North American Pultrusion Conference

Novel Resin for High Strength FST Rated Pultrusion

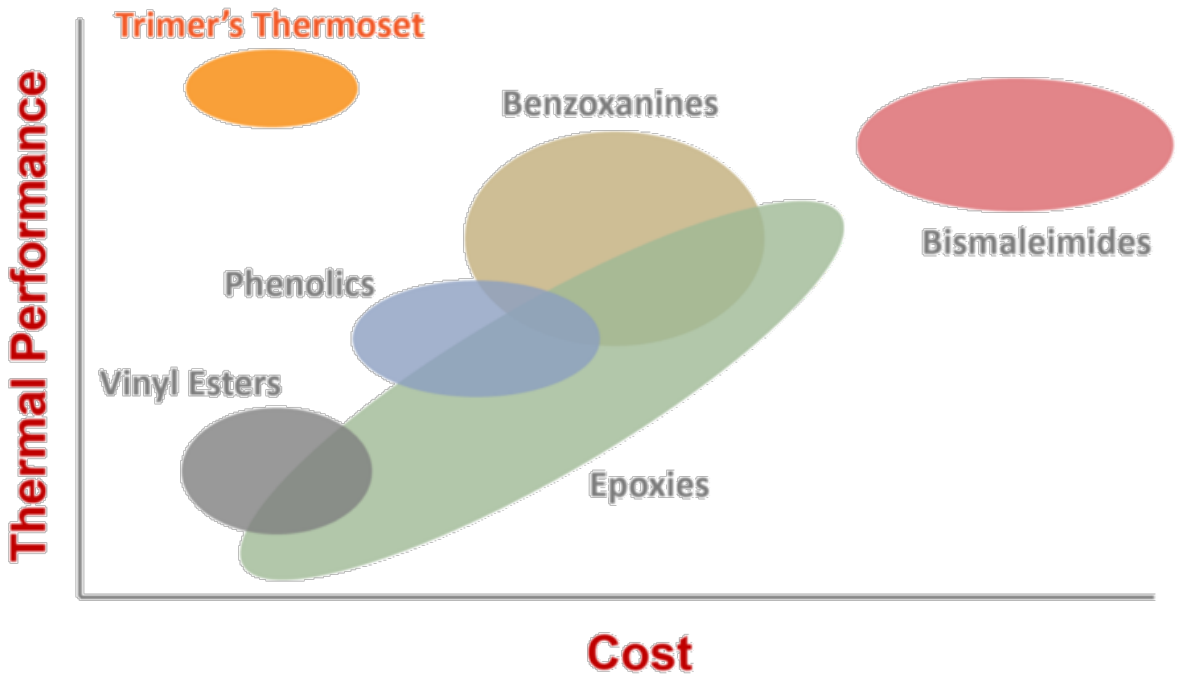
Henry A. Sodano, PhD

Trimer Technologies, LLC

ACMA American Composites Manufacturers Association | EPTA

Advanced Resin Technology

- Trimer has developed pultrusion resins which can enable high pull speed, fire resistance and high strength
- Polymer exhibits:
  - High strength, stiffness and toughness
  - Non-flammable with V0 and Class A E84
  - High glass transition temperature
  - Can be bath or injection processed
  - Pull speeds can exceed 10 ft/min



Resin Performance Comparison

- Trimer has developed low cost, high strength polymers with excellent FST properties which outperform competing resins while enabling faster pull speed

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	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 Stength (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

Resin Performance Comparison

- Trimer's resin outperforms competing 350º F autoclave cured resins while enabling pultrusion

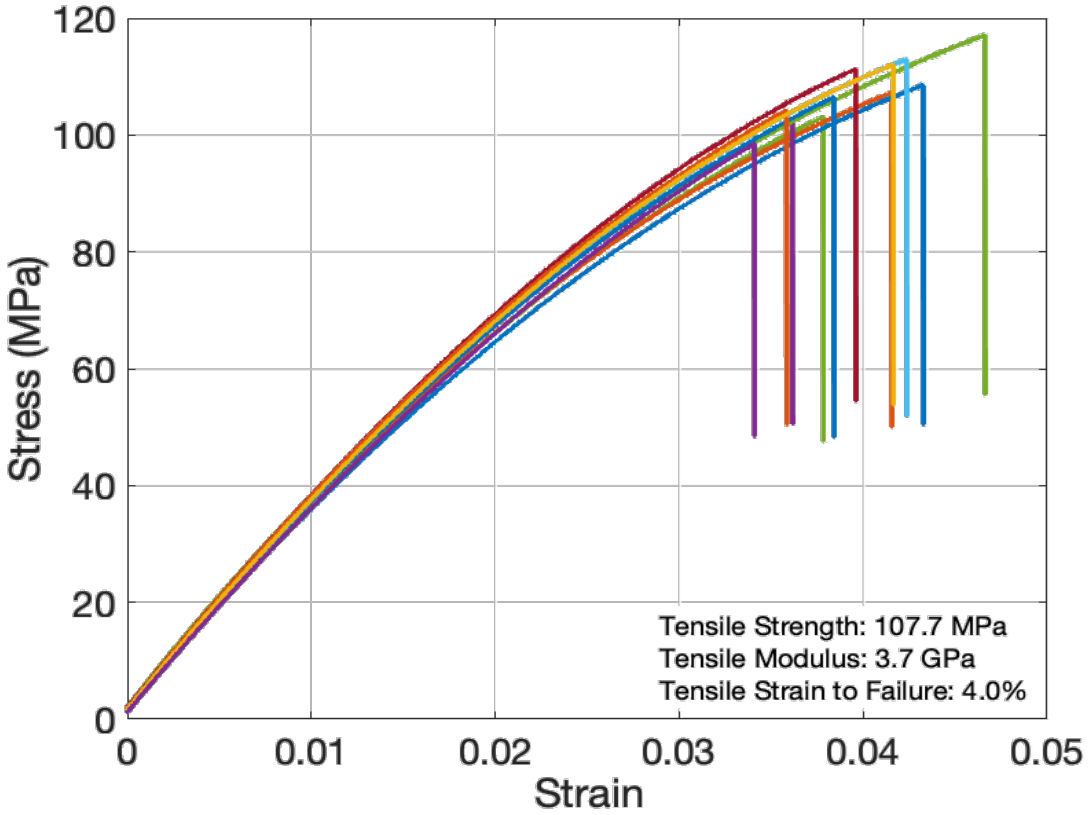
Material Property	Trimer's Resin	Hexcel 8552	Hexcel M74	Hexcel 3501-6	Cytec 5250 BMI	Hexcel F650 BMI	Cytec 2237
Polymer Type/Chemistry	-	Epoxy	Epoxy	Epoxy	BMI	BMI	Polyimide
Glass Transition, Tg Dry ºC	>400*	200	194	210	271	316	338
Tensile Strength (MPa)	105	120	83	45.5	103	-	38.6
Tensile Modulus (GPa)	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

