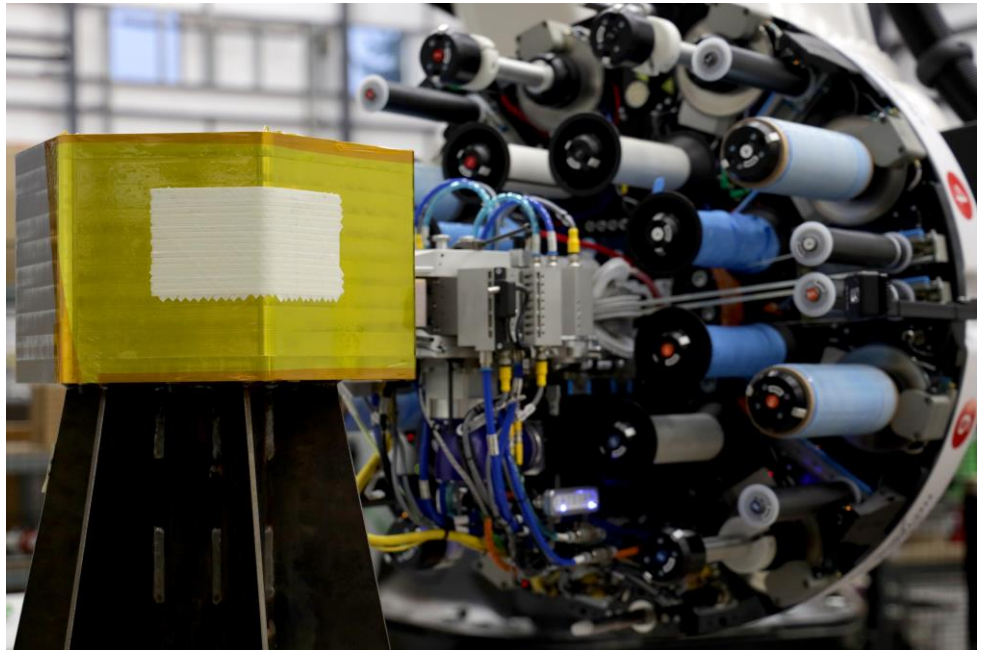
- 5 sided tool to represent multiple features relevant to CMC fabrication
- 90° and 120° features ranging from 10-40 mm radius
- Layup orientation: 0° / +45° / -45°

