Oak Ridge National Laboratory

Project ID: Mat175

2020 DOE Vehicle Technologies Office Annual Merit Review Poster Presentation

Novel Materials for Polymer Composite Engine Blocks*

**** Subtask 5B under the Powertrain Materials Core Program (PMCP)***

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Oak Ridge National Laboratory

June 3, 2020

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Project Overview: Subtask 5C: Novel Materials for Polymer Composite Engine Blocks (1-year Exploratory Project under the PMCP)

Timeline/Budget

- Project start: April 2019
- Project end: April 2020
- Budget: $150k
- Percent complete: 95%

Barriers

- Vehicle (engine) light-weighting
- Lack of temperature resistant polymer matrix composite material
- Limitations of injection/compression molding of hybrid carbon fiber composite engine blocks with metal inserts.

FY20 VTO Powertrain Materials Core Program **Research Thrusts**	FY20 Budget	Participating Labs
Thrust 1. Cost Effective LW High Temp Engine Alloys	$1.05M	ORNL
Thrust 2. Cost Effective Higher Temp Engine Alloys	$1.525M	ORNL, PNNL
Thrust 3. Additive Manufacturing of Powertrain Alloys	$1.075M	ORNL
Thrust 4A. Advanced Characterization & Computation	$1.625M	ORNL, PNNL, ANL
Thrust 5. Exploratory Research(1-year projects) **-Subtask 5C ($150K): Novel Materials for Polymer Engine….** -Subtasks 5A, 5B & 5D ($450K)	$600k	ORNL, PNNL, ANL

COLLABORATION*

- Program Lead Lab
  - –Oak Ridge National Lab (ORNL)
- Scale-up Research Facility – Michigan State University– full scale testing
- University of Tennessee

* See Technical Back Up slides

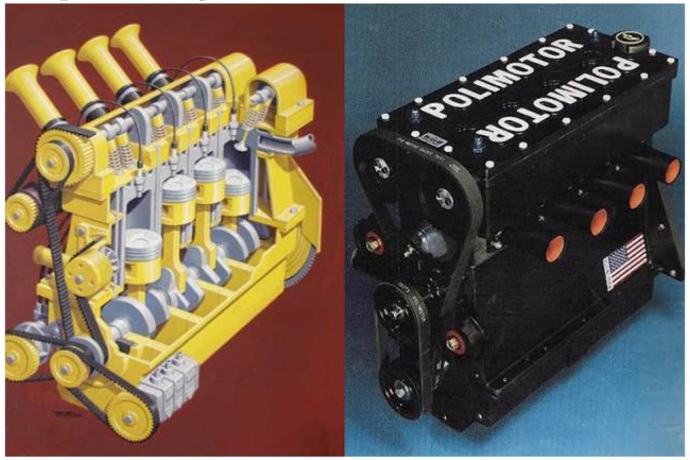
Relevance

- Polymer Composite Components offer significant advantages:
  - Light weight
  - Noise vibration and harshness damping
  - Tailorable solutions
- Challenges remain
  - Temperature limits
  - Cost

- This one-year exploratory project addresses current issues with Bakelite (thermoset phenolic resin) embrittlement with continued thermal exposure
- The goal is to develop affordable novel polymer matrix composite (PMC) systems for light-duty internal combustion engine block applications.
- Identify technology, cost and manufacturing challenges and opportunities

Light-weight engine block materials are desired

Composite engine blocks have been made before.



Mattil Holtzberg previously built a composite engine block for 2.3 liter SOHC engine and 2.0 DOHC liter engine.

Approach

- ❖ Evaluate and down-select base polymer chemistries and additives
- ❖ Evaluate and down-select reinforcing phase and interfacial strength enhancing additives
- ❖ Characterization: Tensile testing, Young's modulus, TGA

Base polymer matrix
Options:
1. Phenolic resin
2. ABL
Toughening additives: rubber, crosslinker

