Snap Cure Infusion Resin System for Fire Resistant Aircraft Structures and Interiors

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Composite Aircraft Interiors

- The global aircraft cabin interior composites market is projected to grow at a healthy rate over the next five years to reach US$ 2,020.8 million in 2024
- Aircraft interiors require FST properties with low cost and efficient manufacturing processes
- Currently used phenolic resins lack mechanical strength, cure via a condensation reaction and utilize toxic chemicals
- Trimer's resin technology provides both properties and is ideally suited for this application

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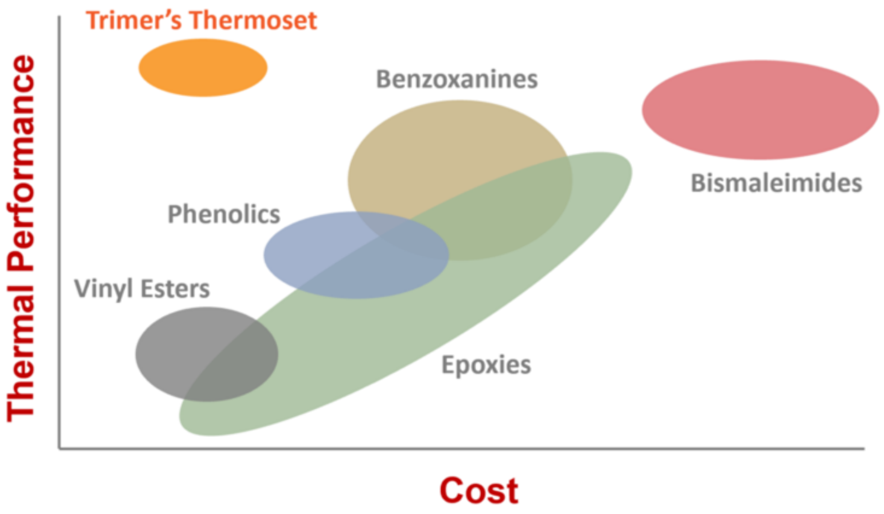
Advanced Resin Technology

- 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 140ºC
  - High strength, stiffness and toughness
  - Non-flammable
  - High glass transition temperature >400ºC



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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 °C	225	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 °C)	200	500	1,000	3,200	170

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Resin Performance Comparison

- Trimer's resin outperforms competing 350º F autoclave cured resins while enabling reduced cycle times

Material Property	Trimer's Resin	Hexcel 8552	Hexcel M74	Hexcel 3501-6	Cytec 5250 BMI	Hexcel F650 BMI	Cytec 2237
Polymer Type/Chemistry	-	Epoxy	Epoxy	Epoxy	BMI	BMI	Polyimide
Glass Transition, Tg Dry ºC	225	200	194	210	271	316	338
Tensile Strength (MPa)	105	120	83	45.5	103	-	38.6
Tensile Modulus (GPa)	4.0	4.6	4.1	4.2	4.6	-	3.9
Tensile Strain to Failure, %	4.0	1.7	-	1.15	4.8	-	1.5
Fracture Toughness, K_{1C} ($MPa/m^{1/2}$)	1.03	1.34	-	0.67	0.85	0.46	0.33
Flexural Strength (MPa)	140	-	69	-	163	-	-
Compressive Strength (MPa)	149	-	-	-	-	-	-
H_2O Equilibrium Absorption	2.5%	3.1%	-	3.1%	4.2%	4.3%	4.4%
Cure Schedule	<60 sec at 250 ºF	1h at 250ºF then 2h at 350ºF	2h at 350ºF	1h at 240ºF then 2h at 350ºF	6h at 375ºF then 6h at 440ºF	4h at 350ºF then 8h at 450ºF	3.5h at 425ºF then 475 ºF for 1h then 600 ºF for 3.5h

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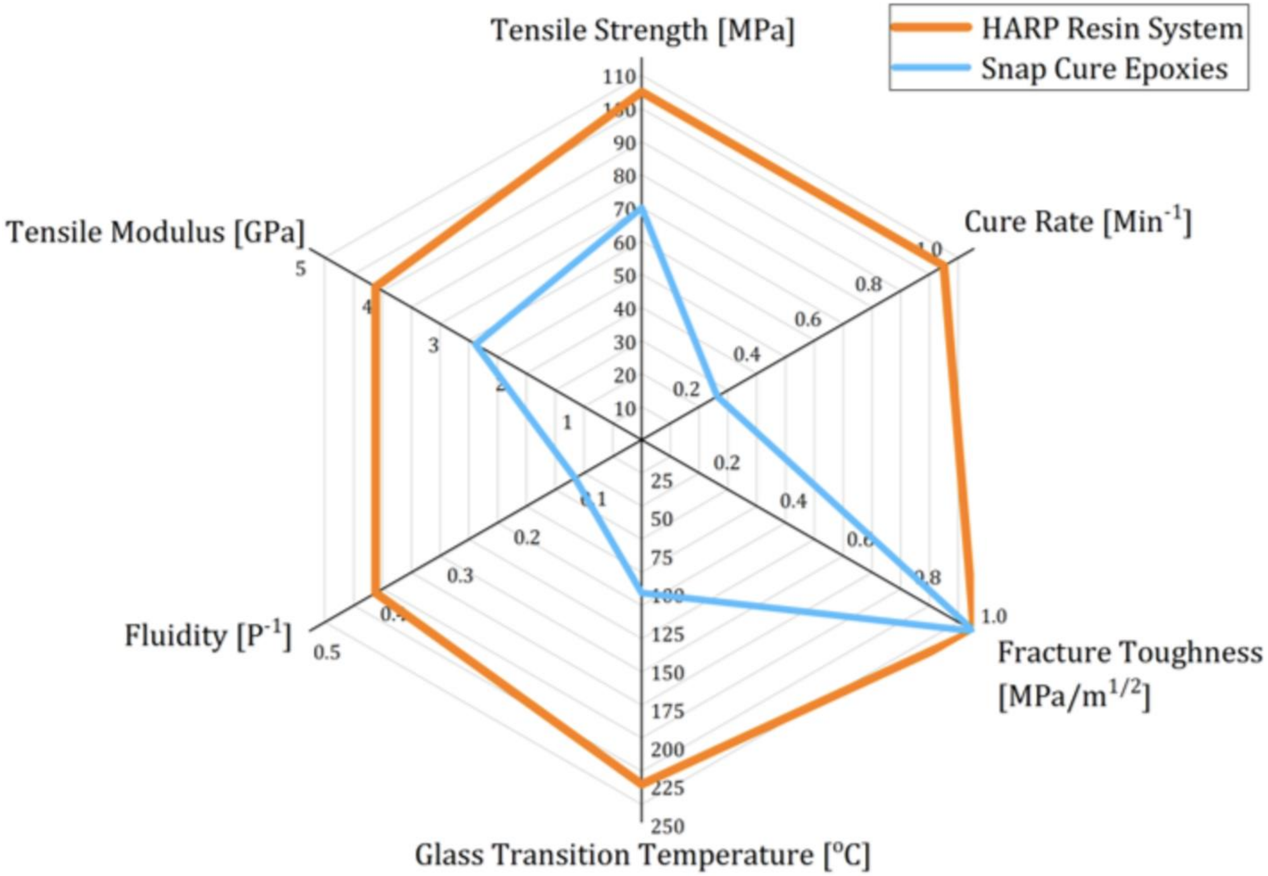
Tensile Strength [MPa]
HARP Resin System
Snap Cure Epoxies
Cure Rate [Min-1]
Tensile Modulus [GPa]
Fluidity [P-1]
Fracture Toughness [MPa/m1/2]
Glass Transition Temperature [°C]

