Short Fiber Preform Technology for Automotive Part Production

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Project ID: mat215

SBIR Phase II Review

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University of Delaware – Center for Composite Materials
Vartega Inc.

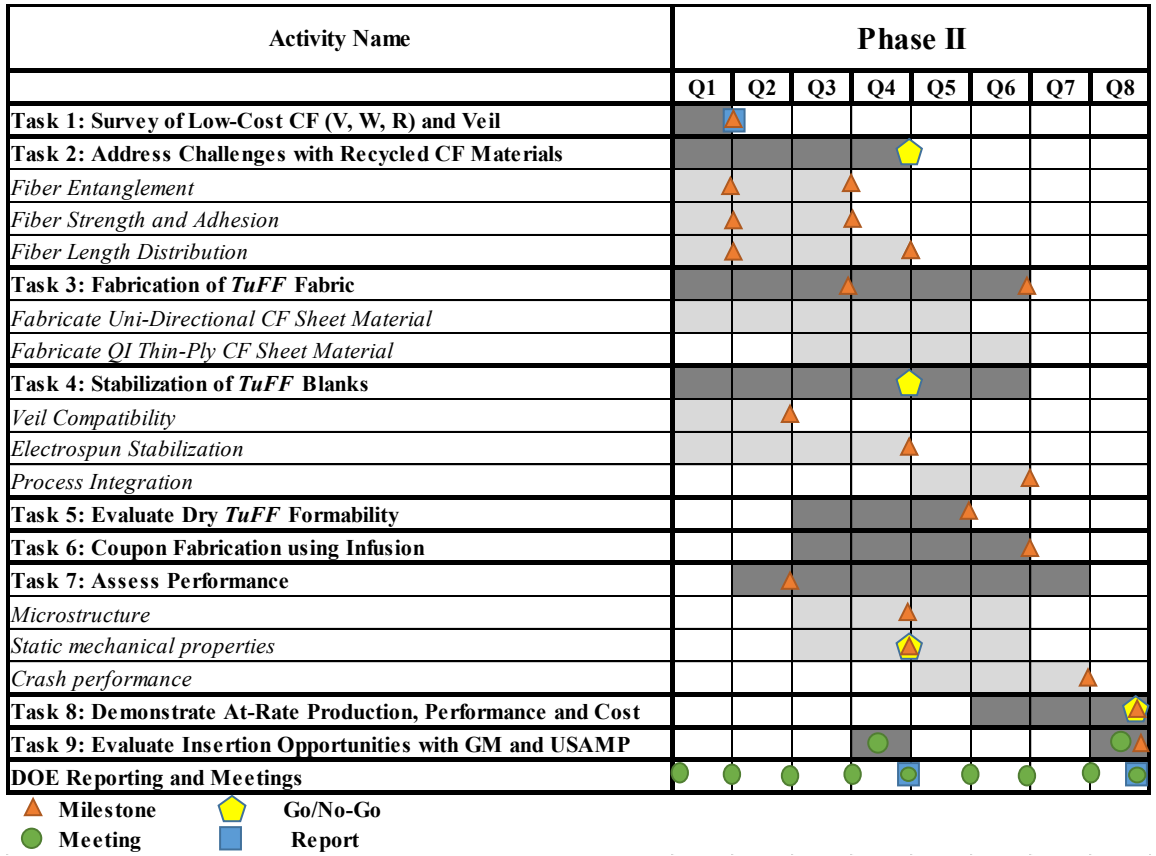
2021 DOE Vehicle Technologies Office Annual Merit Review

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

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



Budget ~$1.1M with 24 months period of performance (09/20-08/22)

Partner in this SBIR is the Univ. of Delaware – Center for Composite Materials (UD-CCM)

