Carbon Fiber Composite Processing Using Isothermal Resins

John M Gardner, Joseph G. Smith, Jr., Elizabeth H. Moore, Godfrey Sauti, Scott R. Zavada, Keith L. Gordon, Benjamin D. Jensen, and Emilie J. Siochi

NASA Langley Research Center

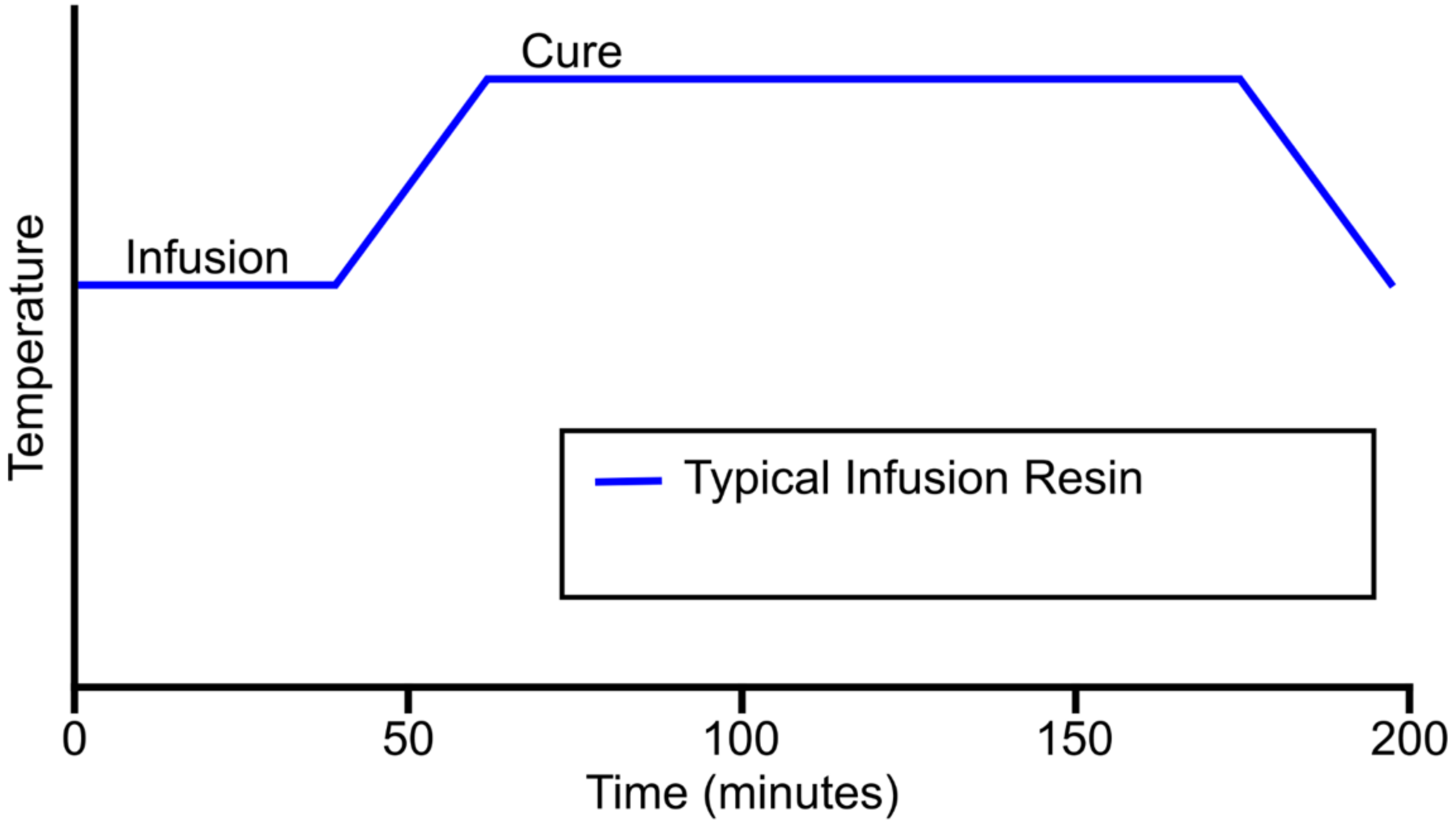
2026
Seattle, WA

High-Rate Composite Aircraft Manufacturing

- Projected demand for 40,000 deliveries of single-aisle composite aircraft by 2040.
- Historic aircraft production rates:
  - Metallic: 60 per month
  - Composite: 10-14 per month
- Target production rate of 80 aircraft per month.

