Short Fiber Preform Technology for Automotive Part Production

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Project ID: mat169

STTR Phase I Review

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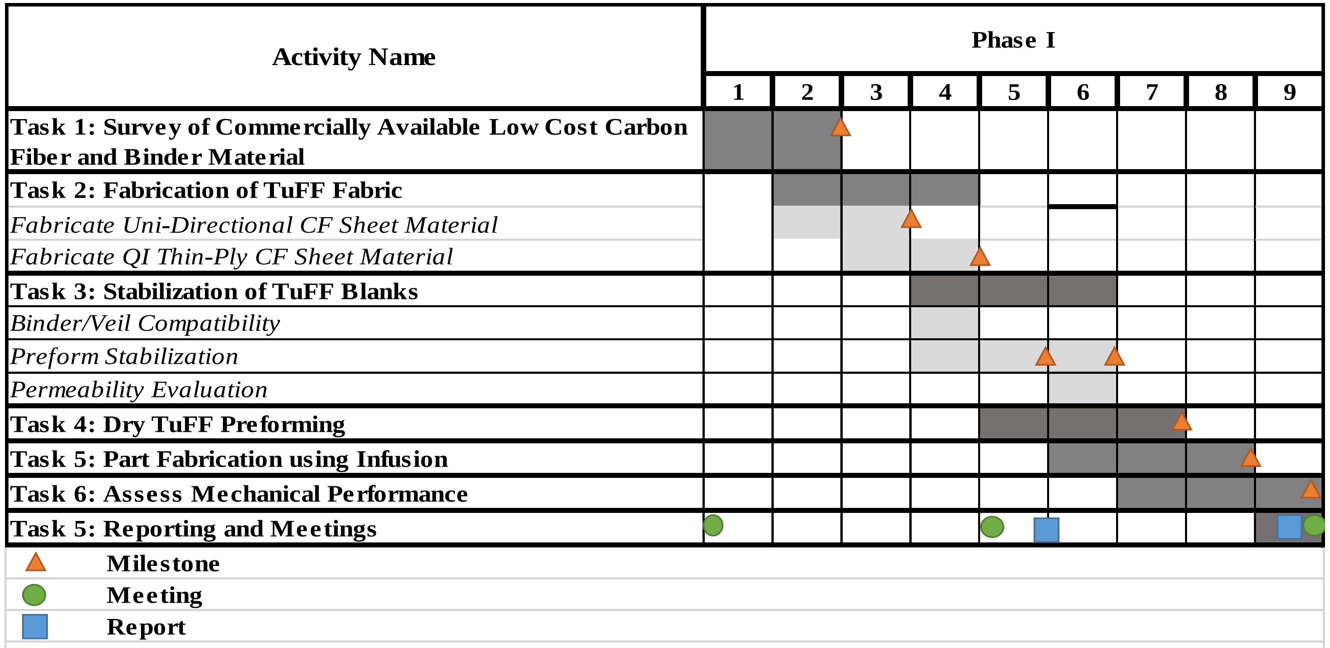
2020 DOE Vehicle Technologies Office Annual Merit Review

Overview

Barriers:

- Current continuous fiber preform technology is limited:
  - Requires cutting and draping of many fabric pieces increasing cost and reduces properties
  - 10%-30% waste generation during fabrication
- Recycled or waste fiber material cannot be utilized
- Current continuous carbon fiber composite material cost and embodied energy is high and not competitive for most automotive mass market applications

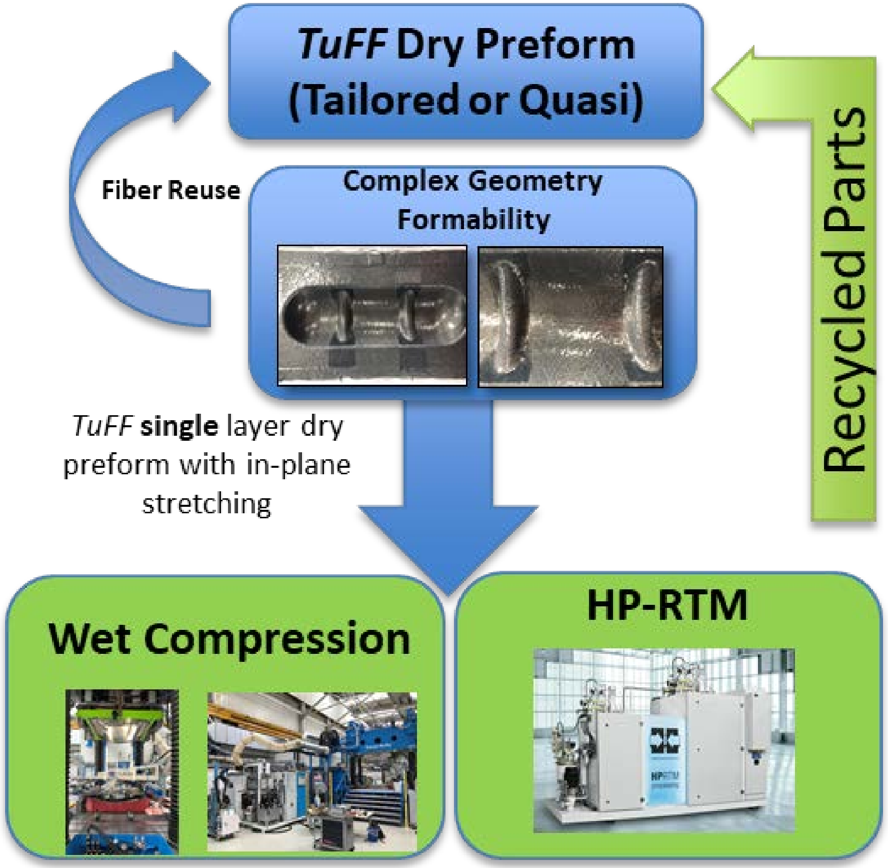
➔ TuFF approach (next slides) eliminates preforming challenges, allows use of recycled fiber and enables at-rate production and lower cost



