Low Cost Resin Technology for the Rapid Manufacture of High-Performance Fiber Reinforced Composites

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Project ID: mat168

Overview

Timeline

- Project Start: July 1, 2019
- Project End: June 30, 2020
- Percent Complete: 80%

Budget

- Total Project funding: $200,000
- Future Funds Anticipated: Applied for Phase II SBIR Funding

Barriers and Technical Targets

- Lack of cost-effective systems and designs, including tooling and high-volume processing
- Joining technologies for carbon fiber composites to each other or within a multi-material system are inadequate
- The ability to bond the fiber to the resin is inadequate to take full advantage of the inherent properties of the fiber, *USDRIVE Materials Technical Team Roadmap October 2017, section 6*

Partners

- IACMI-SuRF
- Project lead: Trimer Technologies, LLC

Relevance

- Vehicle Technologies Office targeting a 25% glider weight reduction at less than $5/lb-saved by 2030
- DOE projects use of lightweight components and high-efficiency engines in only one-quarter of the U.S. fleet could save more than 5 billion gallons of fuel annually by 2030.
  - This translates to a reduction of ~100 billion pounds of CO_2 emissions annually and would further contribute to reducing N_2O emissions.
- Composite usage in automotive applications is growing at a CAGR of 7.6% reaching $26 billion in 2025

Opportunity

- Carbon fiber composites provide 50-70% weight savings over steel
- New materials with both rapid cure and significantly improved mechanical properties are required
- Trimer's resin has shown <1-minute cycle times
- Trimer could achieve the DOE's 2050 goal for cycle time under 1 min

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Milestones

Month/Year	Description of Milestones and Go/No-Go Decisions	Status
October 2019	Characterize resin properties and design catalyst for low cycle time HP-RTM	Completed
November 2019	Demonstrate low cycle time manufacturing of composite parts through liquid compression molding (LCM)	Completed
November 2019	Demonstrate cycle times under 3 minutes	Completed
December 2019	Develop inhibitor to expand the processing window of resin	Completed
February 2020	Demonstrate internal mold release for HP-RTM Manufacture of composites	Completed
June 2020	Mold Composites at IACMI-SuRF using HP-RTM	On Schedule

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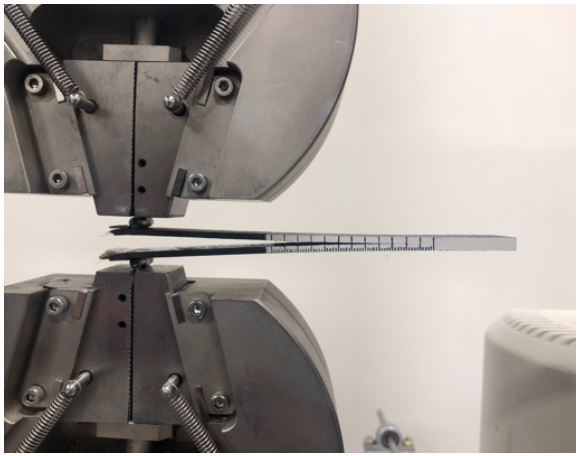
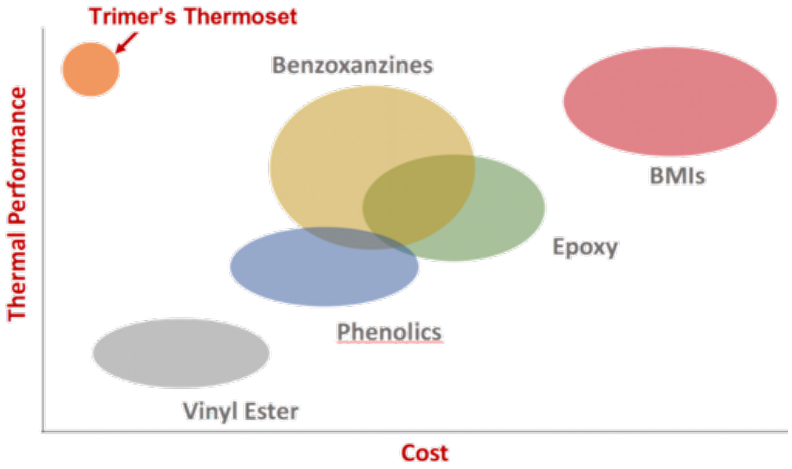
Approach - Resin