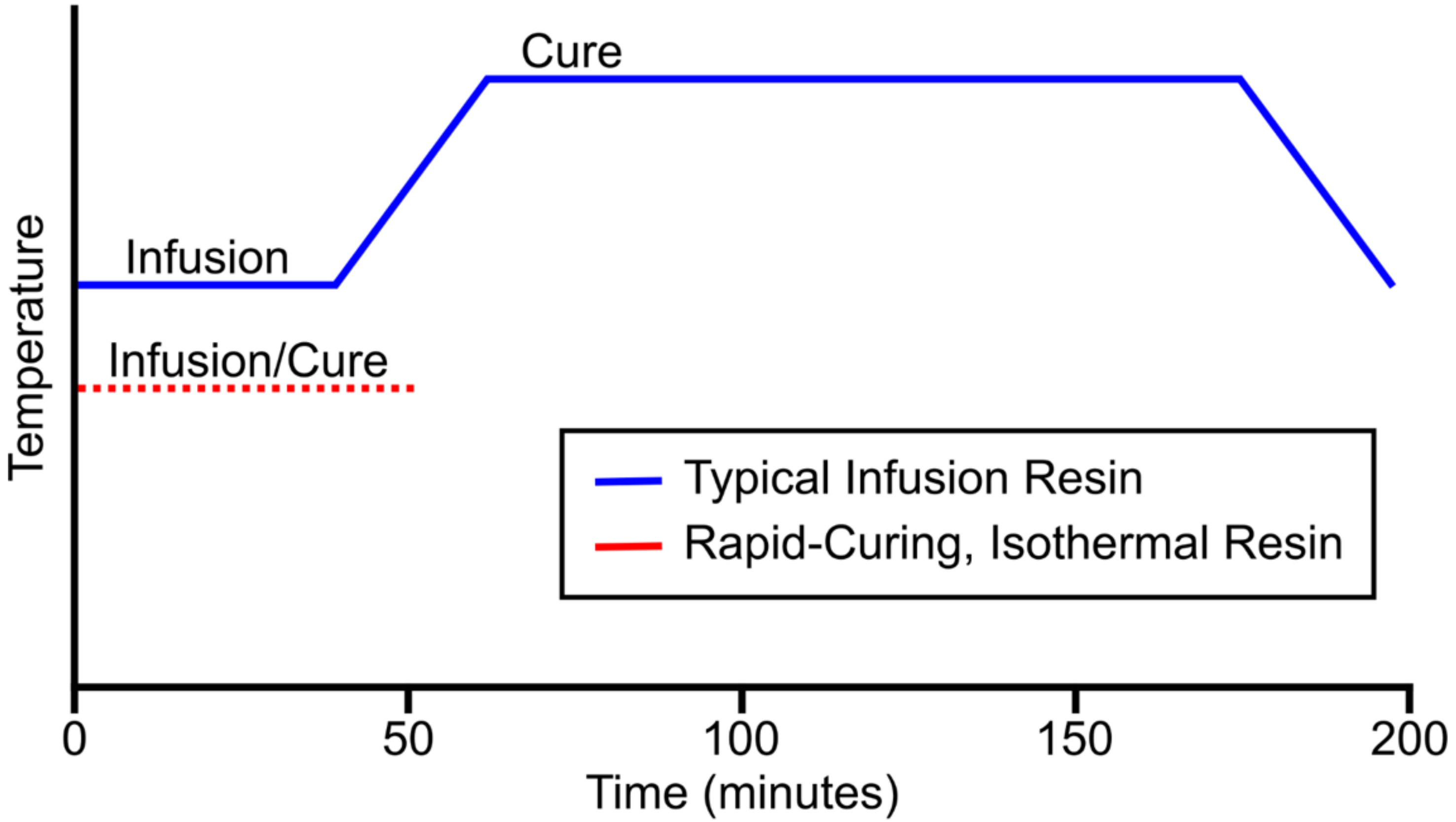
State-of-the-Art Infusion Resins

- In-mold processing time.
- Current resin transfer molding (RTM) resins cannot meet rate goals due to long cycle times and temperature ramps.



Rapid-Curing Isothermal Resins

- Isothermal resins infuse and cure at the same temperature.
- Reduces the overall cycle time by eliminating temperature ramps and shortening cure time.



NASA Isothermal Resin System

- Total infusion/cure cycle of one hour.
- Infusion window: 30 minutes.
- Compatible with two-component infusion systems.
- Sufficient green strength to allow demolding at infusion/cure temperature without damage to the part.
- Free-standing post-cure without damaging or warping the part.
- Glass transition temperature (T_g) and mechanical properties comparable to state-of-the-art aerospace-grade composites.