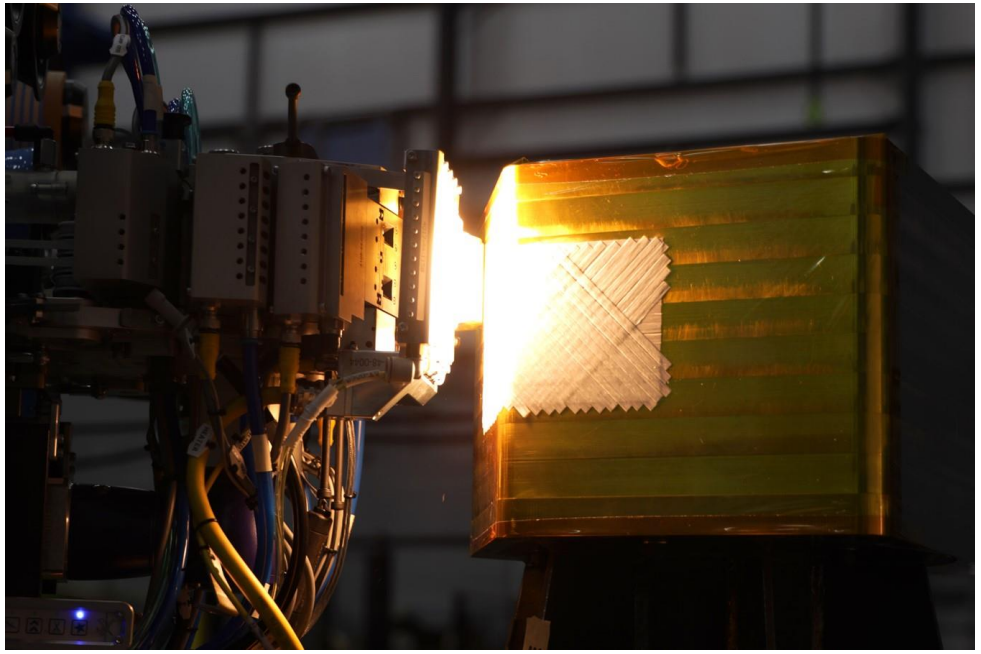




Angled tool trials

- 90° and 120° features ranging from 10-40 mm radius
- Tool wrapped with polyimide film (gold color)
- Layup orientation: 0° / +45° / -45°
- 22 plys





Example of 120°, 30 mm radius layup

Angled tool layup results – 90° radius

Minor defects observed during layup, most notably in 45° plys. These could likely be corrected with additional AFP tuning.

