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Designing with oxide-oxide CMCs: Understanding the price-performance relationship in new fabric designs

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Previous study

- Survey of new fabric designs for CMCs using AXC-610 Matrix
- Presented at the High Temperature Ceramic Matrix Composite conference in Jun 2016 (Toronto)
- Conclusions
  - Minimal changes in Nextel 610 and 720 CMC tensile and flex properties using fabrics with roving as high as 4500 denier
  - >40% cost savings in fabric input
- Available at www.3m.com/ceramics

OXIDE-OXIDE CERAMIC MATRIX COMPOSITES -

ENABLING WIDESPREAD INDUSTRY ADOPTION

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ABSTRACT

Oxide-oxide ceramic matrix composites are gaining increasing attention as a mainstream material option for high temperature components in the aerospace and advanced energy sectors. As the material moves from bench to production, cost reductions are required to ensure that the solutions are market-competitive with titanium and other high temperature alloys. In parallel, a more comprehensive portfolio of fabric geometries and data are desirable to enable flexibility in both engineering and design. 3M, maker of Nextel™ ceramic fibers, joins CMC prepreg developer and manufacturer, Axiom Materials, Inc., and CMC parts designer and fabricator, Composites Horizons, in developing data for the present work. The team jointly compares the properties of Oxide-Oxide CMCs fabricated from conventional Nextel fabric architectures with those of new, lower cost fabric designs.

Current study objectives

- Determine effects of high denier fabrics on CMC fabrication using AXC-610 Matrix
- Replicate results from previous study with larger sample set
- Focus on Nextel 610 and best performing fabric designs
  - DF-11-27-1500 (baseline)
  - DF-11-14-3000
  - DF-19-23-3000
  - DF-11-10-4500
  - DF-24-8-10000
- Expand analytical testing to include
  - Interlaminar shear properties
  - Tuning of composite properties with processing variations
  - Surface roughness
  - Part specific considerations – Bending radius
  - Cost savings – Fabric and CMC

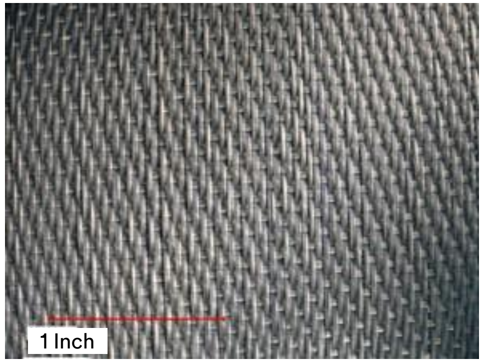
Fabric naming convention

DF – 11 – 27 – 1500

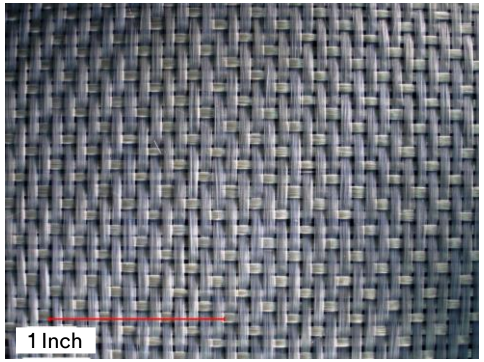
Fiber	Form	Thickness	Thread count	Denier
Nextel 610	Woven fabric	11 mil	27 picks/in	1500 g/9000m

3M™ Nextel™ 610 Fabrics

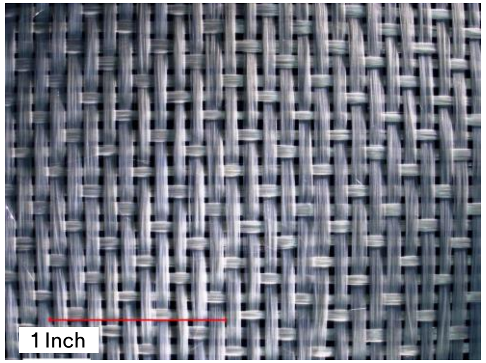
Fabric Type	Input Yarn Nextel 610	Weave	Thread Count	Weight (oz/yd2)		Thickness (inch)	
			(ppi) (warp / fill)	Sized	Heat Cleaned	Sized	Heat Cleaned
DF-11-27-1500	1500 d	8HS	27.5 / 27.5	11	11	0.012	0.010
DF-11-14-3000	3000 d	5HS	15 / 14	~11	11	~0.013	~0.010
DF-11-10-4500	4500 d	5HS	10 / 9	~12	10	~0.014	~0.011
DF-19-23-3000	3000 d	8HS	23.5 / 23.5	19	18	0.020	0.017
DF-24-8-10000	10,000 d	4HS	8 / 8	~ 22	21	~ 0.024	~ 0.019



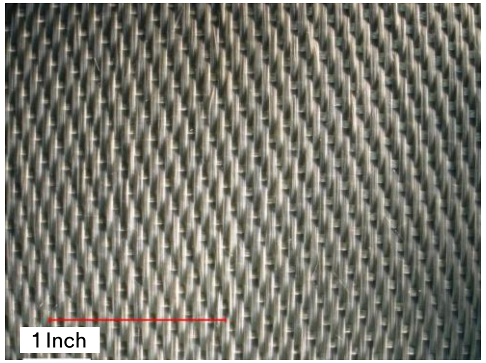
DF11-27-1.5K
8 HS Weave



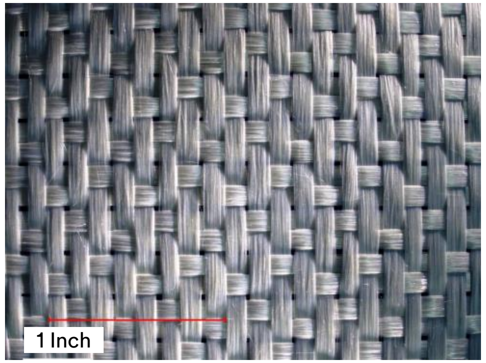
DF11-14-3K
5 HS Weave



DF11-10-4.5K
5 HS Weave



DF19-23-3.0K
8 HS Weave



DF24-8-1000D
4HS Weave

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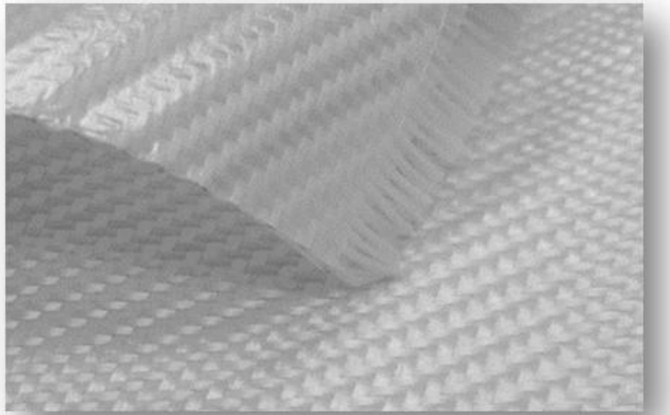
Laminate Physical Properties

Fabric Style	Matrix	# of Plies	Volume % Fiber	Volume % Matrix	Volume % Porosity	Density g/cc	Laminate Thickness (mm)	Per Ply Thickness (mm)
DF-11-27-1500	AXC-610 Alumina Silicate	12	40.8	36.4	22.8	2.82	2.84	0.24
DF-11-14-3000		12	40.7	34.7	24.6	2.76	2.85	0.24
DF-11-10-4500		12	38.5	37.6	23.9	2.77	3.10	0.26
DF-19-23-3000		8	41.8	34.7	23.5	2.80	3.04	0.38
DF-24-8-10000		6	38.3	34.0	27.7	2.64	2.84	0.47