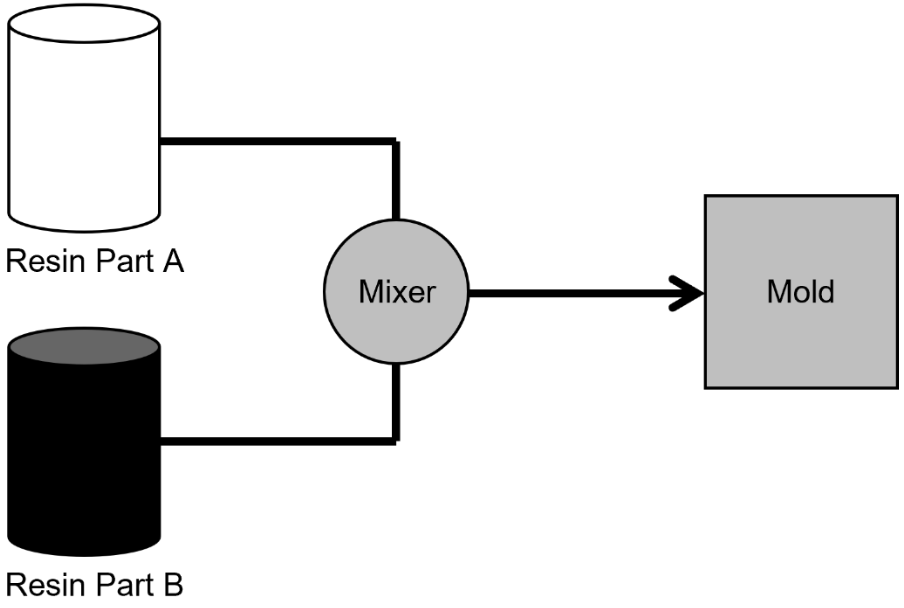
Material	Tensile Strength (Normalized)	Compressive Strength (Normalized)	Fracture Toughness G_{IIC} Mode 2 (Normalized)
Hexcel Hexflow 1078	1 ± 0.06	1 ± 0.18	1 ± 0.07
Isothermal Rapid Cure	0.85 ± 0.02	1.09 ± 0.05	0.62 ± 0.05

Image Credit: NASA

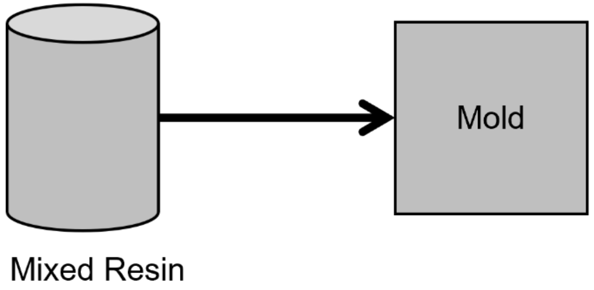
sampe North America

NASA Isothermal Resin

Ideal setup to match industry processes.

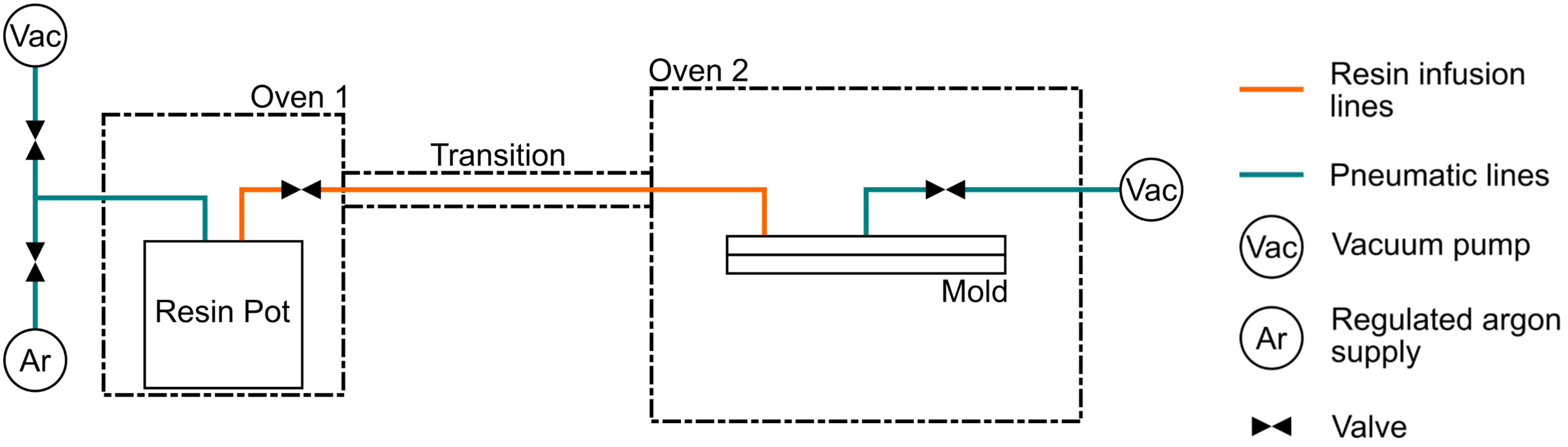


Current setup for candidate resin evaluation.



