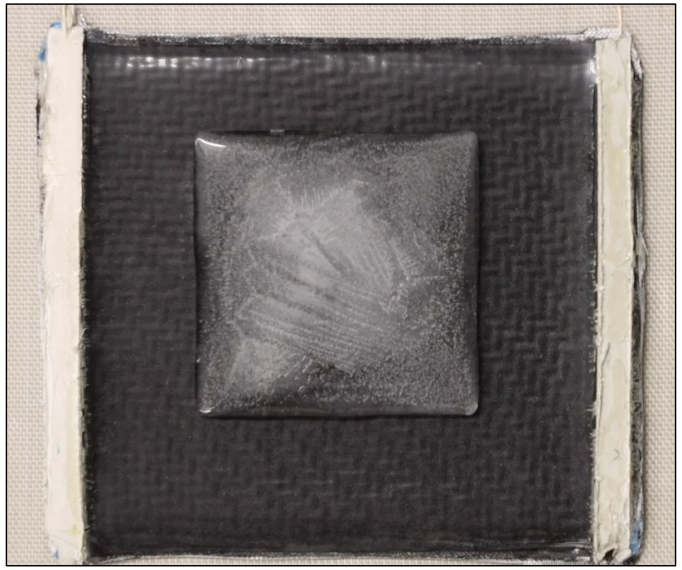
Rapid and Sustainable Manufacturing of Multifunctional Composites via Through-Thickness Frontal Polymerization



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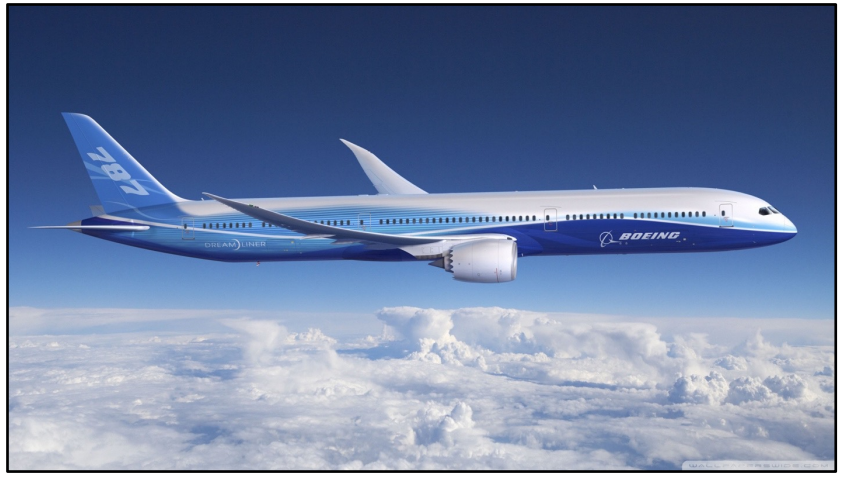
ICCM 23
BELFAST 2023

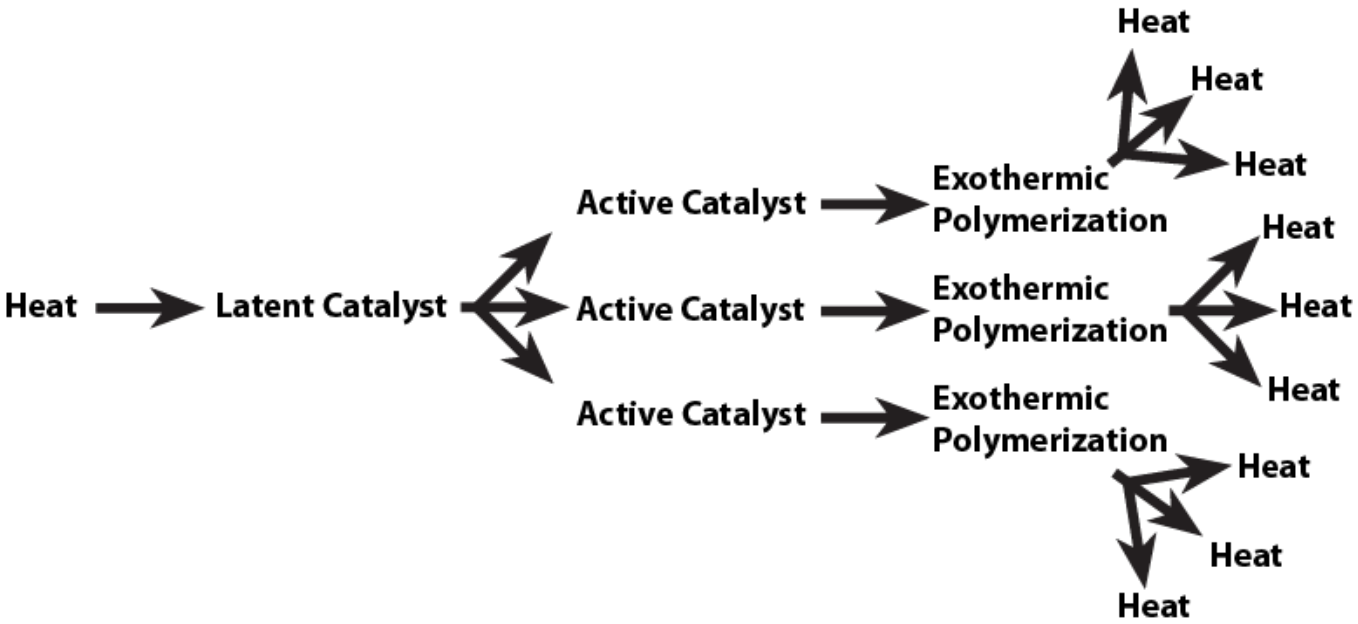
Challenges with Current Composite Technologies