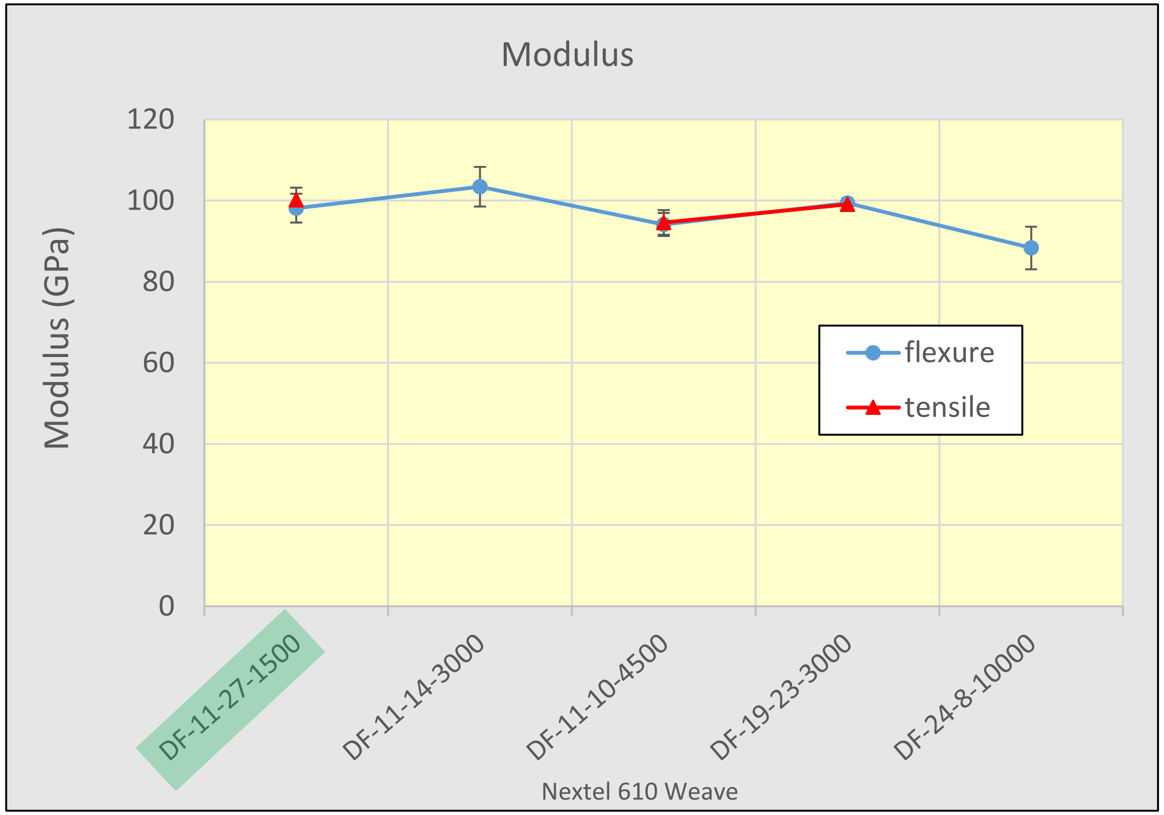
5 Weaves of Nextel 610 were investigated. The denier of the fiber tow ranged from 1500D to 10000D. The number of plies per laminate were selected to produce approximately the same laminate thickness.

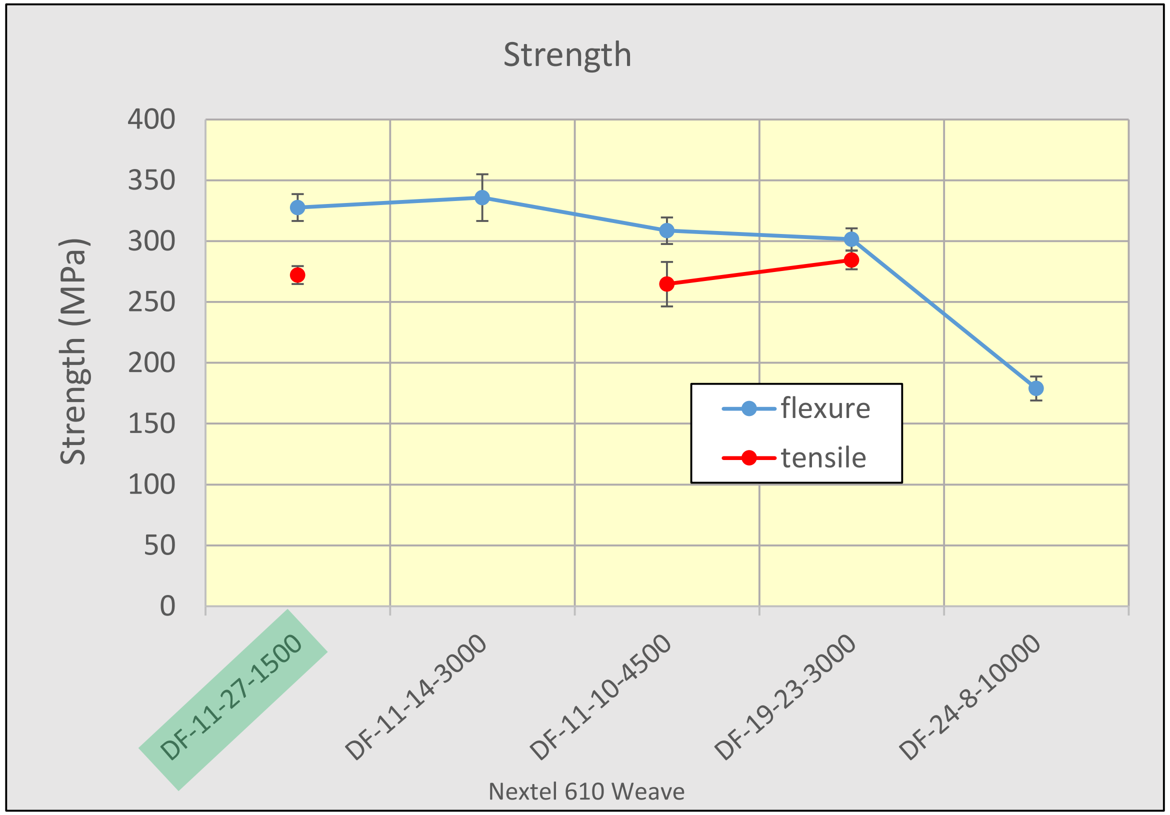


Test methods

- Tensile
  - ASTM C1275-15: Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Composites
- Flexure
  - ASTM C1341-13: Flexural Properties of Continuous Fiber-Reinforced Advanced Ceramic Composites
- Interlaminar shear
  - ASTM C1292-10: Shear Strength of Continuous Fiber-Reinforced Advanced Ceramics
    - Double notched compression
- Bending strength
  - ASTM D6415: Measuring the Curved Beam Strength of a Fiber-Reinforced Polymer Matrix Composite
    - Modified to include variation in bending radius
- Thermal aging
  - 100 hrs at elevated temperatures
- Surface roughness
  - DIN EN ISO 4287: 1D profilometry