* With post cure

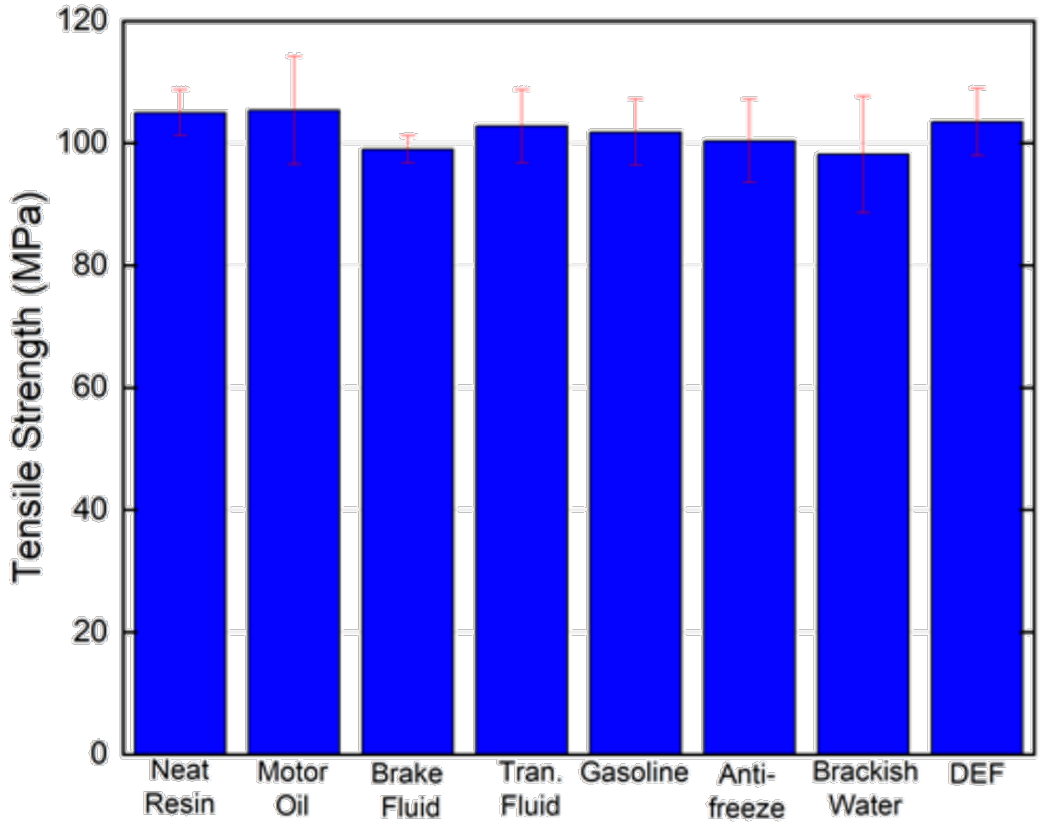
ACMA American Composites Manufacturers Association | EPTA