- Slow, energy-inefficient, and expensive manufacturing processes
- Lack of non-structural functional properties

Frontal Polymerization (FP)

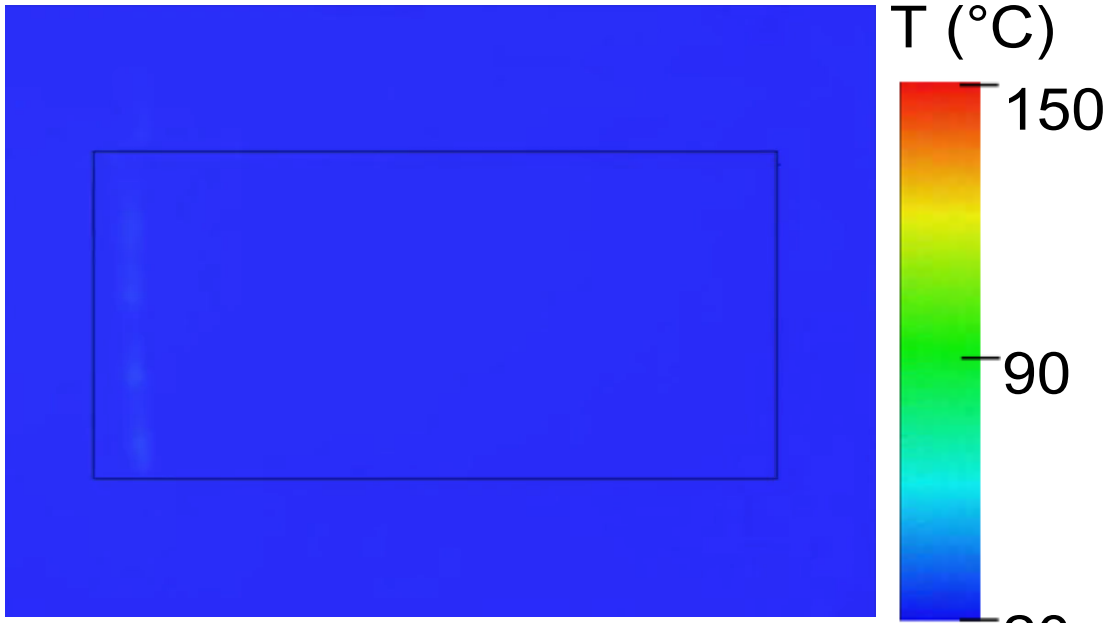
- Self-propagative exothermic reaction wave driven by heat of polymerization



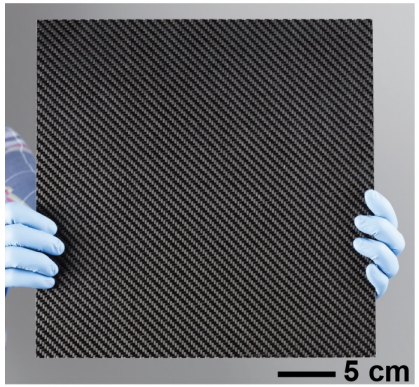
Robertson, Yourdkhani et al., *Nature*, 2018

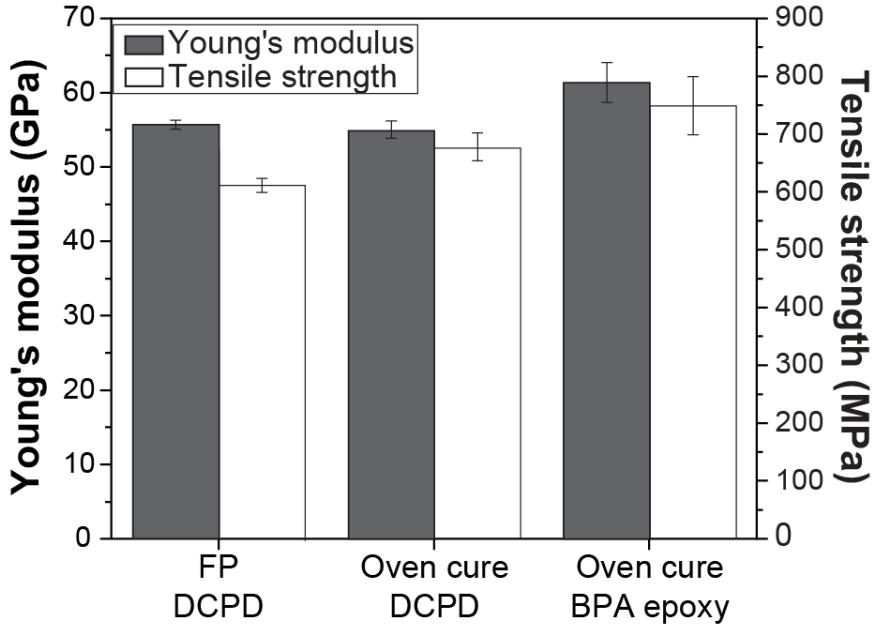
In-Plane Frontal Curing of Composites

- Frontal ring-opening metathesis polymerization of dicyclopentadiene (DCPD)



Curing a 10 cm × 20 cm panel in 2 min





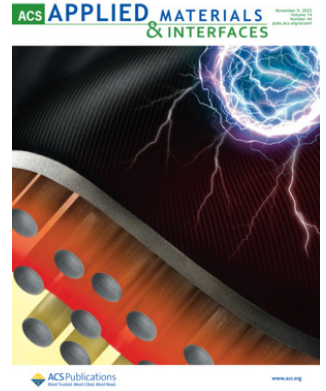
Limitations:

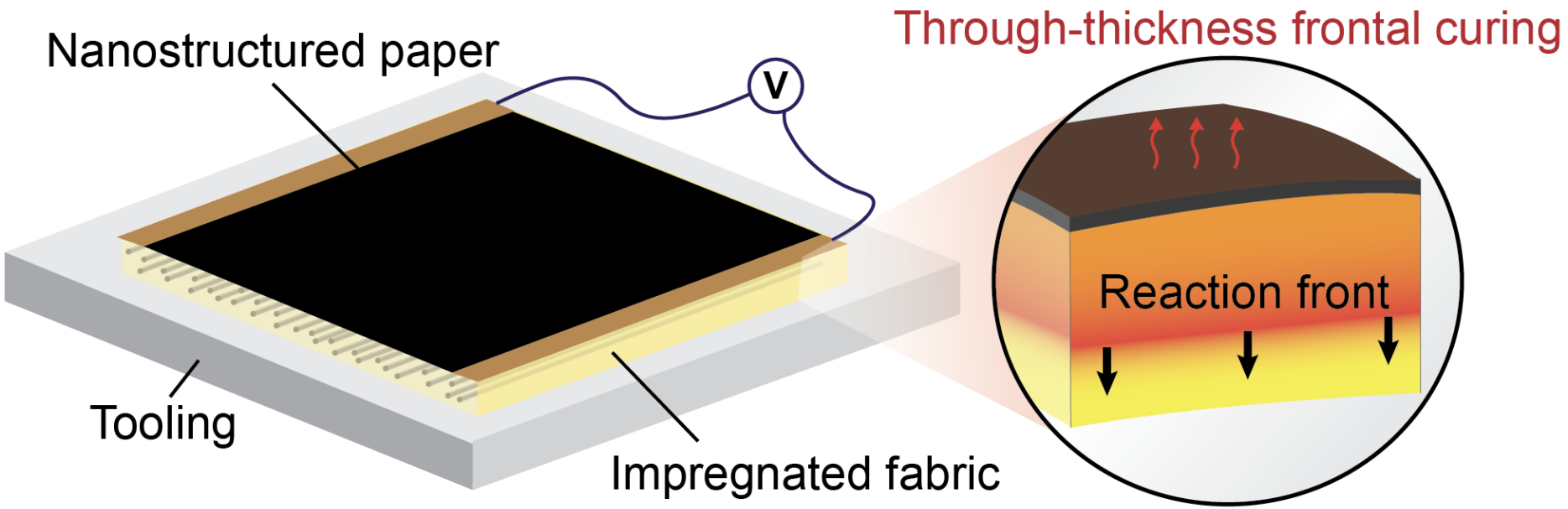
- Highly thermally insulating tooling
- Low resin pot life (20 min)
- Fabrication time scales with travel distance

Robertson, Yourdkhani et al., *Nature*, 2018

Through-Thickness Frontal Curing

- **Through-thickness curing of composites**
  - Curing composite components in <5 min irrespective of the part size
  - Composite curing on any tooling material with a high degree of cure (92-98%)
  - 100,000 times less energy than conventional oven-curing approaches

