Short Fiber TuFF Technology for Automotive Part Production

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Tailorable Universal Feedstock and Forming (TuFF)
Short Fiber Alignment Process

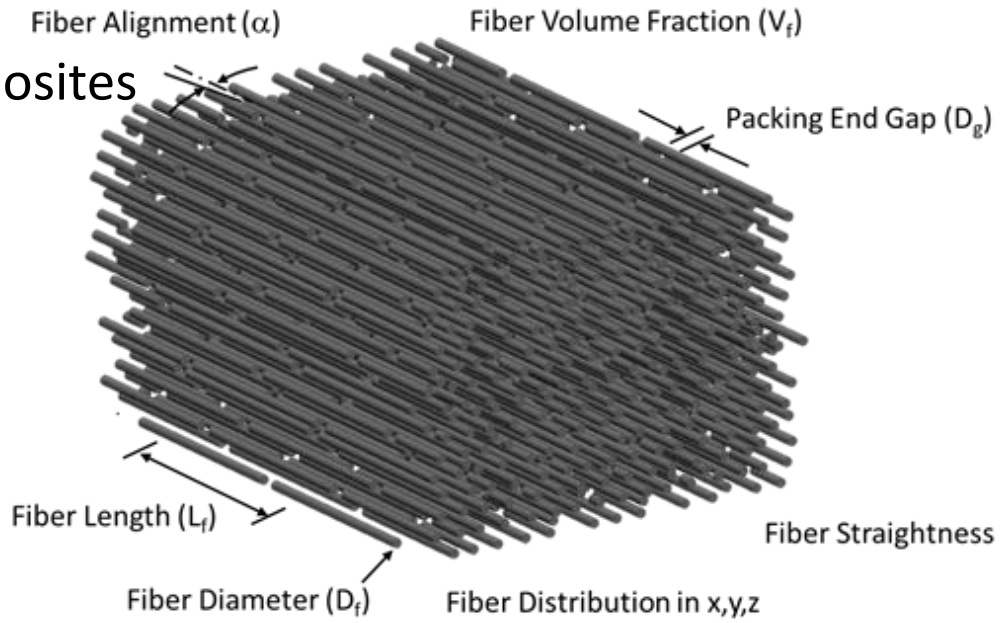
- Patented short fiber alignment process developed at the Univ. of DE – Ctr. for Composite Materials(UD-CCM)
  - Wet-laid process with proprietary headbox
- Material agnostic
  - Incoming Fiber Type
    - Carbon, glass, ceramic, polymer
    - Hybrids
  - Polymer Type (snap-cure TS, TP)
- Aspect ratio of >600 for full strength translation
  - 3mm-5mm for carbon fibers
  - Longer for ceramic and glass fibers
- Ply Areal Weight of aligned sheets ~10gsm, automated stacking to create thin ply (60gsm) to standard ply thicknesses
  - Allows minimum gage designs reducing material usage in automotive applications
- Fiber Volume Fraction up to 60%, automotive target is 50%

Production roll of dry, carbon fiber TuFF material

Other Key Aspects of TuFF

TuFF is a <u>feedstock</u> with **near** ideal aligned short fiber microstructure in tape, sheet and blank formats:

- ~100% property translation equivalent to continuous fiber composites >370ksi (2.55GPa) strength and >23msi (159GPa) stiffness
- Fiber hybridization (including glass/carbon combination) with filament level alignment control: > 95% (± 5°)
- <u>In-plane stretching capability of up to 40% allowing metal-like forming at high throughputs</u>
- Enables recycling of composites with size reduced short fibers with highest property translation to-date demonstrated