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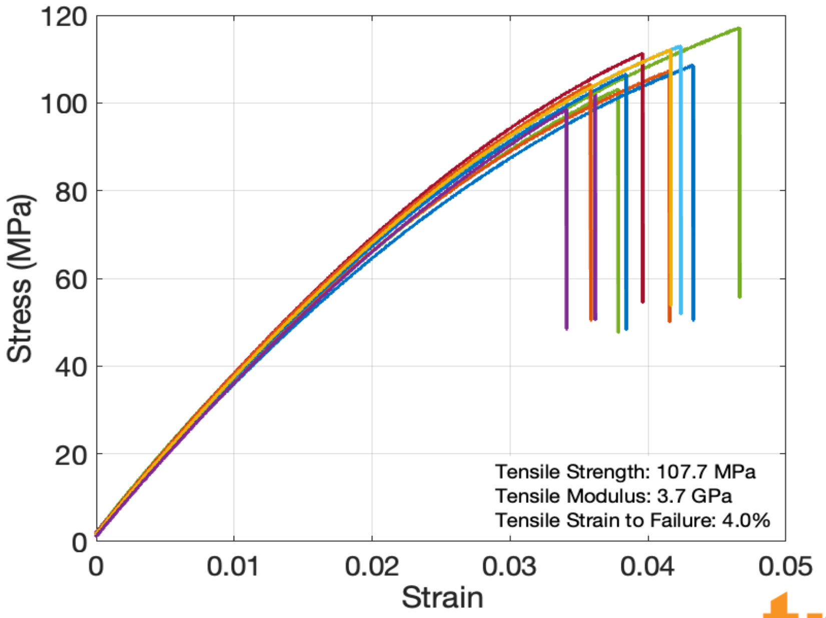
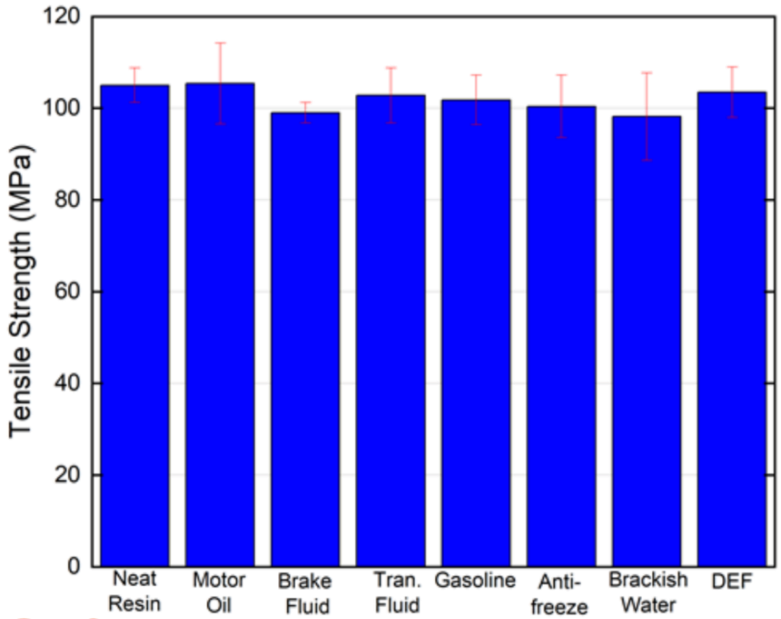
Resin Properties

- Resin exhibits aerospace grade properties and high strain to failure



- Common automotive fluids show no impact on resin properties



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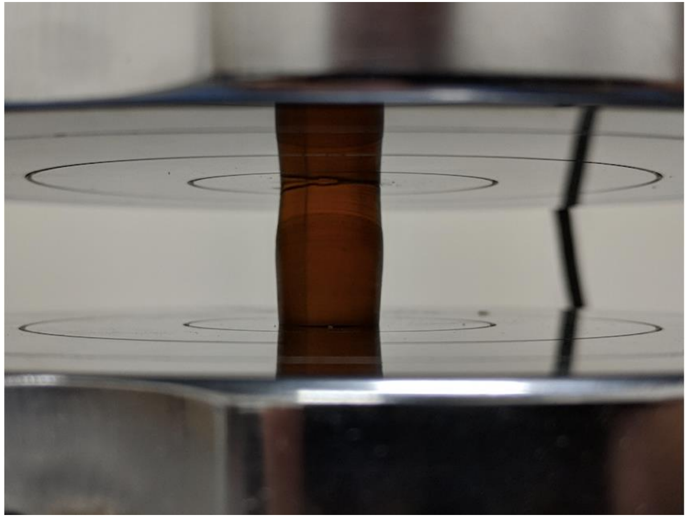
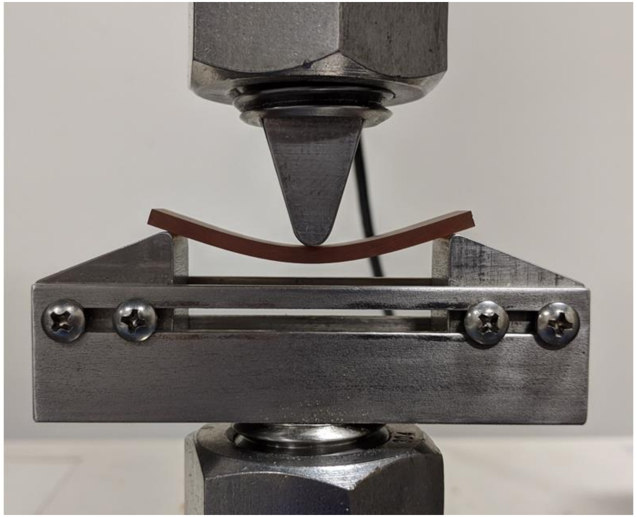
High Strength and Strain to Failure