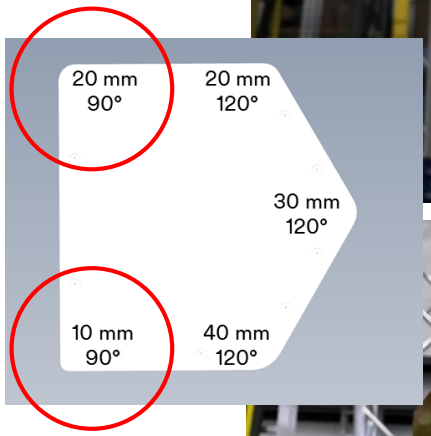
Ply 4: 0°

Ply 5: +45°

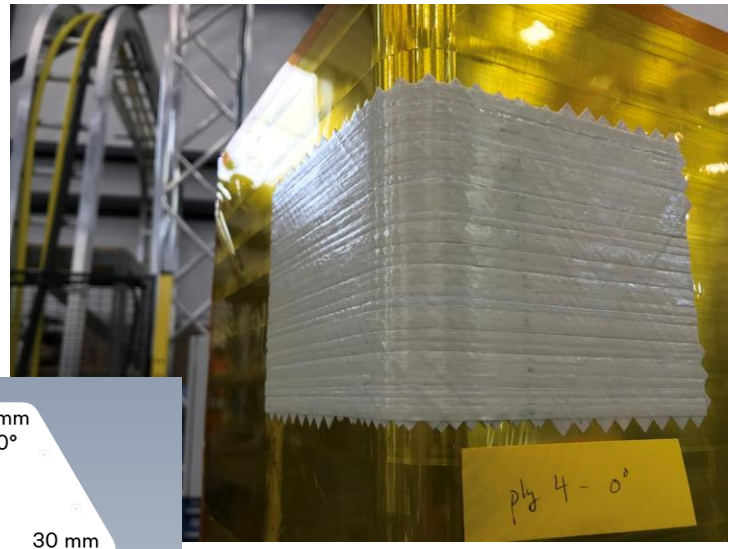
Ply 6: -45°

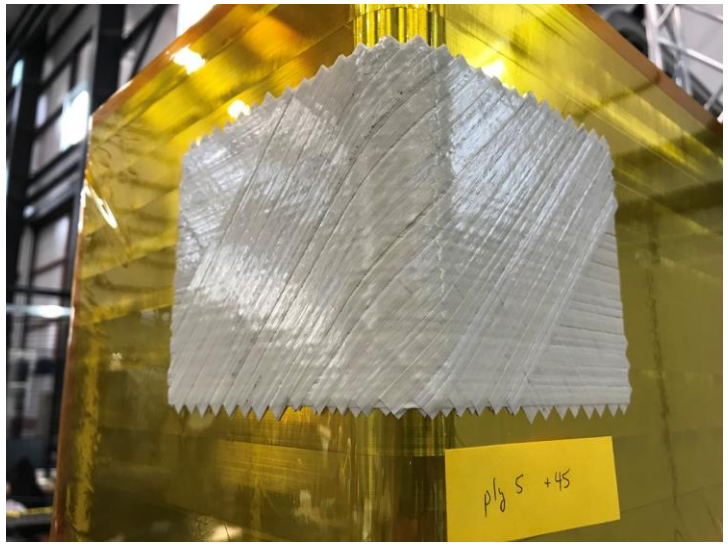
radius

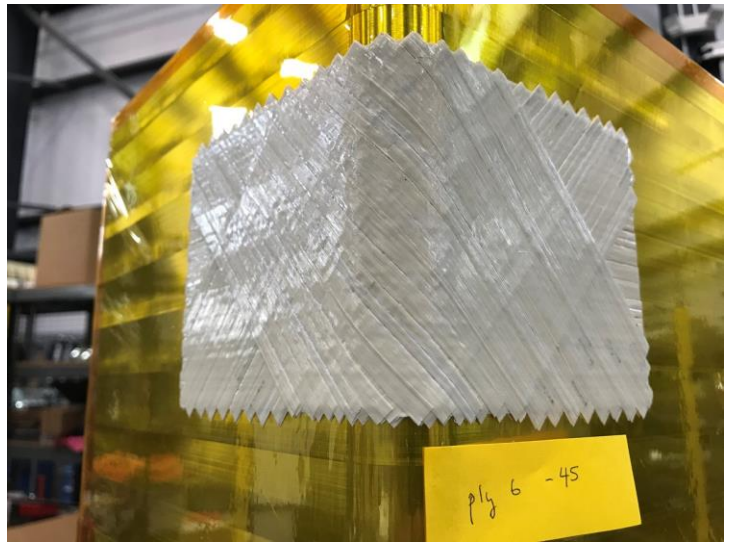
20 mm

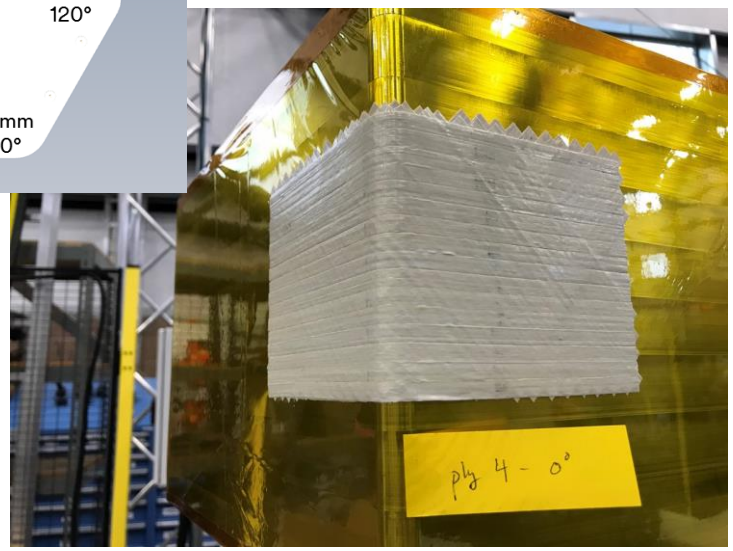


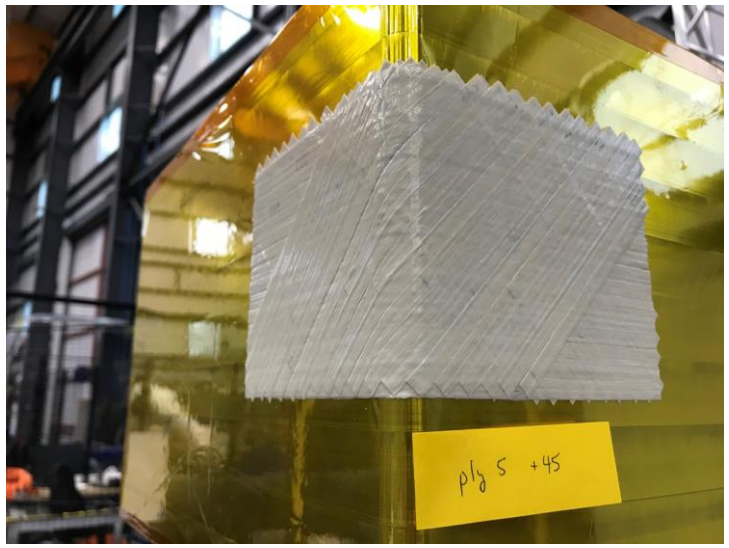
10 mm

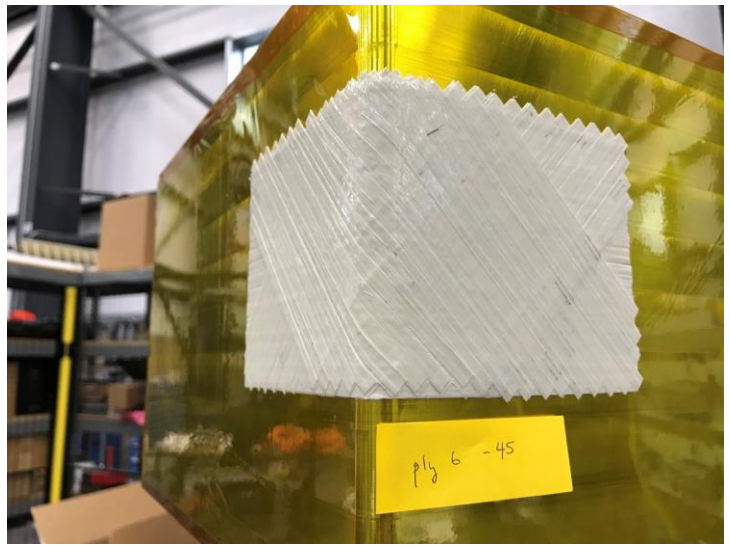