Property:
Heat resistant, tough

Reinforcement
Options:
1. Carbon Fiber
2. Particulates = CNP or CNP-OH

Property: Strength

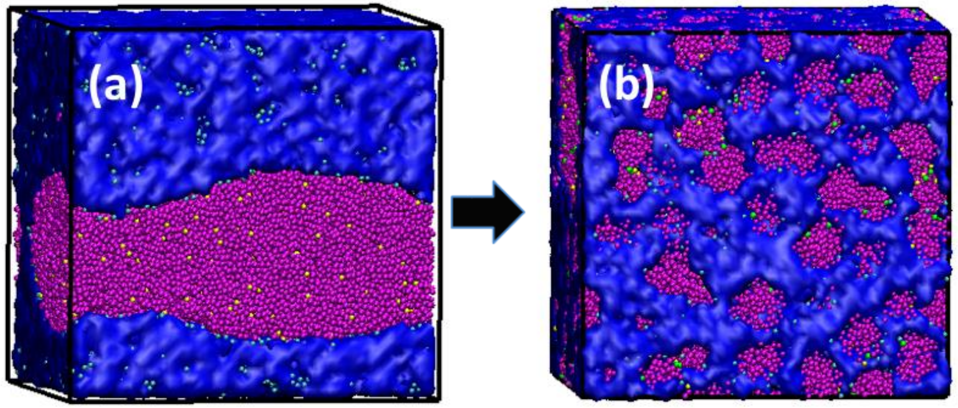
Fiber-matrix interfacial bonding agents
Options:
DL = difunctional linker
TL = trifunctional linker

Property: Strength

Characterization
Tensile testing
Young's Modulus
TGA

Milestones	End Date
Fabricate composites from resin using ORNL produced carbon fiber at < 50 % carbon fiber content (Complete)	Dec 2019
Demonstrate 100 MPa strength equivalent in the temperature resistant composite materials (complete)	March 2020

(a) Phase separated resins are not useful for this application



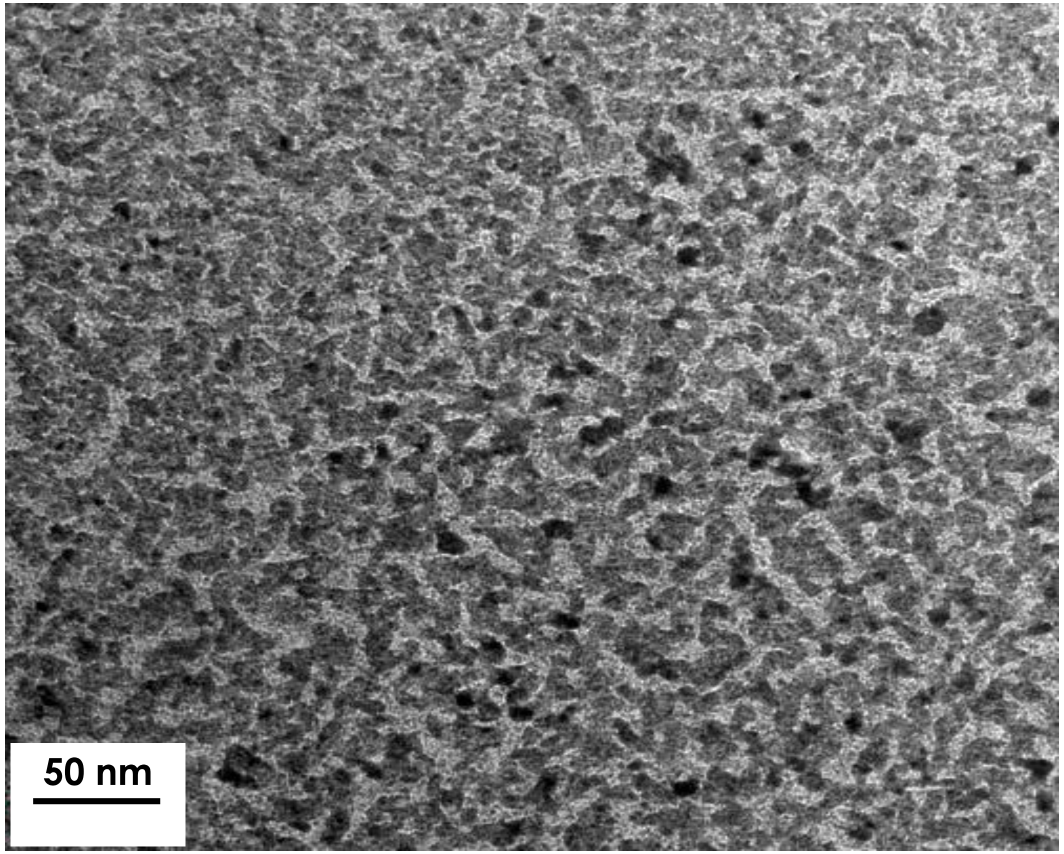
(b) Co-continuous toughened resin is desired: Blue = rigid phenolic resin phase and magenta = soft rubber phase

Carbon fiber or CNP particulate will reinforce the matrix.