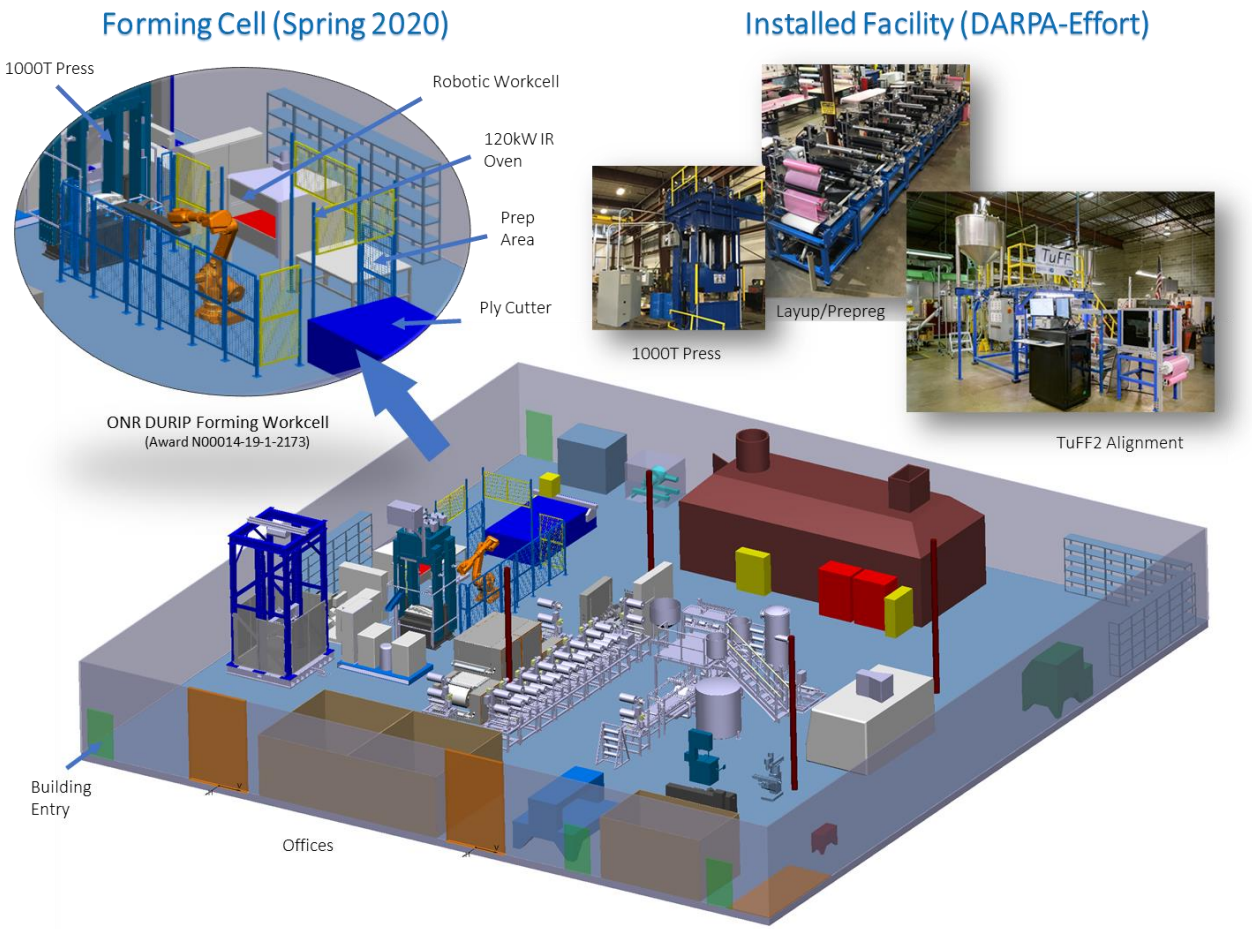
- Predicted material conversion cost at scale from short fiber to *TuFF* prepreg/blank: ~$2/lb - $5/lb

➔ Key to lowering automotive part cost is reduction in 1) material cost thru lower fiber cost and smaller process waste, 2) lower conversion cost from intermediate material form to final parts

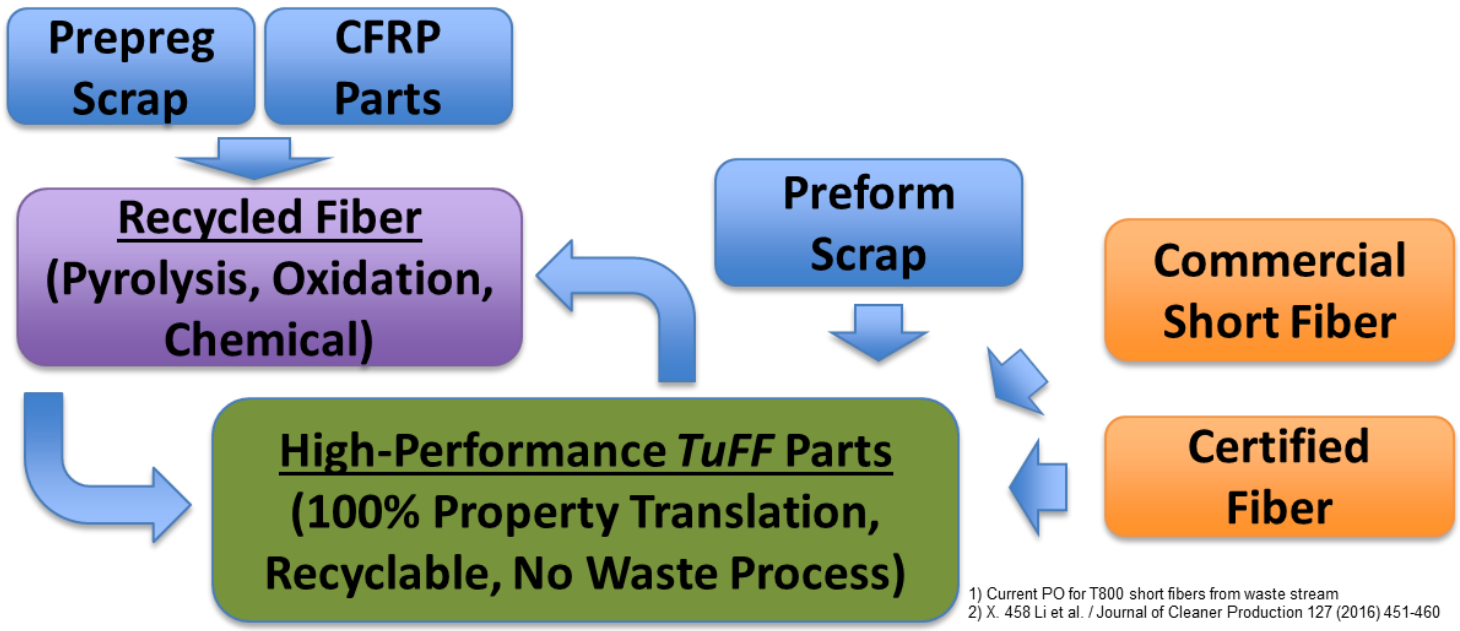
TuFF Pilot Facility at UD-CCM: Fibers to Parts
1k-10k lbs/year capacity pilot production facility

