Malleable thermoset composites with sub-1-minute dwell times; validation of impact performance and evaluation of the compression forming process.

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Mallinda Inc.

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Project ID: MAT147

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

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Overview

Timeline

Project Start: 9/2018
Project End: 8/2020
Percent complete: 41%

Barriers Addressed[1]

- Low cost, high volume manufacturing of carbon fiber composites, with cycle time < 3 minutes
- Non-destructive evaluation of malleable thermoset composites- specifically acoustic approach to QA/QC
- Enhancing crash energy management

1. 2017 U.S. DRIVE MTT Roadmap Report, sections 4 and 5

Budget

Total project funding: $ 1 M
-DOE share: $ 500,000
-Contractor share: $ 500,000
FY 2018: $325,000
FY 2019: $575,000
FY 2020: $100,000

Partners

- **Mallinda** (lead): Philip Taynton
- **PNNL**: Michael Larche/ Leo Fifield
- **SNL**: Bo Song
- **ORNL**: Robert Norris

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

Relevance

IMPACT

Under 1 minute dwell times-

Non-destructive evaluation-

Crash energy management-

(TMAC)

APPROACH

Precured malleable thermoset prepregs

Acoustic microscopy towards QA/QC

Material development informed by split Hopkinson high speed impact testing, & automotive crash-worthiness testing

OBJECTIVES

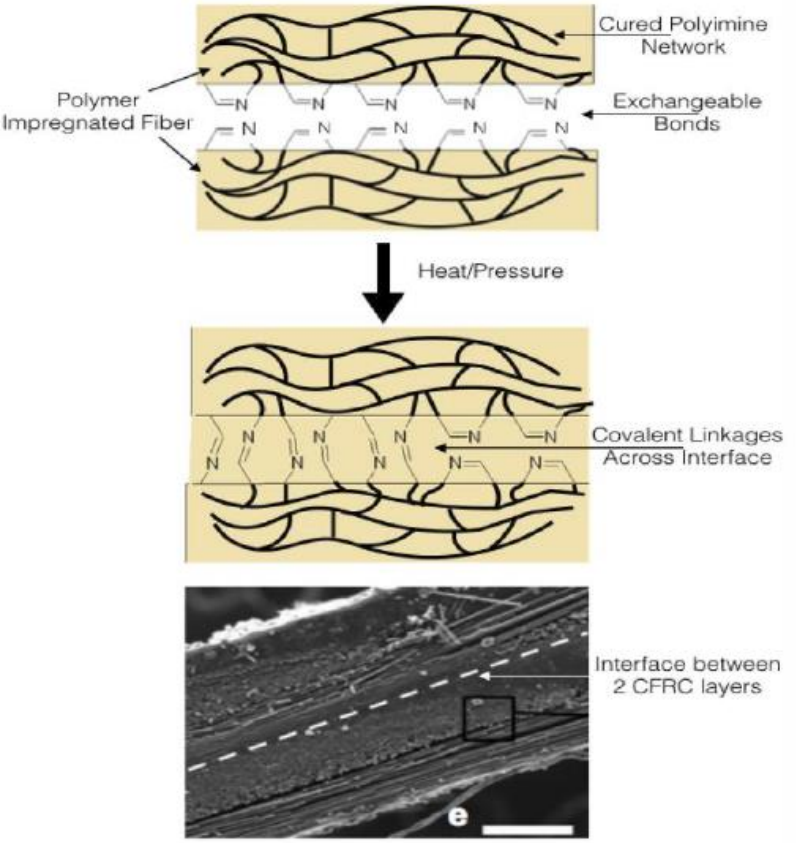
- Develop malleable thermoset resin/fiber combinations for improved crash energy management
- Study the relationship between compression forming conditions, acoustic response, and defects & voids in the composite
- Utilize high speed split-Hopkinson impact testing to characterize candidate composite materials
- TMAC results to demonstrate feasible >20% lightweighting of CEM structures vs. Al

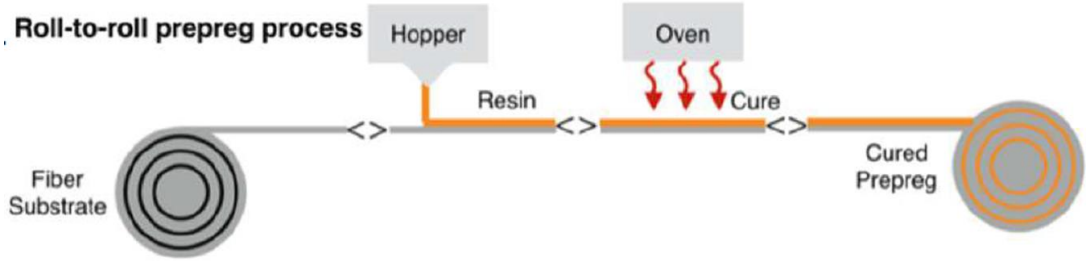
Approach – Resin Background

Malleable thermoset polymers, a.k.a. vitrimers

Covalent bonds exchange when the material is heated above its glass transition temperature.