M1 & M2: Survey of low-cost short fibers & Fabrication of TuFF material
M3 & M4: Stabilization and preforming demonstrated
M5 & M6: Mechanical performance and complex parts produced

Budget $199,979 with 9 months period of performance (07/19-03/20)
Partner in this STTR is the Univ. of Delaware – Center for Composite Materials (UD-CCM)

Relevance: TuFF Enables Zero-Scrap Dry Preforms for Infusion Lowering Part Cost/Energy

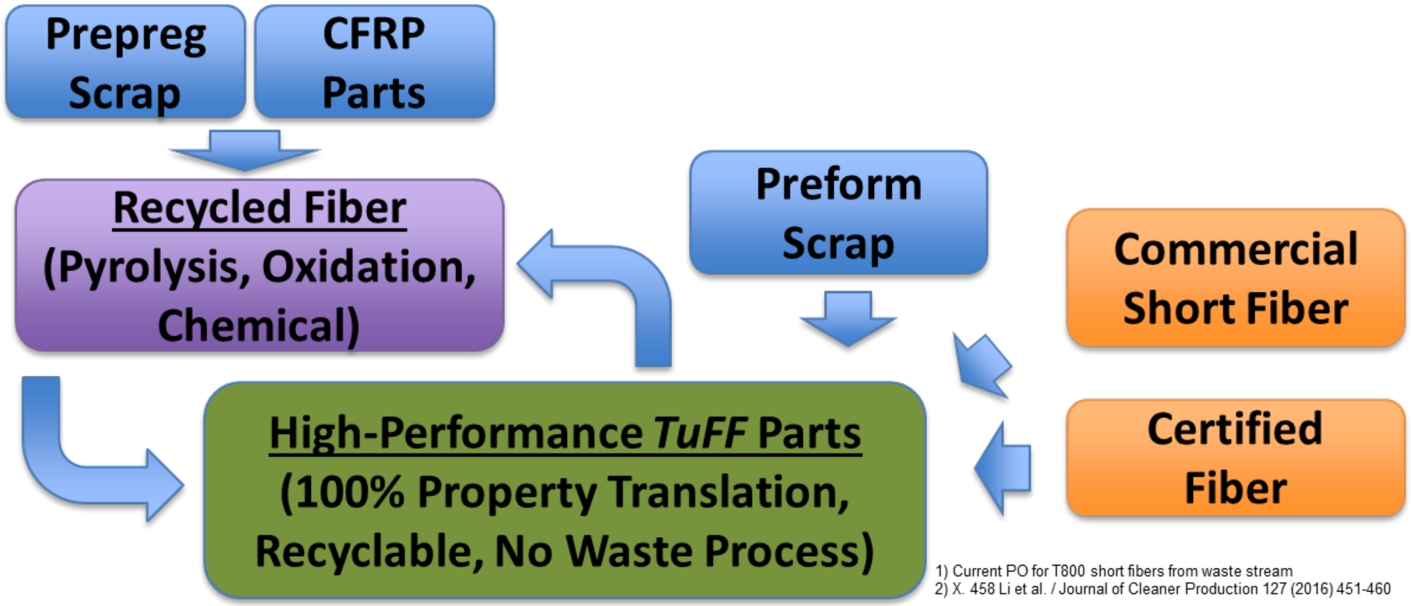


- Net-shape preforming and reuse of fiber waste in *TuFF* process
- Tailored or isotropic preforms allow design flexibility
- Single processing step from flat to complex geometry preform
  - Enables stabilized preforms for HP-RTM
  - In-situ forming and resin impregnation with wet compression molding
- High fiber volume fraction preforms with minimum spring-back
- Eliminating splicing of multiple preform pieces provides superior dimensional control
  - Reduces infusion issues
  - Improves performance
  - Reduces cost

<u>Paradigm Shift in Composite Processing</u>

TuFF Reduces Part Cost, Improves Rate & Yield And Allows True Recycling (not Down-Cycling) Of Composites for the First Time

Relevance: TuFF Enables Closed-Loop Recycling of Carbon Fiber Composites



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

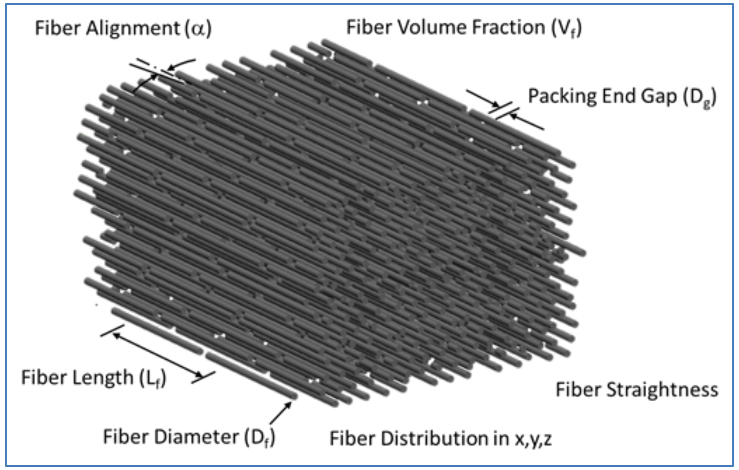
Addresses the targets found in the 2017 U.S. DRIVE MTT Roadmap Report, sections 5