DARPA Program Infrastructure @ UD-CCM

- 2 Alignment lines at 24” wide (net 18” material)
  - 90 degree, and Off-axis
  - Productivity based on quality metric
- Automated aligned preform stacking system (VR2)
  - Dry aligned preform stacking (8x) at 24” wide
- Consolidation system
  - 40” wide indexing twin press system for prepreg and blanks
  - TS or TP (up to PEEK) capable
- Thermoforming and HP-RTM system
  - Robotic pick and place with IR oven
  - 1000 T press, Rapid closing with Platen Alignment
  - HP-RTM system
  - Tape Placement System



TuFF Enables Use of Short Fibers from a variety of low-cost sources



1) Current PO for T800 short fibers from waste stream
2) X. 458 Li et al. / Journal of Cleaner Production 127 (2016) 451-460

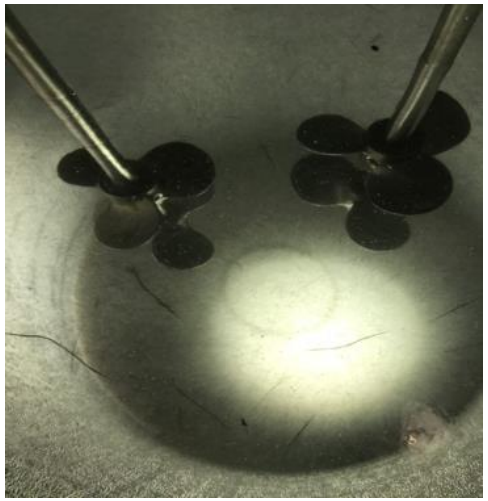
- Commercial low-cost short virgin fibers
- Waste/Recycled fibers reduce environmental burden & cost
  - Waste fiber price[1] ~$5/lb for intermediate modulus CF
  - Recycled fiber cost[2] estimated at ~$1.5/lb

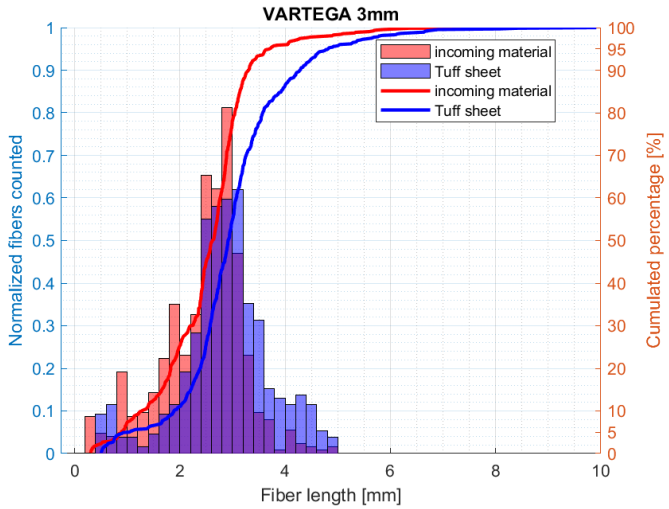
➔ ***TuFF* process is key to convert *LOW-COST* fibers into high-performance parts**

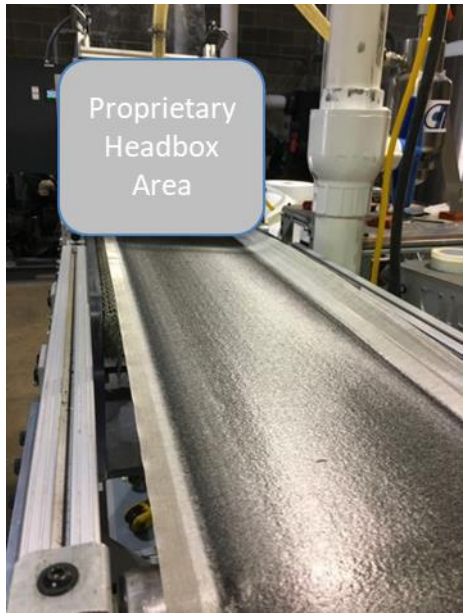
Fabrication of *TuFF* Preforms with non-aerospace Fiber Types (low-cost, waste, recycled)

- *Fabricated uni-directional thin-ply CF sheet material for further processing from Zoltek PX35 (~9/lb), waste ($5/lb) and Vartega (TBD) fibers*
- *Evaluated length control, dispersion and strength of recycled fibers*
  - *Optimized sorting process of fiber material at Vartega*
  - *Full strength retention of recycled fibers*