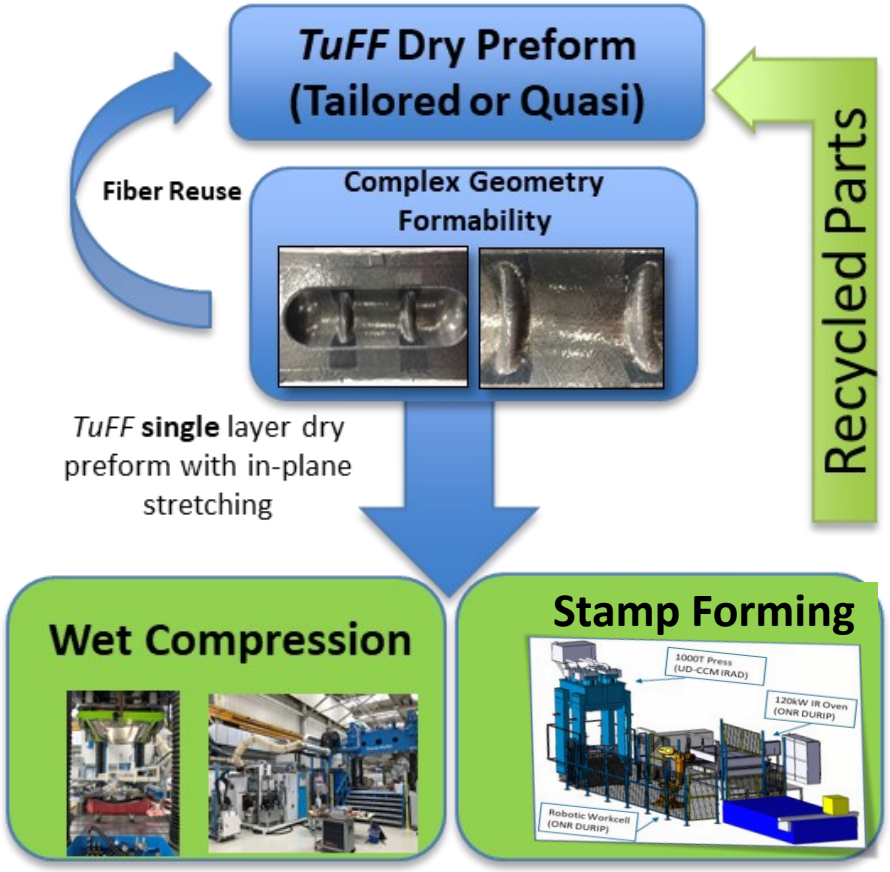
M1: Material Report and Down-Select

M2 – M4: Fab. of TuFF fabric for Processing

M5: Document Infusion/Molding Process

M6: Mechanical Test Report

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



TuFF material allows >40% bi-axial stretch

➔ Net-shape preforming and reuse of fiber waste in *TuFF* process

➔ Tailored or isotropic preforms/blanks allow design flexibility

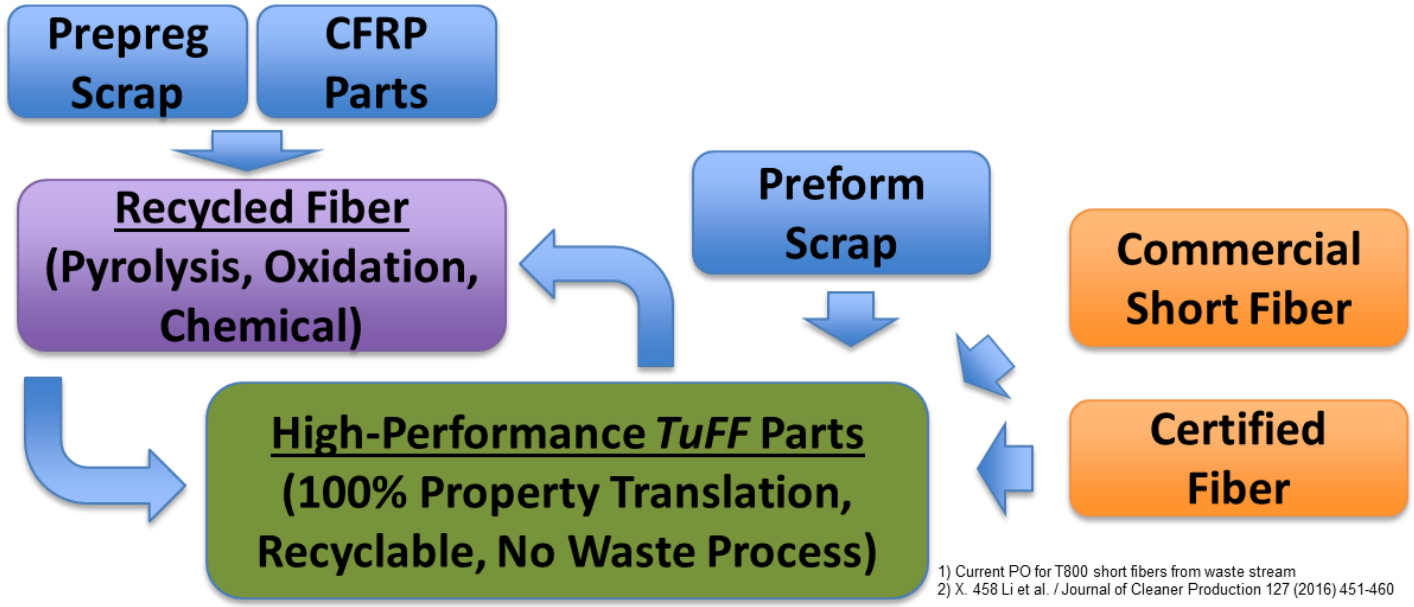
➔ Single processing step from flat to complex geometry preform
- Enables stabilized preforms for wet compression and blanks for compression molding
  - In-situ forming and resin impregnation with wet compression molding