- Waste/Recycled fibers reduce material cost and environmental burden
  - Waste fiber price[1] ~$5/lb for intermediate modulus CF
  - Recycled fiber cost[2] estimated at ~$1.5/lb
- Commercial recycling processes exist and create discontinuous fiber material
- Conversion cost to make TuFF preforms is low (~2/lb)

➔ *TuFF* process is key to convert recycled/waste stream fibers into high-performance parts

Approach: Tailorable Universal Feedstock and Forming (*TuFF*)

- *TuFF* material has been developed under a DARPA program "Tailorable Feedstock and Forming (TFF)" at our academic partner UD-CCM
  - Patent pending "ALIGNED DISCONTINUOUS FIBER PREFORMS, COMPOSITES AND SYSTEMS AND PROCESSES OF MANUFACTURE"
  - International Application No. PCT/US2018/045194
    - Nationalized in UK, France and Germany
  - Focus on TP/TS prepreg for aerospace applications
  - CA has exclusive worldwide license for all *TuFF* IP



- <u>STTR approach</u> is evaluating a stabilized dry fiber preform approach for Wet Compression to meet automotive production rate
  - Low cost fibers (<$5/lb from waste stream, recycled or DOE CFTF facility can be used)
  - Lower conversion cost to make fabric/preforms than continuous approaches
  - No waste process, dry fibers are recovered and reused, no cutting/darting improves fiber yield
  - Goal is to reduce PART cost to $10 per pound

Survey of Commercially Available Low Cost Carbon Fiber

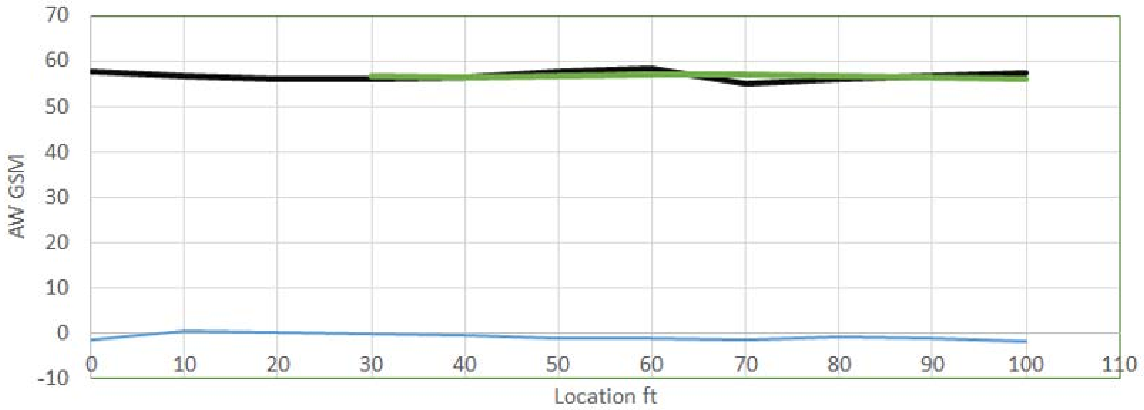
- Conducted survey of commercially available low cost carbon fiber from waste and recycling stream
  - We have experience with intermediate modulus carbon fiber material, which is the standard material for aerospace but is too expensive for automotive parts
  - Lower cost carbon fibers are available and can be considered. This includes low-cost automotive grade chopped fibers (SGL, Zoltek, Hexcel and others) or from waste stream (William Barnet & Son sells at $5/lb)
  - Nevertheless, the biggest cost impact would be to utilize fibers from recycling sources (ELG, Vartega, and others), where material cost is low (less than 1-3 $/lb)
- Phase I acquired waste stream fibers at $5 per pound and started discussion with DOE CFTF, Zoltek, SGL and Vartega for Phase II involvement

Vendor	Fiber Type	Virgin (V) Waste (W) Recycled (R)	Length [mm]	Diameter [um]	Strength [Mpa]	Modulus [Gpa]	Price/lb [$]
Barnet & Son	CF81L	W	3	5.0	5880	294	$5.00
	CF82L	W	5	5.0	5880	294	$8.00
ELG Carbon Fiber Ltd.	CARBISO CT6R	W	6	7	4150	230-255	$5.00
	CARBISO CT6	W	6	7	4150	252	$5.00
	CIM56P	R	3-6	7	3470	246	$1.00
HEXCEL	IM7	V	3	5	5516	276	$50.00
	IM100/BR102	V	6	5	>5309	231	$11.00
	AS100/1925	V	6	7	>4413	276	$11.00
SGL	C T50 4.4/255-E100	V	7	7.0	4400	255	$10.00
Zoltek	PX35	V	3	7.0	4137	242	$9.40

Waste stream and recycled fibers reduce embodied energy at a significant lower price point ($1-$5 per pound carbon fiber cost)

Fabrication of *TuFF* Preforms

- *Fabricated uni-directional thin-ply CF sheet material*
  - *Approximately 800 feet of aligned carbon fiber material was produced*
- *Fabricated cross-ply CF preform material*
  - *Low areal weight dry sheet material is assembled into unidirectional sheet layers at 60gsm*
  - *60gsm material assembled into 0/90 symmetric orientation*
  - *The material has been inspected for areal weight consistency*