- High flexural strength and compressive strength with high strain to failure
  - Compressive strain to failure ~9%
  - Flexural strain to failure ~5%





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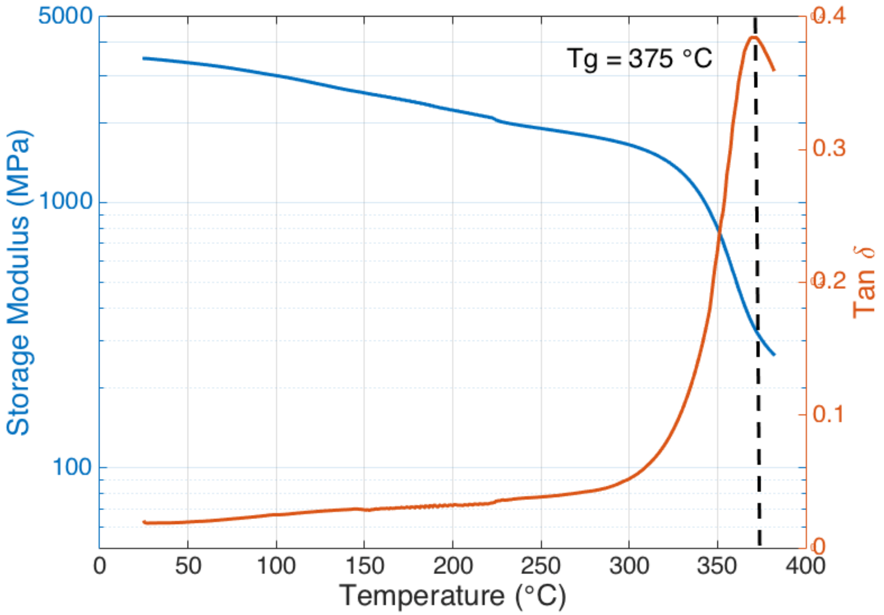
Thermally Stable Composites

- Dynamic mechanical analysis (DMA) used to evaluate the glass transition temperature of the polymer
- Polymers exhibit high glass transition temperature of 707° F (Tg = 375° C)
- Storage modulus ~2.5 GPa at 300° C
- Tg in the range of polyimides yet cure schedule enables low-cost manufacturing
- Trimer has developed a technology which decouples the glass transition temperature from the cure temperature



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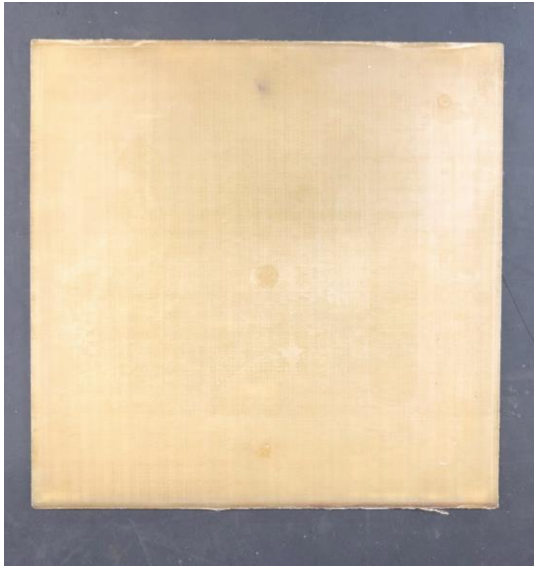
Liquid Compression Molding

- Trimer has used liquid compression molding to demonstrate rapid molding of composites
- Cure monitoring used to study the polymerization and optimize the cycle time



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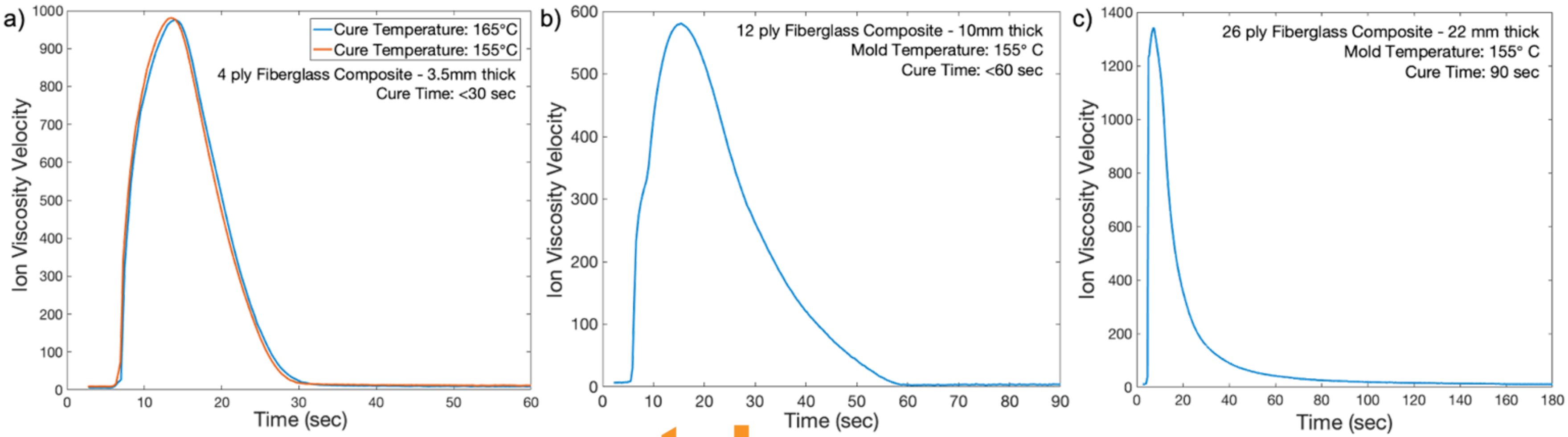
Low Cycle Time Composites