- Trimer has developed low cost high strength polymers which can enable reduced cycle times
- Polymer exhibits:
  - Low viscosity for rapid infusion
  - Rapid Cure - as fast as 30 sec at 140°C
  - High strength, stiffness and toughness
  - Non-flammable
  - High glass transition temperature
- Phase I SBIR effort seeks to demonstrate HP-RTM cycle times under 3 min and provide a path to cycle times under 90 sec





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Approach - Resin Transfer Molding

- HP-RTM injects liquid resin at high pressure into a closed mold which is heated to cure the resin
  - Resin injected at pressures around 100 Bar (~1,500 PSI)
- Viscosity dictates infusion time and can lead to deformation of the weave, known as fiber wash if too high
- Rapid cure required to enable low cycle time and high part count
- Used for complex and high-performance parts with continuous fibers
- Performance can greatly exceed sheet molding compound (SMC)

Images from BMW

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Approach - Resin Performance Comparison

- Trimer has developed low cost, low viscosity and high strength polymers which outperform competing resins while enabling reduced cycle times

Material Property	Trimer Technologies' RTM Resin	Dow Voraforce 5300	Huntsman Araldite LY 3585 / Aradur 3475	AOC VIPEL FO10 BIS-A VE	Reichhold DION IMPACT 9102-75
Polymer Type/Chemistry	-	Epoxy	Epoxy	Vinyl Ester	Vinyl Ester
Glass Transition, Tg Dry ºC	375	120	110	130	99
Tensile Strength (MPa)	105	68	77.5	88	79.2
Tensile Modulus (GPa)	4.0	2.8	2.8	3.2	2.9
Tensile Strain to Failure, %	4.0	7	9	6.2	4.5
Compressive Strength (MPa)	149	-	-	121	108.9
Flexural Strength (MPa)	140	-	-	153	144
Fracture Toughness, K_{1C} (MPa/$m^{1/2}$)	1.03	1.22	0.85	0.6	-
Viscosity (cP at 23 ºC)	200	500	1,000	3,200	170

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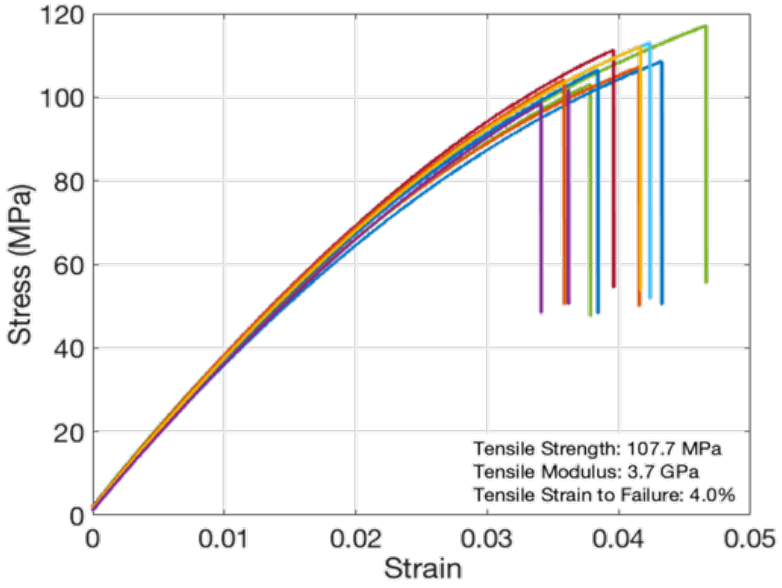
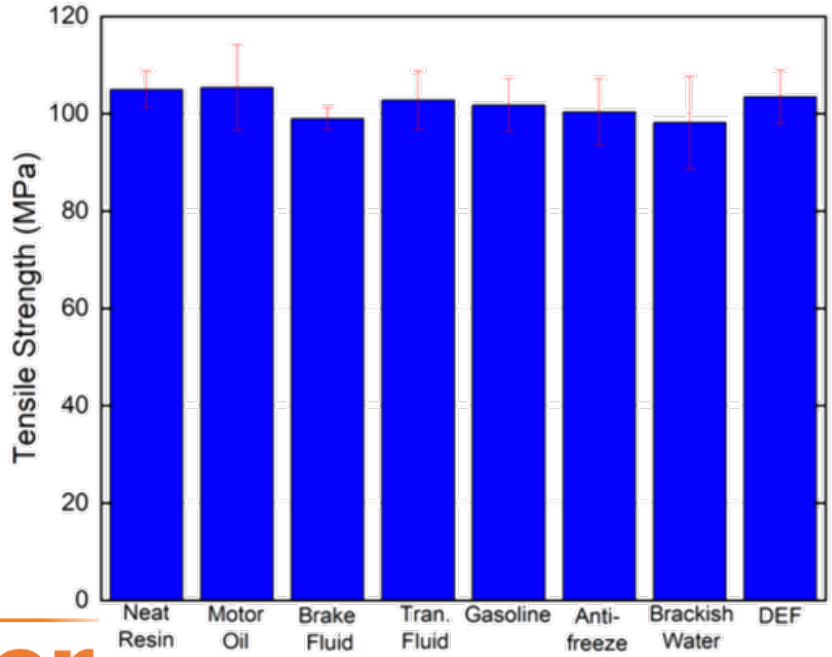
Technical Progress - Resin Properties