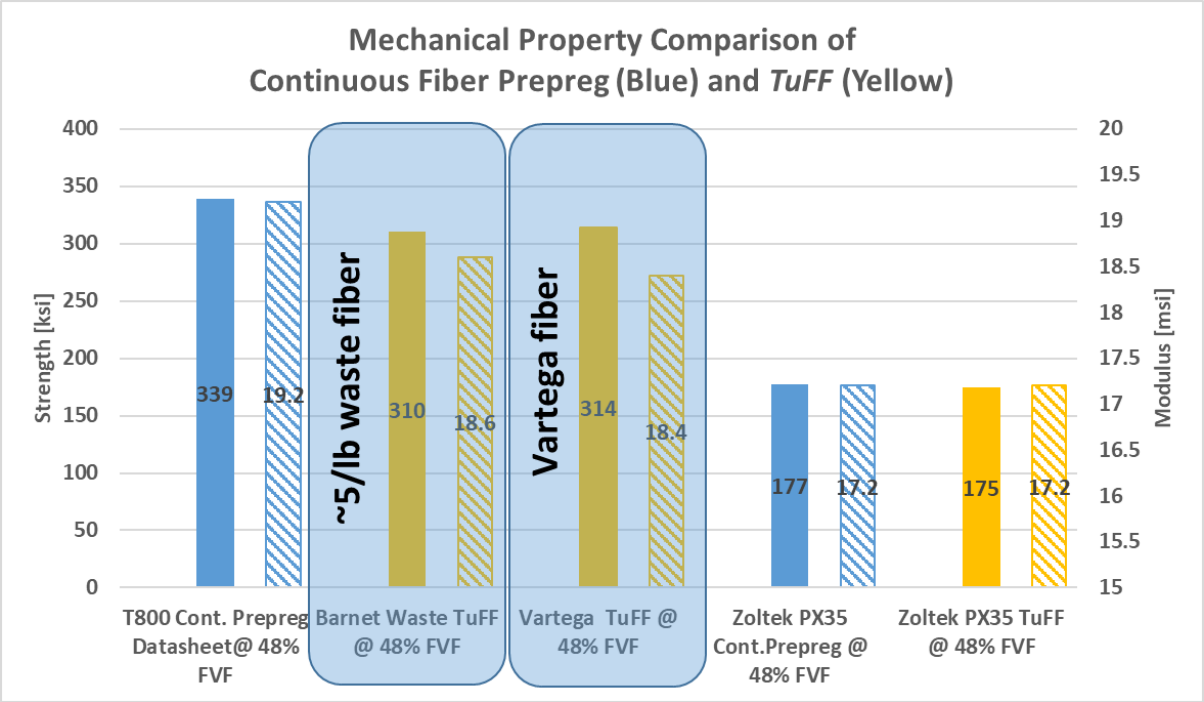
Properties of T800 Virgin and Recycled Fibers		
	Virgin	RECYCLED
Tensile Strength (Gpa)	5.48 ± 1.4 (14 tests)	5.35 ± 1.3 (27 tests)
Filament Diameter (µm)	5.0±0.09	5.2±0.04







Mechanical Performance
Continuous Fibers vs. *TuFF* @ 48% FVF

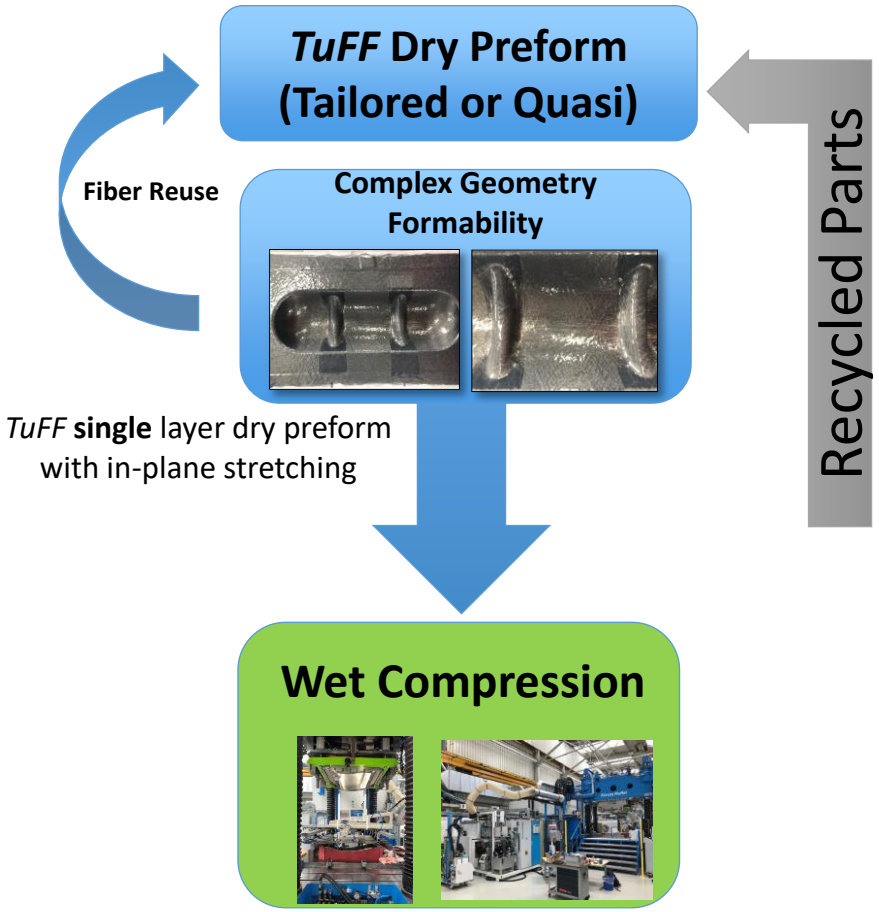


- ~300ksi strength and 19msi modulus with $5/lb chopped waste fiber @ 48% FVF
  - ➔ *Exceeding highest composite properties reported from recycled/waste fibers by a factor of 4x in strength and 2.5x in modulus*

    1) Longana et al., *Composite Structures 153 (2016) 271–277.*
    2) *Khurshid et al., Journal of Composite Materials 2020, Vol. 54(14) 1925–1944.*
- Similar performance with Vartega fiber @ 48% FVF
- 100% property translation with chopped Zoltek PX35 vs. Zoltek continuous prepreg