- Resin designed for use with two-component resin infusion systems where resin is mixed just prior to entering the mold.
- Equipment limitations and short turn-around times required the use of a one-component setup.
- Kinetic modeling used to guide process development.
- Demonstrate use and lessons learned during development of a two-part isothermal resin system using one-component infusion processes.

Processing Overview



RTM Mold Setup

- Large Parts: 343 mm x 343 mm (13.5 in x 13.5 in large mold)
- Small Parts: 152 mm x 152 mm (6 in x 6 in small mold) part sizes.
- Composite Thickness: 2.25 mm (0.089 in) or 4.5 mm (0.178 in) thickness.
- Converging flow path.
- Stainless steel.

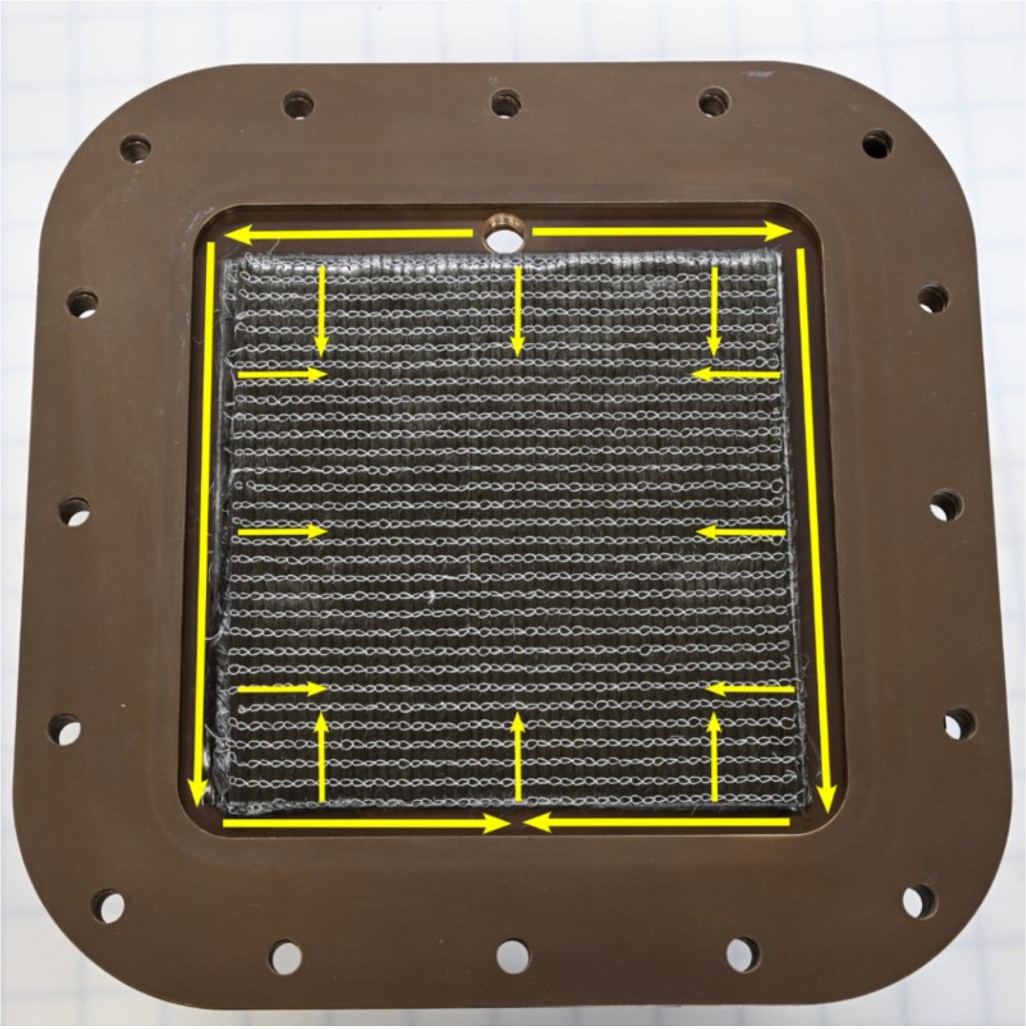


Image Credit: NASA

Resin Reaction Kinetic Modeling

- Freidman method used for modeling of reaction kinetics.
  - Differential scanning calorimeter data at different ramp rates used to approximate conversion dependent parameter $g(\alpha)$ and activation energy E.