Resin Properties

- Resin exhibits aerospace grade properties and high strain to failure

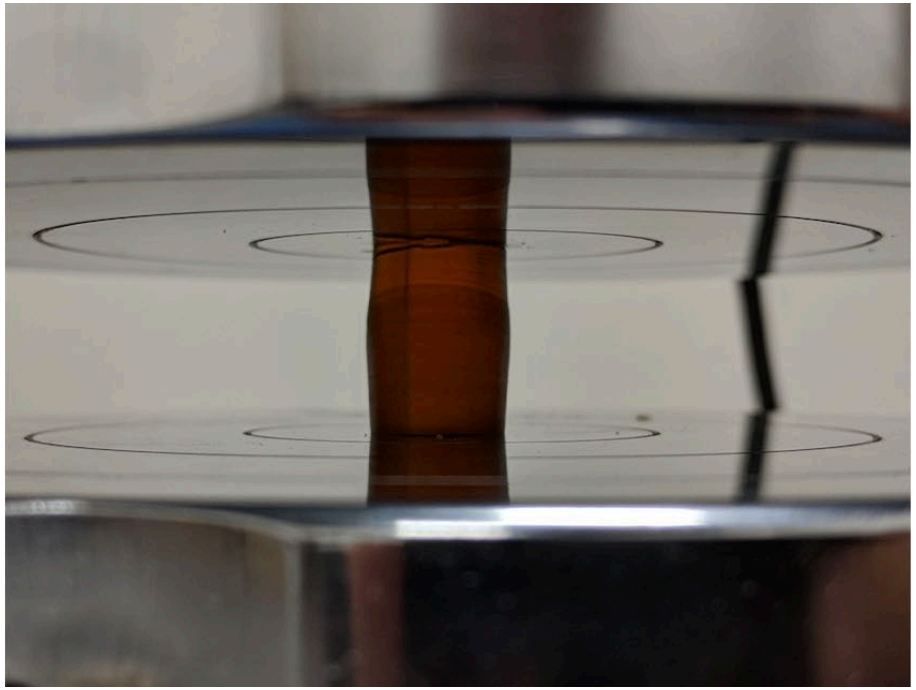


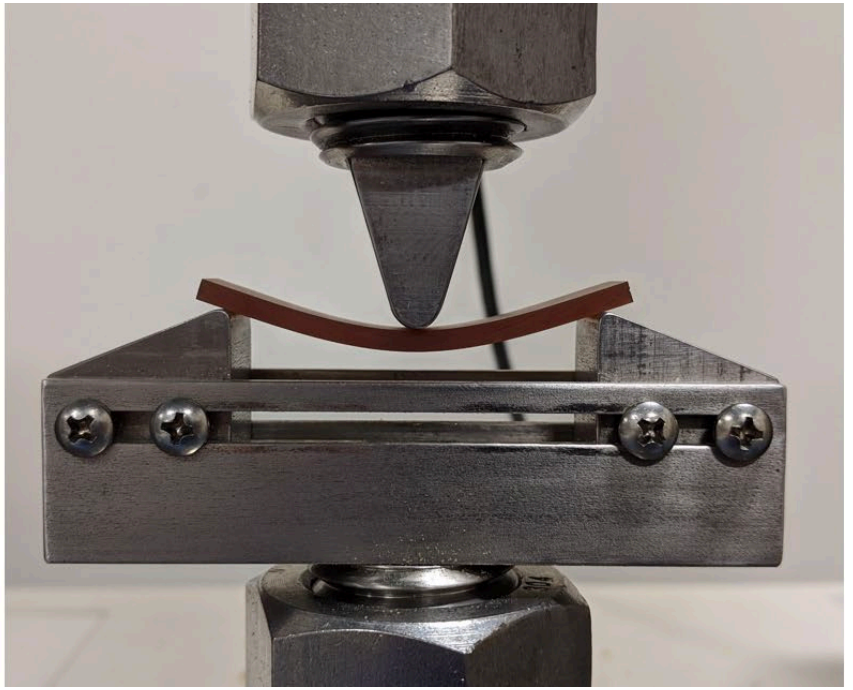
- Excellent resistance to solvents and shows no wet Tg reduction



High Strength and Strain to Failure

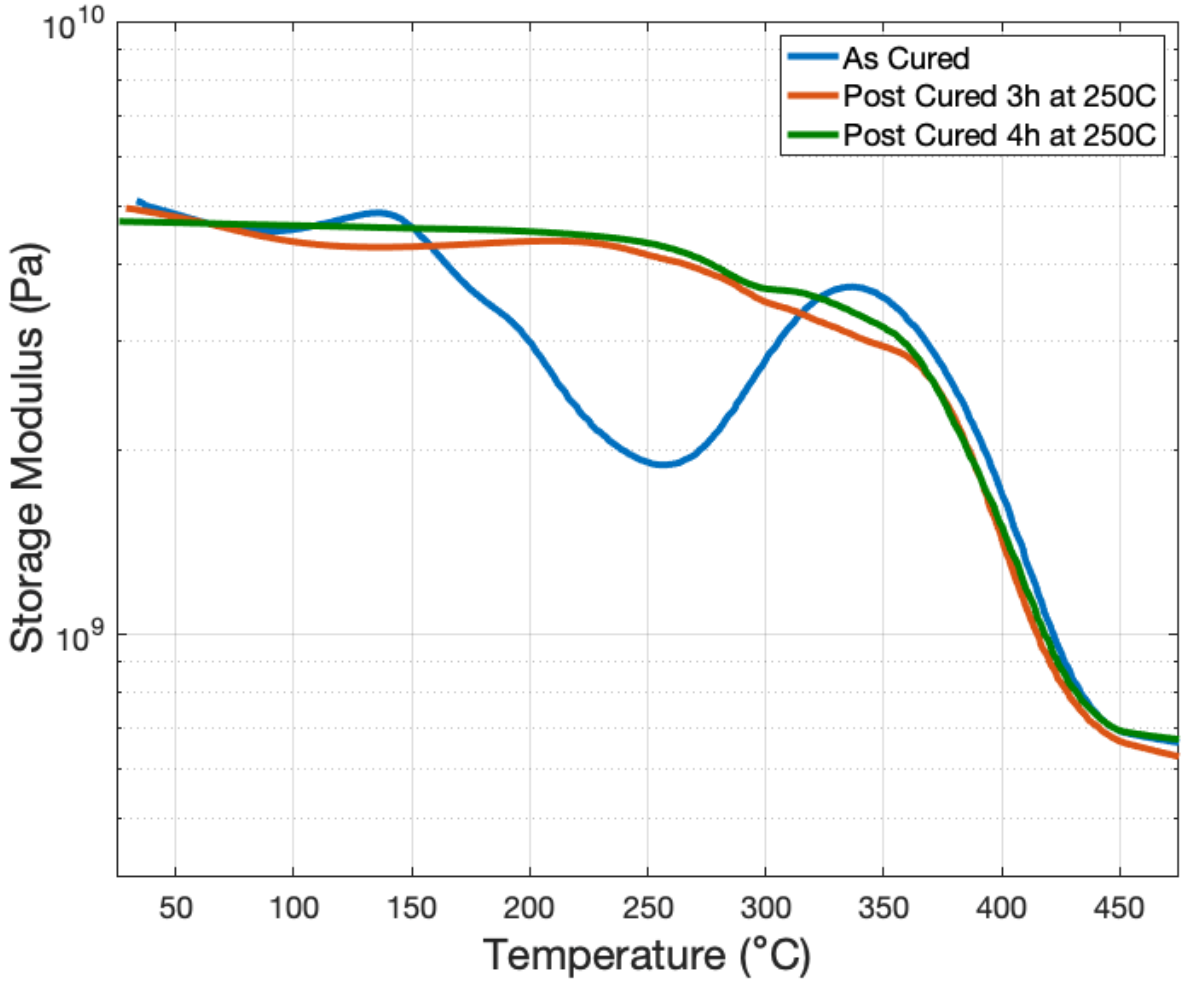
- High flexural strength and compressive strength with high strain to failure
  - Compressive strain to failure ~9%
  - Flexural strain to failure ~5%