- Trimer demonstrated 3.5 mm thick composites could be cured in ~25 seconds with a 30 second cycle time
- 10mm thick composites were cured in under 60sec and 22mm thick composites were cured in under 120 sec with an unheated resin



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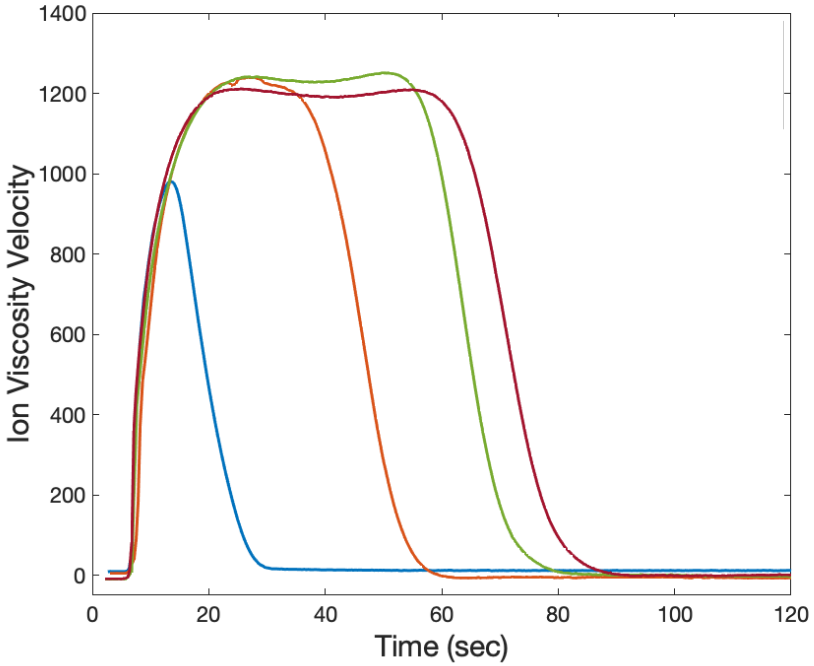
Cure Kinetics

- Trimer wet compression molded 3.5 mm thick fiberglass panels in 30 seconds
- Full cycle time of 30 sec. which exceeds DOE 2050 goal for automotive composites of <1 minute
- Many currently used molding tools are designed for slower curing resins where low cycle time may lead to polymerization prior to full infusion of the resin
- Trimer has developed the chemistry to enable the cure rate to be tailored for a particular application
- Increased the cure time of a 3.5mm panel from 30 sec to 90 sec



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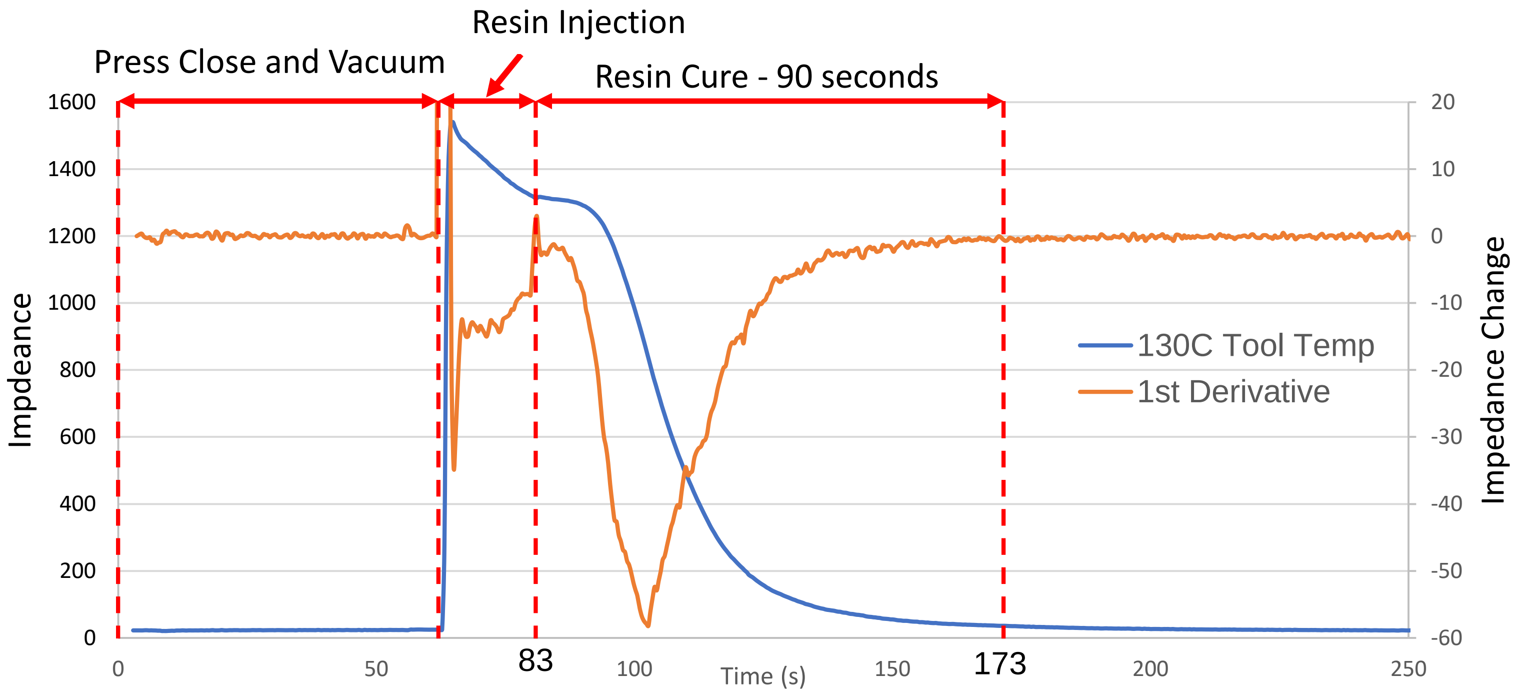
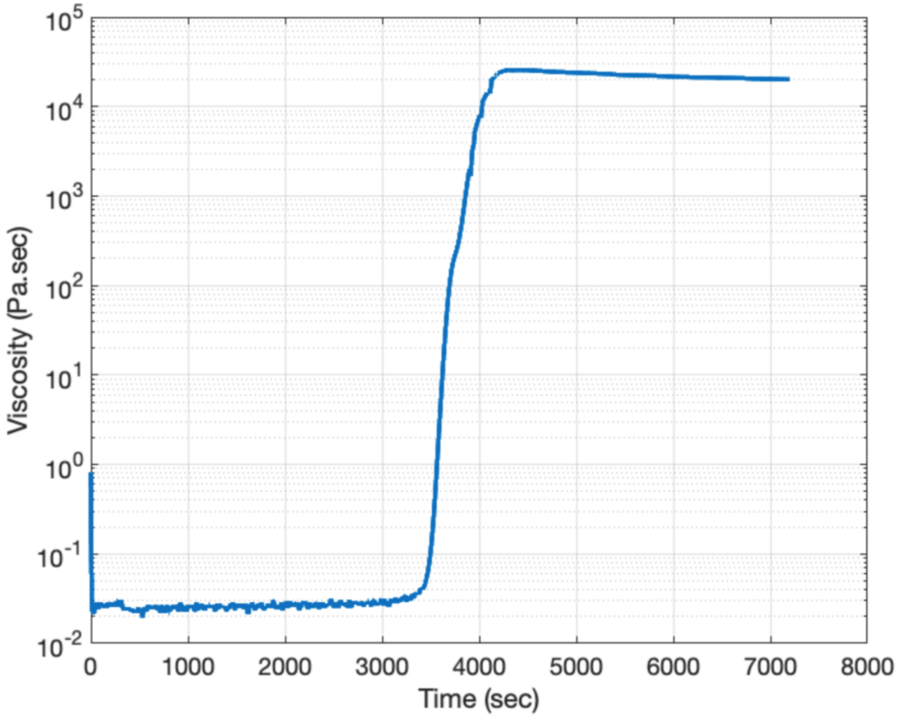
RTM processing of 28 mm Thick Composite