- Tensile testing used to measure resin properties under various treatments
- Resin exhibits aerospace grade properties and high strain to failure



- Common automotive fluids show no impact on resin properties



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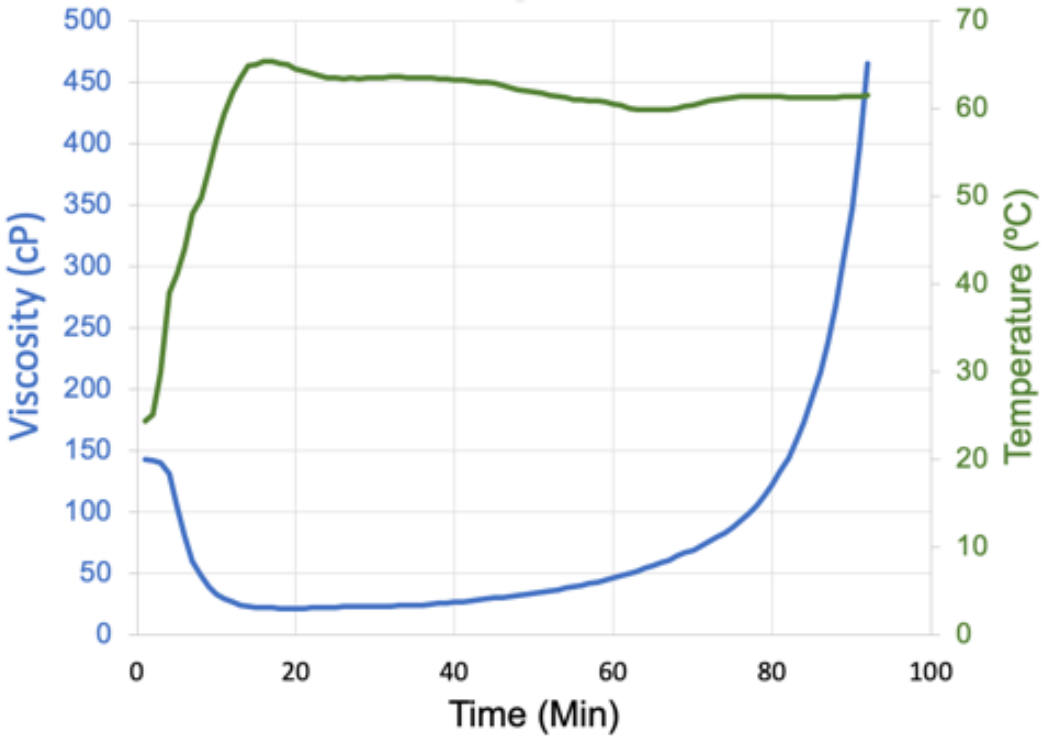
Technical Progress - Resin Properties