Thermoset properties with thermoplastic processing





Approach – Hybrid fiber

Objective:
Combine fiber types for combination of lightness and crash energy management

Fiber	Density (g/cm^3)	Tensile Strength (GPa)	Modulus (GPa)	Elongation at break (%)
Carbon	1.75	7	600	1
Glass	2.49	4.7	86	5.7
Steel	8	0.5	210	5-15
UHMWPE	0.97	3.3	120	3.8

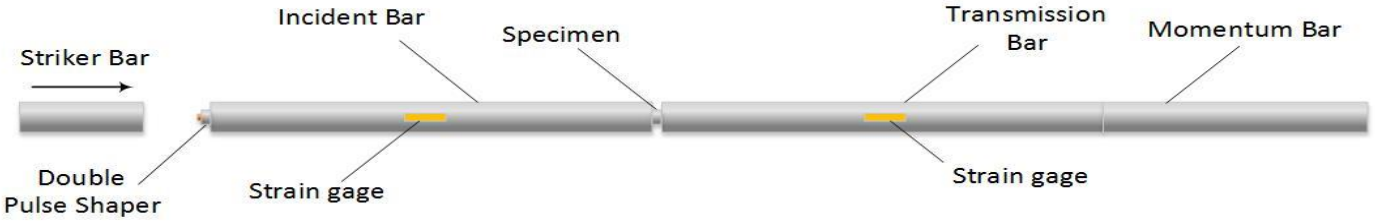
Approach – Impact testing

Objective:

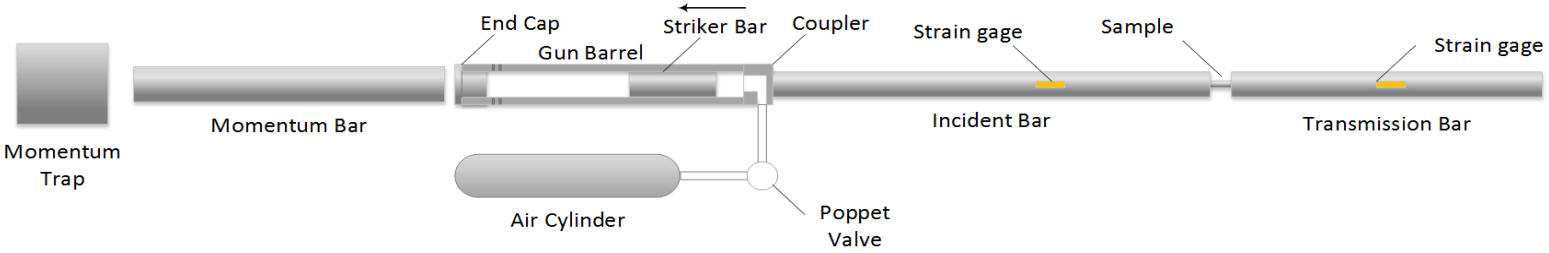
Characterize material response through impact over a range of speeds:

Split Hopkinson Bar (or Kolsky Bar)