Demolding at between a 200-250s cycle time should be feasible (120-150s resin cure time)
Minimal change in material impedance or rate of change during this time frame

Long Working Life Resins

- Trimer was challenged to design the resin with sufficient latency to allow hot infusion of a wing
- Requested at least 30 min at cure temperature followed by snap cure
- Trimer created resin system with 1 hour gel time at 85C followed by a snap cure
- Trimer can provide resins with ambient gel times exceeded 16 hours



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Rapid Manufacture of VARTM Composites

- Long gel-time enables VARTM or RTM processing which can subsequently be cured
- Trimer has demonstrated a cycle time under 5-minute using the RapidClave system
- Cycle time was limited by the rapid clave system rather than the cure cycle
- Fastest curing VARTM system available and provides exceptional thermal stability

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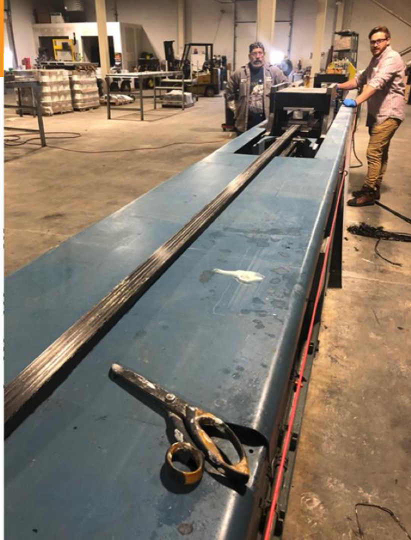
High Speed Pultrusion

- Pultrusion processing offers the capability to rapidly manufacture low-cost high volume fraction composites with continuous cross section
- Trimer has developed the resin system to excel in pultrusion processing
- We have demonstrated both direct injection and resin bath processing on glass and carbon with and without CFM
- Demonstrated the ability to run continuously at 60 in/min at 120C
  - Maximum line speed possible on equipment
- Have demonstrated pull speeds up to 10 ft/min can be achieved with injection box technology



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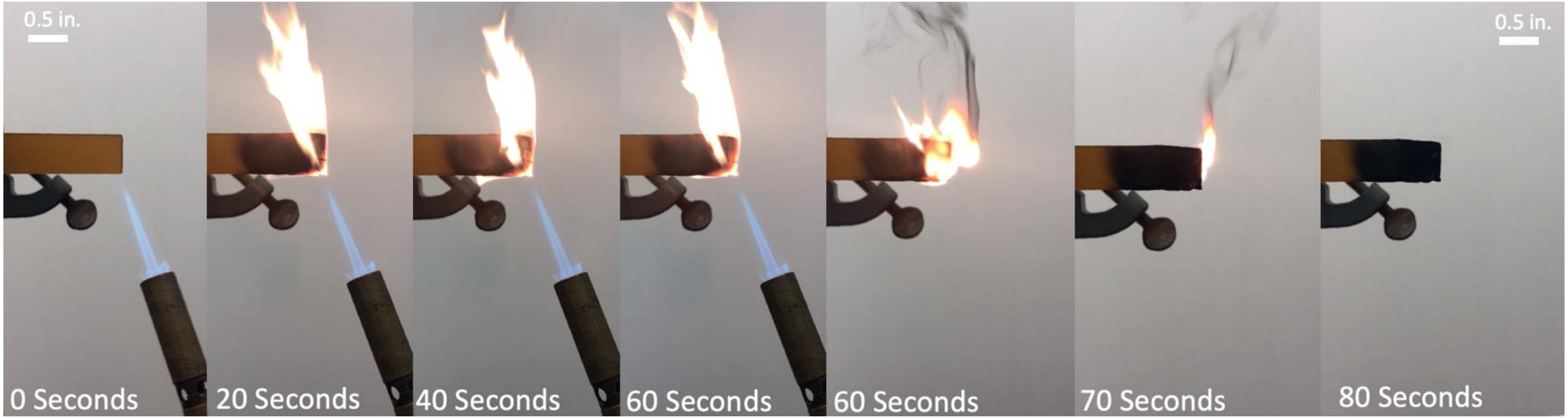
Fire Resistant Polymers