Barnes et al. Macromol. Rapid Commun. (2019)

Technical Accomplishments

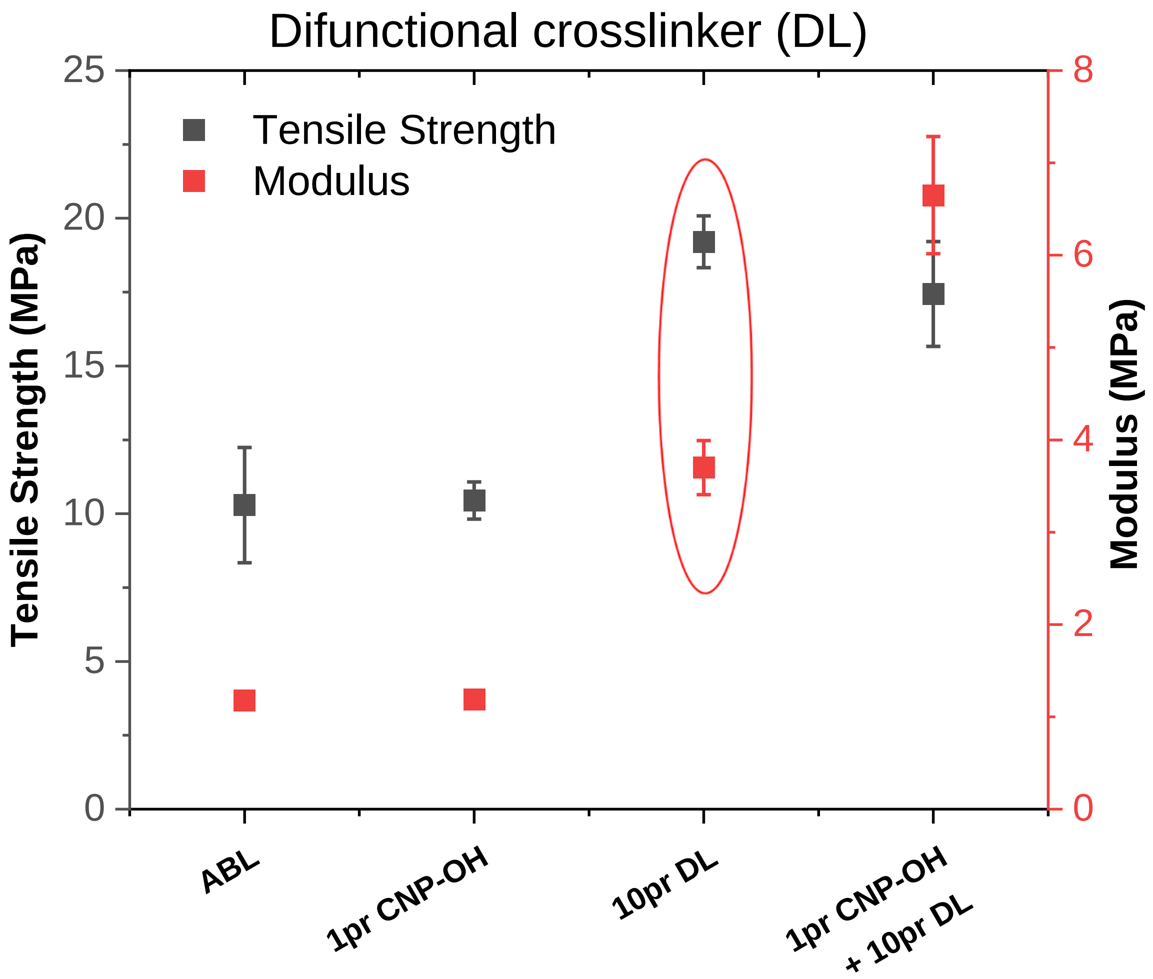
Developed a path for co-continuous toughened phenolic resin from a commercial thermoplastic feedstock.