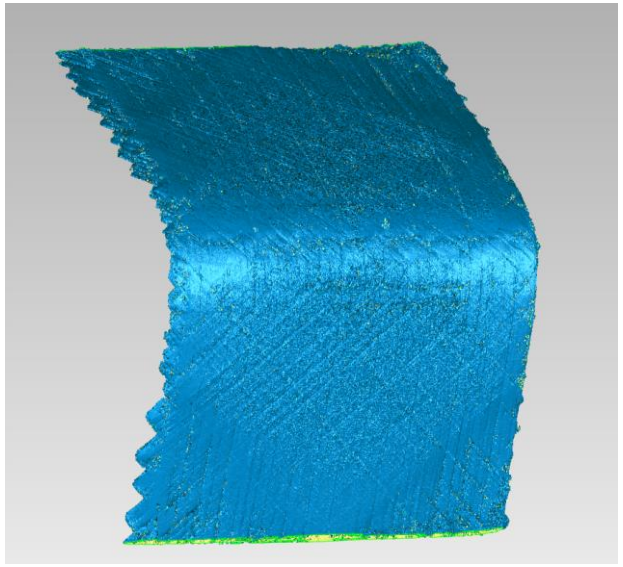


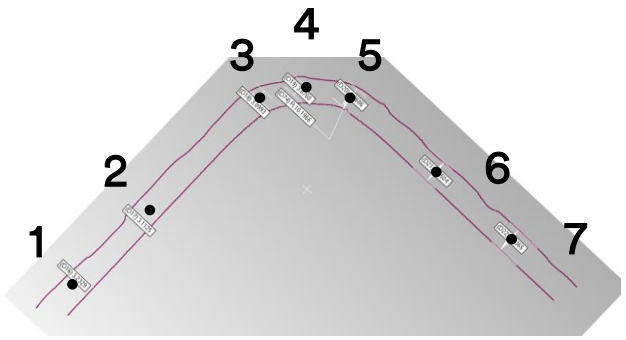


Composite processing – CT analysis – 10 mm, 90°

Parts were scanned using CT after layup, autoclaving, and sintering process steps. Thickness was measured at 7 positions along the part profile and reported as an average along the length of the part.