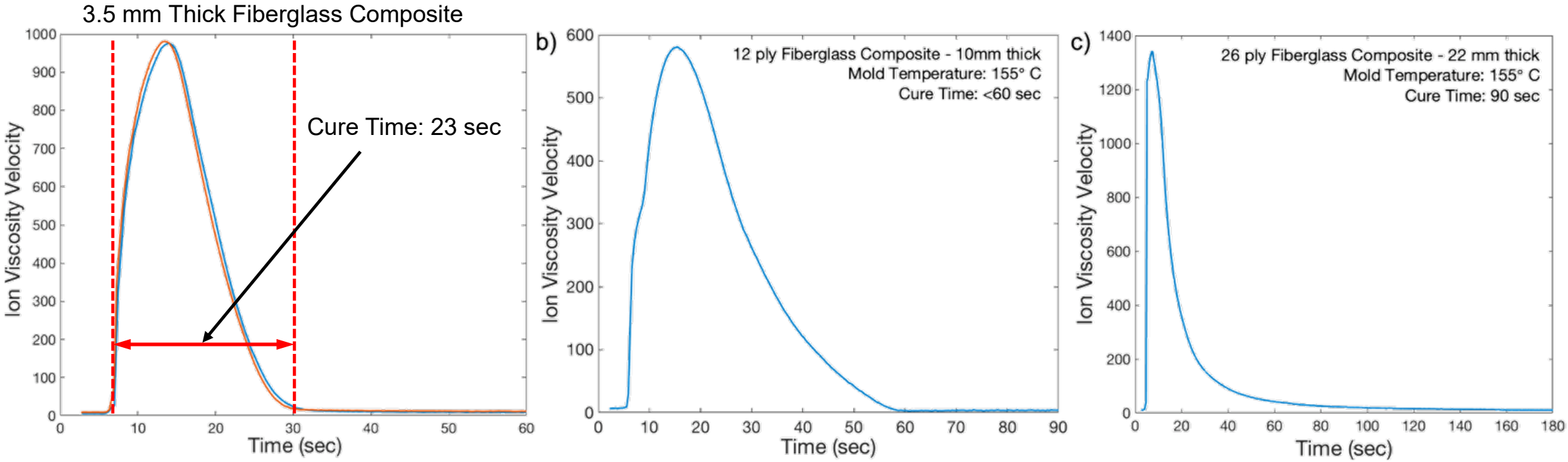
High Glass Transition Temperature

- Dynamic mechanical analysis (DMA) used to evaluate the glass transition temperature of the polymer
- Following post cure the polymers exhibit high glass transition temperature of 707° F (Tg = 375° C)
- Resin post cure can be observed in the DMA curve
- Tg in the range of polyimides yet rapid cure allows high rate pultrusion