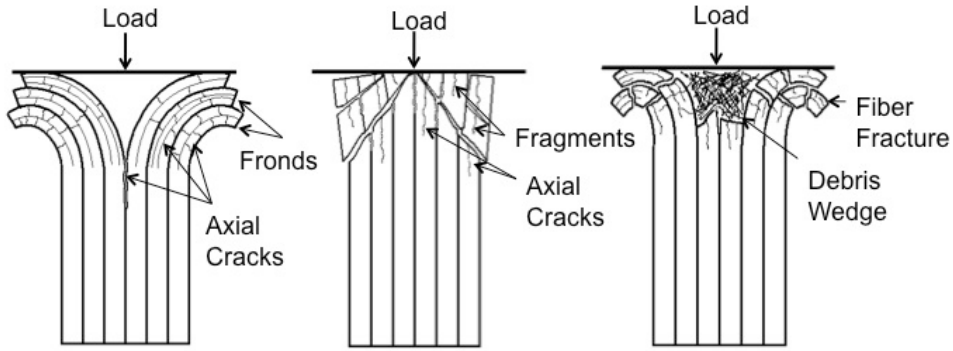
Compression

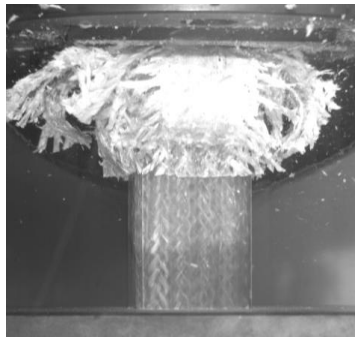


Tension



Test Machine for Automotive Crashworthiness (TMAC)





Approach – Impact testing

- **Test Machine for Automotive Crashworthiness**
  - Tube crushing or tension at 100's of kN
  - Constant velocity to 8 m/s (18 mph) thru 25 cm stroke
- **High speed coupon tester**
  - Coupon tensile testing at loads to 22 kN
  - Constant velocity to 18 m/s (40 mph)
- **High Speed Video and Digital Image Correlation for Failure Analysis**
- **TMAC Specifications:**

Physical:

- 1 m daylight
- 490 kN actuator cap. (static)
- 250 mm stroke
- > 490 kN side-load capacity
- Attachable 450 kg mass

Operating:

- No load: 230 mm travel at 8 m/s
- 113 kN: 230 mm travel at > 6 m/s
- 267 kN: 115 mm travel at 6 m/s
- Target velocity constant within ± 10% for 115 mm

TMAC Machine

Approach – Acoustic analysis

Use Ultrasonic Analysis to optimize composite stamping process

- **Task 4.2: Ultrasonic testing and analysis**
  - Determine baseline ultrasonic responses of materials and components
  - Evaluate signatures from induced defects and compare to baseline
  - Verify defects geometries and validate ultrasound using destructive analysis
  - Provide measurement data from flat, defect-induced and crash test samples
- **Task 4.3: Reporting on Ultrasonic analysis**
  - Report analysis of material signatures and defects
  - Discuss limitations, potential and appropriateness of techniques
  - Report recommendations for technique refinement and future work

Approach - Milestones

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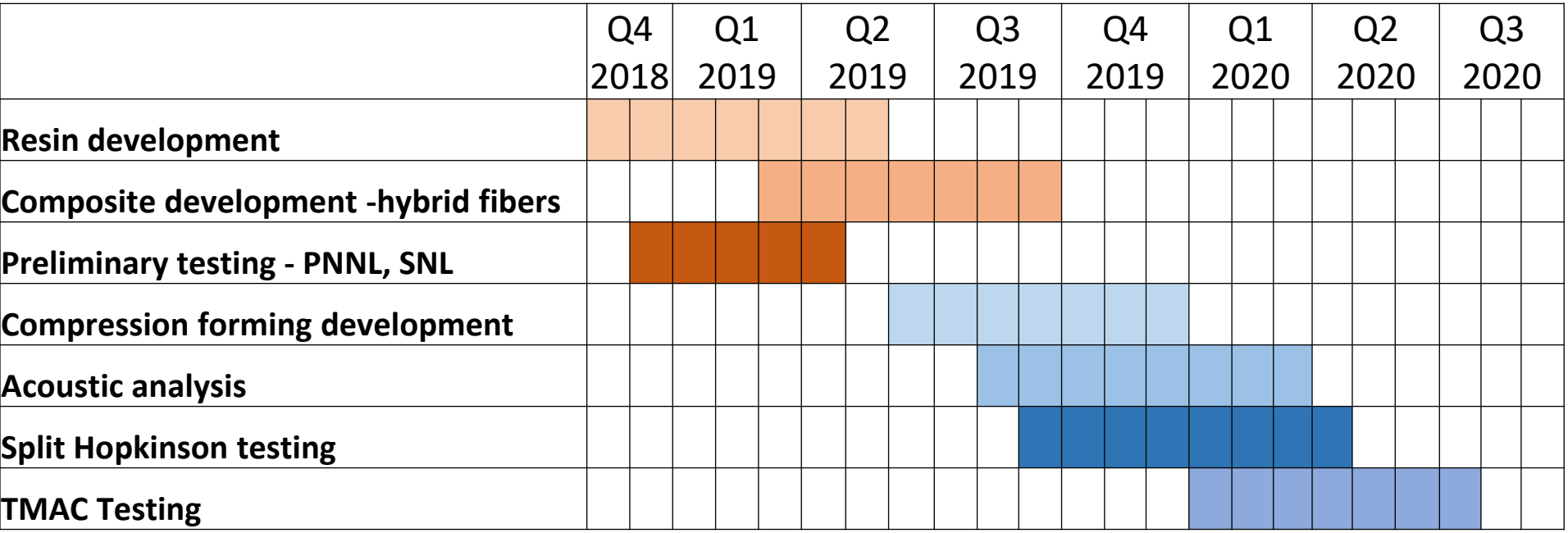