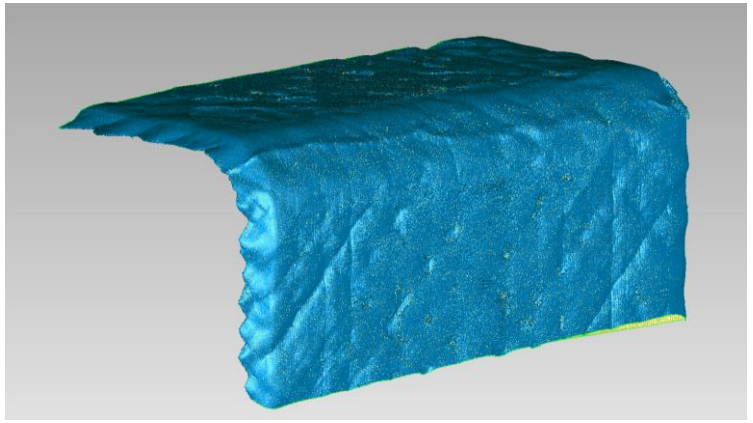
Layup



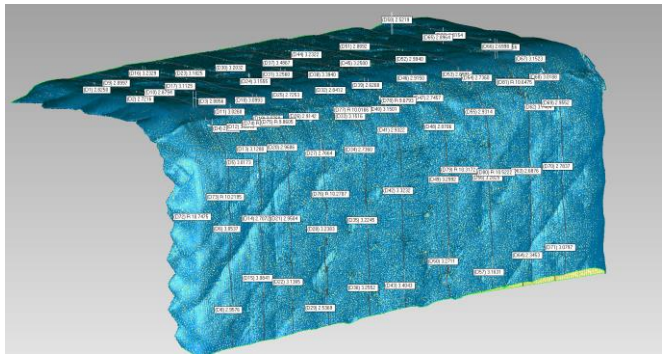


Representative thickness slice and measurement positions (#1-7)