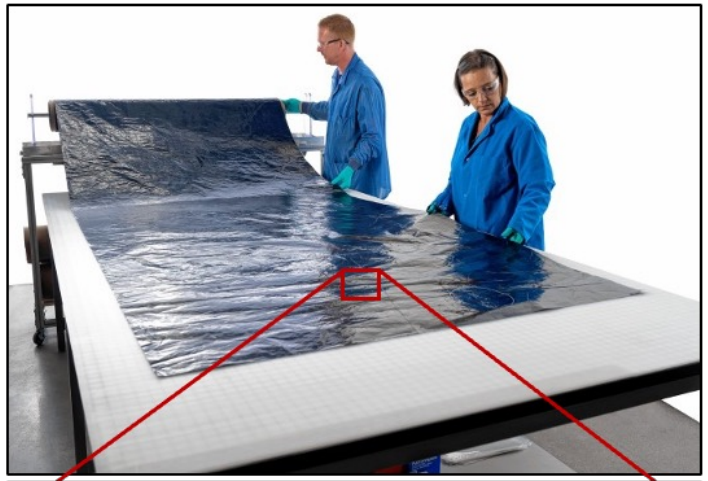


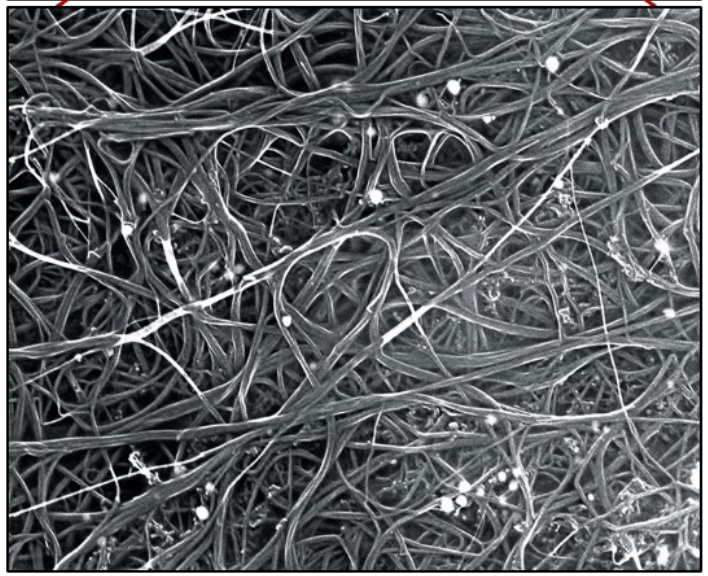


Naseri & Yourdkhani, *ACS Applied Materials & Interfaces*, 2022

Nanostructured Ply

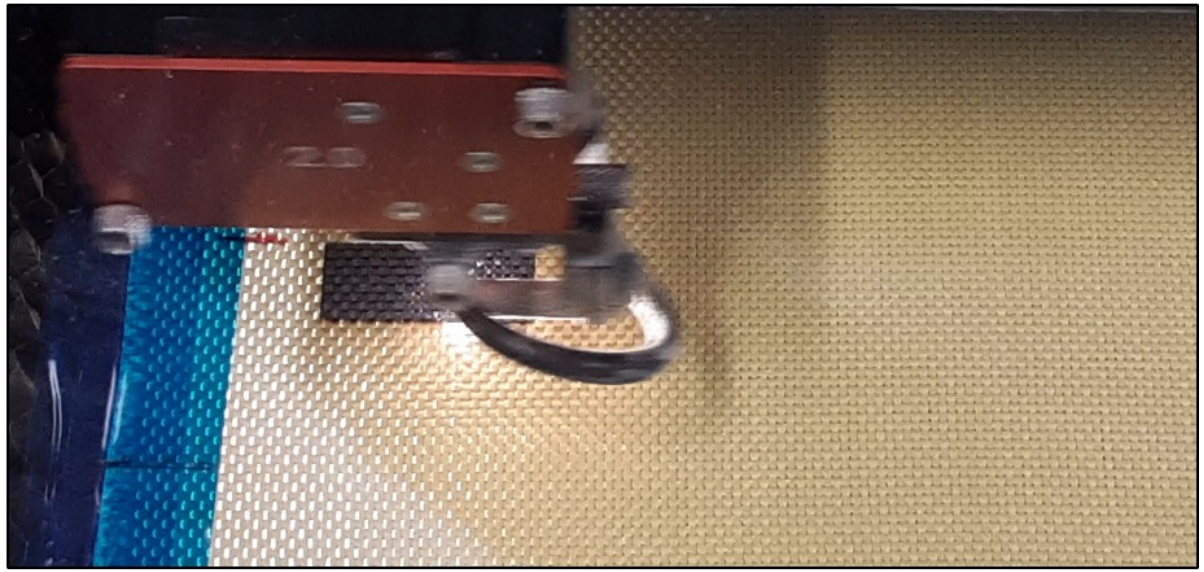
Buckypaper

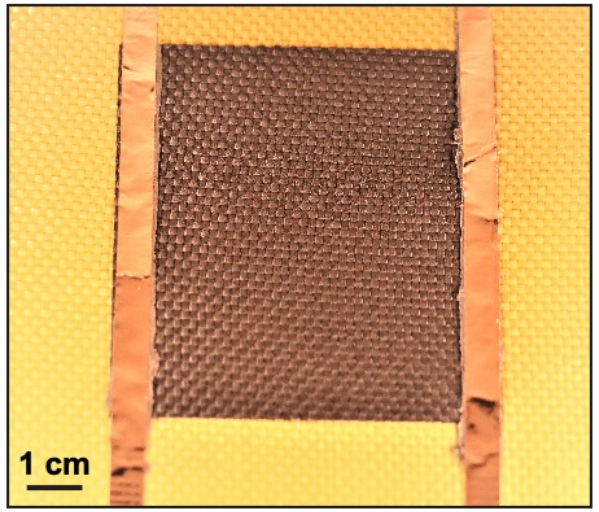