$$\frac{\partial \alpha}{\partial t} = A exp\left(\frac{-E}{RT}\right) g(\alpha)$$

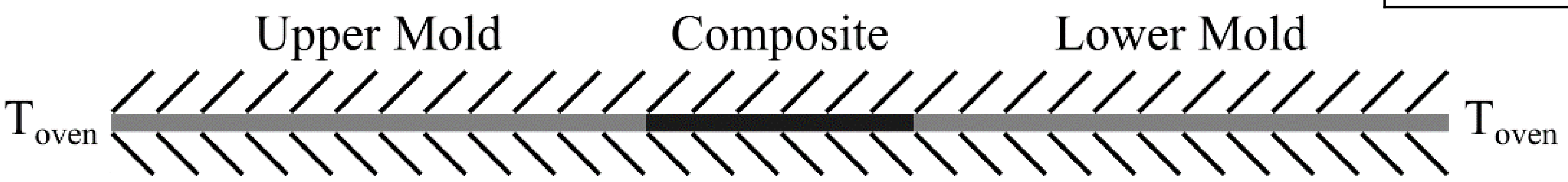
Reaction Kinetics

$$\frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial x^2} + \frac{H_r}{C_p}\frac{\partial \alpha}{dt} = \frac{\partial T}{\partial t}$$

1-D Heat Equation

Parameters Used in Models

	Parameter	Value
Resin	Density	1.2 g/cm^3
	Thermal Conductivity	0.79 W/(m·K)
	Specific Heat Capacity	1.1 kJ/(kg·K)
	Enthalpy	718 kJ/kg
Fiber	Density	1.79 g/cm^3
	Thermal Conductivity	9.3 W/(m·K)
	Specific Heat Capacity	1.1 kJ/(kg·K)
Mold	Density	8 g/cm^3
	Thermal Conductivity	16.2 W/(m·K)
	Specific Heat Capacity	500 kJ/(kg·K)
Composite	Fiber Volume Fraction	58.50 %