Autoclaved

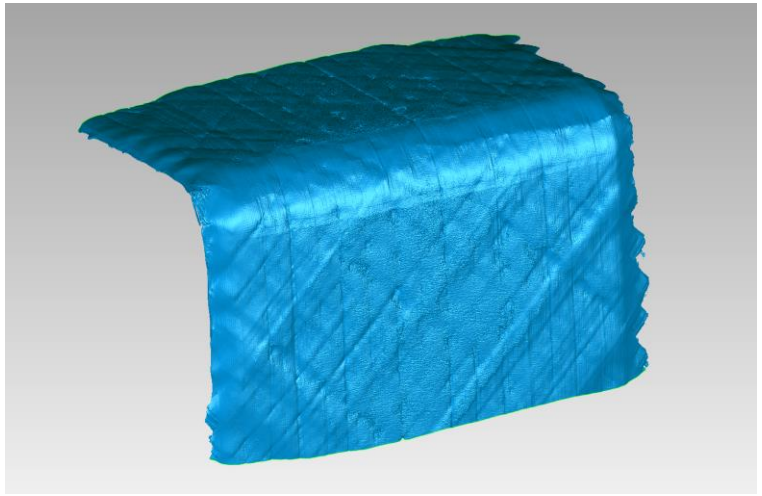


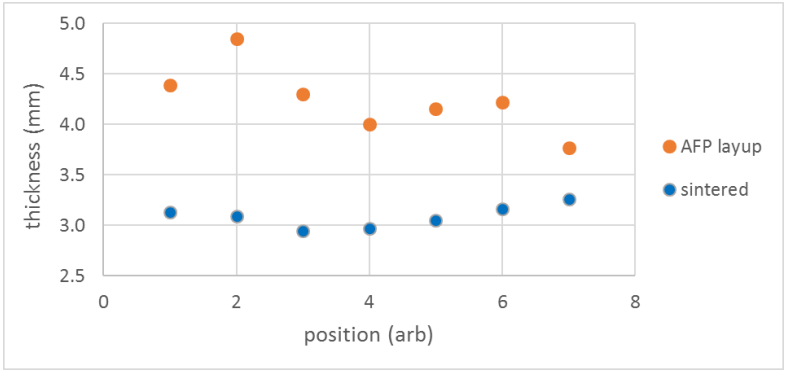
Thickness measurements



Grid of measurement locations

Sintered





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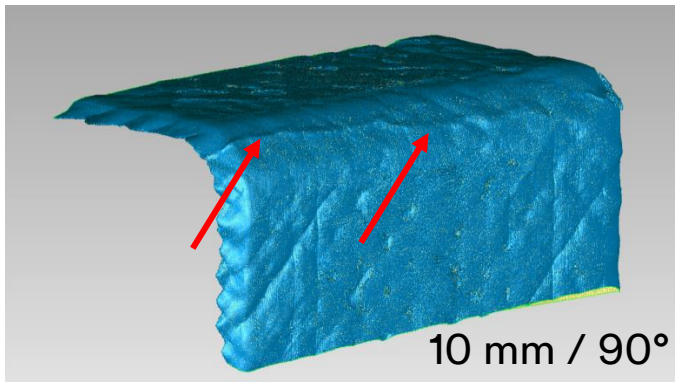
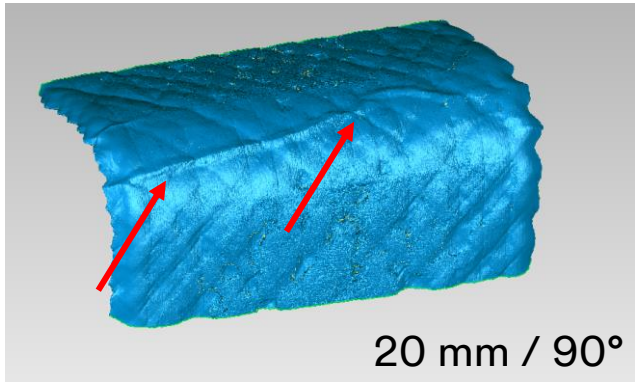
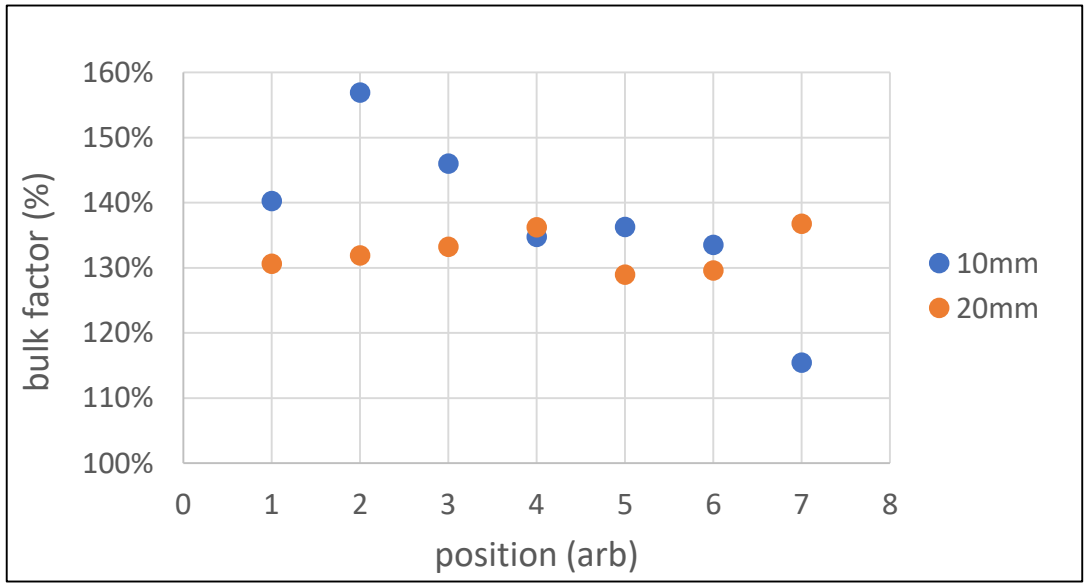
Wrinkling defect