- 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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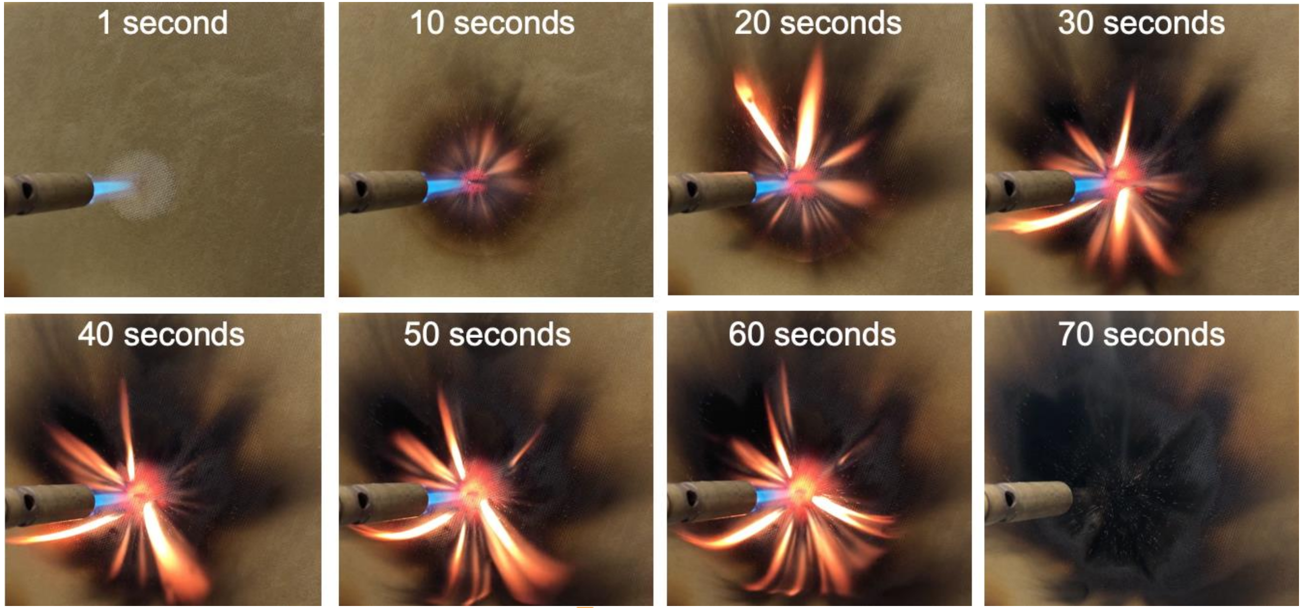
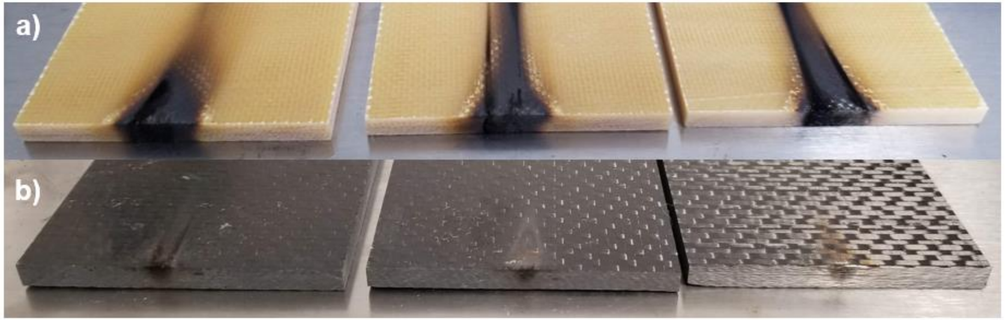
Fire Resistant Polymers

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

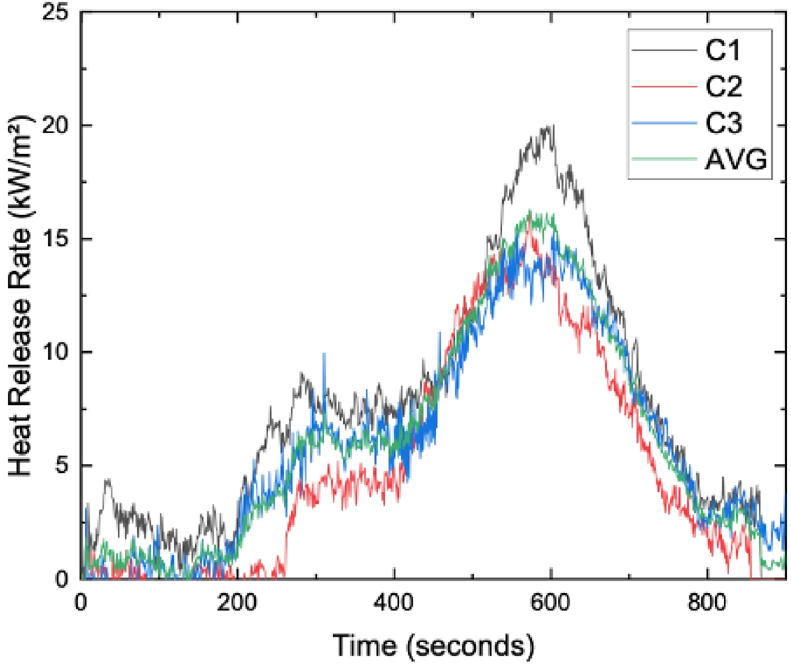


Fire Resistant Polymers

- Fiberglass panels tested at UDRI and SGS in accordance with ASTM E-1354/ISO 5660
- Cone calorimeter with 50 kW/m^2
- Results showed a peak heat release rate of 17 kW/m^2
- Time to ignition was measured at 155 sec.
- Average heat release rate was 17 kW/m^2
- Aeroblaze Laboratory tested vertical flame spread according to ASTM D3801



50 kW/m^2 Heat Flux



OSU Heat Release Testing

- Trimer has worked to demonstrate fire resistance for transportation applications
- Trimer's resin systems can greatly exceed FAR 25.853 for Aircraft Interiors
- Resin provides very low heat release with a low smoke density while providing high strength and stiffness

TEST REQUIREMENTS (MAXIMUM AVERAGE) Per Title 14 CFR/JAR/CS Part 25 Appendix F Part IV (g) [Amdt. 25-66] & ABD0031 (issue G, June 2014)				TOTAL (2 MINUTE) HEAT RELEASE: 65 kW Min./m^2	MAXIMUM (PEAK) HEAT RELEASE: 65 kW/m^2
Sample	Total	Peak	Time	Comments	
1	11.9	21.4	62	MELTING: NONE; SAGGING: NONE; DELAMINATION: NONE; OTHER OBSERVATIONS: NONE; OTHER COMMENTS: NONE	
2	21.4	32.3	158	MELTING: NONE; SAGGING: NONE; DELAMINATION: NONE; OTHER OBSERVATIONS: NONE; OTHER COMMENTS: NONE	
3	15.3	31.6	135	MELTING: NONE; SAGGING: NONE; DELAMINATION: NONE; OTHER OBSERVATIONS: NONE; OTHER COMMENTS: NONE	
Average	16.2	28.4	118		
Pass/Fail	PASS	PASS			