- HP-RTM is greatly accelerated using low viscosity resins which can rapidly infuse the fiber preform
  - Reduces fiber wash
- Trimer's resin has a room temperature viscosity of ~150-250 cP
- Resin can be heated to reduce viscosity further while maintaining gel-time
- At 60° C the viscosity drops to 25 cP with a 90-minute gel time
- Extended gel time important for spray molding or infusion of large parts such as wind turbine blades



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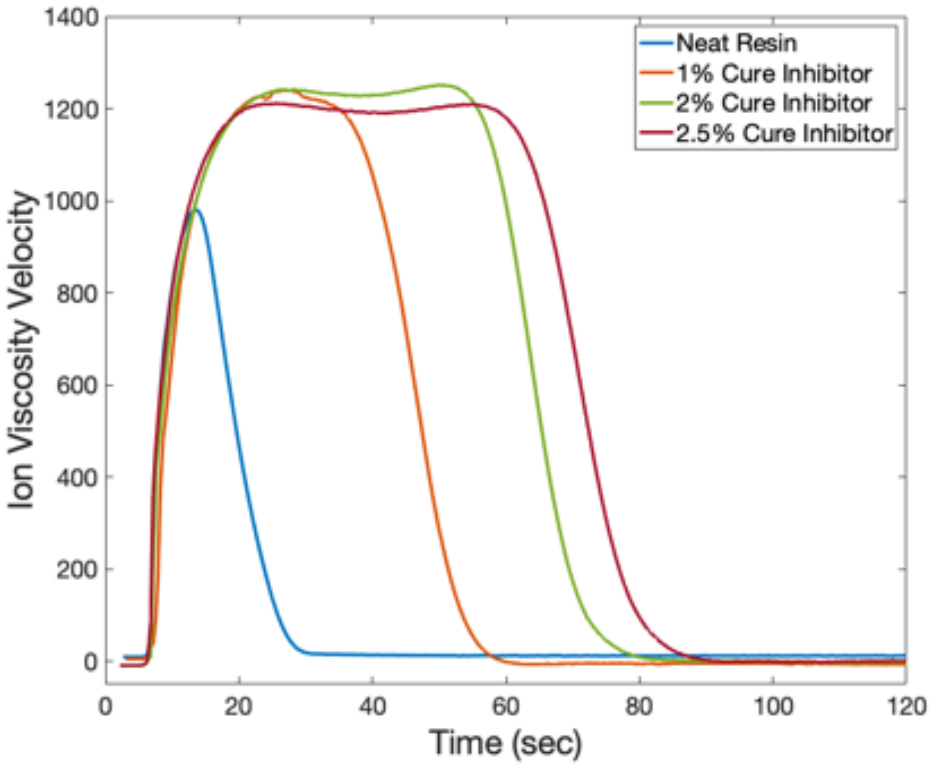
Technical Progress - Cure Kinetics

- Wet compression molded 3.5 mm thick fiberglass panels in 30 seconds
- Full cycle time of 45 sec. which exceeds DOE 2050 goal of <1 minute
- Many currently used molding tools are designed for slower curing resins
- Reaction rate may lead to polymerization prior to full infusion of the resin
- Trimer developed an inhibitor which can expand the processing window
- Increased the cure time of a 3.5mm panel from 30 sec to 90 sec
- Can expand the processing window further if required



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Technical Progress - Cure Kinetics

- Structural chassis components require the capability to rapidly cure thick specimens
- Trimer demonstrated curing of 30 mm thick composites in under 120 sec
- Cycle time could be more than 5 times faster than state of the art resins
- Cure rate is unprecedented and enabled by low exotherm
- Resin and fiberglass preform were added to the mold cold and therefore cure time could be further reduced