Concordmonitor.com

Laser-induced graphene on aramid fabric

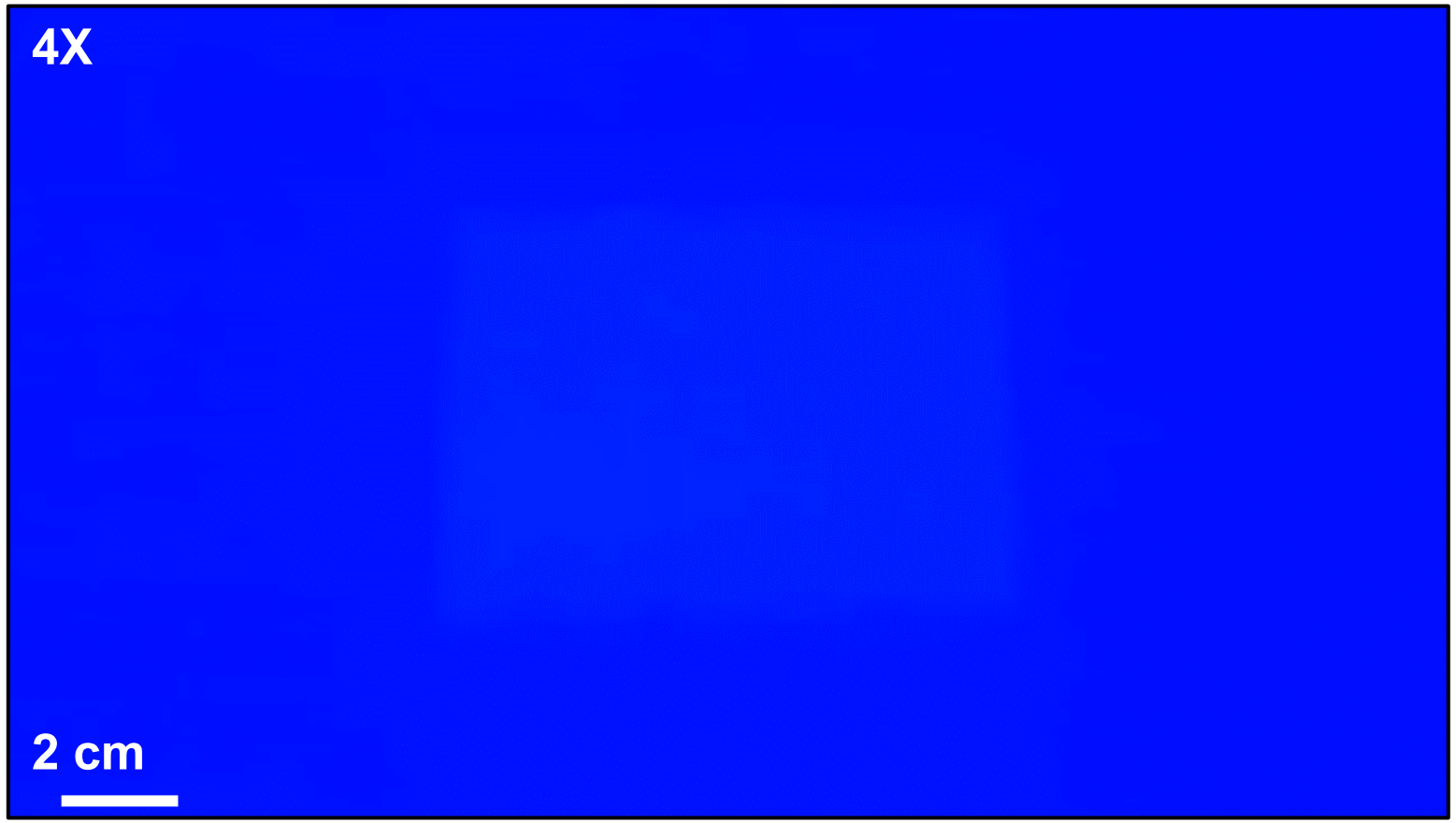


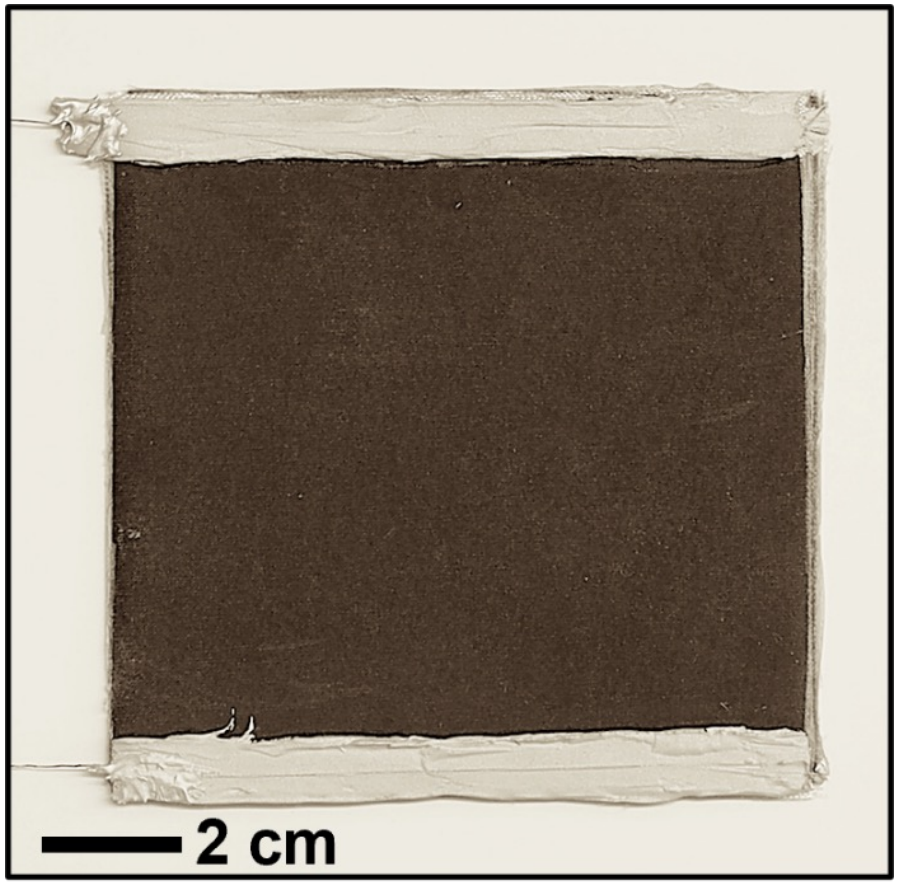


Naseri et al., *ACS Omega*, 2022

Composite Fabrication