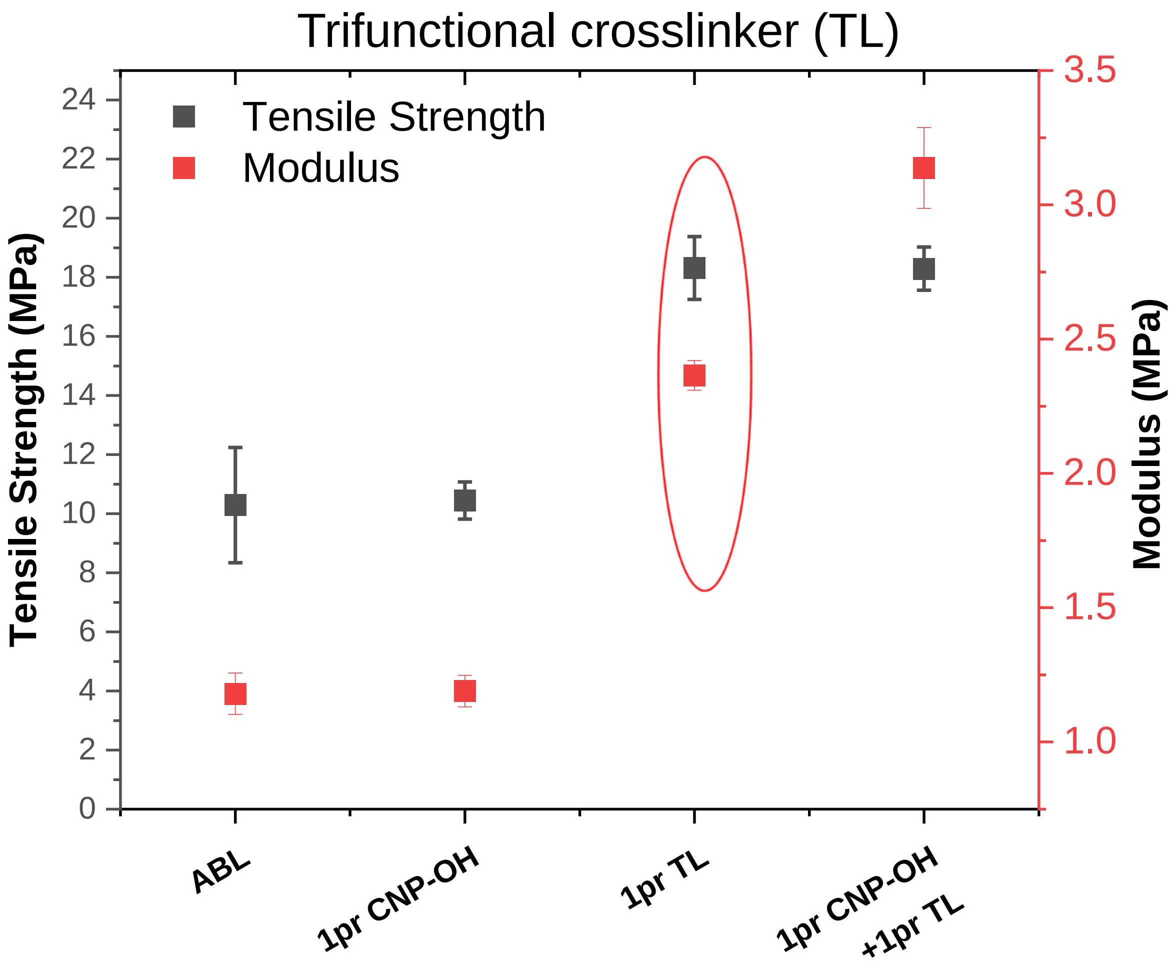


TEM micrograph of a co-continuous toughened phenolic resin—dark phase is phenolics and light phase represents rubber

- Phenolic resins are expensive and are of numerous grades (includes both thermoplastics and thermosets). In addition, it requires toughening.
- Bakelite is a thermoset, temperature resistant material but difficult to modify and process further.
- To avoid complexity we have formulated an in-house composition, ABL resin, that has similar co-continuous morphology.
- ABL has been used in this study for composite performance analysis.