➔ High fiber volume fraction short fiber parts (FVF>50%)

Paradigm Shift in Composite Processing

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



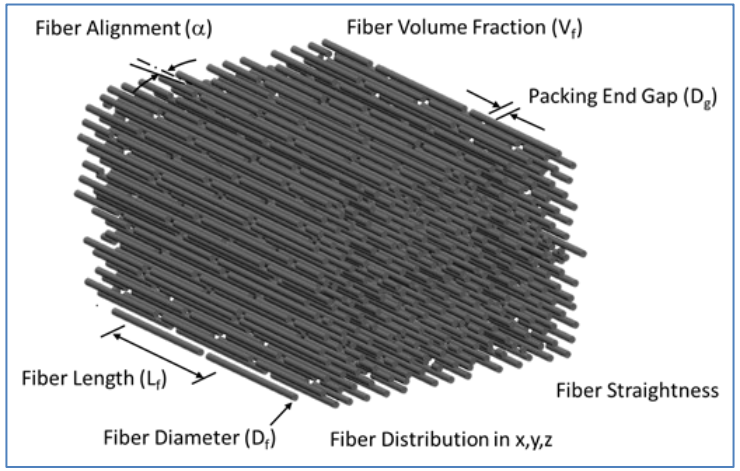
Addresses the targets found in the 2017 U.S. DRIVE MTT Roadmap Report, sections 5

- 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
- 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 issued "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



- SBIR approach is evaluating a stabilized dry fiber preform approach for Wet Compression or Stamp Forming 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, 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
  - Lower cost short carbon fibers are available and have been purchased. This includes low-cost automotive grade chopped fibers (SGL, Zoltek, Hexcel and others) or from waste stream (~$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 II teamed up with Vartega for recycled fibers and acquired CF waste stream fibers, and low-cost virgin fibers from Zoltek