- Wrinkle observed in both 10 and 20 mm parts (red arrow)
- Likely the result of excessive part contraction during consolidation
- Using thickness measurements, a bulk factor of 130-140% was calculated. Plot to the right shows bulk factor for each measurement location across the part profile.
- High bulk factor can be addressed through
  - AFP parameters
  - Tooling / debulking
  - Towpreg formulation

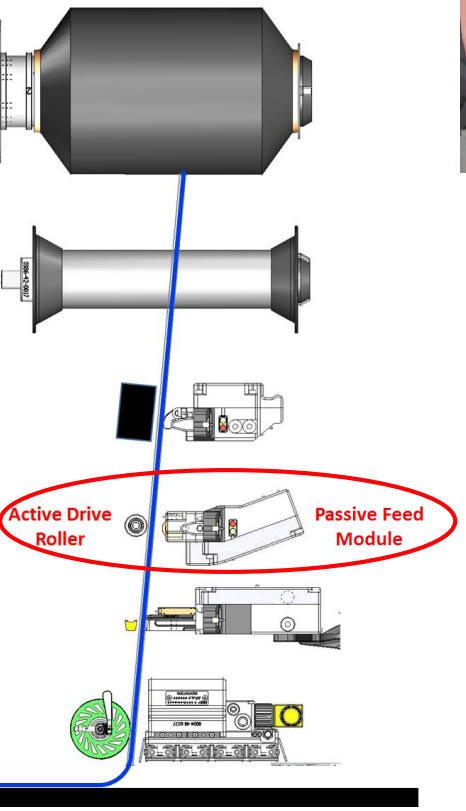




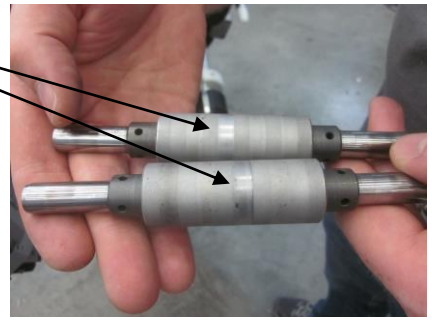


Challenges with AFP rollers – Metal abrasion

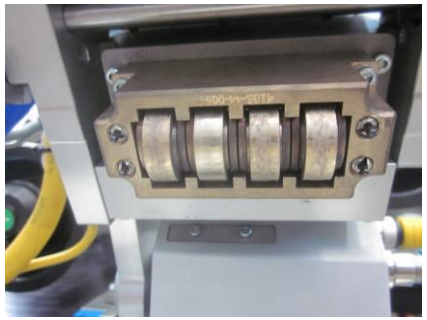
Drive rolls polished by processing Nextel Towpreg



Driven feed roll (440C SS)



Passive feed roll (Bronze 954)