Technical Progress- Resin Development

Initial targets:

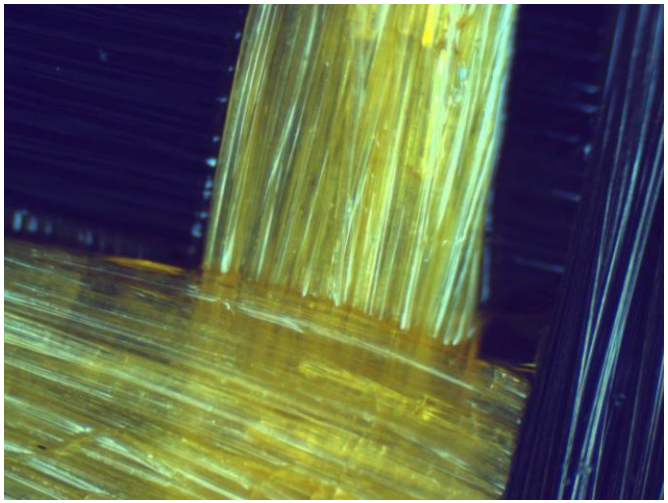
- *Fiber- and tool-limited compression conditions*
- *Glass transition temperature in range*
- *Minimum Interlaminar shear strength (ILSS)*
- *Maximum moisture absorption (2 h boil)*
- *Adhesion to ultrahigh molecular weight polyethylene (UHMWPE)*

Efforts:

>70 unique formulations prepared

Accomplishments:

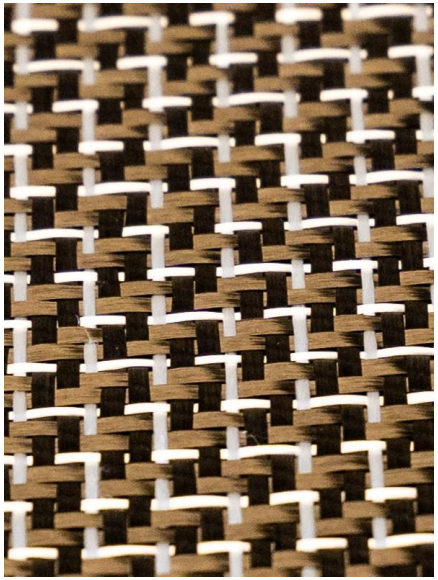
- *Successful initial resin development*
  - *Hit targets*
  - *Impregnates UHMWPE fibers well*



Technical Progress- Fiber/Composite

Acquired partners/suppliers for:

- *Steel Fiber (range of thicknesses & properties available)*
- *UHMWPE (range of weaves including hybrid fibers with CF)*