TEST REQUIREMENTS (MAXIMUM AVERAGE) Per Title 14 CFR/JAR/CS Part 25 Appendix F Part V (b) [Amdt. 25-66] & ABD0031 (issue G, August 2014)			MAXIMUM (PEAK) SMOKE DENSITY: 200 Ds
Sample	Maximum Smoke Ds	Time	Comments
1	4.8	235	MELTING: NONE; SAGGING: NONE; DELAMINATION: NONE; OTHER OBSERVATIONS: NONE; OTHER COMMENTS: NONE
2	3.9	236	MELTING: NONE; SAGGING: NONE; DELAMINATION: NONE; OTHER OBSERVATIONS: NONE; OTHER COMMENTS: NONE
3	6.0	240	MELTING: NONE; SAGGING: NONE; DELAMINATION: NONE; OTHER OBSERVATIONS: NONE; OTHER COMMENTS: NONE
Average	4.9	237	
Pass/Fail	PASS		

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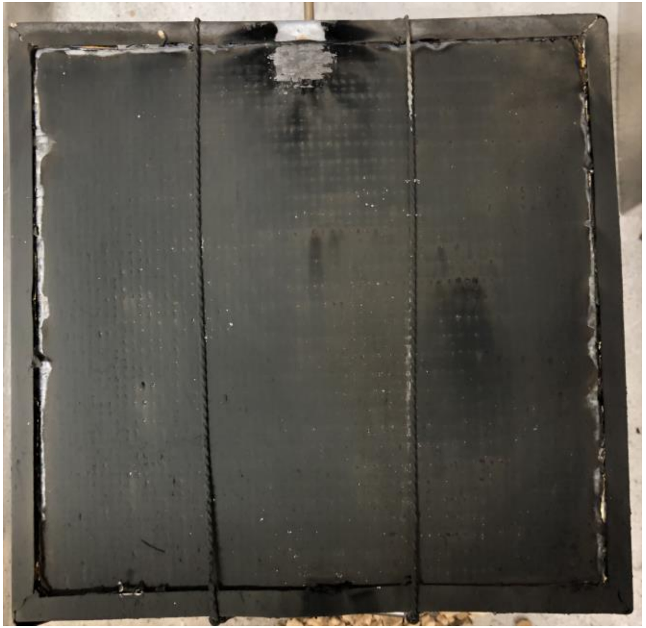
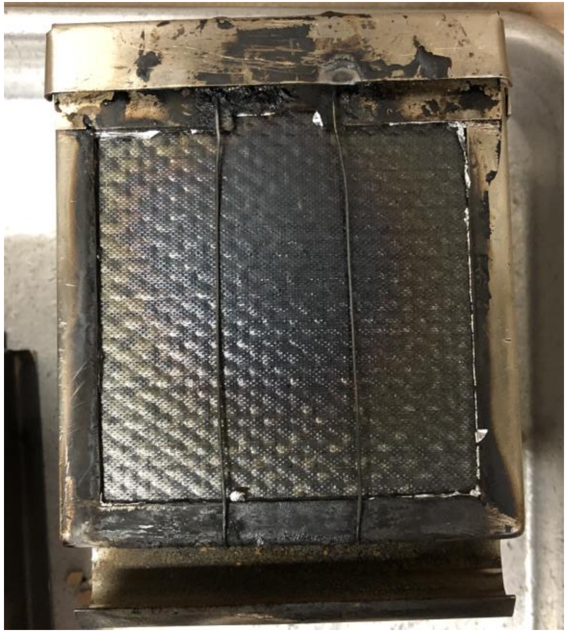
OSU Heat Release



Smoke Density



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Vertical Flame Spread

- Vertical flame spread has been evaluated for 0.5 mm and 6mm thick carbon fiber panels
- Flame spread is typically larger in thinner specimens
- Results easily meet FAR 25.853 for Aircraft Interiors

6 mm Thick Specimen

Sample	Ignition Time (sec)	Flame Time (sec)	Drip Flame Time (sec)	Burn Length (inch)
1	60.0	0.0	0.0 No Drips	0.0
2	60.0	0.0	0.0 No Drips	0.0
3	60.0	0.0	0.0 No Drips	0.0
	Average:	0.0	0.0	0.0
	Result:	PASS	PASS	PASS

0.5 mm Thick Specimen

Sample	Ignition Time (sec)	Flame Time (sec)	Drip Flame Time (sec)	Burn Length (inch)
1	60.0	0.0	0.0 No Drips	0.7
2	60.0	0.0	0.0 No Drips	0.6
3	60.0	0.0	0.0 No Drips	0.6
	Average:	0.0	0.0	0.6
	Result:	PASS	PASS	PASS

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Smoke Density

- Trimer's resin generates very low smoke density
- Meets all specifications for ASTM E662 smoke density testing
- Trimer's resin also passed smoke toxicity testing

Specimen	Flaming Mode: 90 Second Maximum Specific Optical Smoke Density	Flaming Mode: 4 Minute Maximum Specific Optical Smoke Density	Non-Flaming Mode: 90 Second Maximum Specific Optical Smoke Density	Non-Flaming Mode: 4 Minute Maximum Specific Optical Smoke Density
A	0	17.0	0	0
B	0	5	0	0

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SMP 800 Testing

- Trimer’s resin Is non-halogenated
- Minimizes toxic fumes during combustion processes
- Resin system is well suited for aircraft interiors and mass transit applications

Results:	Toxic Gas Generation		
	Flaming Mode	Non-Flaming Mode	Specified Maximum
Carbon Monoxide (CO ppm)			
At 1.5 Minutes	LT 1	LT 1	-
At 4.0 Minutes	17	LT 1	-
At Maximum	398	LT 1	3500
Carbon Dioxide (CO2 ppm)			
At 1.5 Minutes	114	LT 10	-
At 4.0 Minutes	1,033	LT 10	-
At Maximum	10,952	804	90,000
Nitrogen Oxides (as NO@ ppm)	LT 1	22	100
Sulfur Dioxide (SO2 ppm)	LT 1	LT 1	100
Hydrogen Chloride (HCL ppm)	20	12	500
Hydrogen Bromide (HBr ppm)	LT 1	LT1	100
Hydrogen Fluoride (HF ppm)	LT 2	LT2	100
Hydrogen Cyanide (HCN ppm)	15	1	100