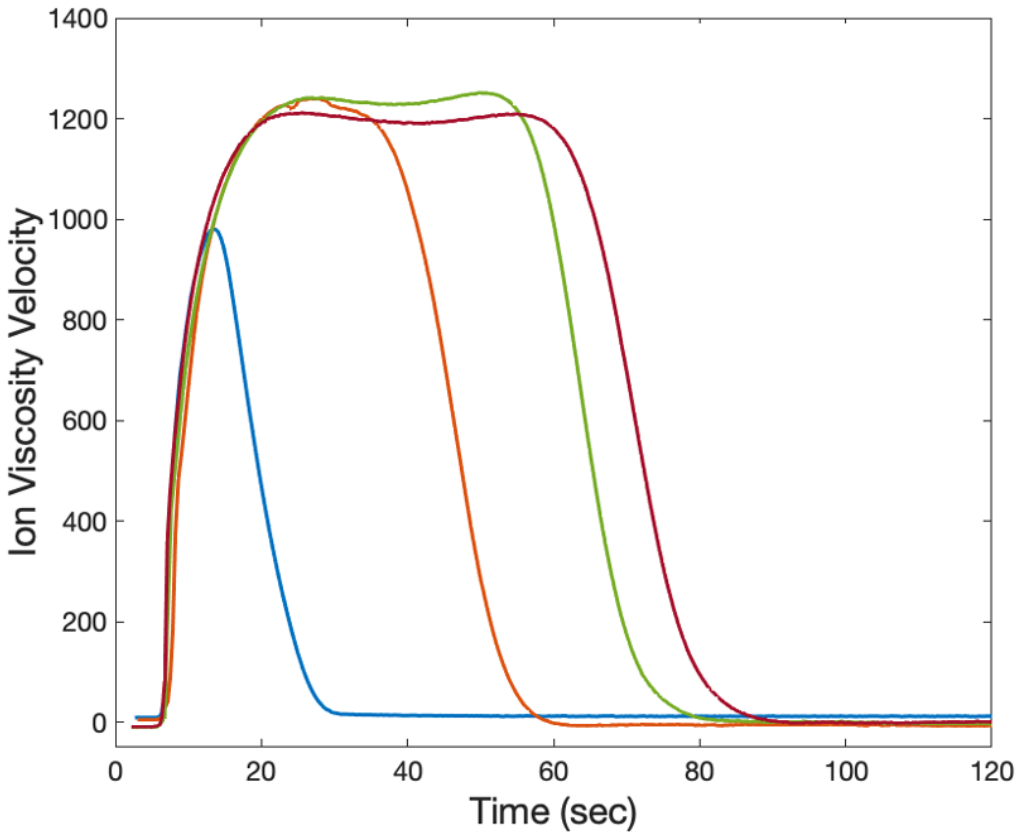
Controlled Reactivity

- 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



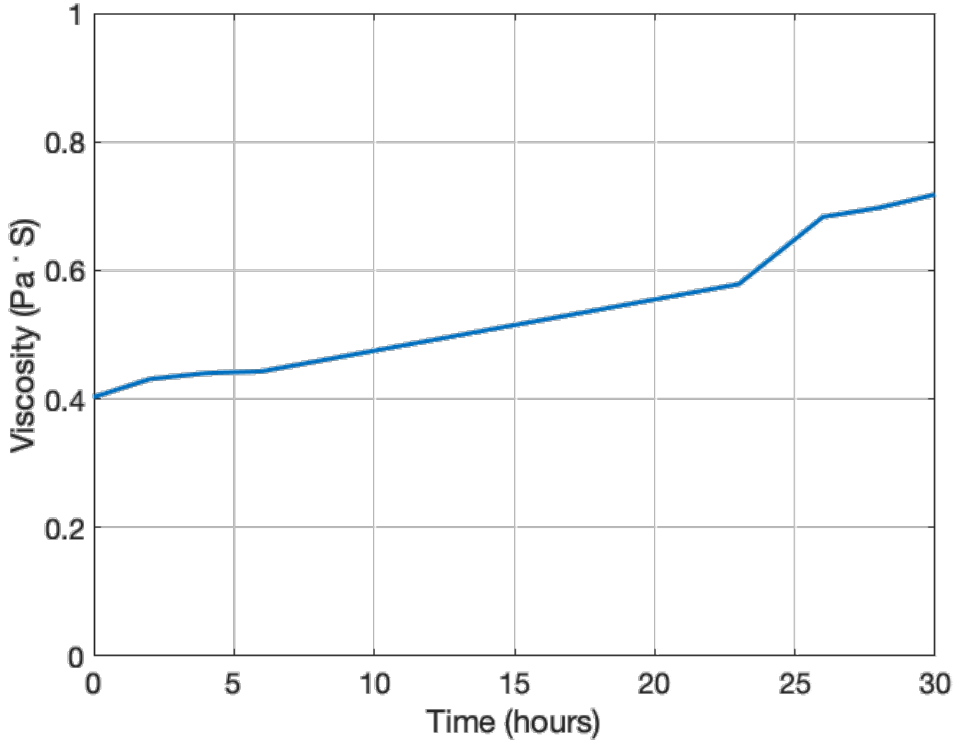
Cure Kinetics

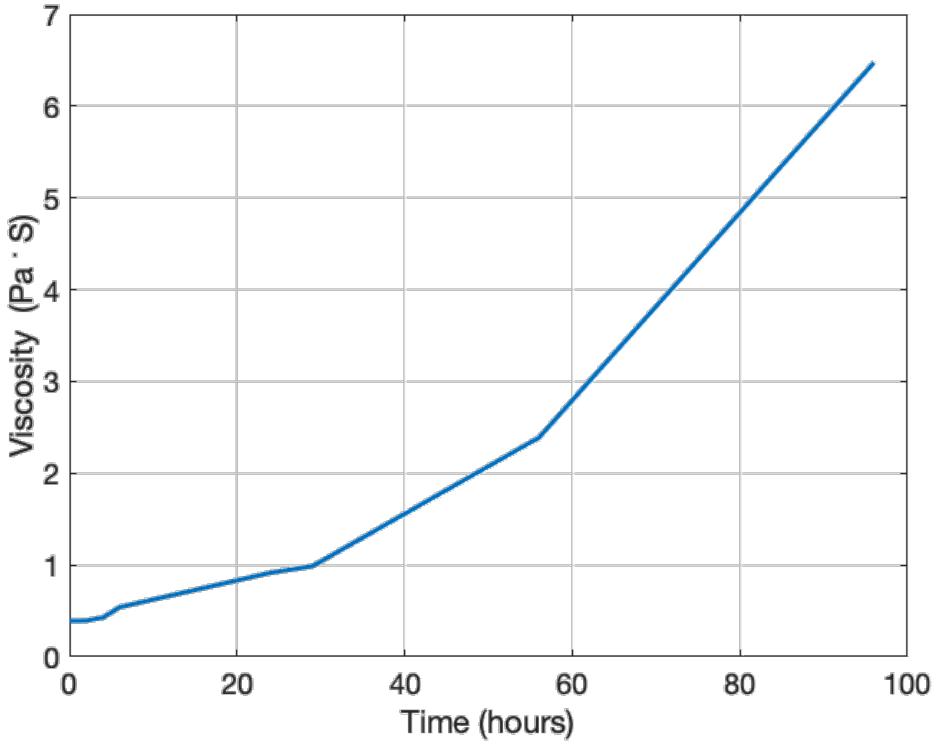
- Trimer wet compression molded 3.5 mm thick fiberglass panels in 30 seconds
- Full cycle time of 30 sec. could be achieved which exceeds the DOE's 2050 goal of <1 minute
- Many currently used molding tools are designed for slower curing resins where low cycle time may lead to polymerization prior to 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



Rapid Cure with Extended Pot Life

- Trimer has developed latent systems which can be bath pultruded
- Latency can extend from hours to days with high pull speed still obtainable
- New resin system is latent but still allows the use of highest catalyst reactivity





ACMA American Composites Manufacturers Association | EPTA

High Rate Pultrusion

- Trimer has used both direct die injection and resin bath techniques
- Demonstrated the ability to run continuously at over 120 in/min
- High thermal stability and allows pultrusion with a higher die temperature profile
- Die typically run at 390º F although die temperature can be varied greatly