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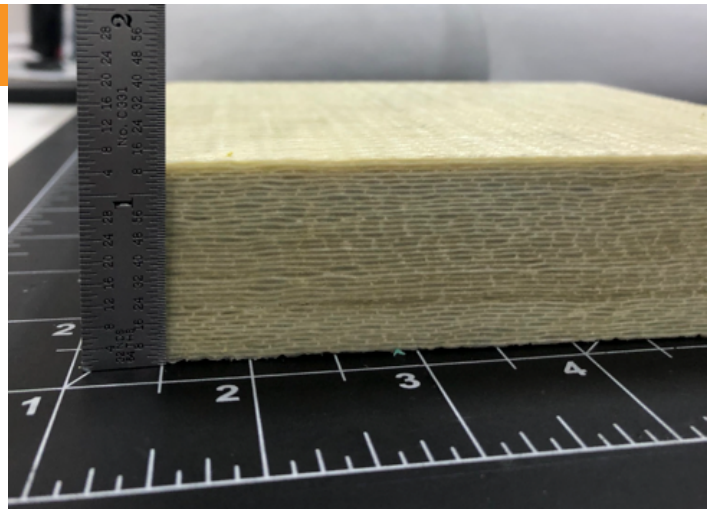
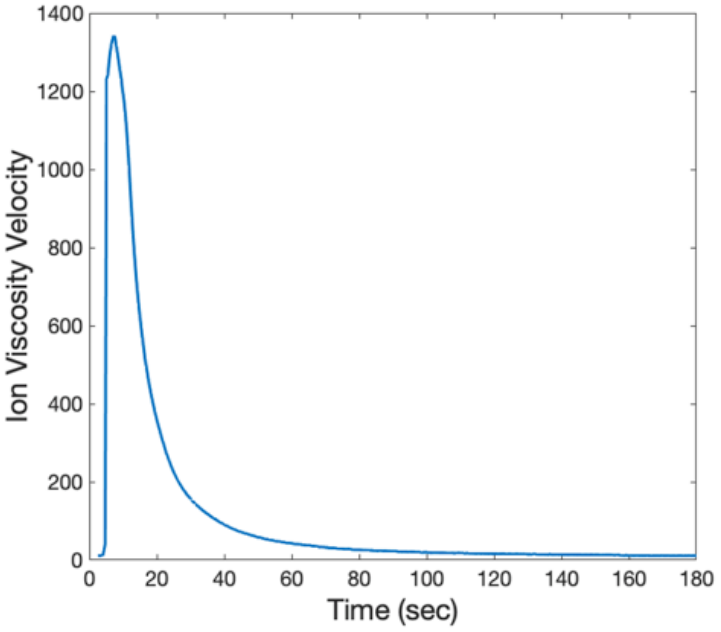
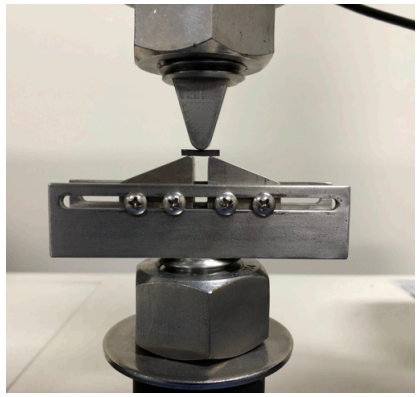
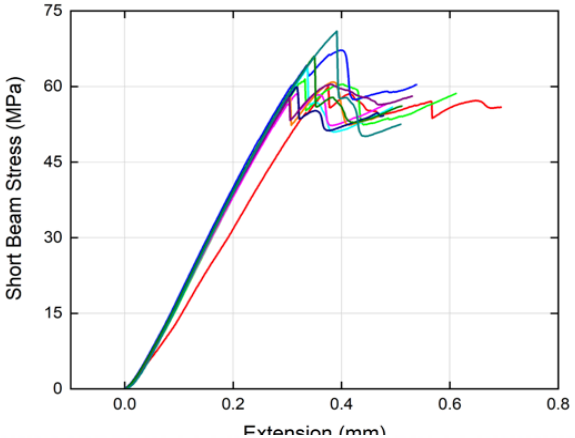