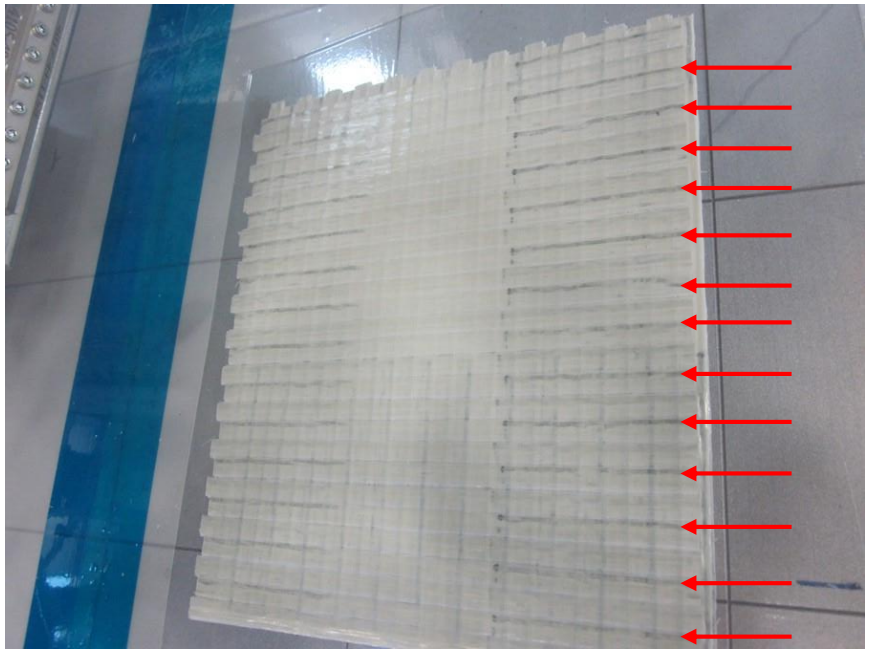


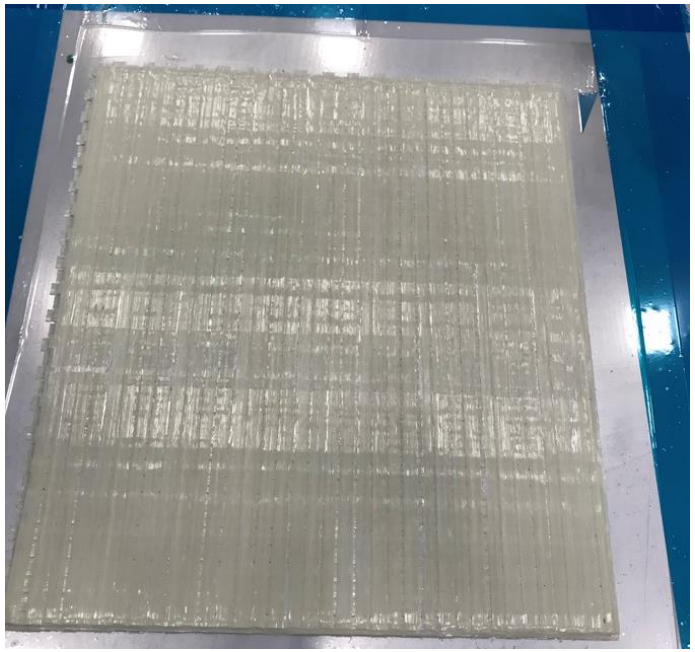
Potential solution: PVD coated rollers

Coating polished, but much less debris observed on panels

Black contamination on panels (red arrows) identified as:

- Copper from passive rollers
- Iron from active rollers





Conclusions

- Introducing a new experimental product: Nextel 610 Towpreg
- Unique dry matrix providing room temperature stability and heat-activated tack
- AFP compatibility
- In family room temperature mechanical performance

Next steps

- Continue to evaluate product performance, including small volume sampling
  - Process window/constraints for AFP
  - Demonstration part(s), in-service testing
  - Composition/construction development
    - Mechanical data set for elevated temperature performance

Acknowledgements

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ElectroImpact

- Kyle Jeffries
- Matt Warnock
- Andy Purvis

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3M Advanced Materials Division

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