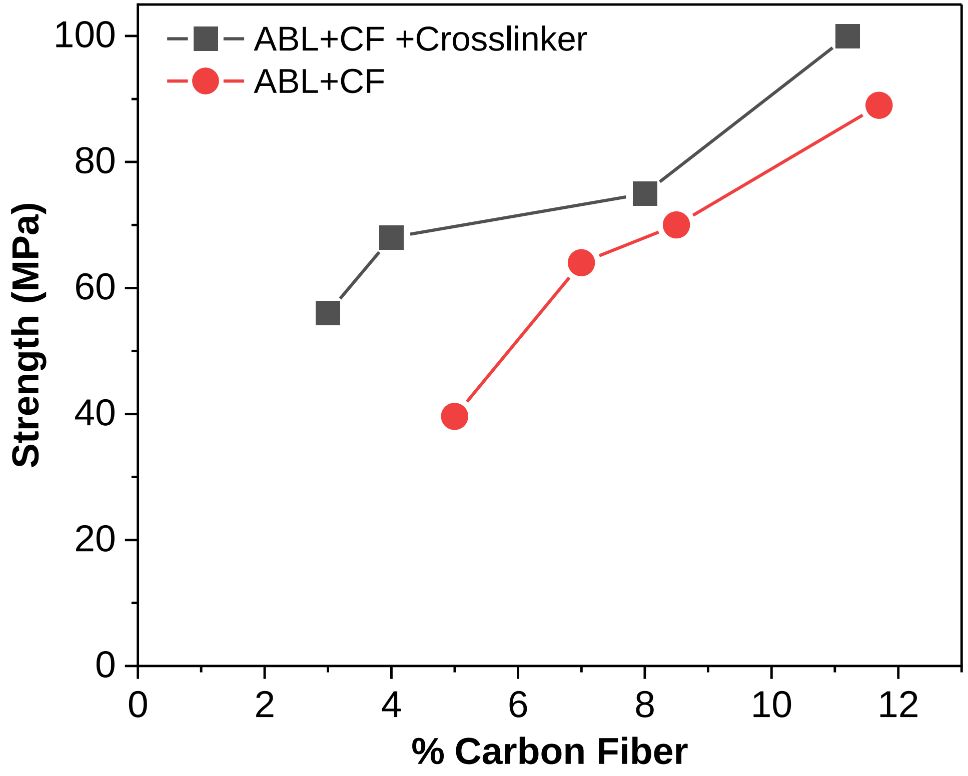
Technical Accomplishments: Mechanical Properties of ABL





While carbon nanoparticle (CNP) additions do not affect the properties of ABL, both DL and TL enhanced the tensile strength and modulus. DL is better for bulk matrix crosslinking.

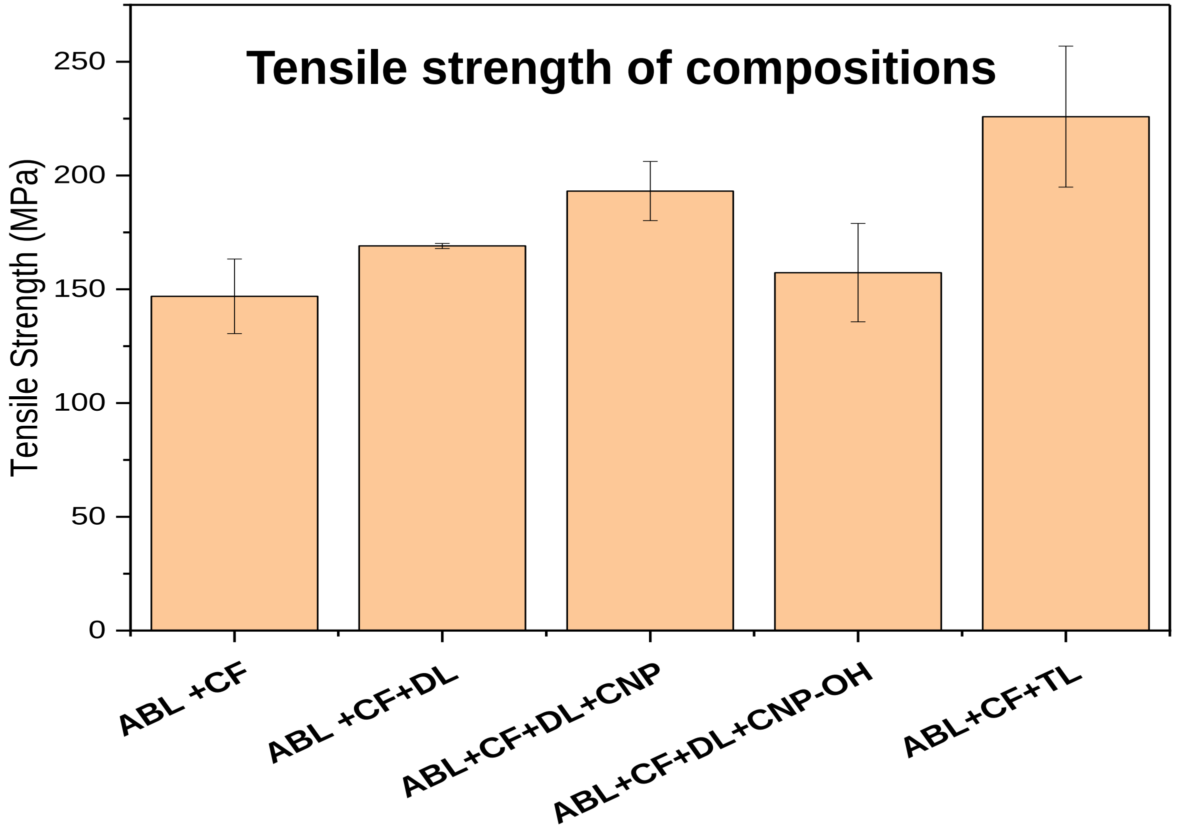
Technical Accomplishments: Long carbon fiber composite