- *TuFF* enables full fiber property translation (cont. T800 & cont. Zoltek vs. short fiber *TuFF* in tension)
- *TUFF* with waste fibers increases properties compared to low-cost automotive grade prepreg (Zoltek PX35 uni-directional prepreg)

Wet Compression of Complex Geometries with TuFF "Blanks"



<u>Wet Compression:</u> In-situ resin impregnation and forming with flat preform into complex mold surface

- Reuse of fiber waste in *TuFF* process prior to resin dispensing
- Resin dispensing onto flat preform
- Tailored or isotropic preforms allow design flexibility
- Eliminates splicing of multiple preform pieces provides superior dimensional control

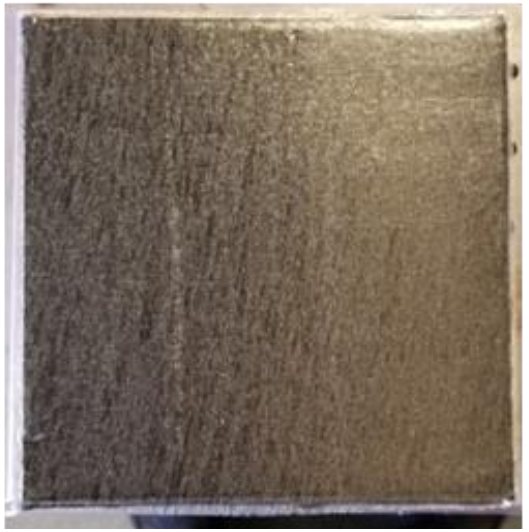
➔ Single processing step from flat to complex geometry preform reduces cost

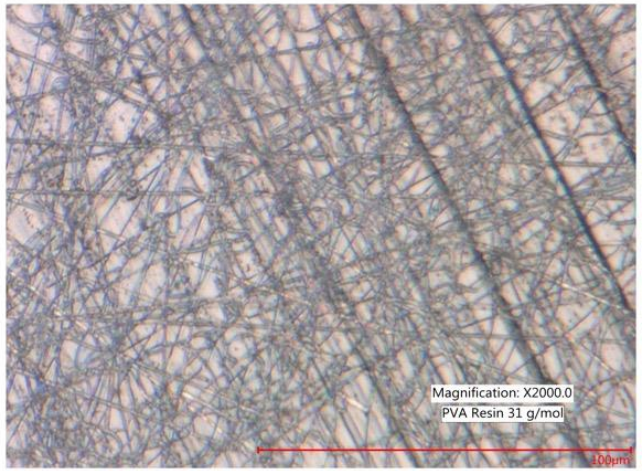
➔ Wet compression meets automotive rate and other performance targets

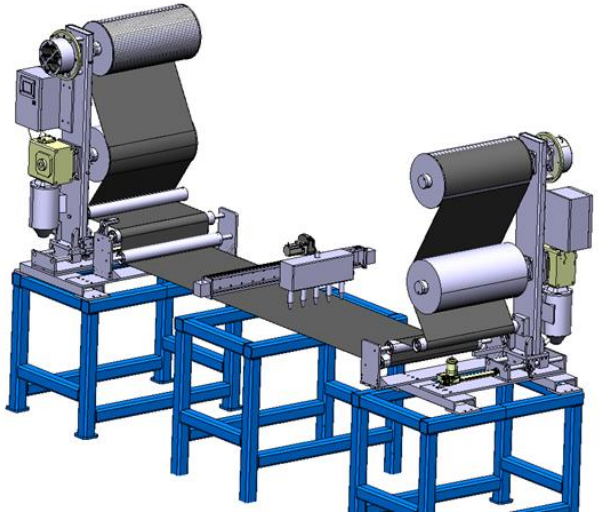
Stabilization of Dry Preform Blanks

- *Electrospun veil approach to stabilize TUFF sheets*
- Veil material exhibits good stabilization without affecting permeability and formability
  - Can be integrated in preform process to create continuous rolls of stabilized fabric
  - Veil has to be optimized for mechanical properties and to retain formability
  - Created low areal weight <1gsm electrospun material successfully using aqueous solution

TuFF with Veil







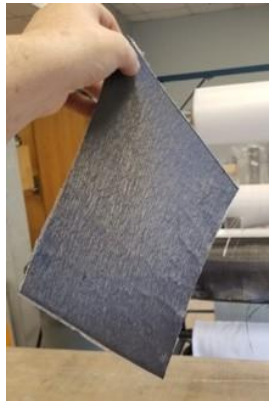
Complex Geometry *TuFF* Forming and Part Manufacturing

Composites Automation LLC

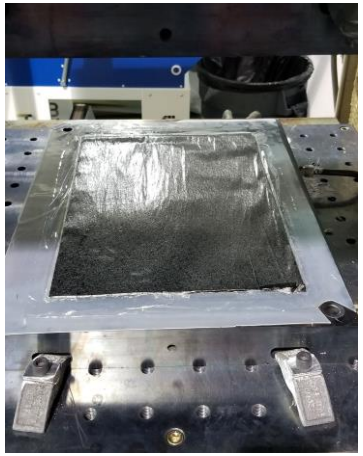
Demonstrated complex part geometry forming using wet compression molding