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

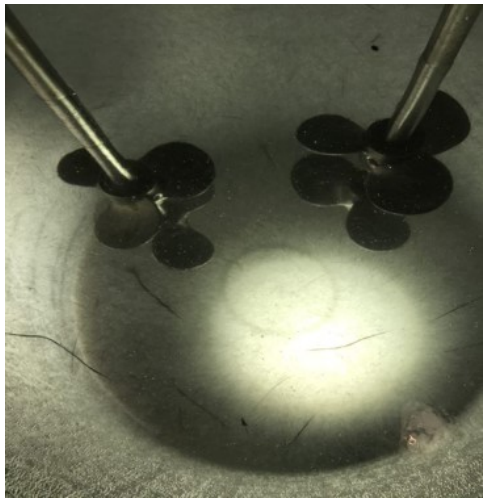
ZOLTEK Toray Group

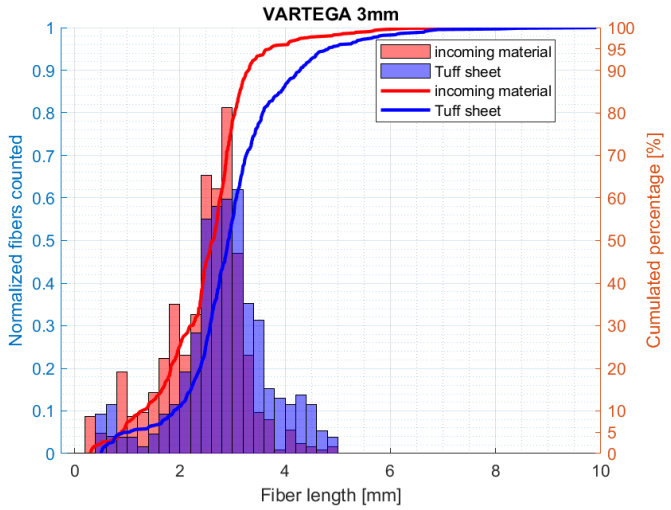
vartega

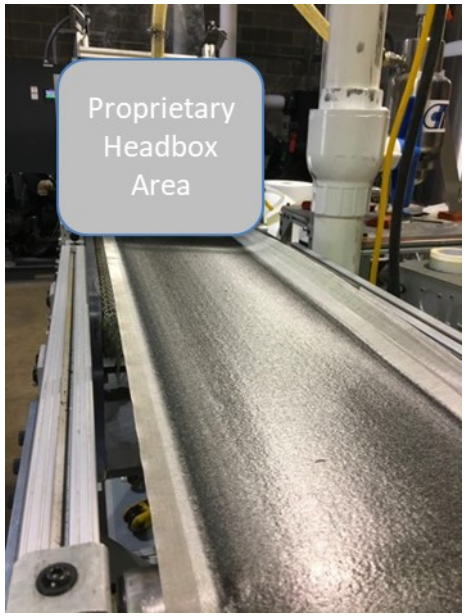
Fabrication of *TuFF* Preforms with Different Fiber Types

- *Fabricated uni-directional thin-ply CF sheet material for further processing from Zoltek PX35, waste fibers and Vartega 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







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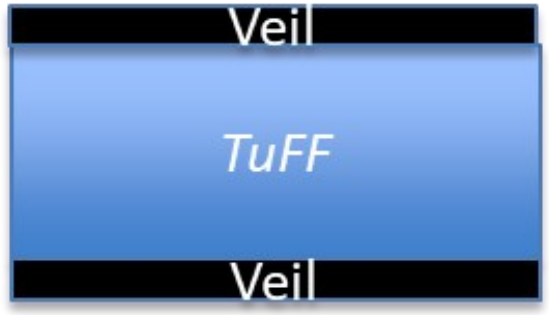
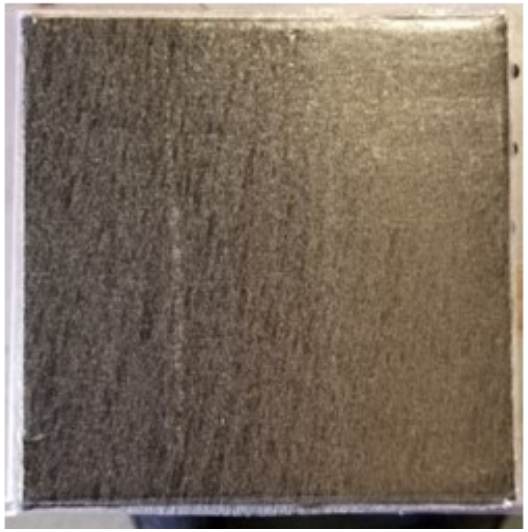
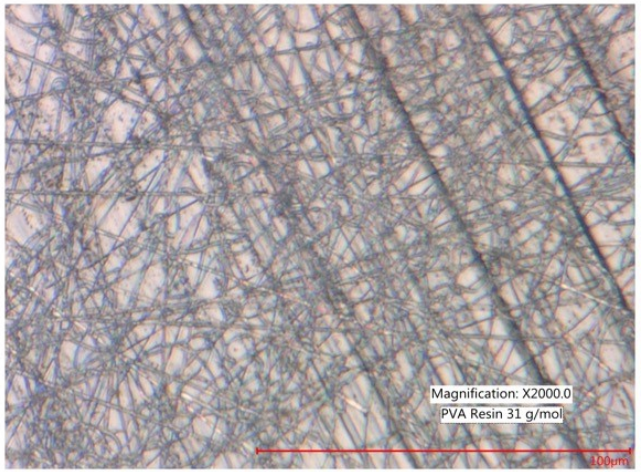
Stabilization of Dry Preform Blanks