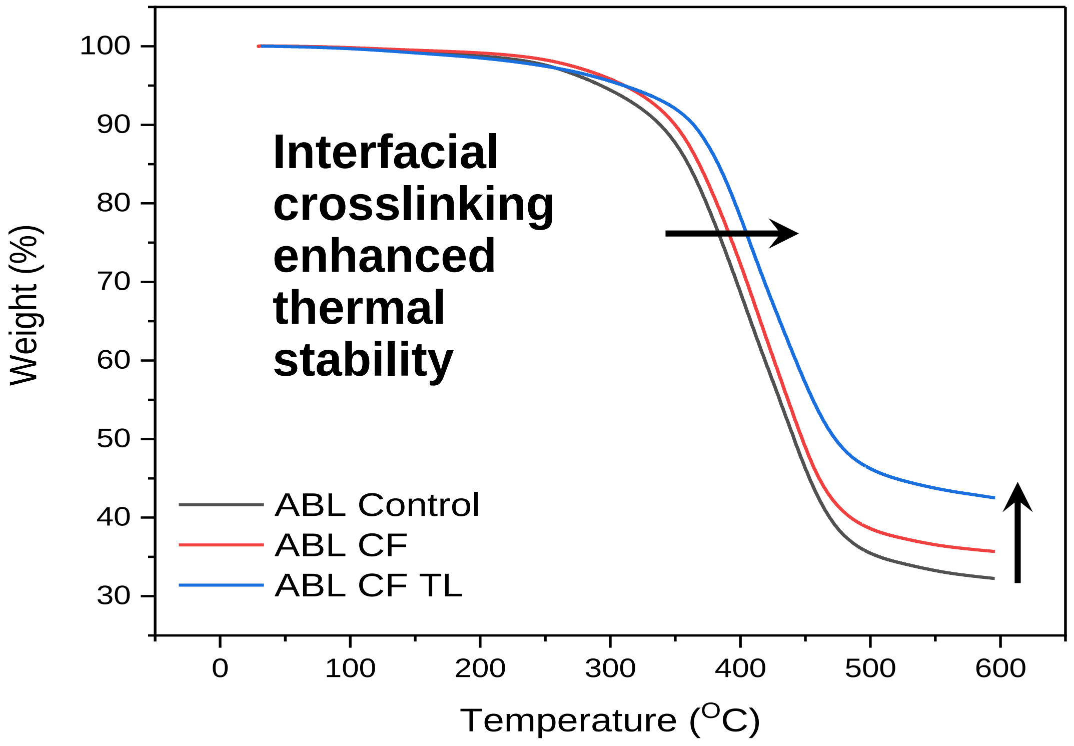


- Long carbon fiber (CF) composites of ABL are stronger material.
- The same DL crosslinker when used at CF-resin interface it is effective at very low CF loading (2-6 wt%).