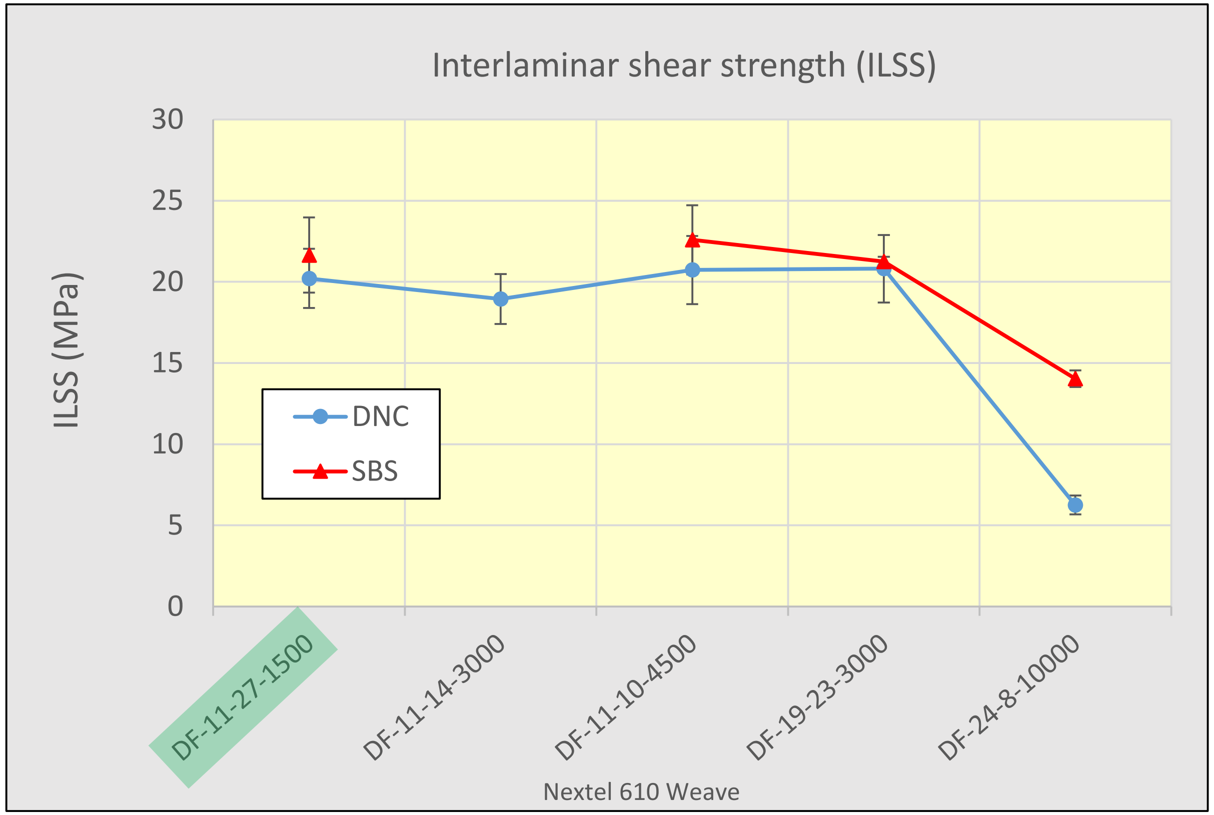
Room temperature tensile/flex modulus and strength

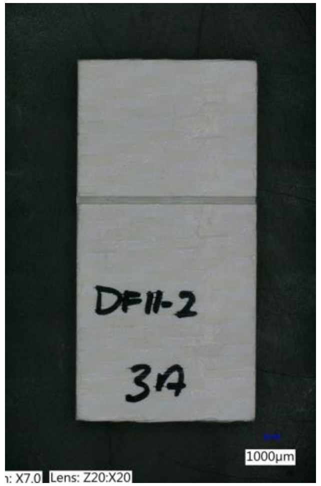


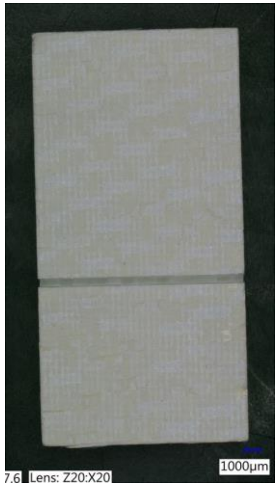


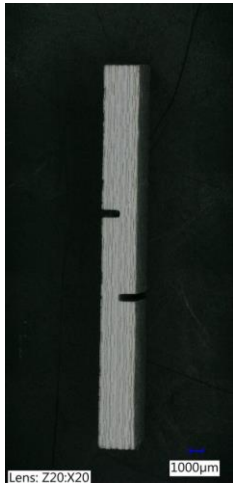
Across the weave styles the variation in strength and modulus is 10%, except for the laminate made using the 10000 denier fiber tow. All samples used the AXC-610 Alumina Silicate Matrix.