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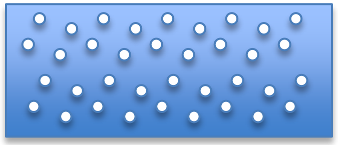
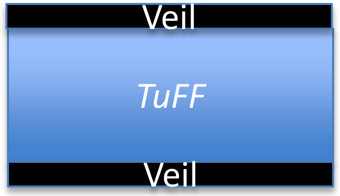
Stabilization of Dry Preform Blanks

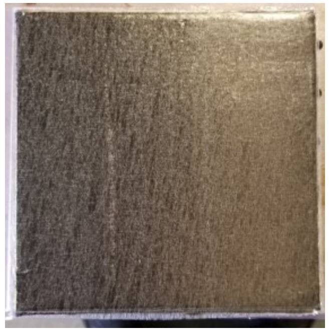
- *Different binder approaches have been evaluated*
  - *Aerosol spray*
  - *Veil material*
- Aerosol spray approach showed significant gradient in binder content and requires additional R&D investment
  - Binder application at the aligned fiber sheet level vs. preform to distribute binder volume uniformly
  - In-plane control of binder volume difficult using manual spray process
  - Automation is possible and can be evaluated in Phase II
- 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
  - Two approaches are evaluated and included a commercially available PU veil (12gsm) and in-house produced electro-spun veil material (1-2gsm)

TuFF with Binder Particles



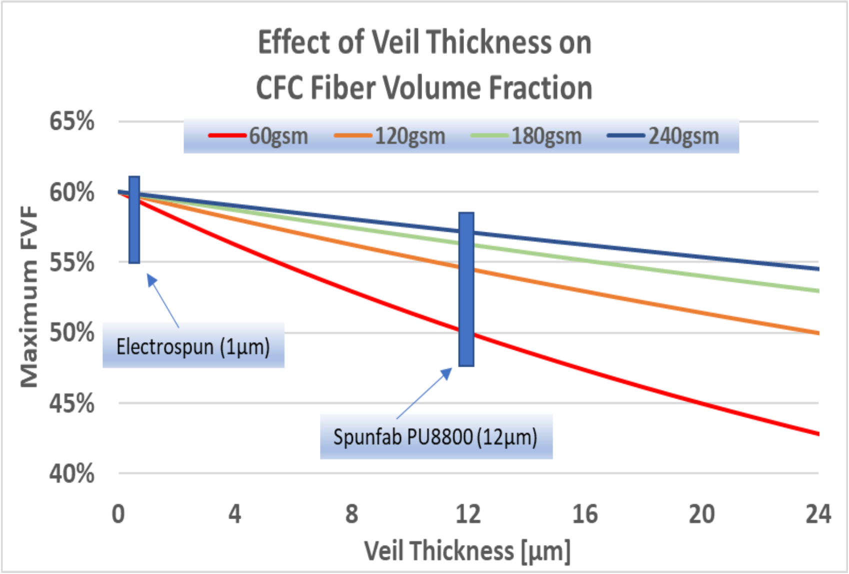
TuFF with Veil



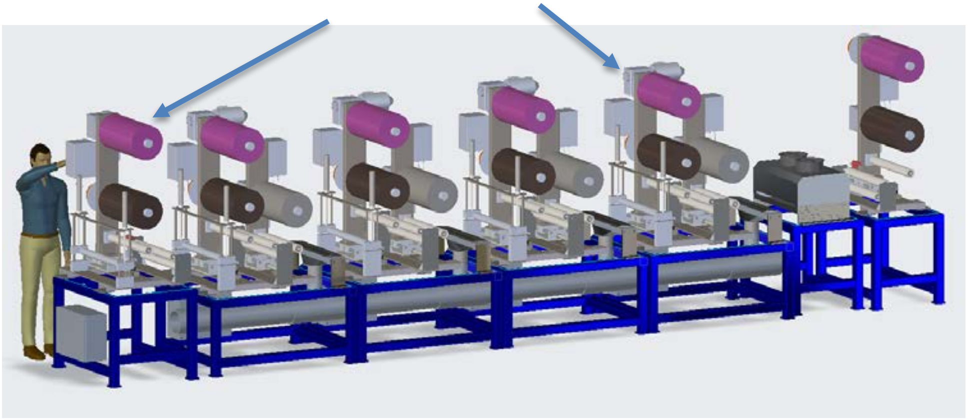


Commercial vs. Electro-Spun Veil Material

- Commercial veil material is available from various companies
  - Most commercial veils are 10gsm or higher
  - FU8800 from Spunfab at 12gsm is being used in Phase I
  - High veil areal weight increase binder content and reduces properties
- Electro-spun veil
  - Low areal weight material (1-2 gsm) can be electro-spun minimizing binder content
- Veil integration will be fully automated to make continuous rolls of multi-axial stabilized *TuFF* fabrics in potential Phase II



Veil rolls to stabilize TuFF multi-axial fabric



Complex Geometry *TuFF* Forming and Part Manufacturing

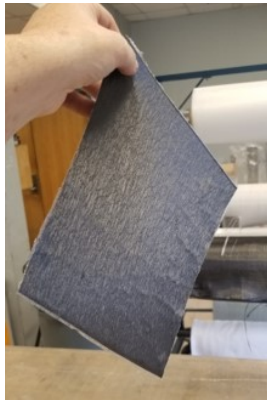
CA demonstrated complex part geometry forming using wet compression molding

- Small part (10in by 14 in) with complex geometry was impregnated and formed within 30 seconds with 100 psi molding and infusion pressure
- Both veil and electro-spun stabilized preforms were evaluated
- In-plane strains up to 40% have been demonstrated
- Resin required extended curing time