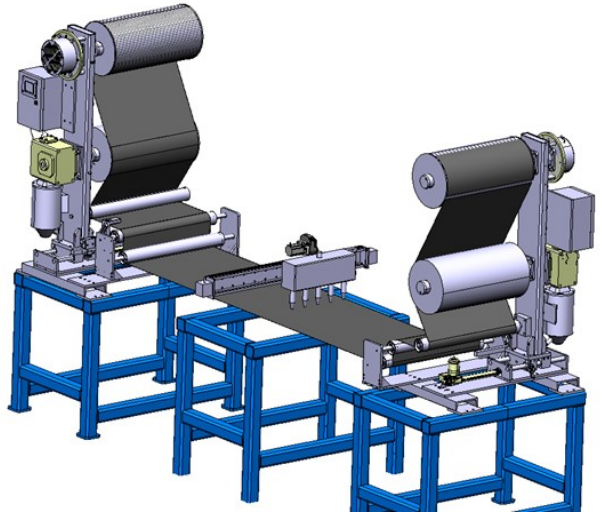
- *Phase II focuses on implementing electrospun approach evaluated in Phase I*
- Veil material exhibits good stabilization without affecting permeability and formability
  - Can be integrated in preform process to create continuous rolls of stabilized fabric
  - Veil has to be optimized for mechanical properties and to retain formability
  - Created low areal weight <1gsm electrospun material successfully using aqueous solution

TuFF with Veil









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Complex Geometry *TuFF* Forming and Part Manufacturing

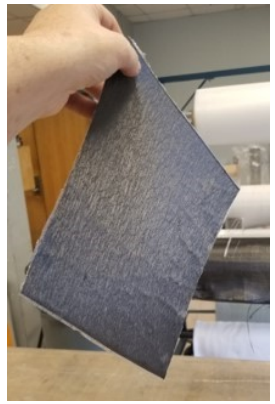
CA demonstrated complex part geometry forming using wet compression molding