Room temperature interlaminar shear strength – SBS and DNC



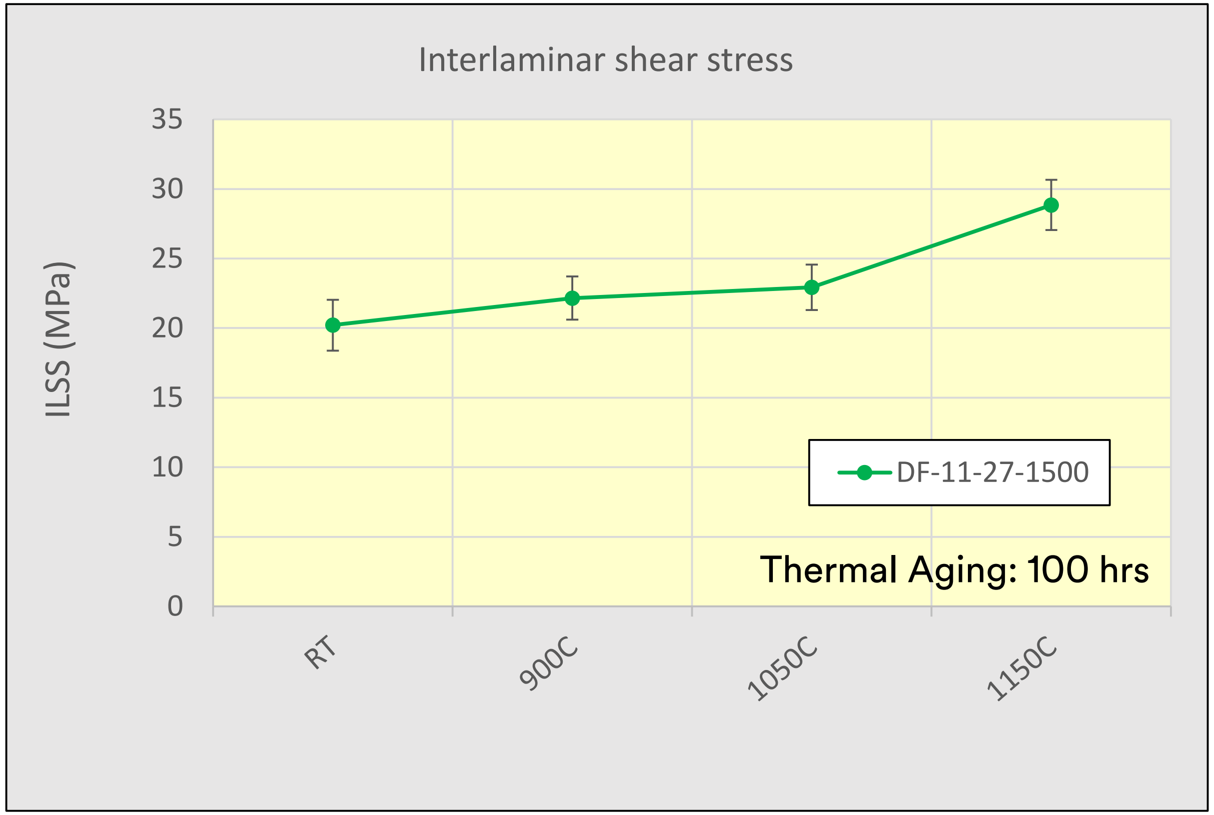


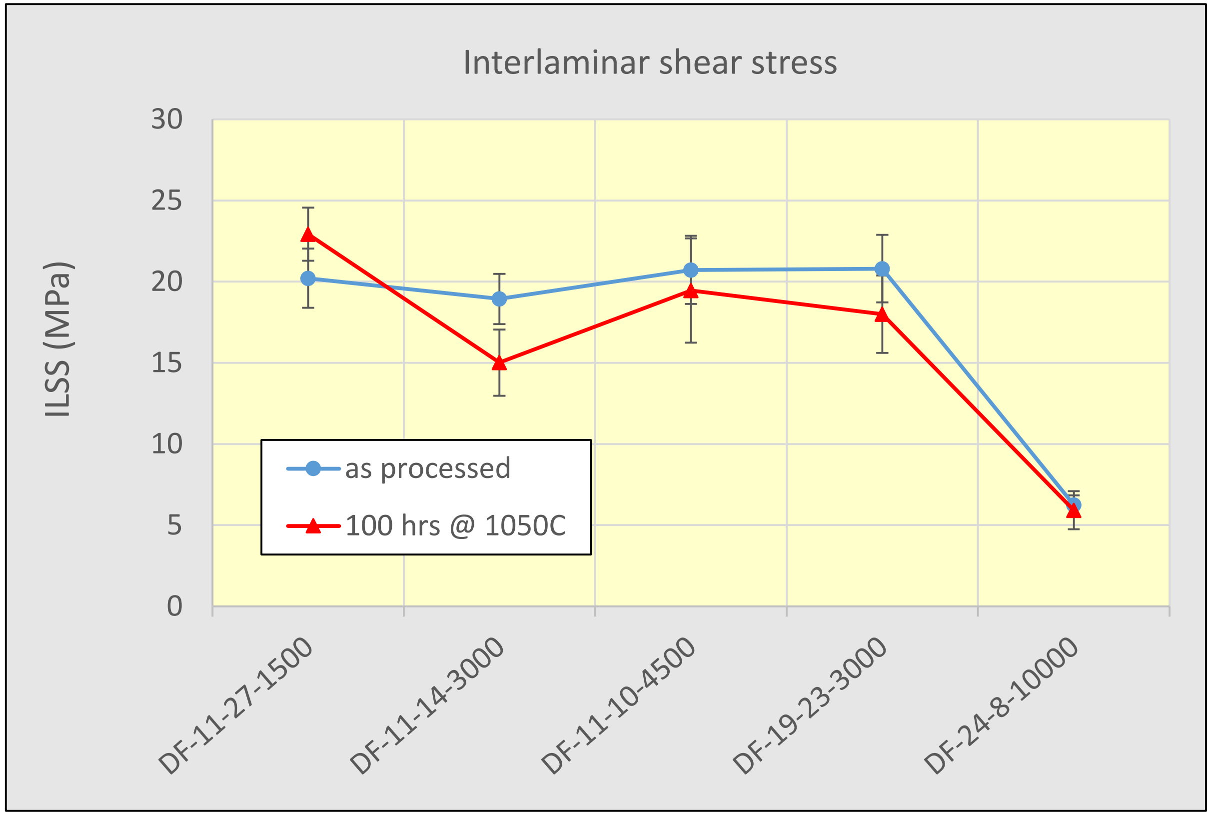




Interlaminar shear strength (ILSS) follows the same trend as flexure strength and modulus. There is good correlation between short beam shear (SBS) and double-notch compression (DNC) measurements.

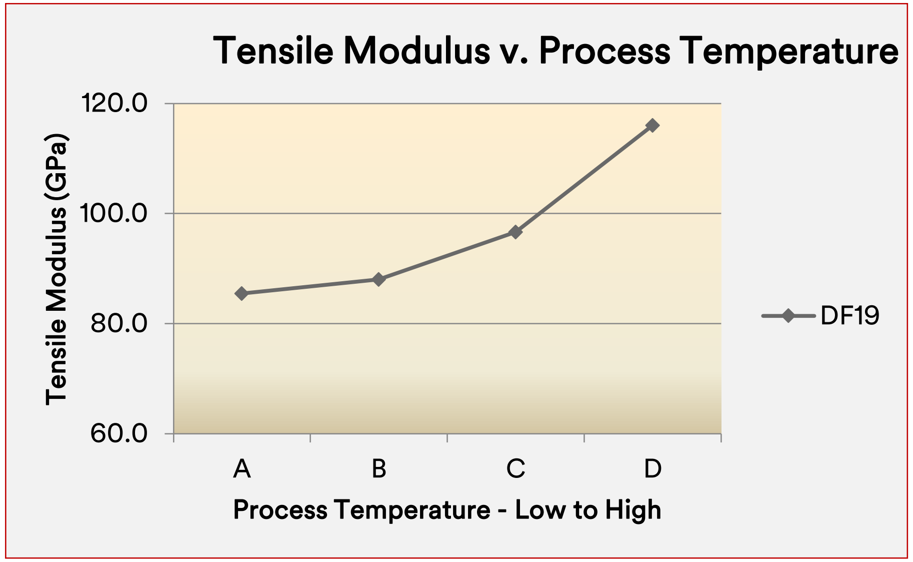
Interlaminar strength after thermal aging – DNC

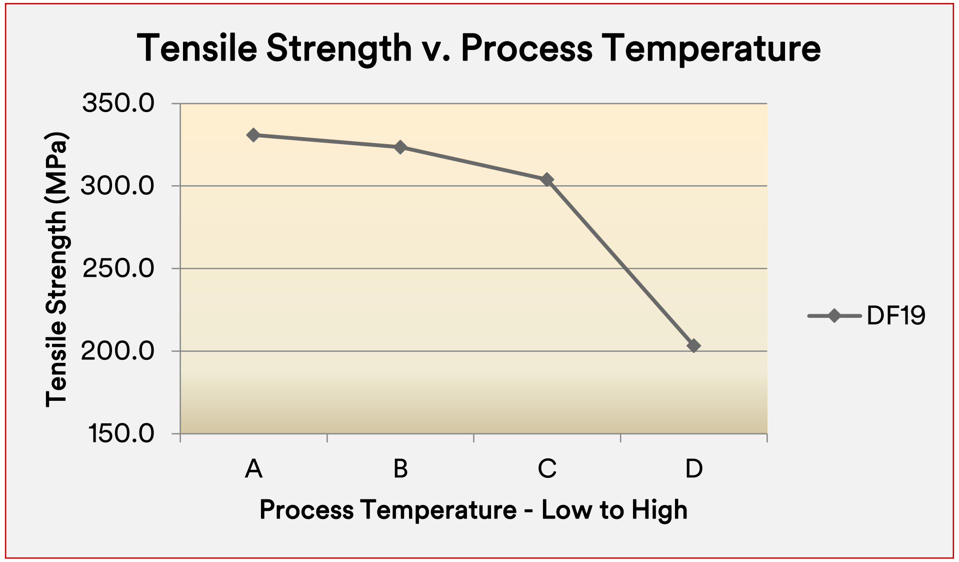


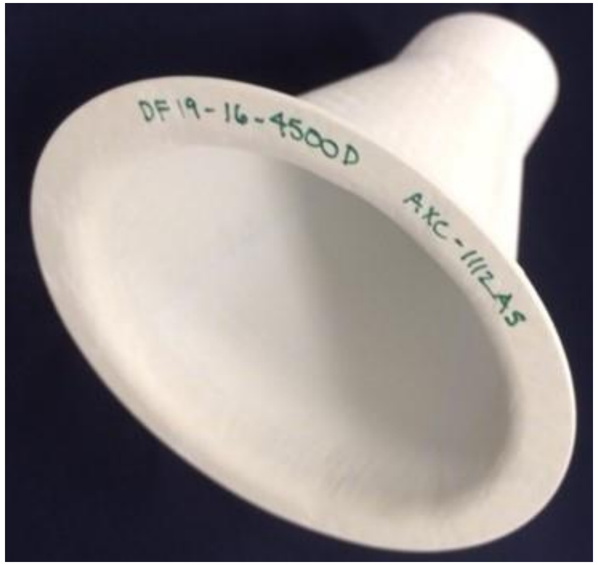


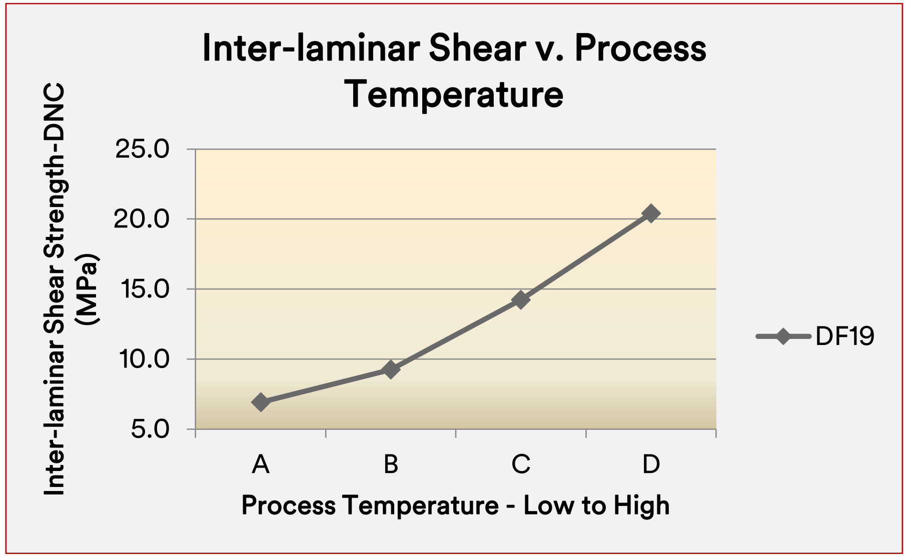
The long term service temperature of Nextel 610 is limited to 900-1000°C. For shorter durations, higher temperatures can be tolerated. Since the different weaves all use Nextel 610 fiber and AXC-610 Alumina Silicate Matrix, they all show similar thermal aging.