- Small part (10 in x 14 in) with complex geometry was impregnated and formed within 30 seconds with 100 psi diaphragm molding and infusion pressure
- In-plane strains up to 40% have been demonstrated
- Resin required extended curing time

1. Stabilized preform produced



2. Resin film applied on flat fiber blank in press

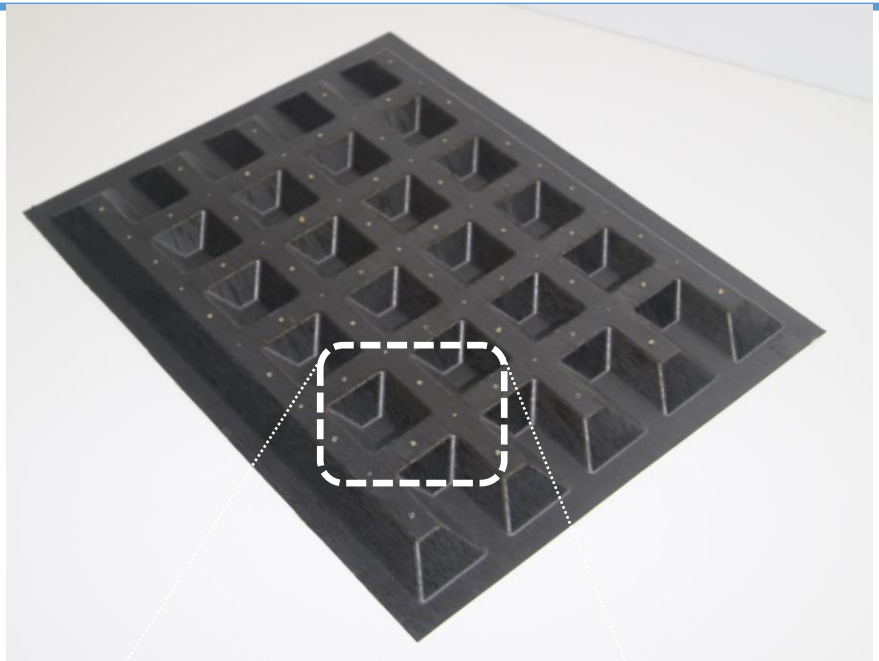


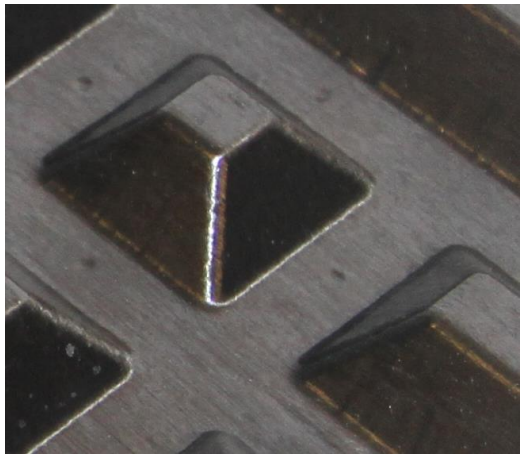
3. Final molding step forms geometry and cures part in hot press

HEXION™
Responsible Chemistry

Current effort started to work with snap-cure resins from Hexion

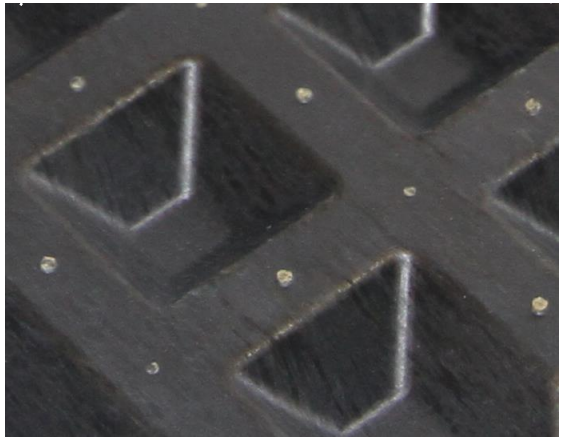
Close-Up of Demonstration Part





<u>Complex geometry with repeatable feature forming</u>

- 10” by 14” part with minimum flash/waste
- 1/8” corner radii
- 50% Fiber Volume Fraction
- 30% stretch