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

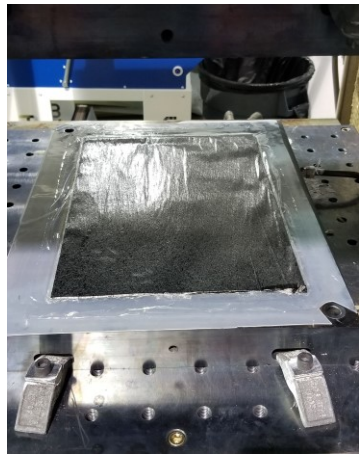
HEXION™
Responsible Chemistry

Phase II started to work with snap-cure resins from Hexion

1. Stabilized preform produced

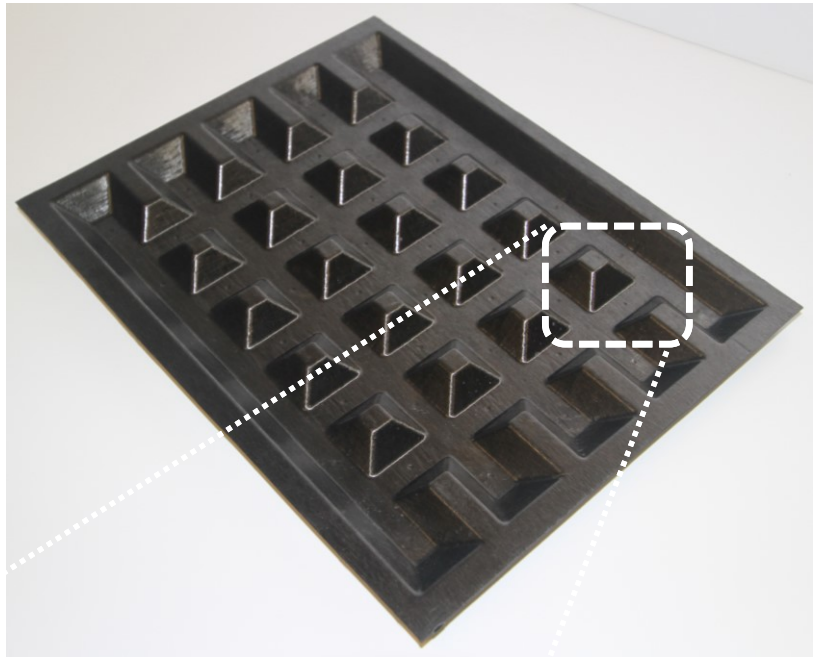


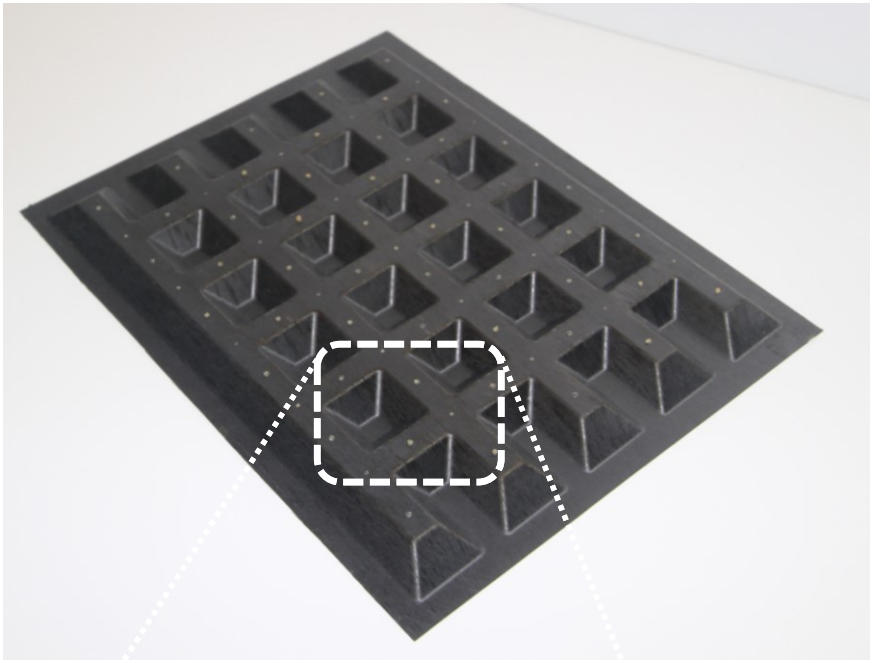
2. Resin film applied on flat fiber blank in press