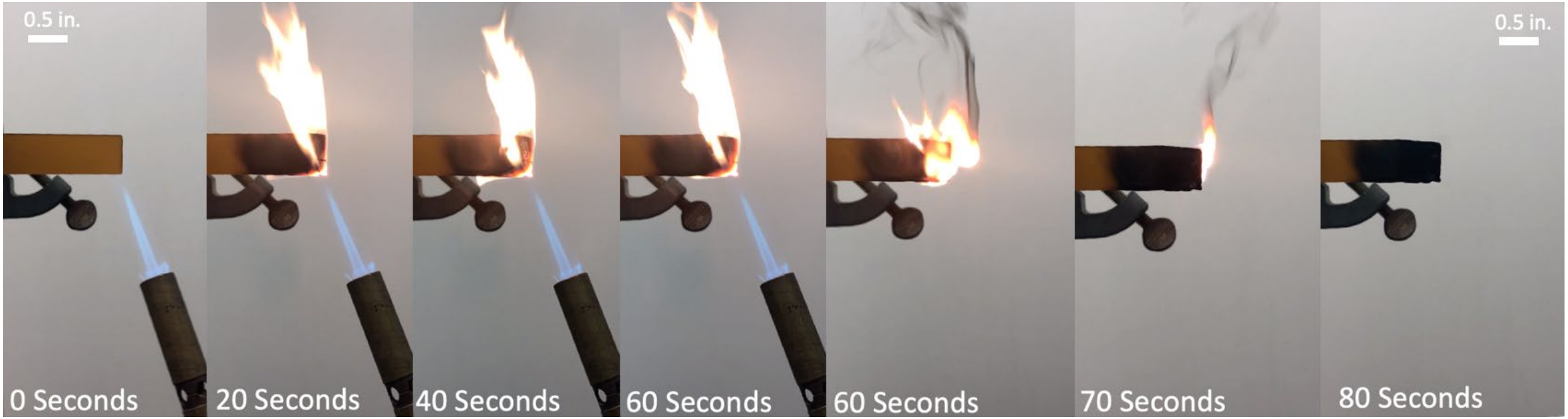
Trimer Resin Pultrusion Properties

- Trimer's resin system generates excellent mechanical, thermal and fire properties
- Combination of properties not typically found in a pultrusion resin
- Resin is non-halogenated and contains no volatile components such as styrene
- Cure does not generate volatiles that create high void content
- Composite exhibit excellent adhesion to fibers

Material Property	Trimer Pultrusion Resin
0º Flexural Modulus	55-57 GPa
0º Flexural Strength	1.7-1.8 GPa
90º Flexural Modulus	16-17 GPa
90º Flexural Strength	75-100 MPa
0º Compressive Strength	1.1 GPa MPa
0º Compressive Modulus	58.4 GPa
Axial Short Beam Strength	60-80 MPa
Transverse Short Beam Strength	17 MPa
UL 94	V0
ASTM E84	Class A
FAR 25.853	Pass