Diaphragm/Stamp Forming of Complex Geometries with TuFF Impregnated Blanks

***TuFF* Prepreg Blanks (Tailored or Quasi)**

Stamp/Diaphragm Forming

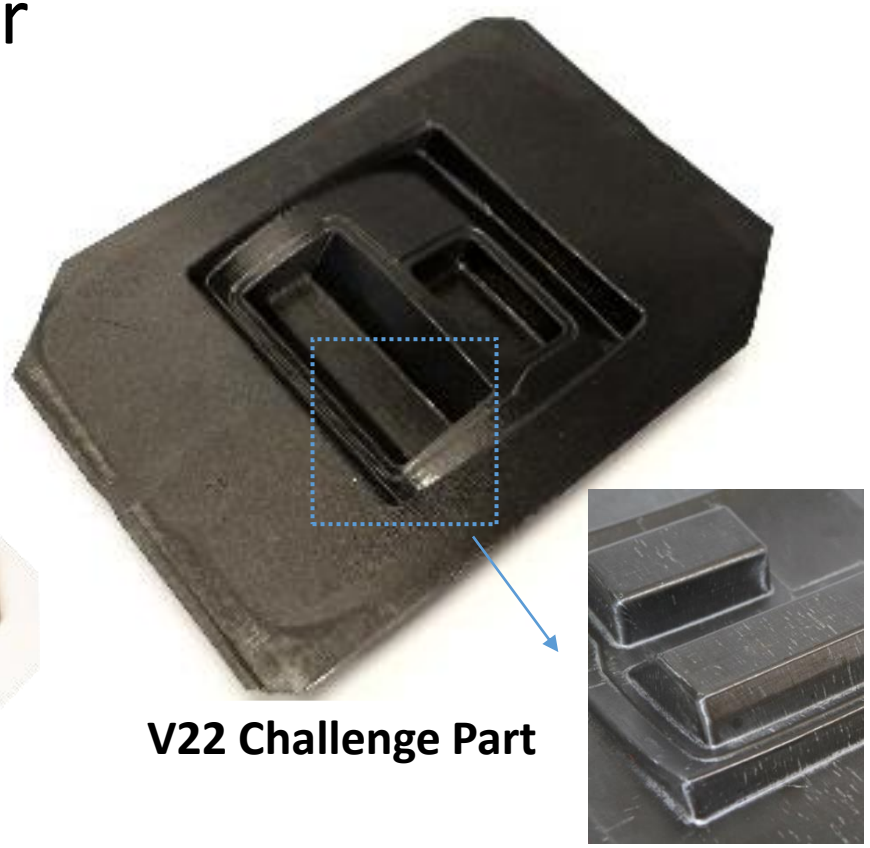
- Diaphragm or stamp forming: Pre-made impregnated blanks are formed under pressure and cured (TS) or consolidated (TP)
  - Thermoset, snap-cure resin or thermoplastic resin blanks
  - Tailored or isotropic blanks allow design flexibility
- Dual processing step from intermediate material form to complex geometry parts
  - Flat impregnated blank fabrication
  - In-situ forming and consolidation
- Eliminates splicing/darting with flat blank form greatly reducing material/form cost

➔ Diaphragm or stamp forming also meets automotive rate and other performance targets

Forming Cell Walkthrough

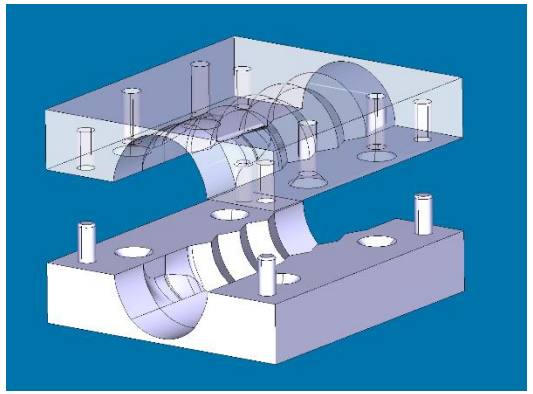
TuFF Enables Forming of Complex Features

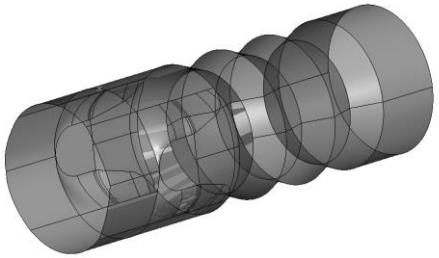
- *TuFF* Diaphragm Formability demonstrated for
  - 40-57% Fiber Volume Fraction
  - 3 and 5mm TP or TS composite blanks
  - [0], [90], [0/90], $[0/90/45/-45]_s$ layups
  - Bi-axial in-plane stretch of >40%