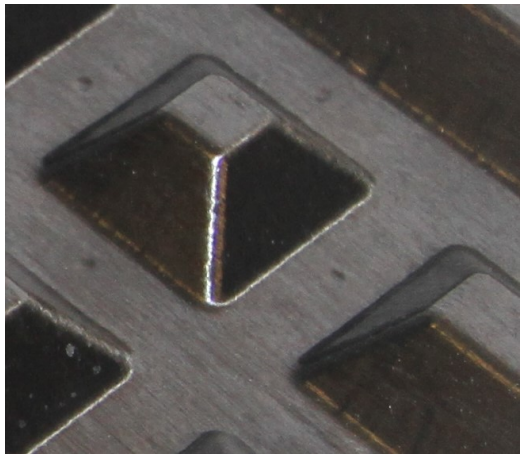


3. Final molding step forms geometry and cures part in hot press

Close-Up of Demonstration Part

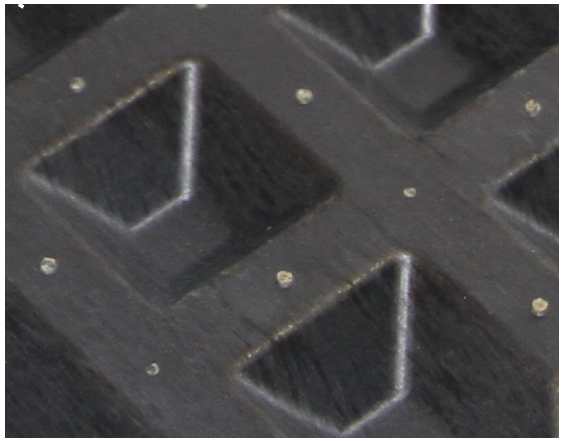






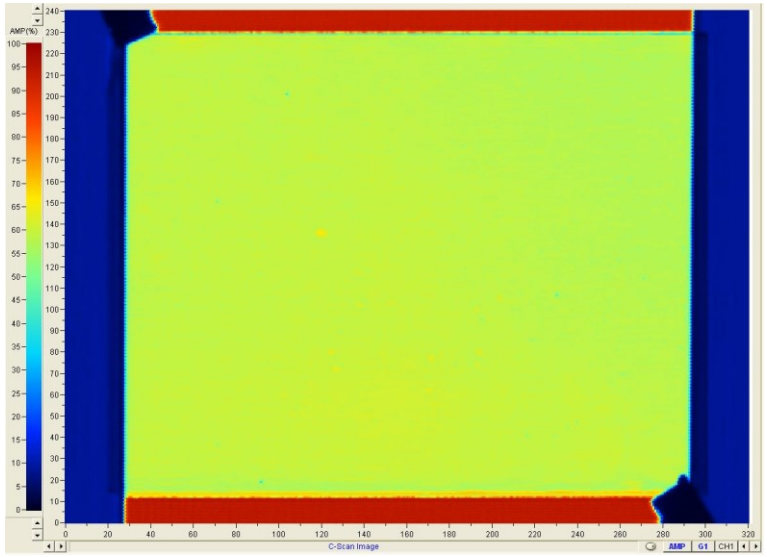
Complex geometry with repeatable feature forming

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

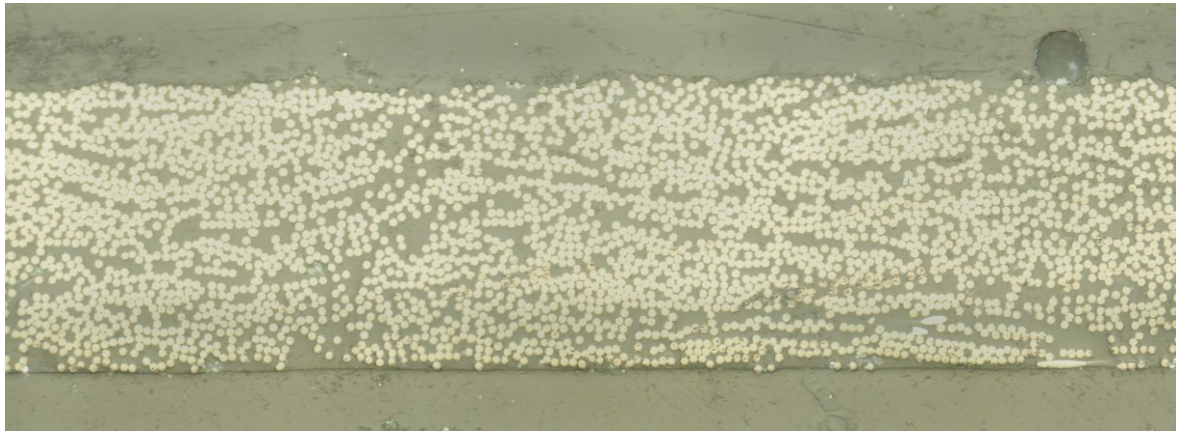


Mechanical Performance

- Flat coupons for mechanical testing have been fabricated in Phase II
  - Zoltek PX35, Vartega and waste fibers
  - Quality assessment using ultrasonic C-scan shows no/low porosity and close to 50% FVF (increase from previous Phase I effort)
  - Microstructural and mechanical evaluation show good alignment and property translation