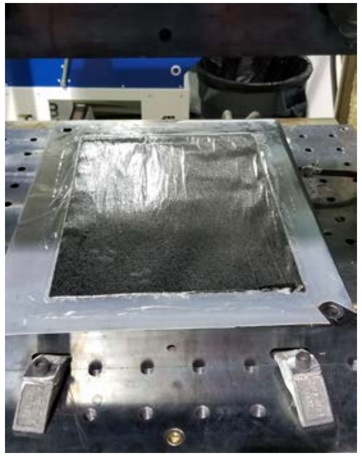
HUNTSMAN
Enriching lives through innovation

Discussion with Huntsman to provide snap-cure resins
They will be Phase II technology partner for part production

1. Stabilized preform produced

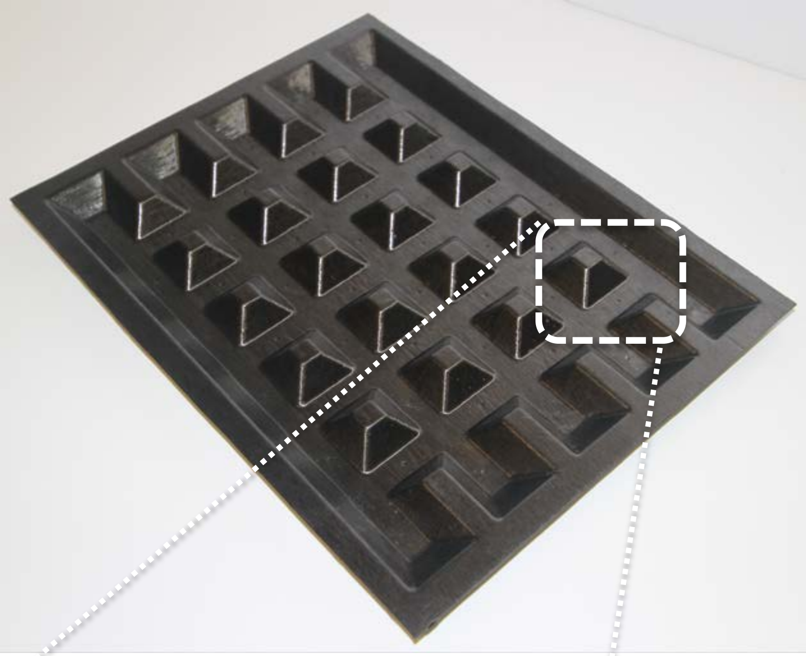


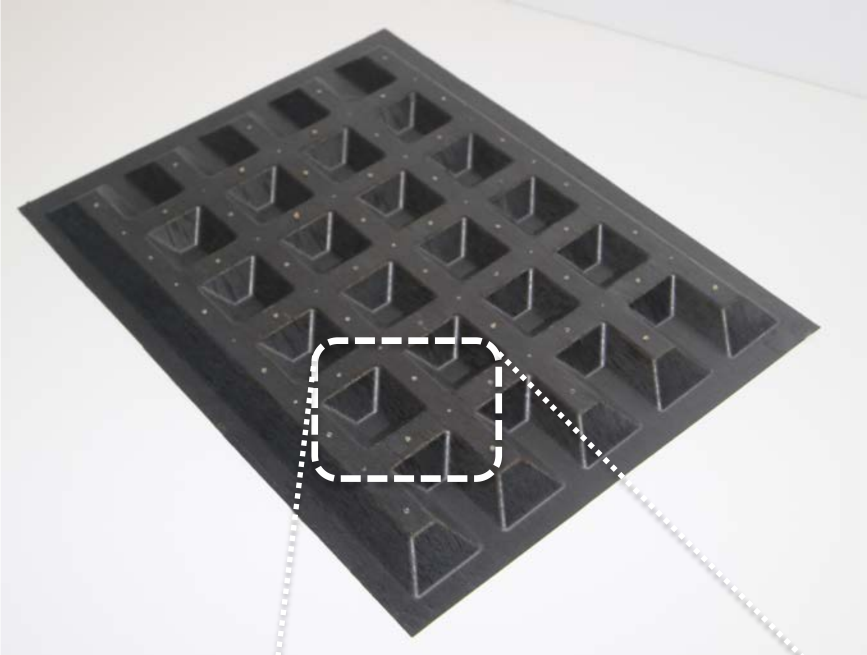
2. Resin film applied on flat fiber blank in press