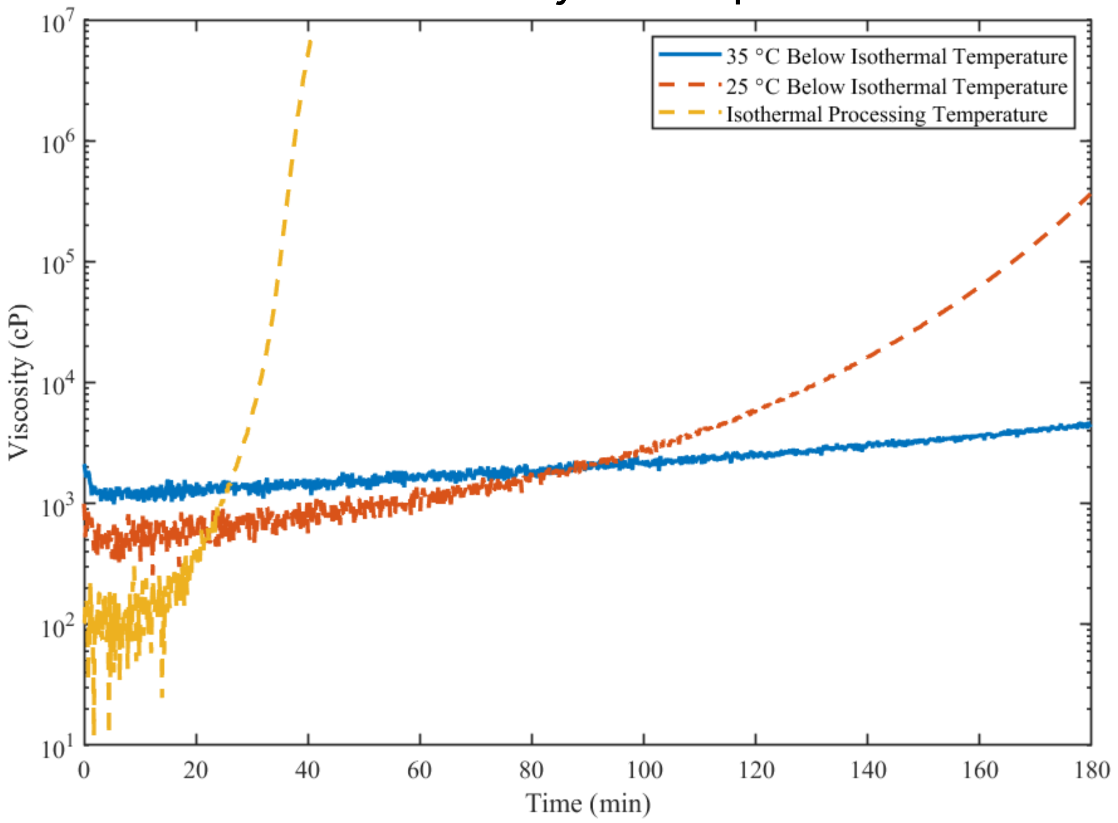


1-D Cure Model for Composite in Mold

Resin Degas

- Resin is currently processed as a one-component system.
  - Reaction will progress during degas.
  - Initial degree of cure can affect viscosity and total infusion time.
- Control resin degas to prevent the following:
  - Shortened degas time.
  - Higher viscosity during infusion.
  - Exotherm events during degas.

Resin Viscosity at Temperature



Resin Degas

- Kinetic modeling used to determine effect of resin degas time and temperature on infusion time.
- Used reaction kinetics model to approximate degas time for two degas procedures.
  - 40 °C, 3.5 hrs.
  - 50 °C, 2.5 hrs.
- Cure cycle modeled with degree of cure results from degas model used as initial conversion.
- Degree of cure after degas more affected by temperature than time.
  - Lower degas temperature is better than short duration.
- Small change in initial degree of cure can shorten working time.

Degas Model Results

Degas Temperature (°C)	Degas Time (min)	Degree of Cure After Degas
40	210	0.01
50	150	0.04

Cure Model Results

Degas Temperature (°C)	Degas Time (min)	Working Time (min)
No Degas		35.5
40	210	29.5
50	150	20.5

Resin Infusion

- Premature curing in resin rich sections of RTM setup can lead to incomplete infusion.
- Material selection of transfer tube between mold and resin pot is important to ensure complete infusion.
  - Small panels used 6.35 mm diameter PTFE tubing.
  - Large panels used 9.53 mm diameter stainless steel tubing.
- Other considerations:
  - 2-component resin infusion system.
  - Resin mixing near inlet to maximize processing time.