Tensile vs shear properties – Firing study



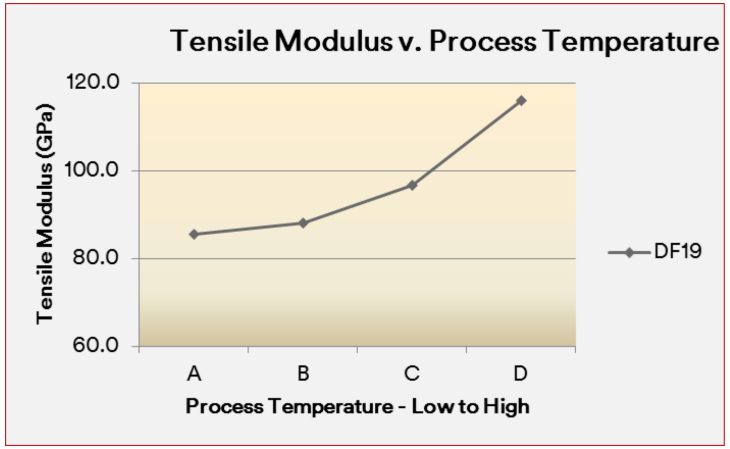




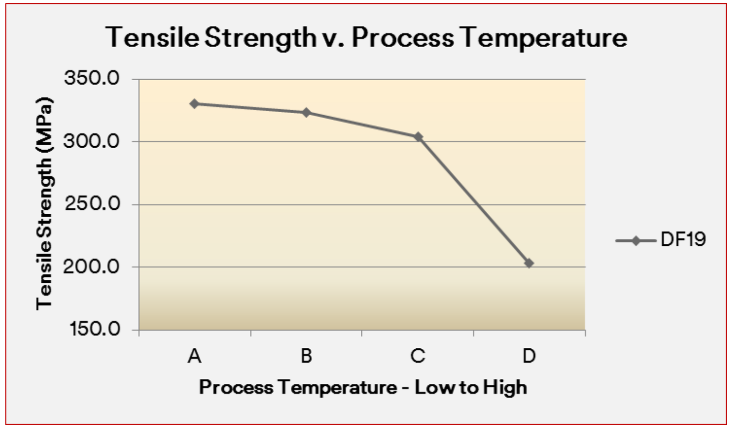


Many factors effect the quality of the final part.
One key factor is the process (sintering) temperature.
Higher sintering temperatures typically favor Shear and Modulus properties at the expense of the Tensile and Flexure properties.

DF-19-23-3000

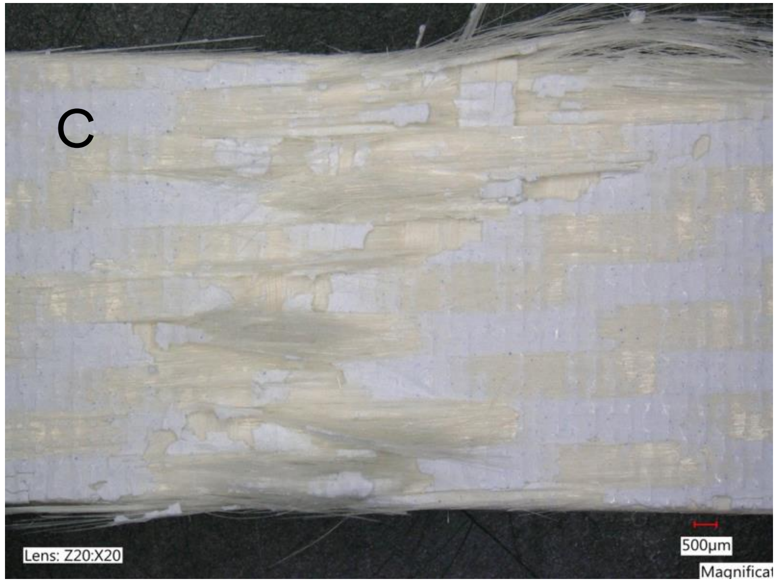


Tensile Modulus v. Process Temperature
Tensile Modulus (GPa)
120.0
100.0
80.0
60.0
A
B
C
D
Process Temperature - Low to High
DF19



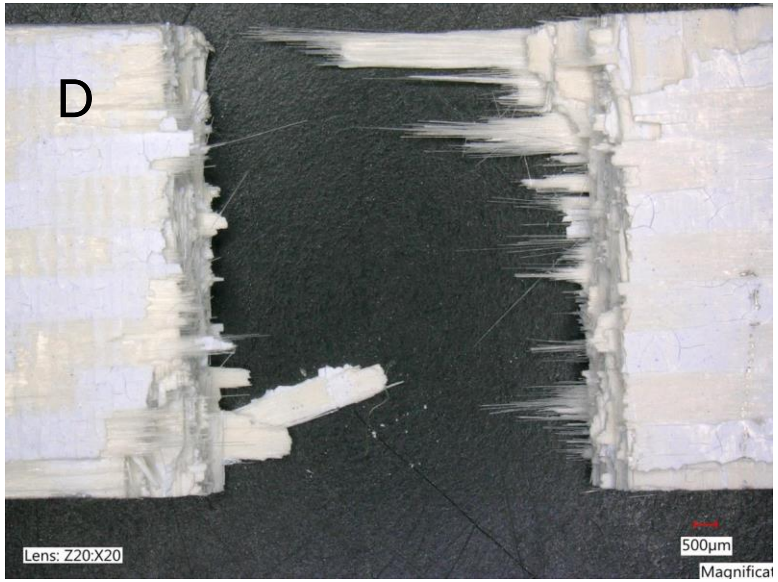
Tensile Strength v. Process Temperature
Tensile Strength (MPa)
350.0
300.0
250.0
200.0
150.0
A
B
C
D
Process Temperature - Low to High
DF19