- Use of 4-12 wt.% carbon fibers delivered compositions with 60-100 MPa tensile strength.
- An ABL composite with 12 wt.% carbon fiber exhibits 1.6% strain to failure.

Technical Accomplishments: Interfacial crosslinkers enhance mechanical properties of unidirectional long fiber composites

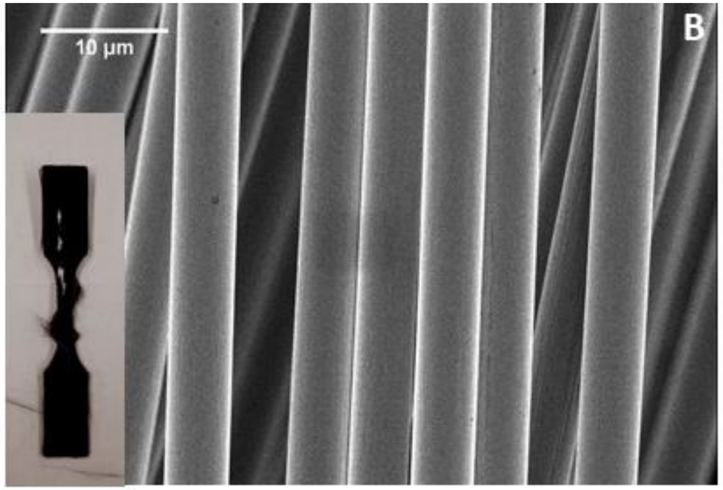




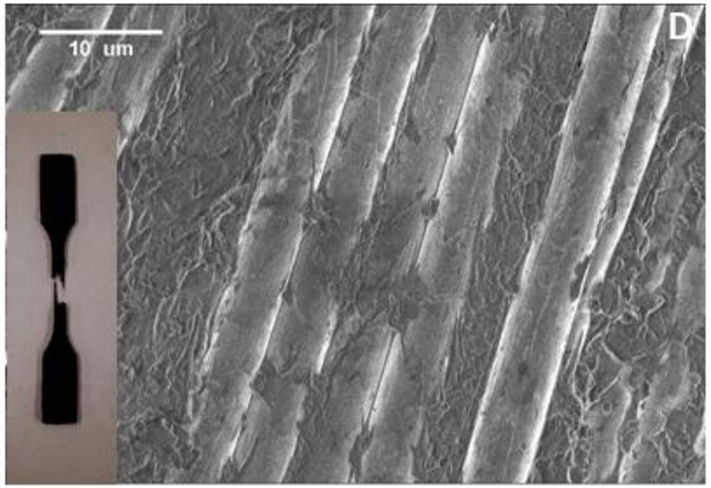
TGA thermogram

- DL is a better crosslinker for bulk ABL.
- For ABL composites (@12 wt% CF), TL is a better fiber-matrix interfacial crosslinker.
- These compositions have low glassy-to-rubbery transition temperature (40-50°C) that assures better damping characteristics.

Technical Accomplishments:
Evidence of interfacial bonding between CF and resin



ABL+CF



ABL+CF+TL

TL is effective as interfacial crosslinker.
TL crosslinked composites (15% fiber loading) fail by fiber fracture (inset images), and ABL stays adhered with CF surface indicating superior interfacial adhesion.

All Milestones met:

Milestones	End Date
Milestone 1: Fabricate composites from resin using ORNL produced low-cost carbon fiber at < 50 % loading	Dec 2019 (Complete)
Milestone 2: Demonstrate 100 MPa strength equivalent in the temperature resistant composite materials	March 2020 (Complete)

Summary

- **Relevance:** This exploratory project aimed significant weight reduction and ease of manufacture of composite engine block.

- **Approach:** Creep resistant composition toughened thermoset as engine block material.

- **Technical Accomplishments:**
  - Fabricated composites from resin using ORNL produced resin and carbon fibers at < 50 % CF content (Dec 2019)
  - Demonstrated 100 MPa strength in the composite materials (March 2020)
  - Developed new interfacial engineering method for CF and resin

- **Future Work:**
  - None – 1-year seed project.

Back up slides

Collaboration and Coordination with Other Institutions

- Program Lead Lab
  - Oak Ridge National Lab (ORNL)
- Scale-up Research Facility – Michigan State University– full scale production testing
- University of Tennessee

Proposed Future Research

- This is a one year exploratory project=no future work

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