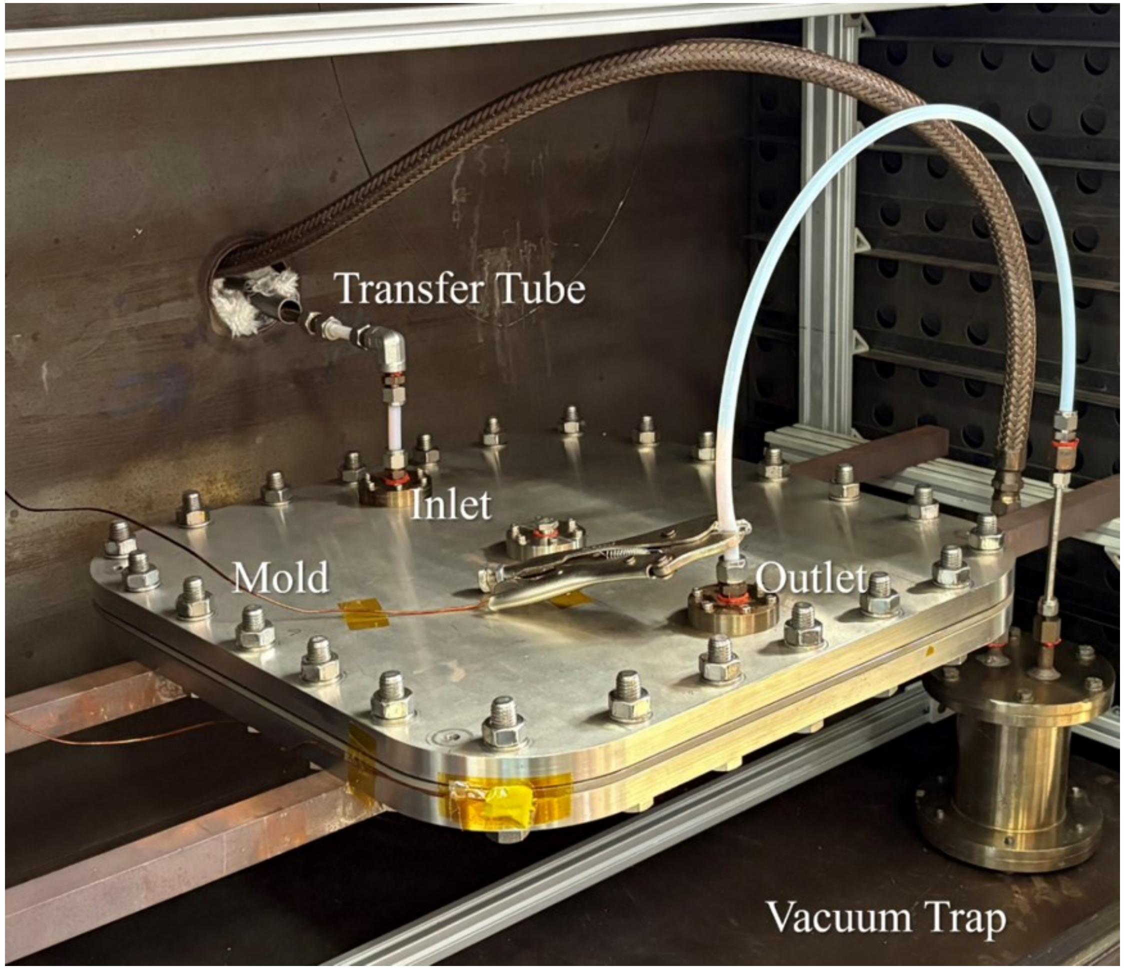
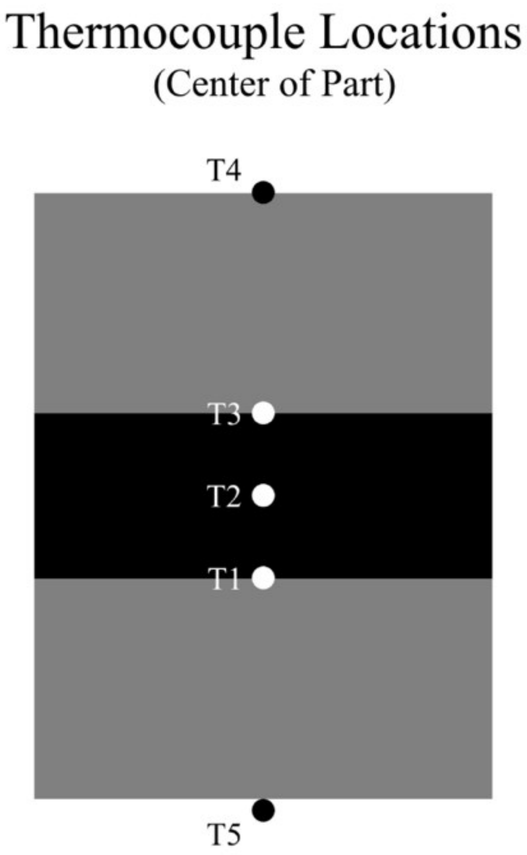


Image Credit: NASA

Resin Cure

- Resin exotherms can shorten processing times and negate advantages of isothermal cure.
- Processing temperature and mold design affect resin exotherm temperature and processing time.
- Model different mold thickness and processing temperatures. Mold thickness remain constant at 12.7 mm (0.5 in).
- Measure composite exotherm temperature during typical cure cycle.