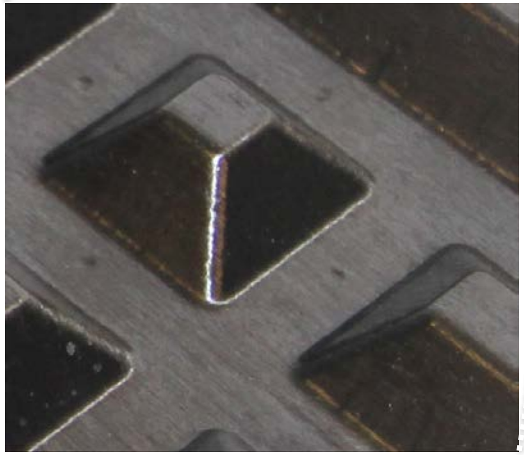


3. Final molding step forms geometry and cures part in hot press

Close-Up of Demonstration Part

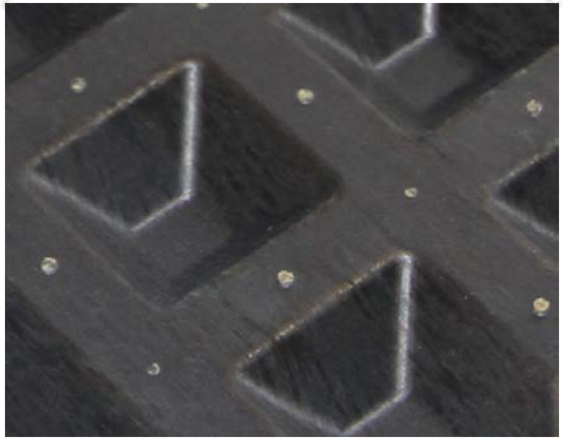






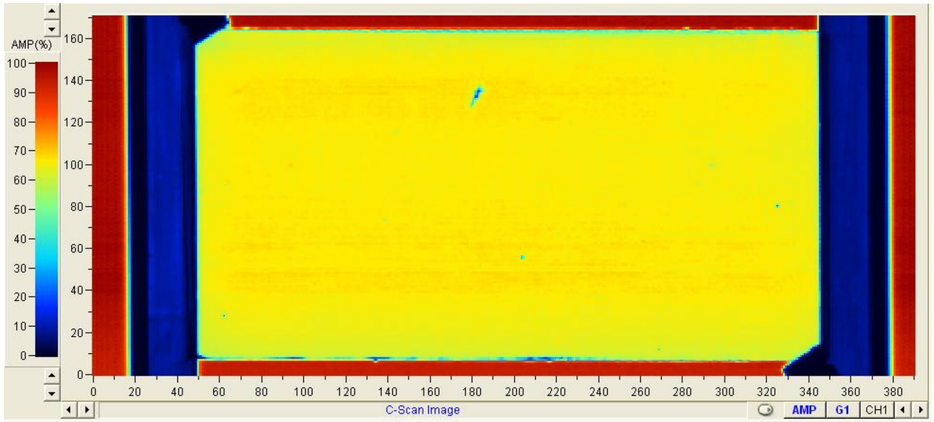
<u>Complex geometry with repeatable feature forming</u>

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

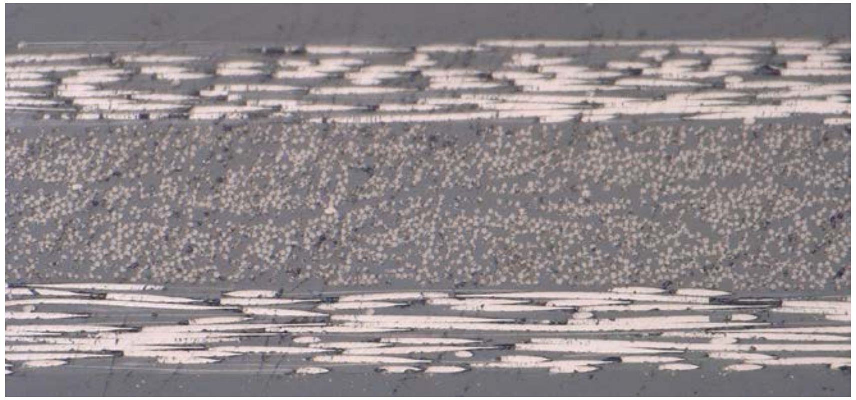


Mechanical Performance

- Flat coupons for mechanical testing have been fabricated
  - Quality assessment using ultrasonic C-scan shows no/low porosity and close to 45% FVF
  - Phase I also fabricated higher fiber volume fraction parts (up to 55%) but testing could not be completed as CA was closed due to COVID-19
    - We expect up to 20% property improvement is possible and testing will commence in the Phase II effort.
  - Microstructural and mechanical evaluation show good alignment and property translation
    - Addition of veil reduces FVF
    - Handling in current manual electro-spun process disturbs microstructure and reduces properties by 10%