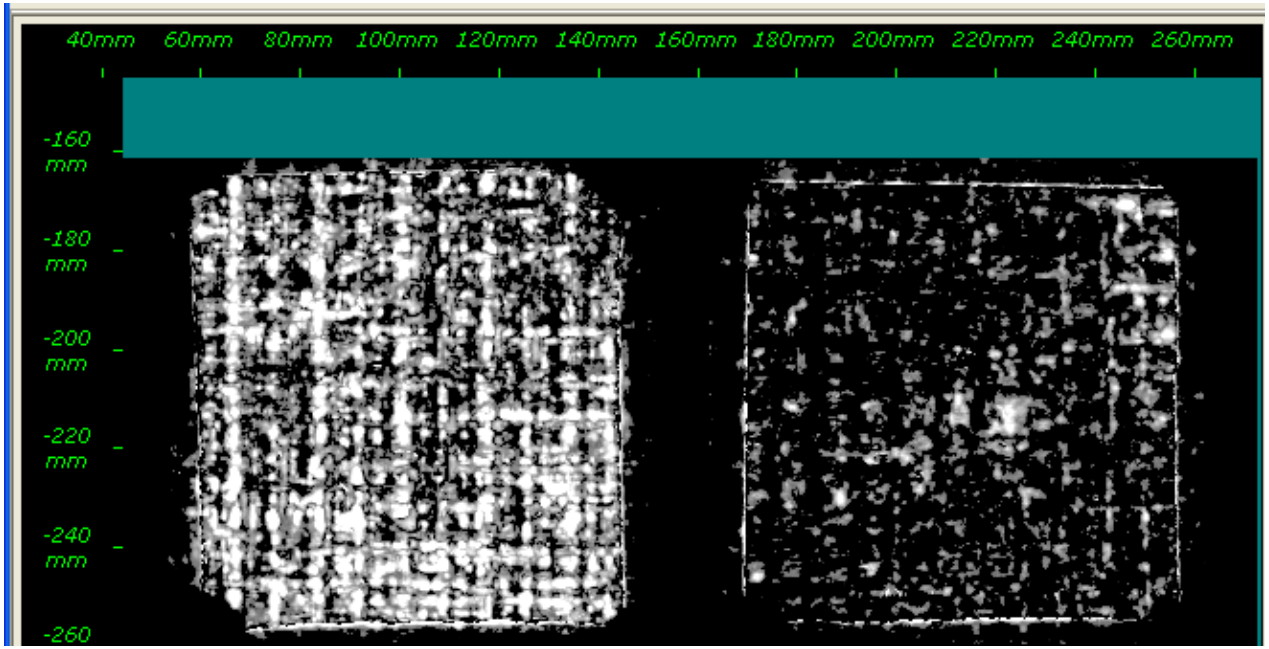


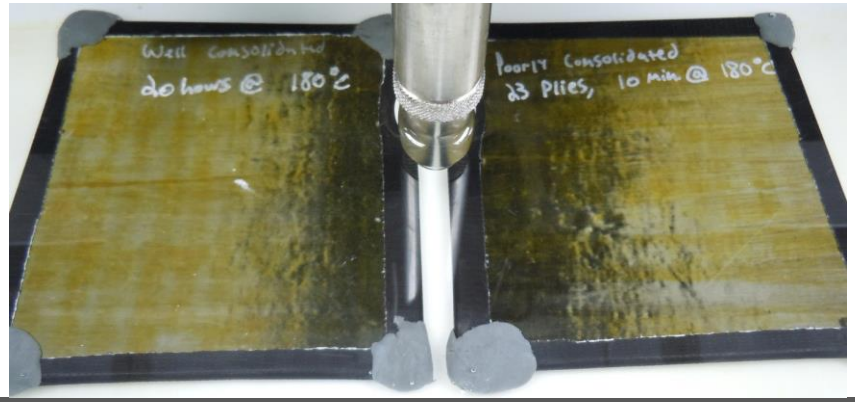
Hybrid composite before ILSS

Hybrid composite after ILSS

Technical Progress- Acoustic Testing

10 MHz C-scan Results





- Well consolidated sample, shown on the left, shows good reflection of sound off of the back surface – this is indicated by the high amplitude reflections (white pixels) observed in the gated window.
- Poorly consolidated sample, shown on the right, shows scattering of the sound through the depth of the sample which is observed by the lack of reflection (black pixels) off the back surface.

Response to previous reviewers' comments

This is a new project and was not previously reviewed.

Collaboration & Coordination

Pacific Northwest National Lab:
Leading Acoustic method development
-Michael Larche/ Leo Fifield

Sandia National Lab:
Leading split Hopkinson bar high speed testing
-Bo Song

ORNL:
Leading TMAC testing
-Robert Norris

Remaining Barriers

- Malleable thermosets are still poorly understood- especially critical is the dynamics of bond exchange during consolidation at the interface

- High speed impacts can induce brittle behavior in thermoset resins, decreasing the specific sustained crushing stress. The theory is that inclusion of higher strain fibers will restrict brittle failure modes, improving crash energy management.

Proposed Future Research

- Compression forming development- establish correlation with C-scan artifacts vs. mechanical performance
- High Speed impact testing of various hybrid fabric composite designs & lay-ups for down-selection
- TMAC testing and correlation with high speed impact results

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

Summary

- Malleable thermoset resins reformulated to meet the specific challenges of hybrid fiber composites
- Initial samples & preliminary testing performed for Acoustic & High Speed Impact testing
- The bulk of the project remains ahead. Essential questions of acoustic analysis of malleable consolidation efficiency & the efficacy of hybrid fabric composites in constraining crash failure modes remain untested.