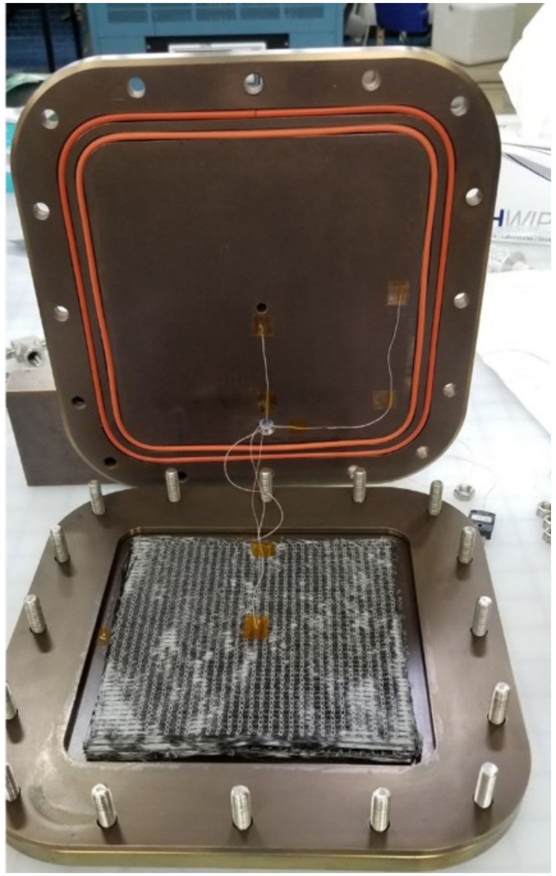


Image Credit: NASA

sampe North America

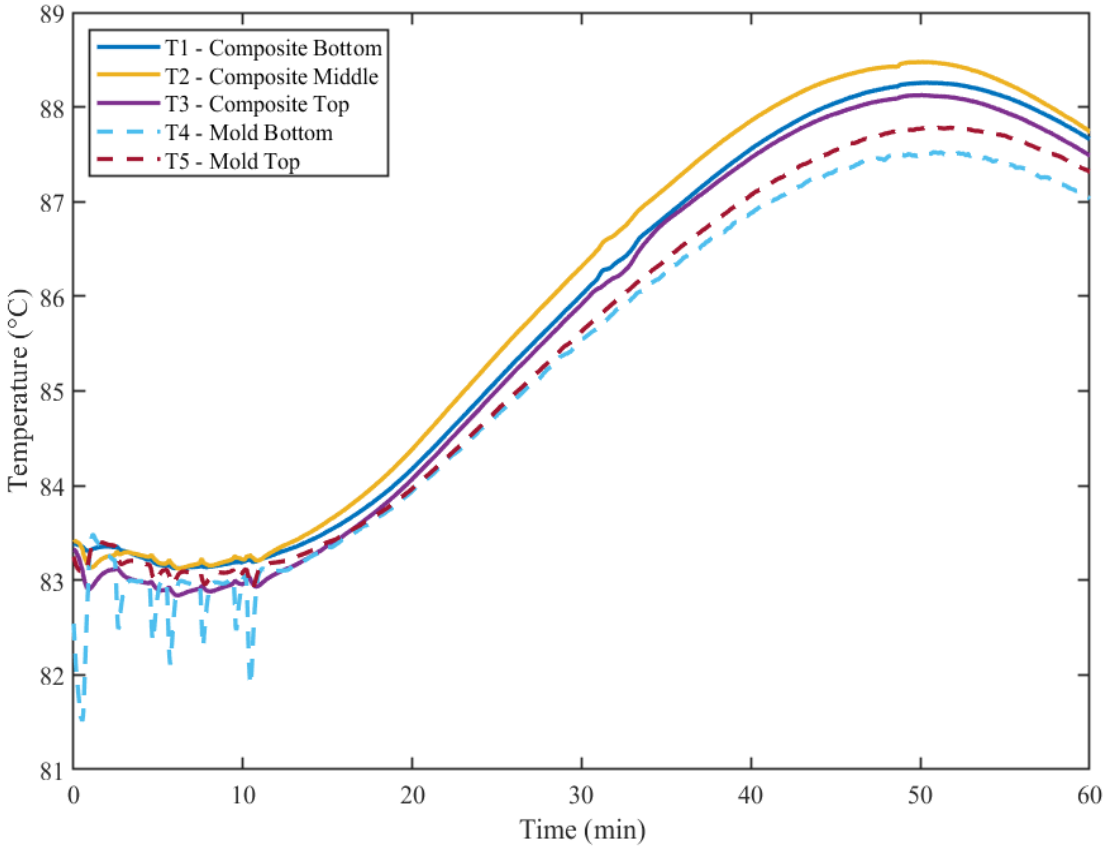
Resin Cure

Resin Cure Modeling Results

Part Thickness (mm)	Temperature from Nominal (°C)	Exotherm ΔT (°C)	Working Time (min)	Final Degree of Cure
2.25	-5	1.6	40.7	0.58
2.25	0	2.4	27.9	0.85
2.25	+5	3.4	19.3	0.94
4.5	-5	3.7	38.7	0.65
4.5	0	5.8	25.8	0.90
4.5	+5	9.1	17.5	0.96
9	-5	11.6	33.8	0.84
9	0	19.8	22.0	0.96
9	+5	47.5	14.5	0.99

- Composite part thickness and temperature affects the working time.
- Temperature can be adjusted to control working time.

Part and Mold Temperatures During Cure



sampe North America

Conclusions

- Demonstrated development of a two-part isothermal resin system using one-component resin transfer molding processes.
- Kinetic modeling of resin used to guide process optimization.
- Lower degas temperatures are preferred to maximize processing time.
- Careful selection of RTM setup materials is required as areas with high concentrations of neat resin can be prone to premature cure.
- Resin temperature remains low during cure cycle and is influenced by factors such as mold thickness.