A
Lens: Z20:X20
500μm



C
Lens: Z20:X20
500μm

B
Lens: Z20:X20
500μm



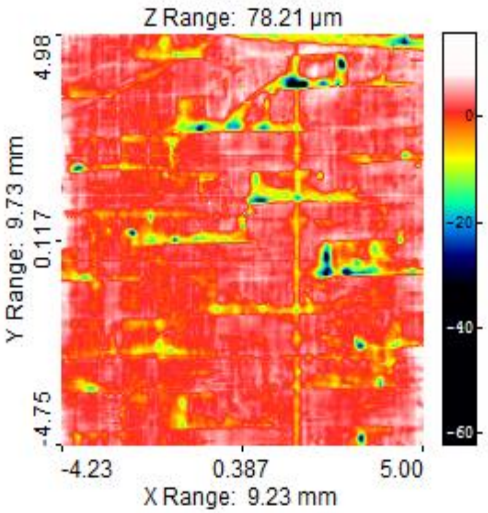
D
Lens: Z20:X20
500μm

Surface roughness – Tool vs bag side

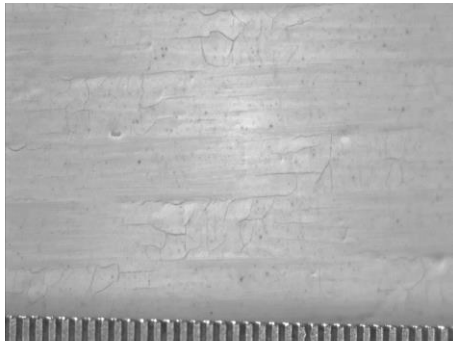
DF-11-27-1500

Tool

Profilometry

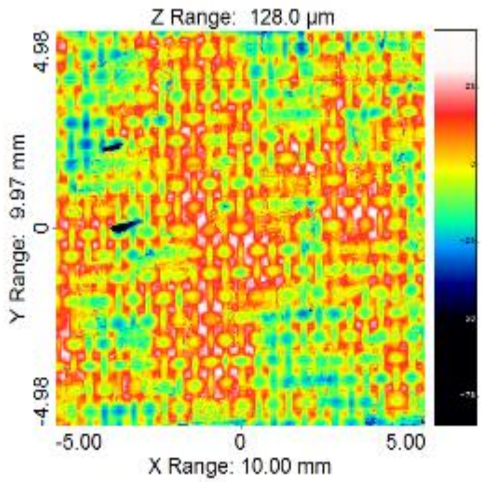


Optical microscopy

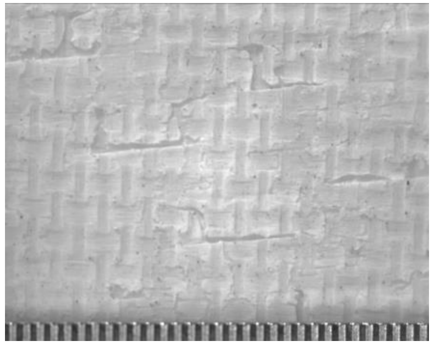


Bag

Profilometry



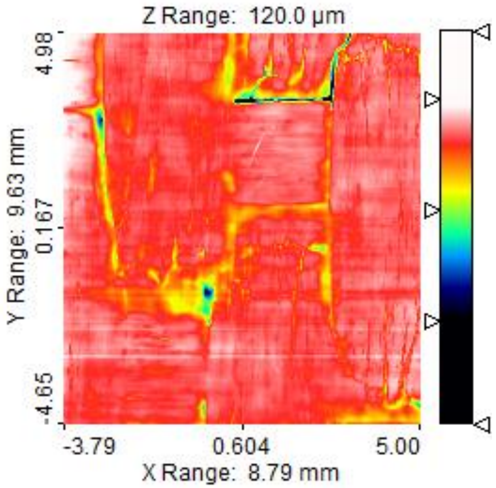
Optical microscopy



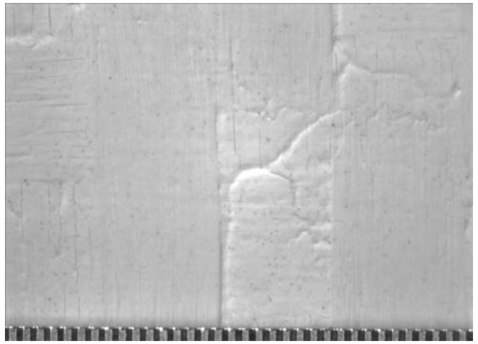
DF-11-10-4500

Tool

Profilometry