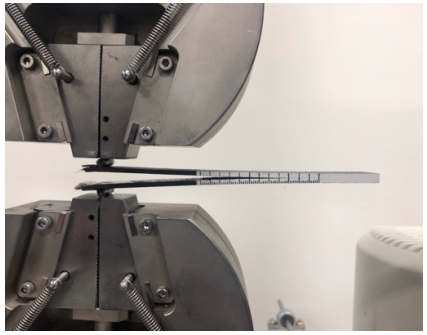


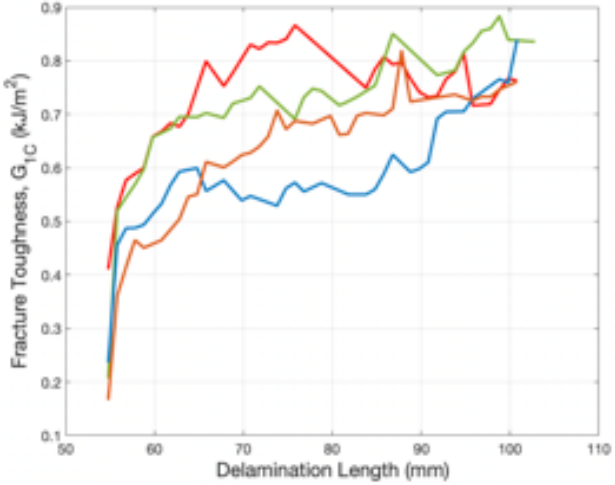
Technical Progress - Composite Properties

- Composite panels were tested for short beam strength and Mode I fracture toughness
- Short beam strength measured to be 62.9 +/- 3.96 MPa
- Fracture toughness is important to the fatigue life of laminated composites
- Mode I fracture toughness measured to be ~0.5 – 0.9 kJ/m^2 which greatly exceeds existing high Tg polymers
- Composites cured under rapid conditions









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Technical Progress - Fire Resistance

- Trimer tested the neat polymer for horizontal flame spread (ASTM D635) and passed the horizontal burning test after 30 sec exposure to flame
- To further demonstrate the polymer's nonflammable properties the polymer was subjected to a 60 second burn time under more intense flux than the ASTM

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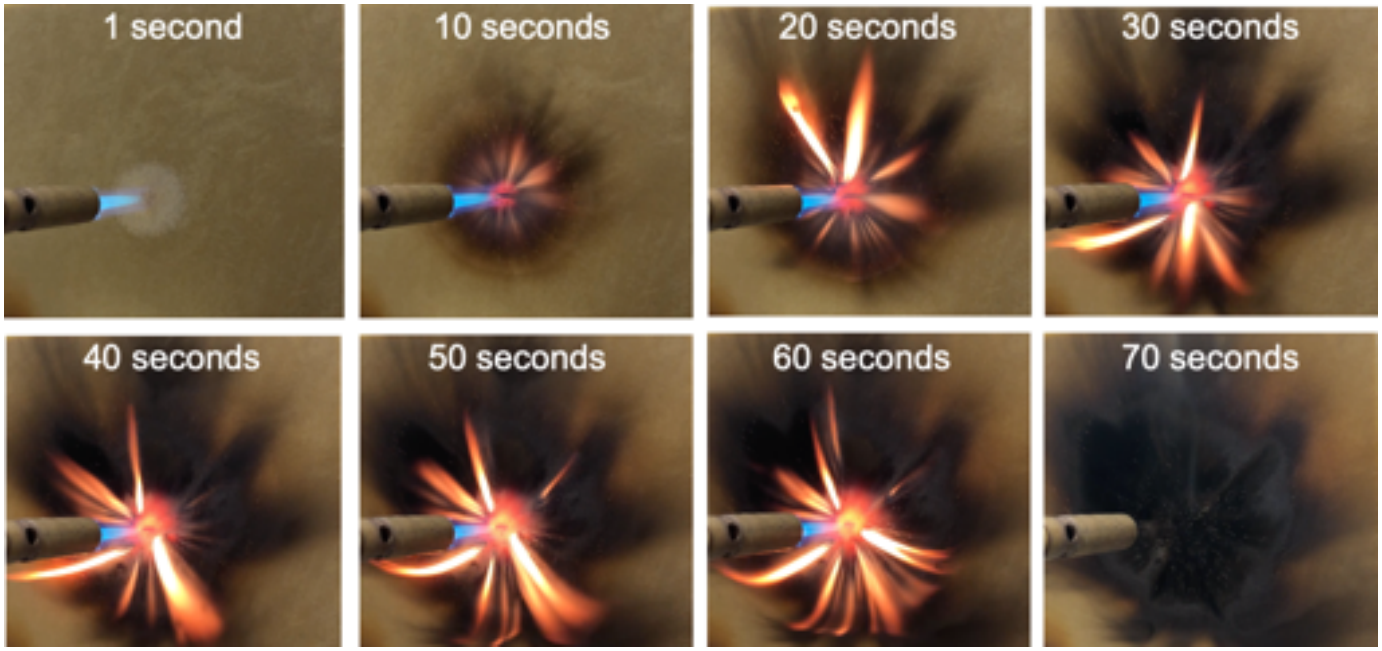
Technical Progress - Fire Resistance