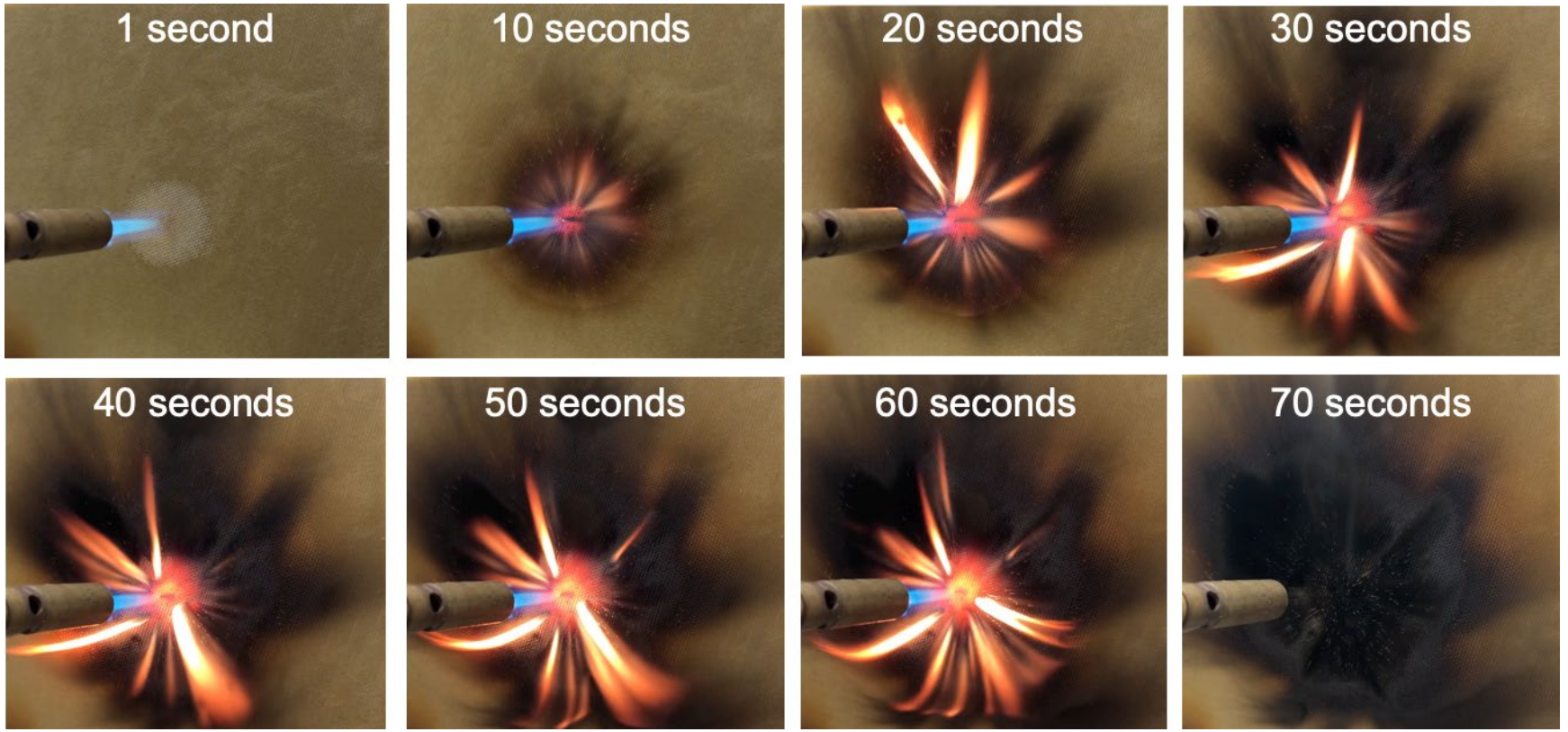
Fire Resistant Composites

- 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 D635 standard



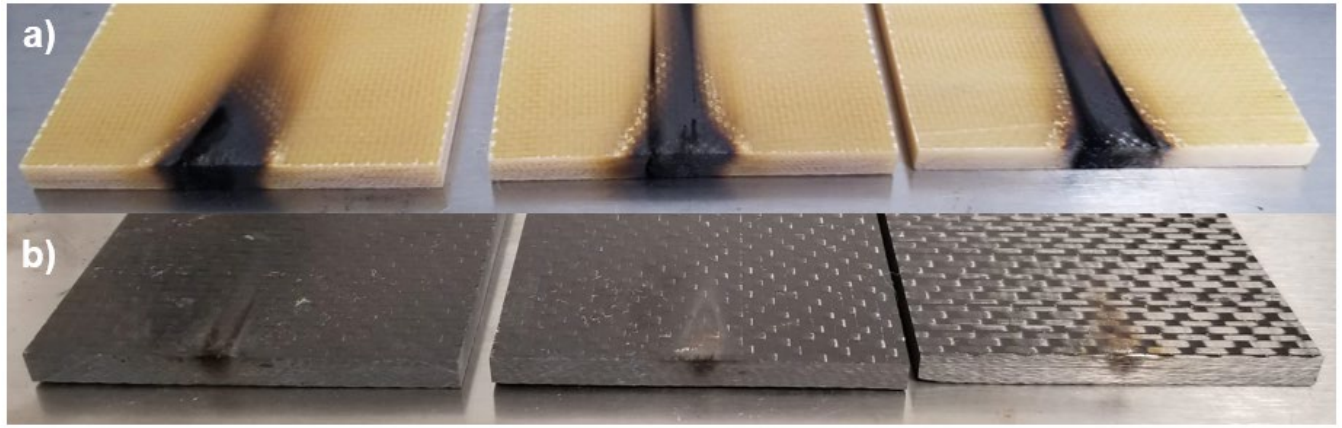
Fire Resistant Composites

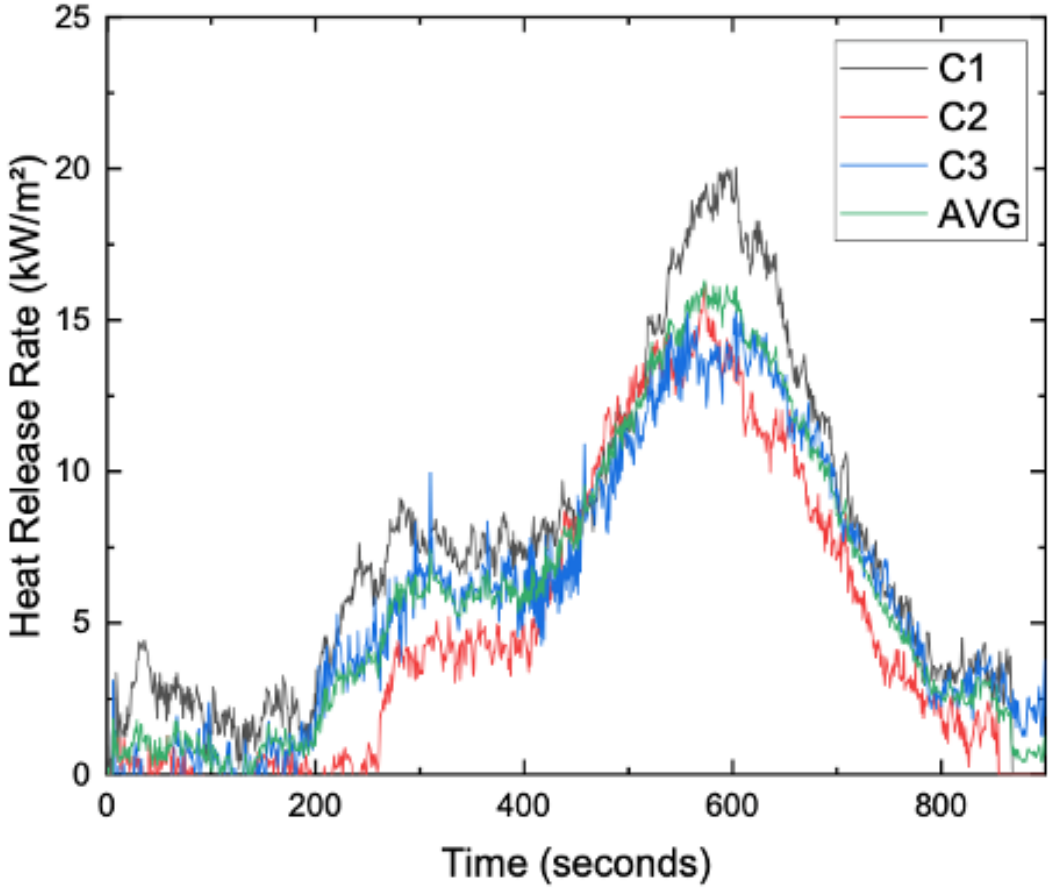
- Fiberglass reinforced composite panel (3mm thick) exposed to MAPP Gas torch for 60 sec then allowed to self extinguish