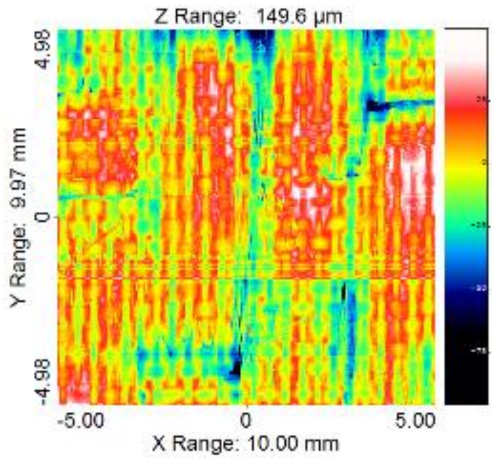


Optical microscopy

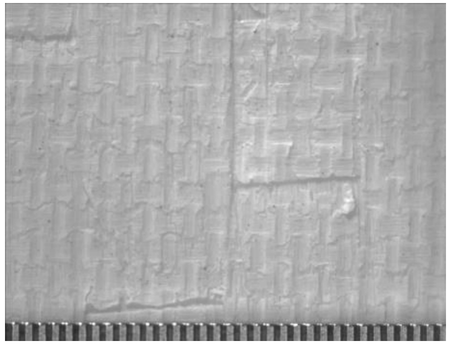


Bag

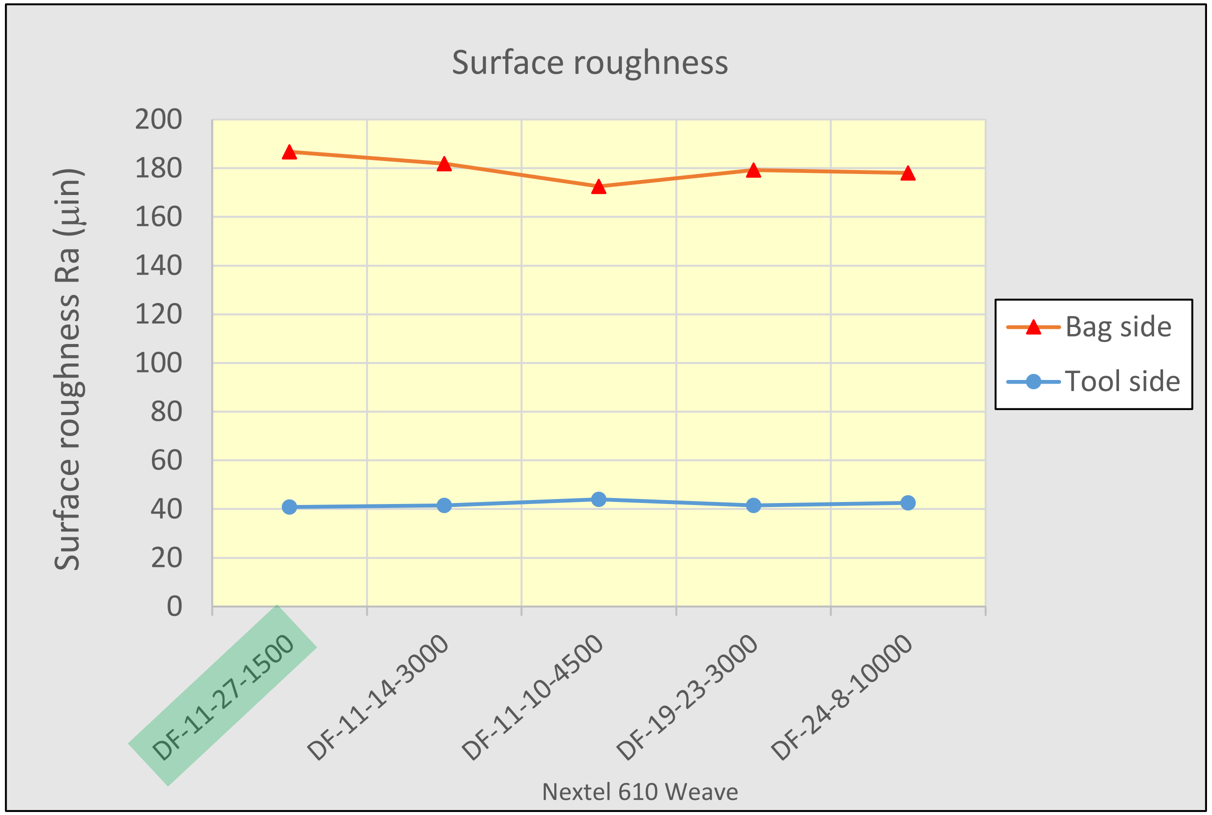
Profilometry

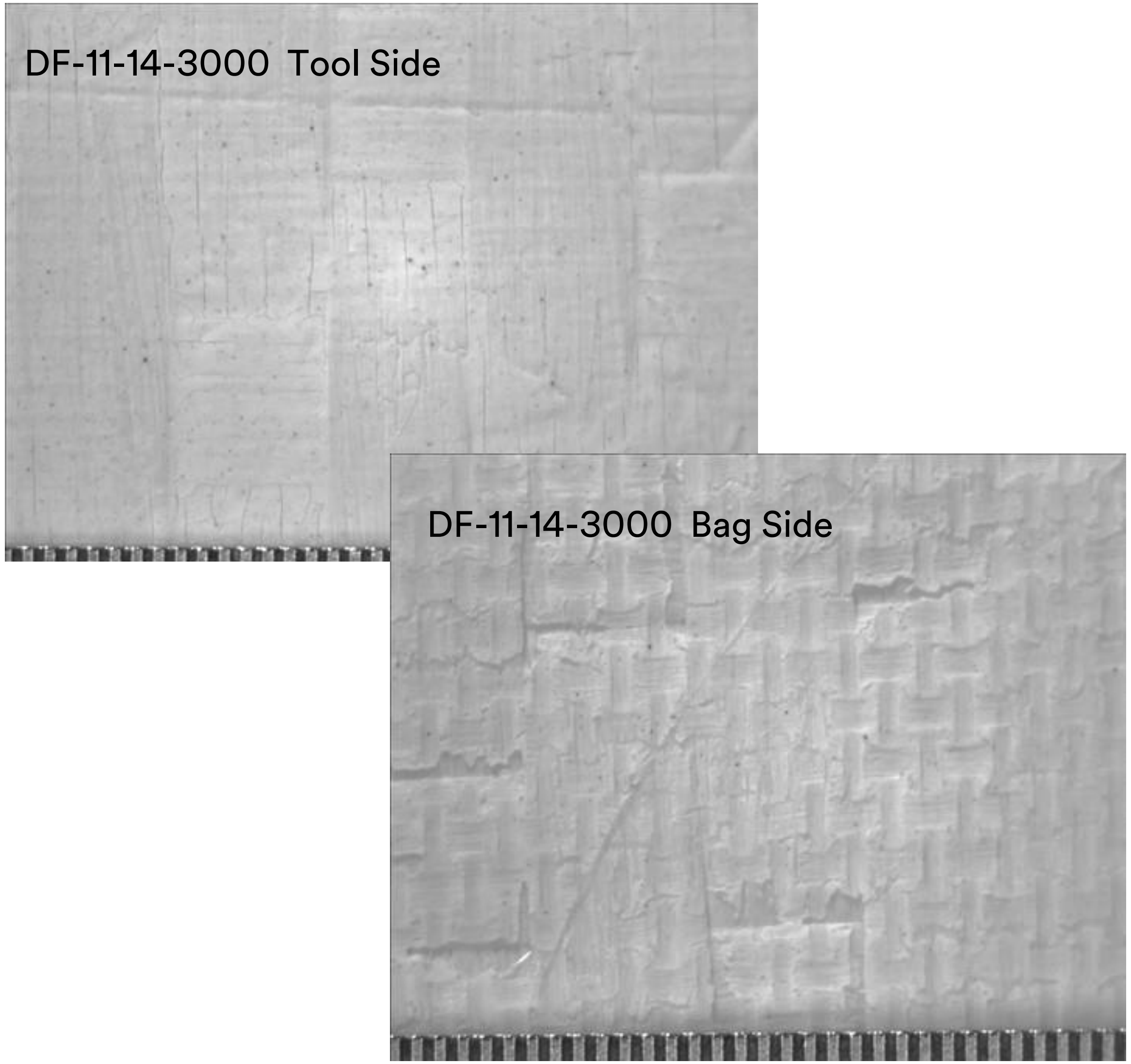


Optical microscopy



Surface Roughness – Line scans

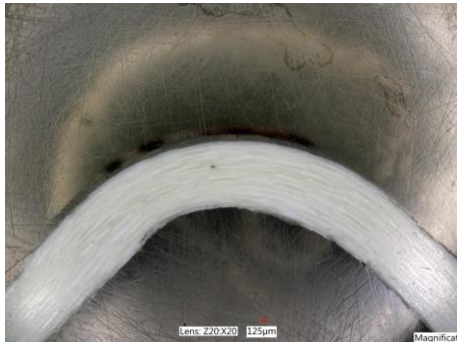


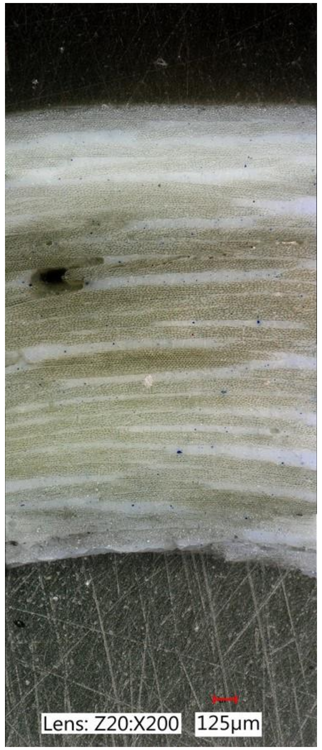


The surface texture of the composite laminate is affected by the tool surface texture or any release plies contacting the prepreg during the consolidation process.