- Fiberglass reinforced composite panel (3mm thick) exposed to propane torch for 60 sec then allowed to self extinguish



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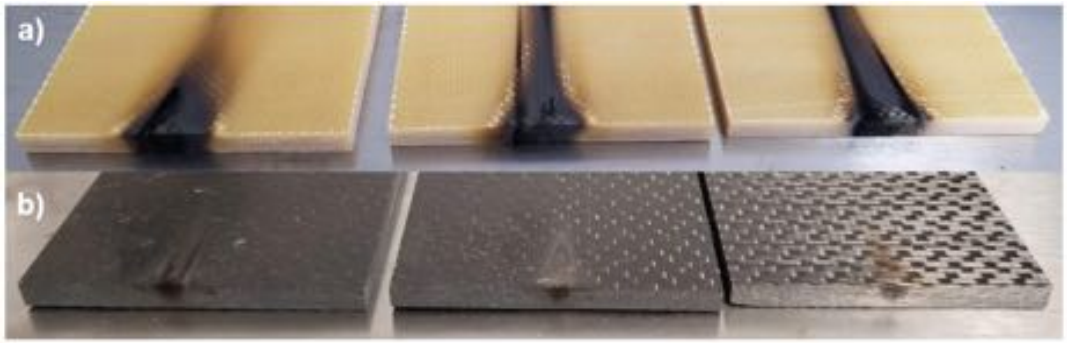
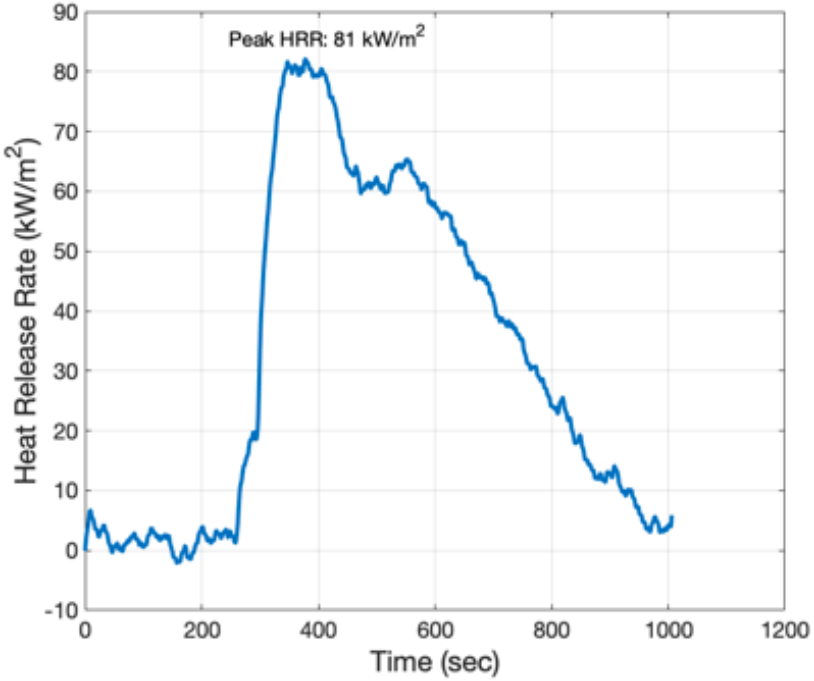
Technical Progress - Fire Resistance