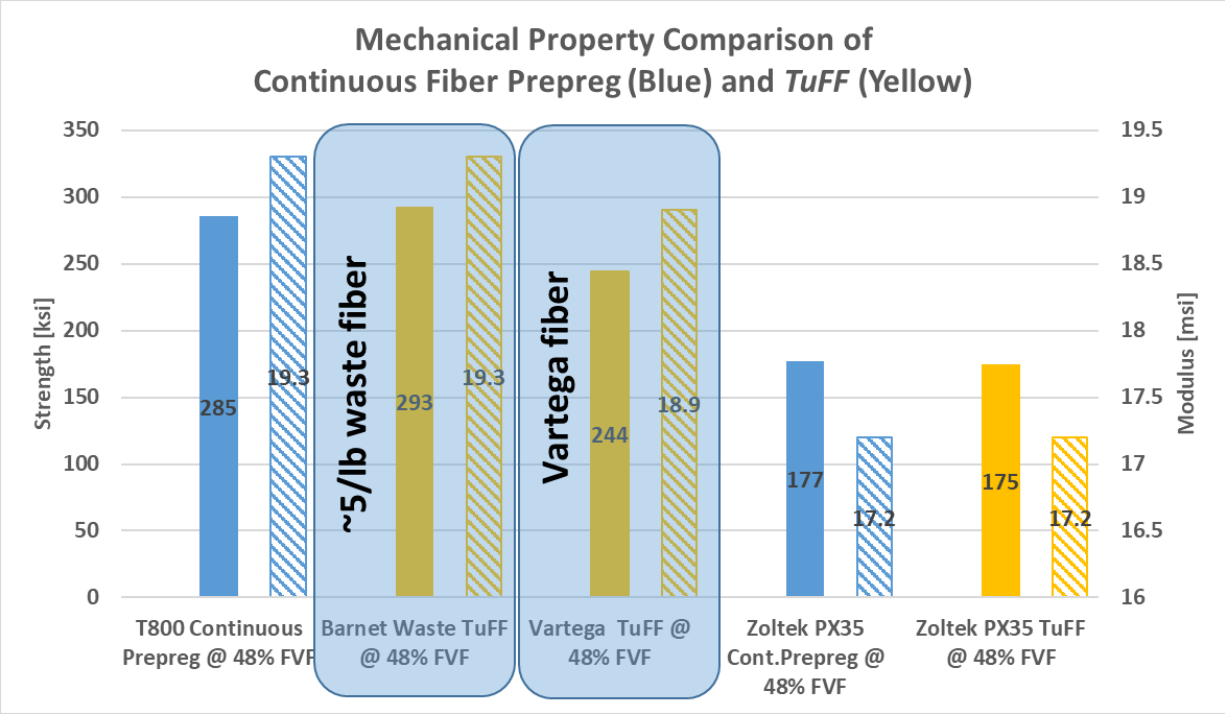


Ultrasound shows uniform quality



Micrograph shows no porosity
and around 50% FVF

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.
- ~245ksi strength and 19msi modulus with Vartega fiber @ 48% FVF (work in progress)
- 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)
- First iteration *TuFF* with Vartega fibers shows potential for high property translation (work in progress)

Next Project Period Effort

- Technical tasks
  - Finalize recycling approach at Vartega (fiber recovery, length reduction and sorting)
  - Finalize stabilization approach at UD-CCM
  - Scale and create snap-cure *TuFF* blank material and stabilized *TuFF* preforms
  - Demonstrate automated processing approaches
    - Wet compression (automated dispensing and forming)
    - Stamp forming in UD-CCM forming cell
  - Create full database of properties (short commercial CF, recycled and waste stream CF)
  - Study cycle time, rate and cost benefits of *TuFF* approach
- Transition technology to USAMP/OEMs and commercial partner
- Commercialization: Substantial interest by various OEMs/Tier supplier during our Phase I and II

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

Summary Phase II 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 meet/exceed current automotive grade, continuous carbon fiber composite properties @ 50% fiber volume fraction
  - *Full property translation with lower cost, but higher performing discontinuous fiber feedstock*
- Two processing routes are proposed and materials are under development: 1) Dry *TuFF* preforms in combination with wet compression or 2) snap-cure blanks with compression molding allows complex geometry part fabrication meeting automotive performance, rate and cost targets
  - *Lower material cost combined with lower mfg 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"[3]
  - *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" [3]
  - *TuFF* allows use of waste and recycled materials
  - *TuFF* processing compatible with lower energy manufacturing processes
- "Manufacturing processes that reduce the cost of production" [3]
  - *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)

3) 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.