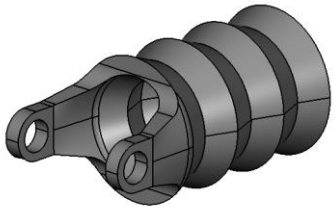


V22 Challenge Part

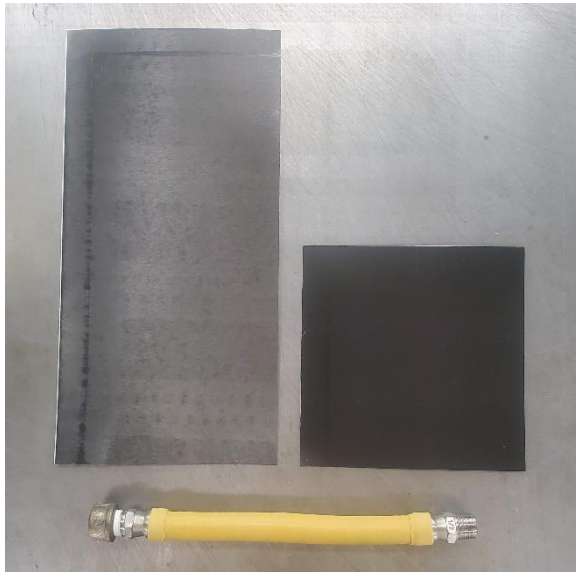
Radial Forming Process



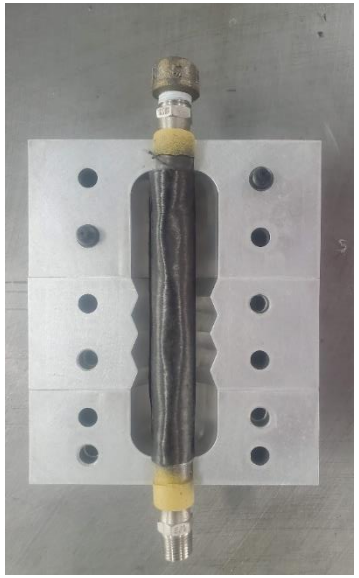




Multi-orientation prepreg
Wrapped onto mandrel



In Mold



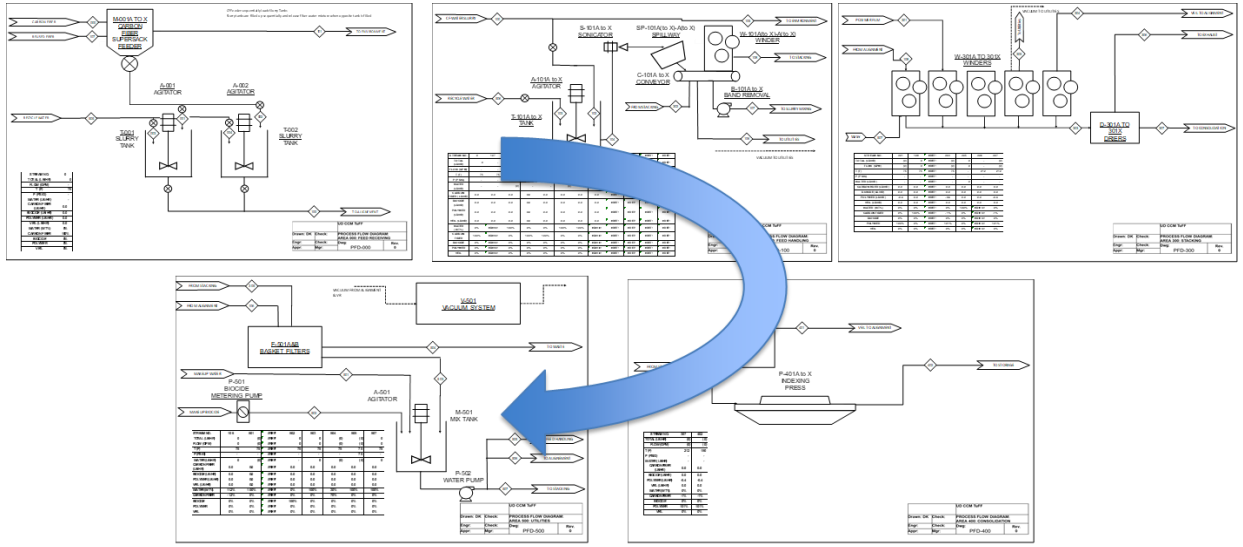
After
Pressure
and Cure
Cycle

Cure Cycle

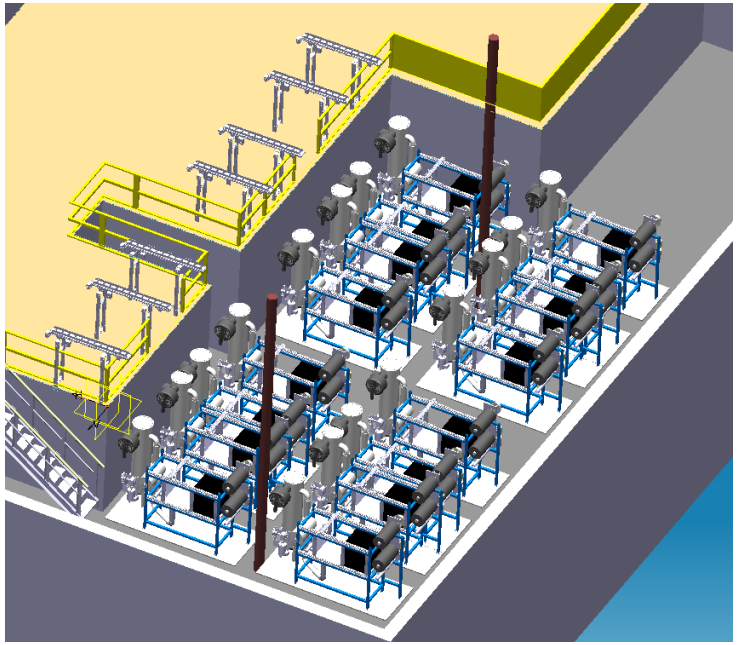
- Ramp to 250°F
- Slowly apply 80 psi at 135°F
- Hold 1 hour
- Ramp to 350°F
- Hold 2 hours

Cost Model and Scale-Up of *TuFF*

- Cost model framework provides precise process description
  - Cost model calculates Capital Investment, Operating Expenses and required material price for zero net present value
  - Variables are plant size and configuration, material cost, rate of return, etc.
  - *Cost model to include savings in part manufacturing (TBD)*
- ***Fiber to prepreg conversion cost for 2500 ton plant is ~$2-$5 per pound***



Cost Model Process Design



TuFF Production Factory Design currently being implemented at CA

Opportunities for Part Cost Reduction Enabled by *TuFF*

- Performance equivalence to continuous fiber materials
- Cost reduction
  - Lower cost fiber feedstock (virgin, waste, recycled, hybrid)
  - Eliminates dry preform scrap through reuse of recovered fibers
  - Rapid manufacturing (forming, stamping or infusion) with reduction of process steps (no draping, darting) and pressure lowers processing cost
- Cost effective metal replacement provides 40-60% weight savings, no corrosion and multi-functionality

➔ Looking for automotive partners for first-article demonstration

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