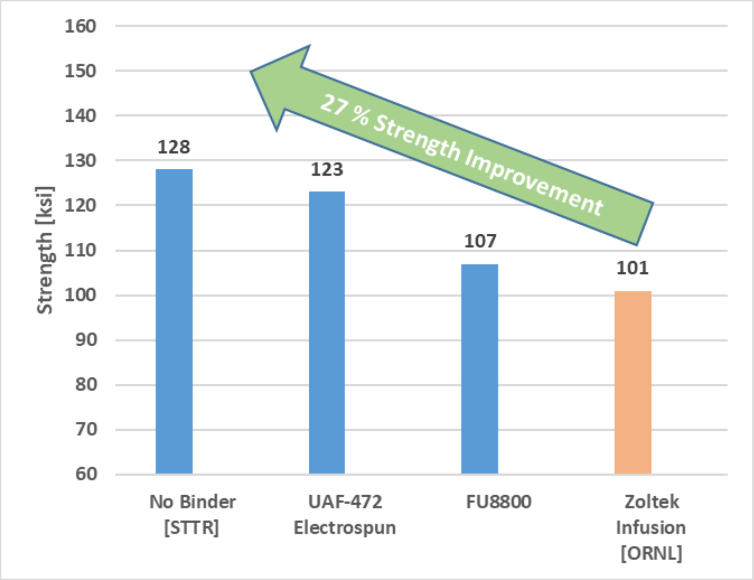


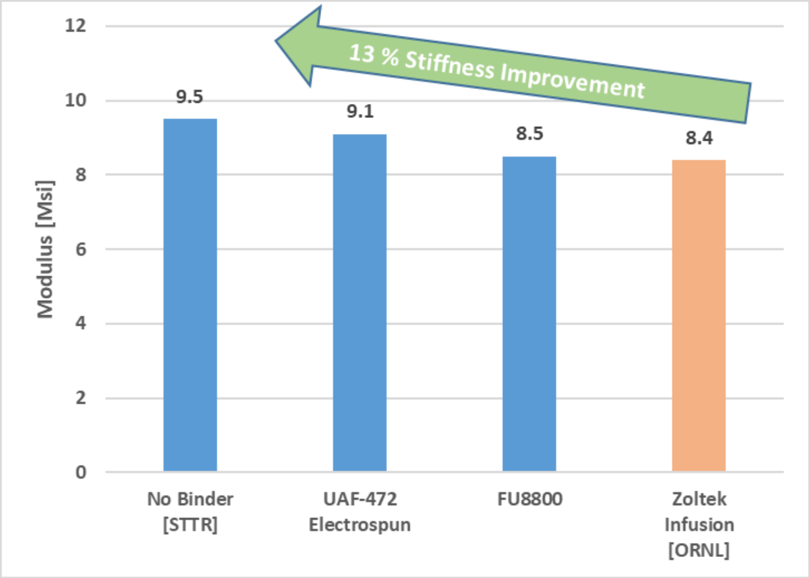
Ultrasound shows uniform quality



Micrograph shows no porosity and around 45% FVF

Tension $[0/90]_S$ Performance





- *TuFF* enables full fiber property translation
- Small knock-down with stabilization compared to Baseline *TUFF*
  - 12gsm veil reduces FVF
  - Handling in current manual electro-spun process reduces properties
- *TUFF* increases properties compared to standard automotive grade fabrics
  - Up to 27% improvement in strength and 13% in stiffness compared to ORNL database with continuous Zoltek fiber

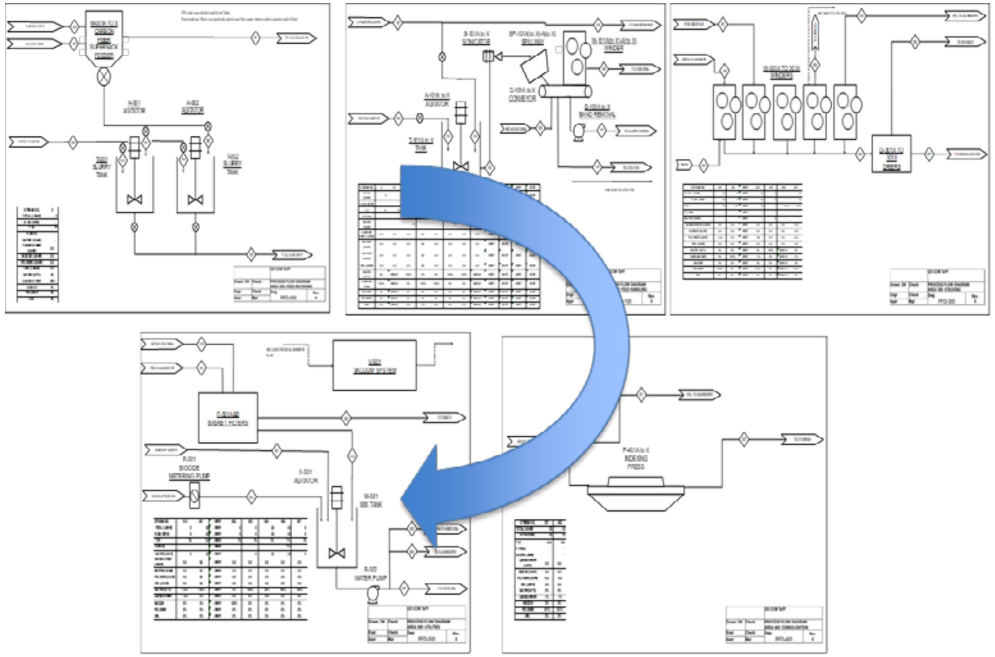
Short Fiber | Cont. Fiber

	TuFF (Wet Compression) [STTR]			Zoltek Infusion [ORNL]
	No Binder	UAF-472 Electrospun	FU8800	
Strength [ksi]	128	123	107	101
Norm Strength	127%	122%	106%	100%
Modulus [Msi]	9.5	9.1	8.5	8.4
Norm. Modulus	113%	108%	101%	100%
FVF	46%	46%	42%	48%

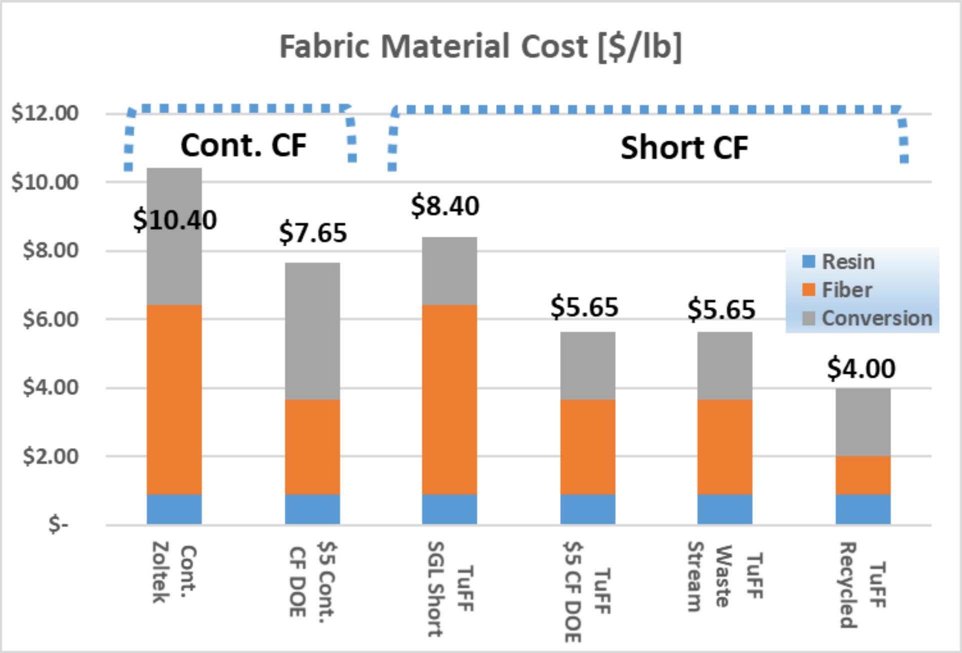
Further TuFF increase expected with higher FVF (~55%)