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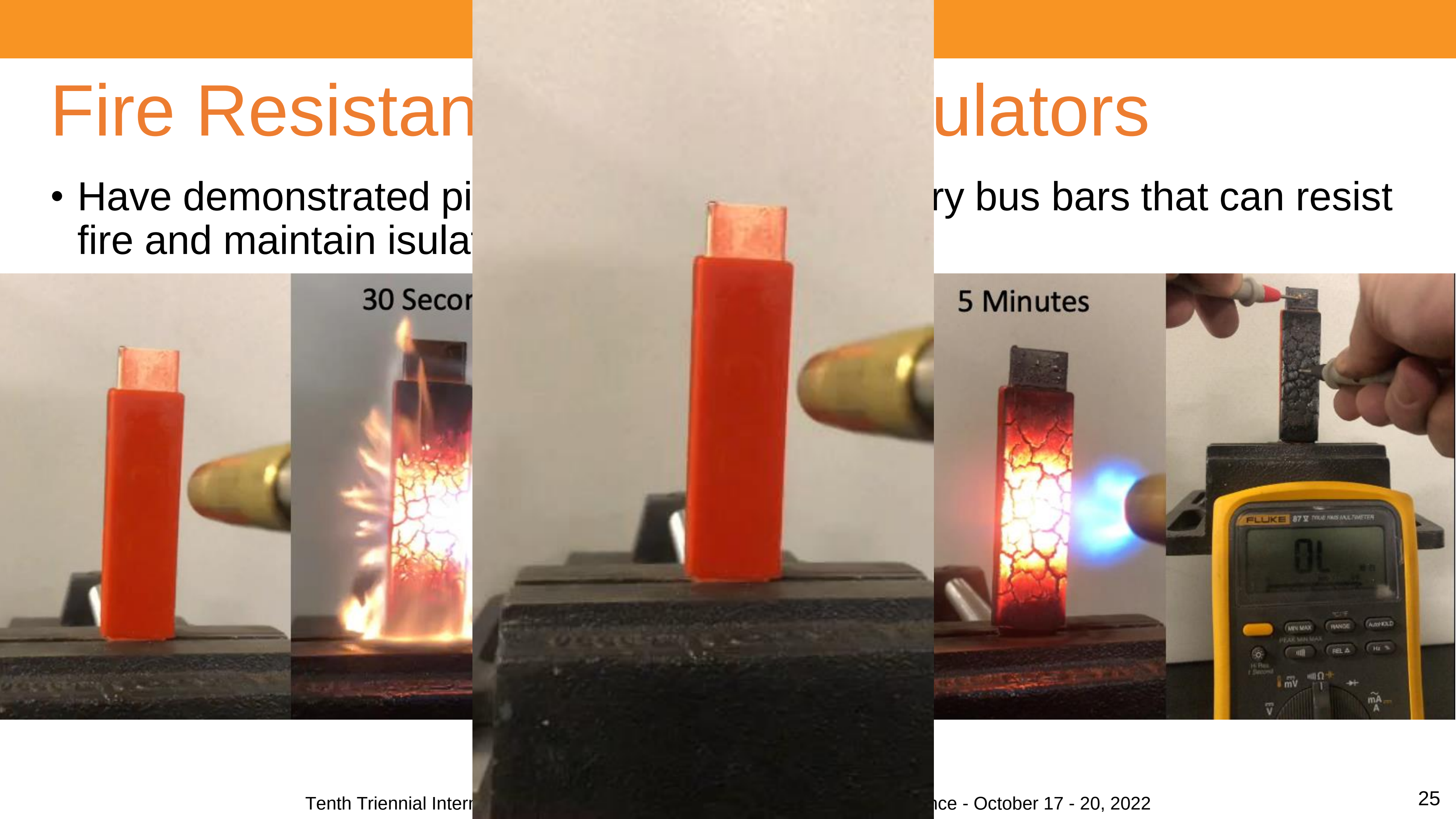
Fire Resistan ulators

- Have demonstrated pi ry bus bars that can resist fire and maintain isula



Composite Properties

- Trimer to perform testing of composite for MAT261 card with pultrusion resins
- Testing performed on Crestapol 1250, a urethane acrylate pultrusion resin used for the new Corvette bumper
- Trimer's Resin cured in 3 minutes compared to 45 min for Crestapol 1250
- Results showed Trimer's resin greatly outperformed Scott Baders' Crestapol 1250
- 0º compressive strength increased by 70% while 90º compressive strength increased by 85.2%
- 90º tensile strength was increased by 86.7%
- Much greater heat deflection temperature

Property	Trimer Rapid	Crestapol 1250
0º Tensile Strength, GPa (ASTM D3039)	**1.04**	1.03
0º Tensile Modulus, GPa (ASTM D3039)	44.2	46.45
0º Compression Strength, MPa (ASTM D6641)	**966.0**	568.7
0º Compression Modulus, GPa (ASTM D6641)	**47.2**	43.9
90º Tensile Strength, MPa (ASTM D3039)	**36.4**	19.5
90º Tensile Modulus, GPa (ASTM D3039)	14.3	14.9
90º Compression Strength, MPa (ASTM D6641)	**184.3**	99.5
90º Compression Modulus, GPa (ASTM D6641)	**31.0**	12.9
In-Plane Shear Strength, MPa (ASTM D3518)	**64.7**	57.77
In-Plane Shear Modulus, GPa (ASTM D3518)	**3.4**	2.66
Mode I Fracture Toughness, J/m^2, (ASTM D5528)*	437	809
Mode I Fracture Toughness, J/m^2, (ASTM D7905)†	1,510	1,640
Translaminar Fracture Toughness, MPa•m$^{1/2}$ (ASTM E1922)	**60.64**	51.87

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Revolutionary Aerospace Polymers

- Trimer Technologies has developed a revolutionary thermosetting polymer
- Aerospace thermal and mechanical properties through automotive manufacturing cycle time
- Have demonstrated aerospace grade composites manufactured faster than the DOE's 2050 goal for automotive composites

Benefits

- Rapid cure can reduce manufacturing time and cost
- Roughly an order of magnitude lower viscosity than current HP-RTM resins
- Long gel-time enable the manufacture of large structures
- Tg more than twice the value of current state of the art materials
- Resin has high fire resistance and easily meets FAR 25.853

Questions?

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