Fire Resistance

- 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





OSU Heat Release Testing

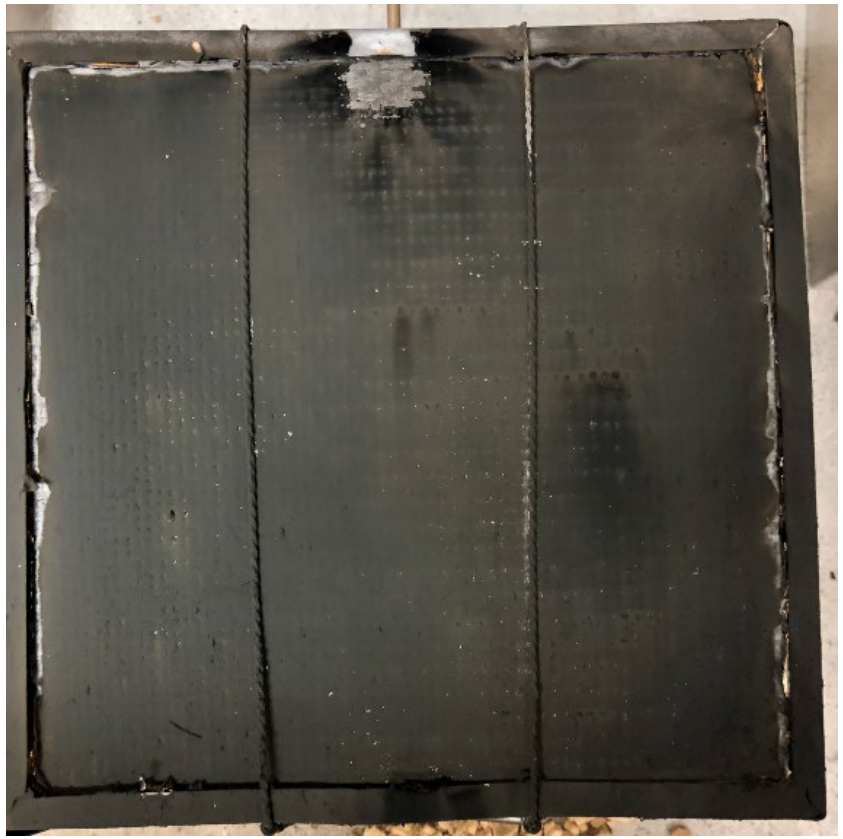
- Trimer has worked to demonstrate fire resistance for transportation applications
- Trimer's resin systems can greatly exceed FAR 25.853 for Aircraft Interiors
- Resin provides very low heat release with a low smoke density while providing high strength and stiffness

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		

ACMA American Composites Manufacturers Association | EPTA

OSU Heat Release



Smoke Density

Vertical Flame Spread

- Vertical flame spread 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
- Flame spread under ASTM E162 testing shows a flame spread of only 1.1 in.

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

Smoke Density

- Trimer's resin generates very low smoke density
- Meets ASTM E662 for smoke density without intumescent coating
- Have received an ASTM E84 Class A rating with a FSI of 15 and SDI of 250
- E84 testing of panel with Technofire intumescent veil showed equivalent FSI but nearly double SDI

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

SMP 800 Testing

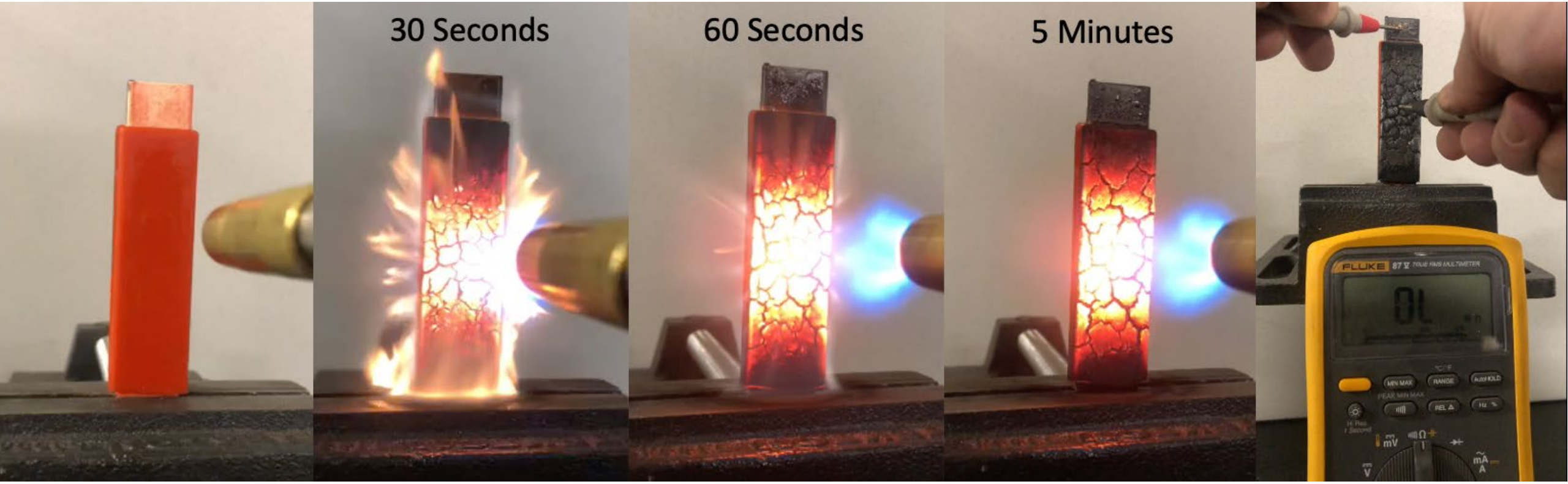
- Trimer's resin is non-halogenated and requires no additives for fire resistance
- Minimizes toxic fumes during combustion processes
- Resin system is well suited for aircraft interiors, mass transit and marine applications

Results:	Toxic Gas Generation		Specified Maximum
	Flaming Mode	Non-Flaming Mode	
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

ACMA American Composites Manufacturers Association | EPTA

Fire Resistant Electrical Insulators

- Have demonstrated pigmented coating for battery bus bars that can resist fire and maintain insulation



Trimer's Value Proposition

- Trimer has developed a new IMR which can enable excellent surface with fast pull rate
  - Have developed one-part IMR/Catalyst package to simplify meter mixing
- Resin cost of ~ $5/lb with IMR and catalyst at volume
- Trimer's resin can enable 3-4 times fast pull speed than phenolic
- Trimer's resin has no VOC and does not exhibit exothermic run away
  - Recent air sampling has shown the resin meets permissible exposure limits without ventilation
- Have developed new resin system which can be bath pultruded without reducing resin reactivity
- Trimer has scaled our manufacturing process with near term production for automotive, industrial and infrastructure applications

ACMA American Composites Manufacturers Association | EPTA

Questions?

hsodano@trimer-tech.com

www.trimer-tech.com