Cost Assessment

- Material costs associated with LCM parts include fiber, resin and fiber conversion into fabrics and preforms
  - Fiber conversion cost into non-crimp fabrics is between \$6-\$8 per pound (does not include fiber cost) based on pricing data (100 ton production volume) provided by fabric supplier in 2017 for DOE door project, GM provided \$4 per pound as a reasonable high volume cost target (verbal communication 2/19/20)
  - Associated waste generated during preforming is between 10%-30% reducing material yield
- DARPA cost model calculates Capital Investment, Operating Expenses and required material price for zero net present value, ~\$3/lb (100 ton plant) and \$2/lb (2500 ton plant) conversion cost to create TuFF material
- Evaluated commercial short fiber from SGL (\$10/lb), waste stream fiber (\$5/lb) and recycled fiber (anticipated volume price \$1.5/lb)
- Snap-cure resin (\$2/lb) from Huntsman is used



Cost Comparison
Short vs Continuous Fiber Fabric



- Best current large-volume continuous fiber, non-crimp, epoxy *CFC material cost* is $10.40 per pound (DOE $5 CF reduces CFC material cost to $7.65/lb)
- TuFF material cost is $8.40 with existing supply chain availability due to reduced conversion cost
- Long-term cost can be further reduced with DOE $5 and waste stream fibers ($5.65/lb) and recycled fibers ($4/lb)
- *Another significant saving is improved yield and reduced processing steps minimizing FINAL part cost*

Proposed Phase II effort

- Technical tasks
  - Integration of stabilization into TuFF process
  - Create full database of properties (short commercial CF, recycled and waste stream CF, DOE CF)
  - Leverage EERE door tooling and expertise to demonstrate part production and cost reduction (material and process)
  - Evaluate crash performance of *TuFF* material
  - Study cycle time, rate and cost benefits of TuFF approach
- Focus on recycled fiber with Vartega (US carbon fiber recycler) under contract
  - Other low-cost short fiber commercial sources will support Phase II to reduce carbon fiber cost at or below $5 per pound
    - SGL with commercial, low-cost chopped fibers
    - Waste stream fibers from other sources
    - ORNL fiber evaluation
- Huntsman will provide resins and potential transition of technology
- Letters of support from USAMP and CFC supplier TPI to support project and technology transfer to OEMs
- Commercialization: Substantial interest by various OEMs during our Phase I
  - Porsche, VW, Honda, Ford, GM and others

Any proposed future work is subject to change based on funding levels

Summary Phase I Accomplishments

- Low-cost, short fibers have been evaluated
  - Commercial virgin
  - Waste Stream
  - Recycled
- Successful demonstration of TuFF short fiber stabilization process
  - *Scalable, low-cost preforming of TuFF material using veil approach*
- Tensile properties exceed current automotive grade, continuous carbon fiber composite properties
  - *Full property translation with lower cost, but higher performing discontinuous fiber feedstock*
- Dry *TuFF* preforms in combination with wet compression allows complex geometry part fabrication meeting automotive performance, rate and cost targets
  - *Lower material cost combined with lower manufacturing cost minimizes part cost*
  - *Reduced part count possible with complex geometry part fabrication*

Final Thoughts on *TuFF* Technology for Automotive

Need for Enabling Technology for a Circular Economy Approach to Advanced Composites Manufacturing[1]

- "Recycling is a key element for circular economy, but the most important mindset is to design materials and processes with the ultimate goal of reuse, and to support methodologies where multiple materials can be utilized through one process"[1]
  - TuFF enables use of 100% recycled materials (fibers and polymers)
  - Near-zero waste process
  - TuFF is fiber agnostic and allows multi-material solutions through hybridization
  - TuFF allows new design space for composites with increasing complexity in geometry, layups and materials usage
- "Reducing the embodied energy of fiber-reinforced polymer composites" [1]
  - TuFF allows use of waste and recycled materials
  - TuFF processing compatible with lower energy manufacturing processes
- "Manufacturing processes that reduce the cost of production" [1]
  - TuFF with wet compression / stamp forming has the potential to reduce part cost below $10/lb (at least 50% part cost reduction compared to current BMW i3 technology)

1) Uday Vaidya, Chief Technology Officer At IACMI," Enabling A Circular Economy Approach To Advanced Composites Innovation, Manufacturing And Use", https://www.compositesworld.com/blog/post/enabling-a-circular-economy-approach-to-advanced-composites-innovation-manufacturing-and-use-part-1, 02/04/2020.