- Fiberglass panels tested at UDRI in accordance with ASTM E-1354/ISO 5660
- Cone calorimeter with 50 kW/m^2
- Results showed a peak heat release rate of 81 kW/m^2
- Time to ignition was measured at 258 sec.
- Average heat release rate was 46 kW/m^2
- Aeroblaze Laboratory tested vertical flame spread according to ASTM D3801





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Advantages of Trimer's Resin

- Trimer's polymer offers:
  - Cycle time under 1-minute demonstrated
  - Roughly an order of magnitude lower viscosity than current HP-RTM resins allowing rapid infusion, minimum distortion of the fiber preform and low void content
  - Nearly two times the tensile strength of Dow's VORAFORCE epoxy and without reinforcement
  - Equal strength to 30% fiberglass SMCs
  - Tg more than twice the value of current state of the art materials
  - Non-flammable without additives

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Responses to Previous Year Reviewers' Comments

- This is a new project and was not previously reviewed.

Collaboration and Coordination with Other Institutions

- IACMI-SuRF is a subcontractor to our Phase I effort and is providing access to their HP-RTM system and press
- We have formed a close collaboration with OEMs during the Phase I effort with them providing access to facilities, tooling and testing
  - Our partner has provided extensive mechanical testing and fatigue testing of specimens out to 10M cycles with our composite panels showing exceptional fatigue resistance
- We have collaborated with TPI Composites over the past two years with TPI providing manufacturing and testing of composites utilizing our resin

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Remaining Challenges and Barriers

- Trimer has demonstrated the capability to achieve molded continuous fiber composites in under 60 seconds, a critical lightweighting goal
- Commercialization of Trimer's resin requires extensive process development and material testing necessitating further work
- Process development necessitates rheology and kinetic studies to enable modeling
- Internal mold release (IMR) agents must be developed to enable continuous HP-RTM manufacturing
- Resin adoption in high volume automotive manufacturing requires scale up of the manufacturing process
- Component level testing will be required for the commercialization of Trimer's resin in production automotive components therefore requiring close partnerships with OEMs

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Proposed Future Research

- Trimer has applied for Phase II funding to further develop our resin system and demonstrate it in production environment
- We have formed collaborations with OEM's and Tier 1 manufacturers to development the processing requirements for the technology and to characterize material properties
- Future research efforts will focus on:
  - Rheology to enable process modeling
  - HP-RTM process development on flat plates and production tooling in coordination with OEMs
  - Characterization of material properties when subjected to various automotive fluids and environments
  - Evaluation of the fire resistance for application to battery enclosures

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Summary

- Carbon fiber composites provide 50-70% weight savings over steel providing a critical technology to enable lightweighting in vehicles
- Trimer Technologies has developed a revolutionary low viscosity thermosetting resin which can enable rapid cure and achieves excellent mechanical properties
  - Mechanical properties greatly exceed state of the art automotive resins
- Polymer exhibit very high glass transition temperature (up to 235º C) which can enable body in white structures
- Phase I has demonstrated composite panel can be molded in under 45 sec
  - Cycle time exceeds the DOE's 2050 goal for cycle time under 1 min
- We have developed cure inhibitors to reduce the reaction rate allowing extended molding times for larger structures
- Testing has shown the resin to be non-flammable and offers FST performance exceeding the needs of the automotive industry
- Have formed collaborations with OEMs and Tier I manufacturers to further develop the technology through Phase II funding

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Questions?

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