Part layup

DF-11-27-1500





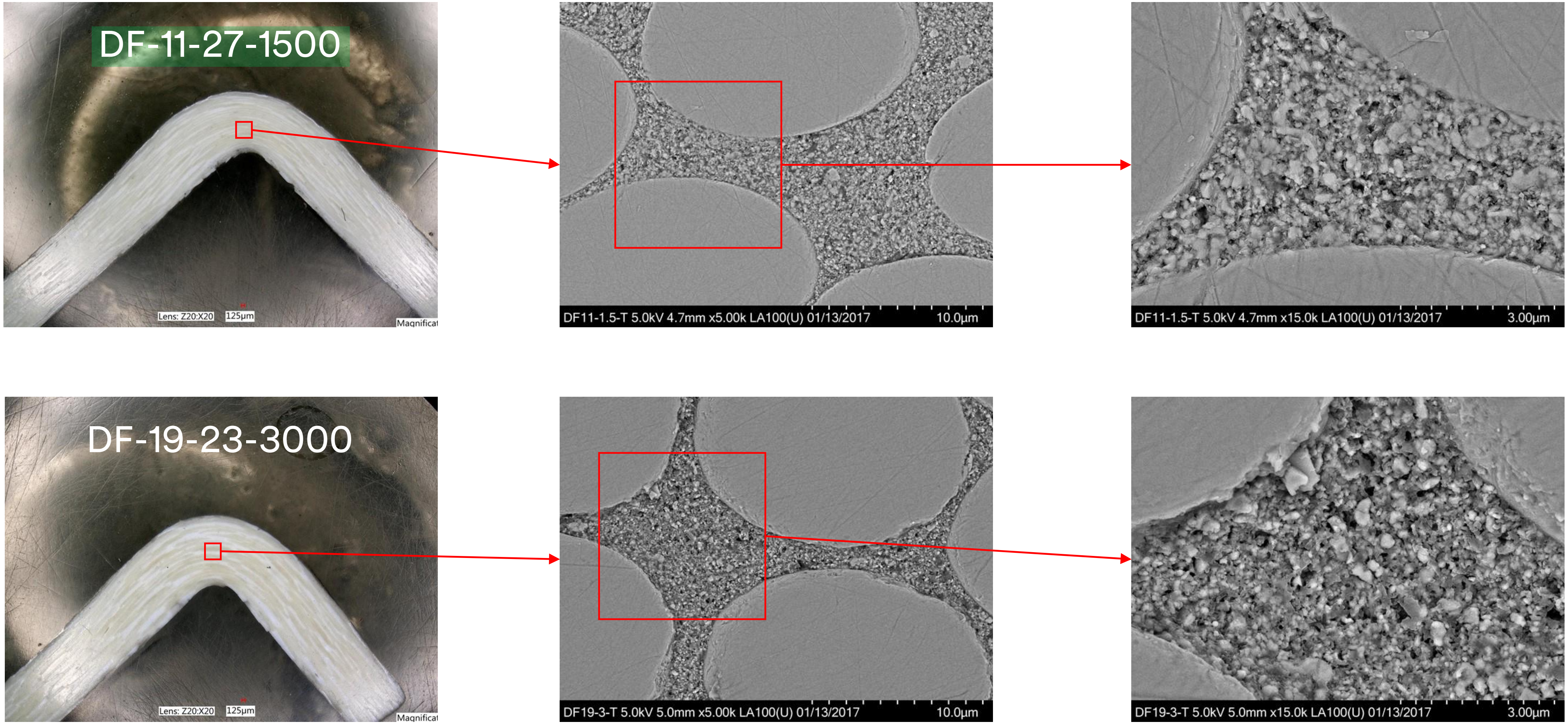
DF-11-14-3000

DF-11-10-4500

DF-19-23-3000

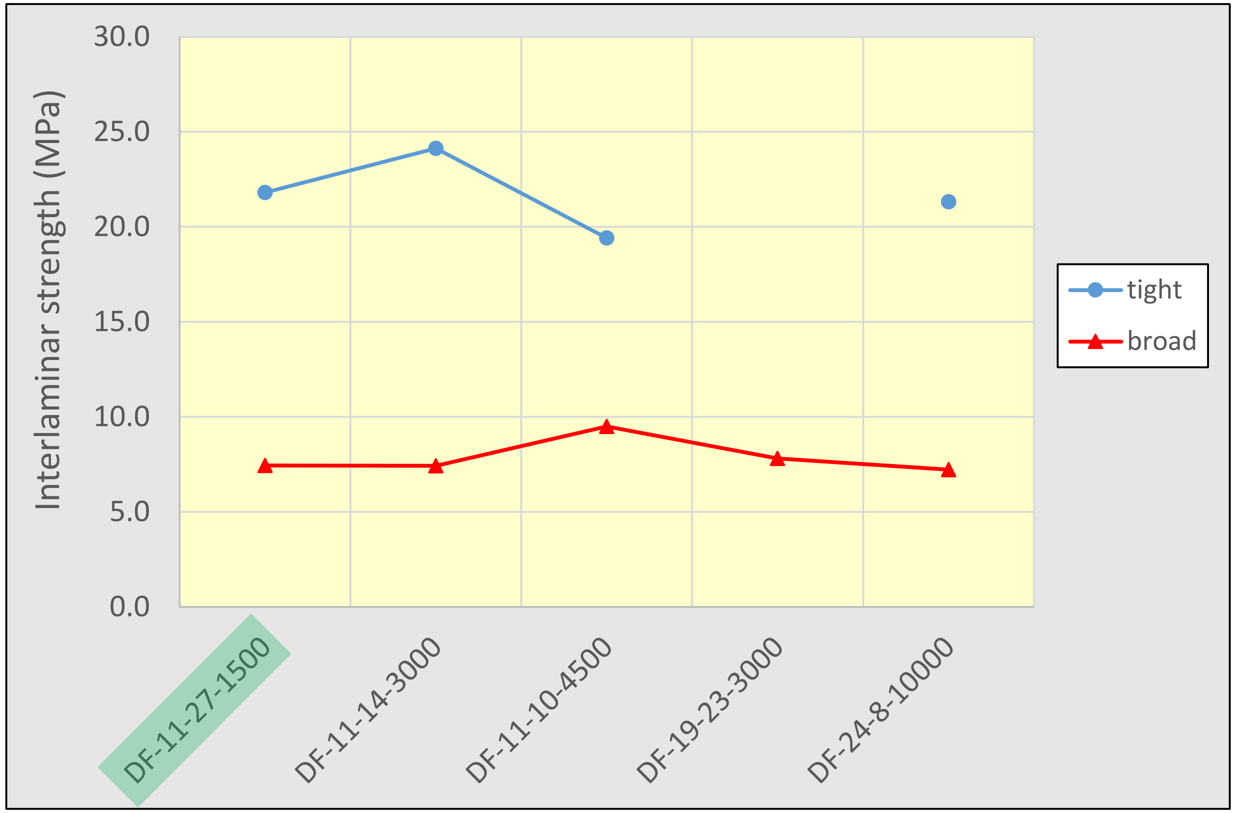
DF-24-8-10000

Infiltration

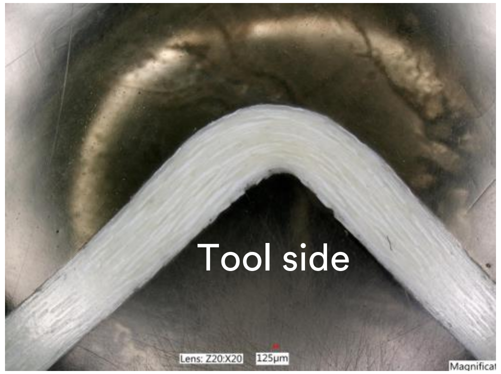


Part design – Bending radius

- Modified ASTM D6415
  - 4-pt bending fixture with MoS_2 lubricated dowels
  - Specimen inner radius varied



Tight (R~0.8-1.0 mm)



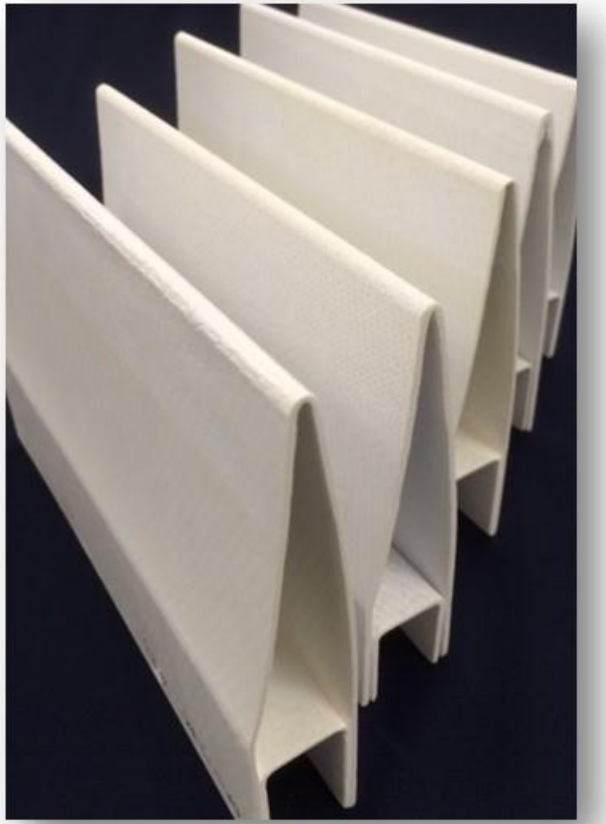
Broad (R~6.8-7.2 mm)

Cost analysis

Estimated cost reduction for the following weaves

Fabric Style	# of Plies	Cost reduction (%) Fabric only*
DF11-27-1500	12	0
DF11-14-3000	12	19
DF11-10-4500	12	34
DF19-23-3000	8	24
DF24-8-10000	6	47

*Based on 2016 pricing



Summary / Conclusions

Laminate processing was equivalent for all laminates.

Variation in mechanical properties was less than 10% for all weave types except DF-24-8-10000. The variation was generally with in the normal scatter.

High temperature limits for long durations was confirmed.

Various mechanical properties can be enhanced through process modifications.

Surface roughness is controlled by the tool surface or release fabrics, localized measurements. Higher denier weaves can contribute to surface roughness when measured over larger areas.

Parts can be fabricated with broad or tight radii without damaging the fiber for all weave types.

AXC-610 Matrix is compatible with all fabric forms.

Significant cost reductions can be achieved with minimal variation in physical and mechanical properties. More work will be required to achieve both cost reduction and mechanical performance with fabrics made using 10000 denier yarns.

This presentation will be available soon at www.3m.com/ceramics

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