- Fabricating a 10 cm × 10 cm composite panel on a glass tool in 1 min

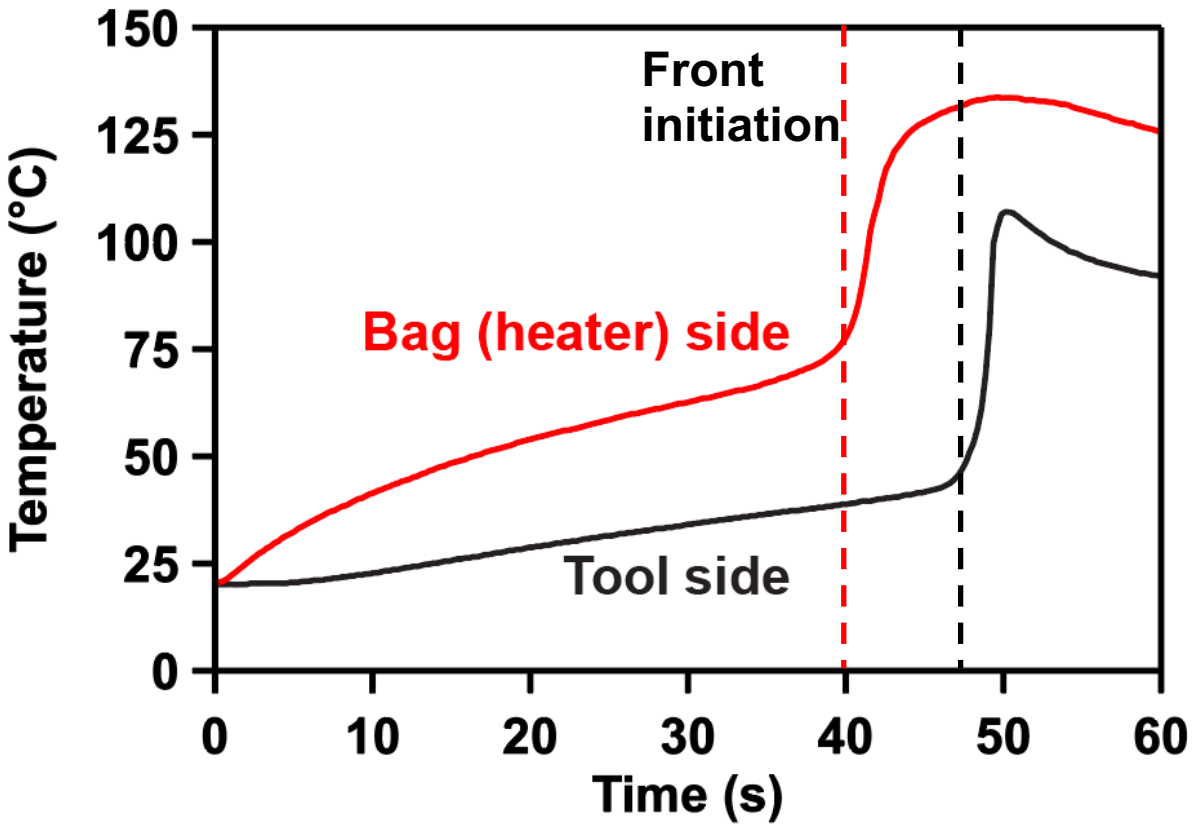


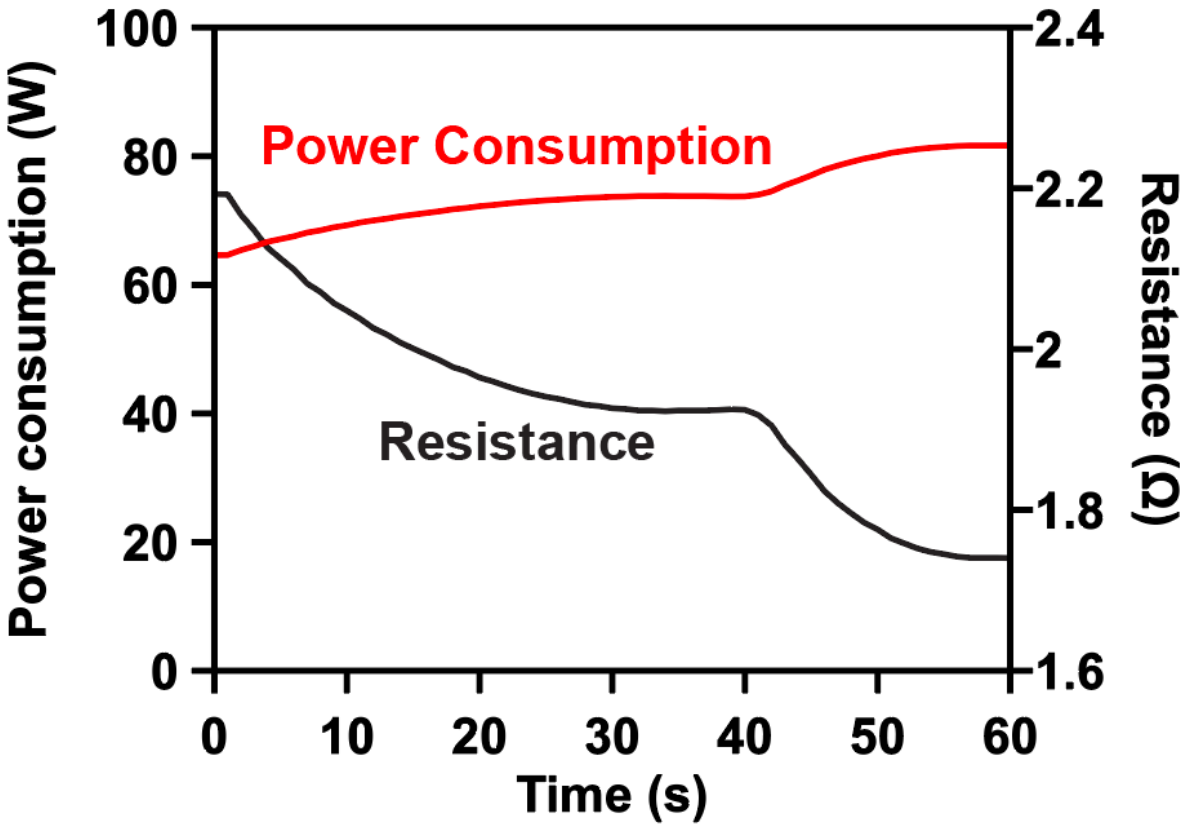


- **Only 4.2 kJ of energy is consumed**

Naseri & Yourdkhani, *ACS Applied Materials & Interfaces*, 2022

Temperature and Power Monitoring





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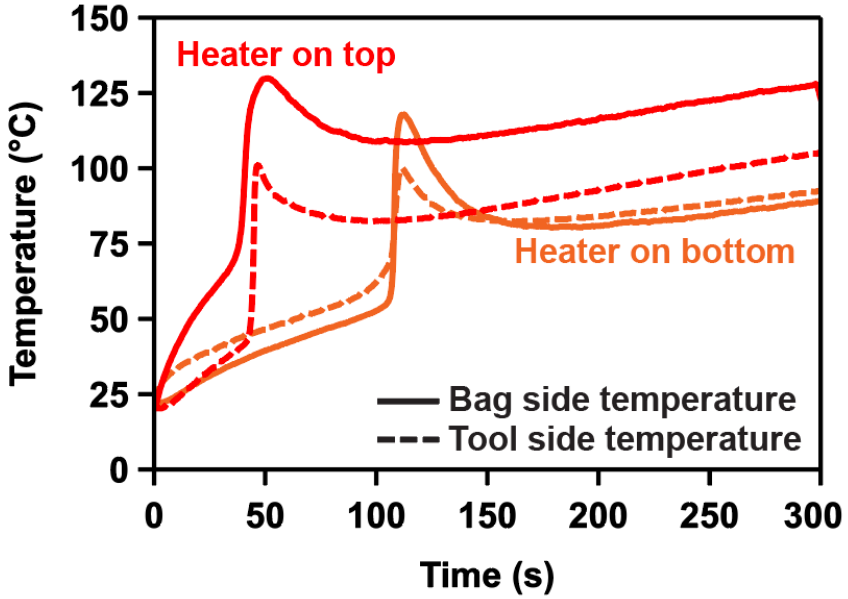
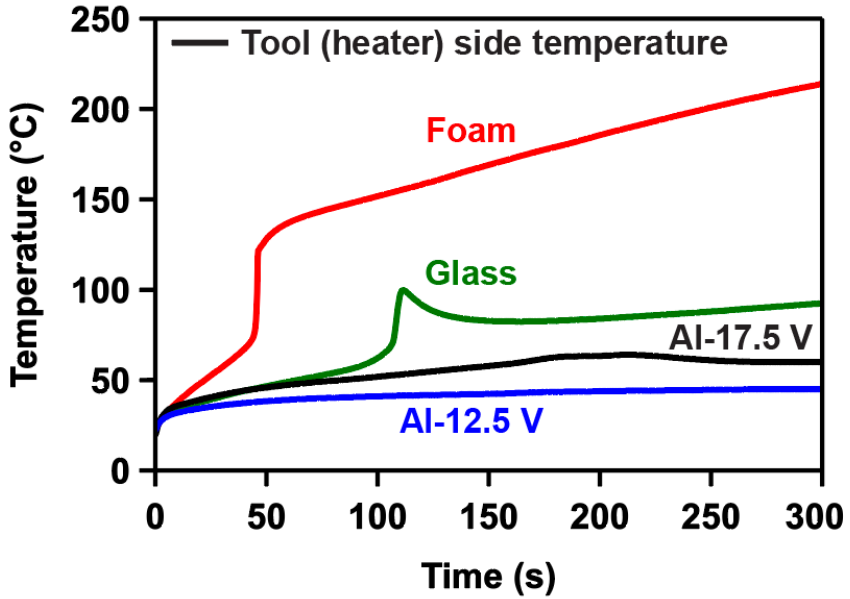
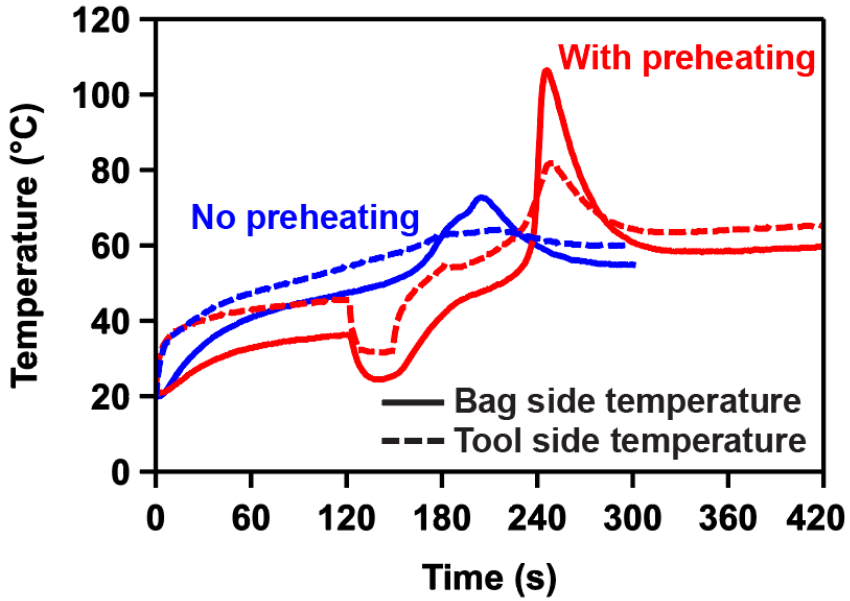
Effect of Processing Parameters







- No post-heating or post-curing required
- Heater ply can be placed under the layup but leads to longer cure times
- Successful curing of composites on various tooling with degree of cure > 95%

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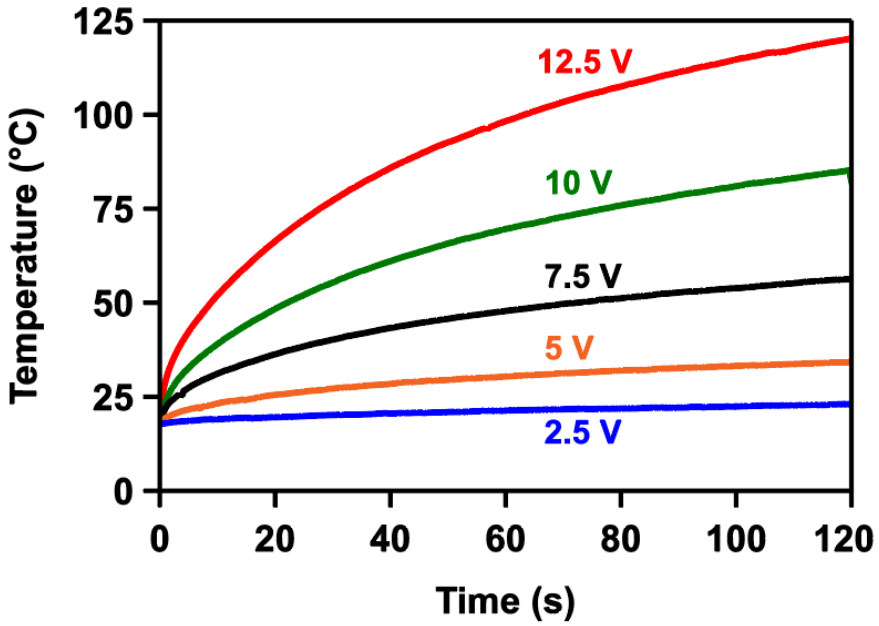
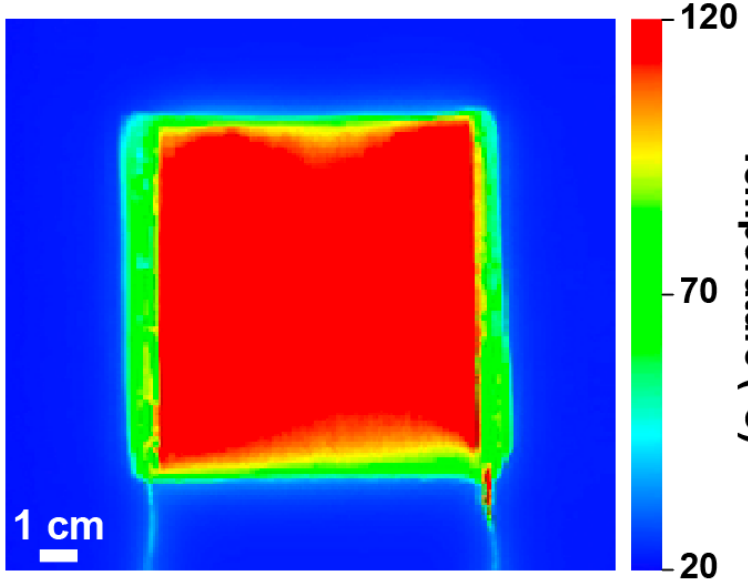
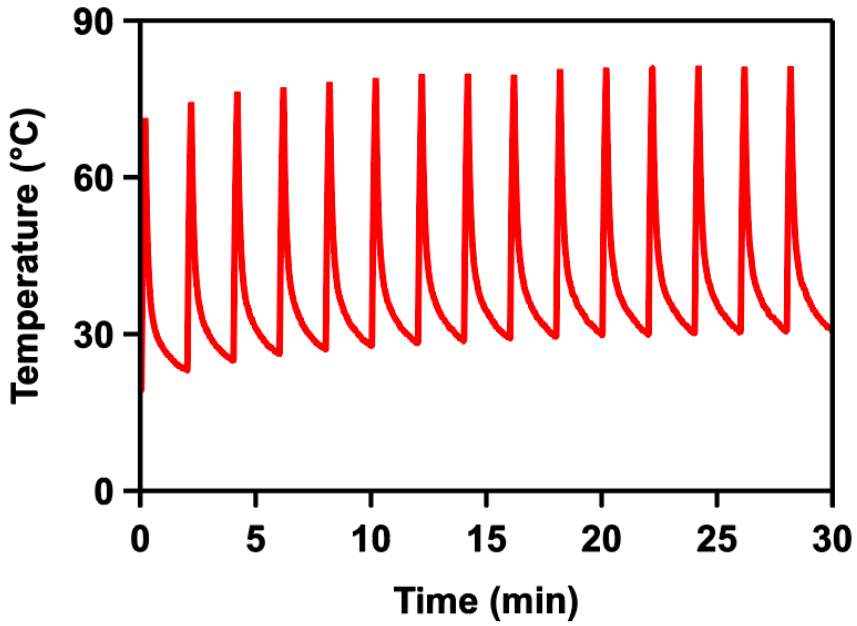
Electrothermal Characterization of Cured Laminates

- Cured laminates show excellent Joule heating properties at low input voltages







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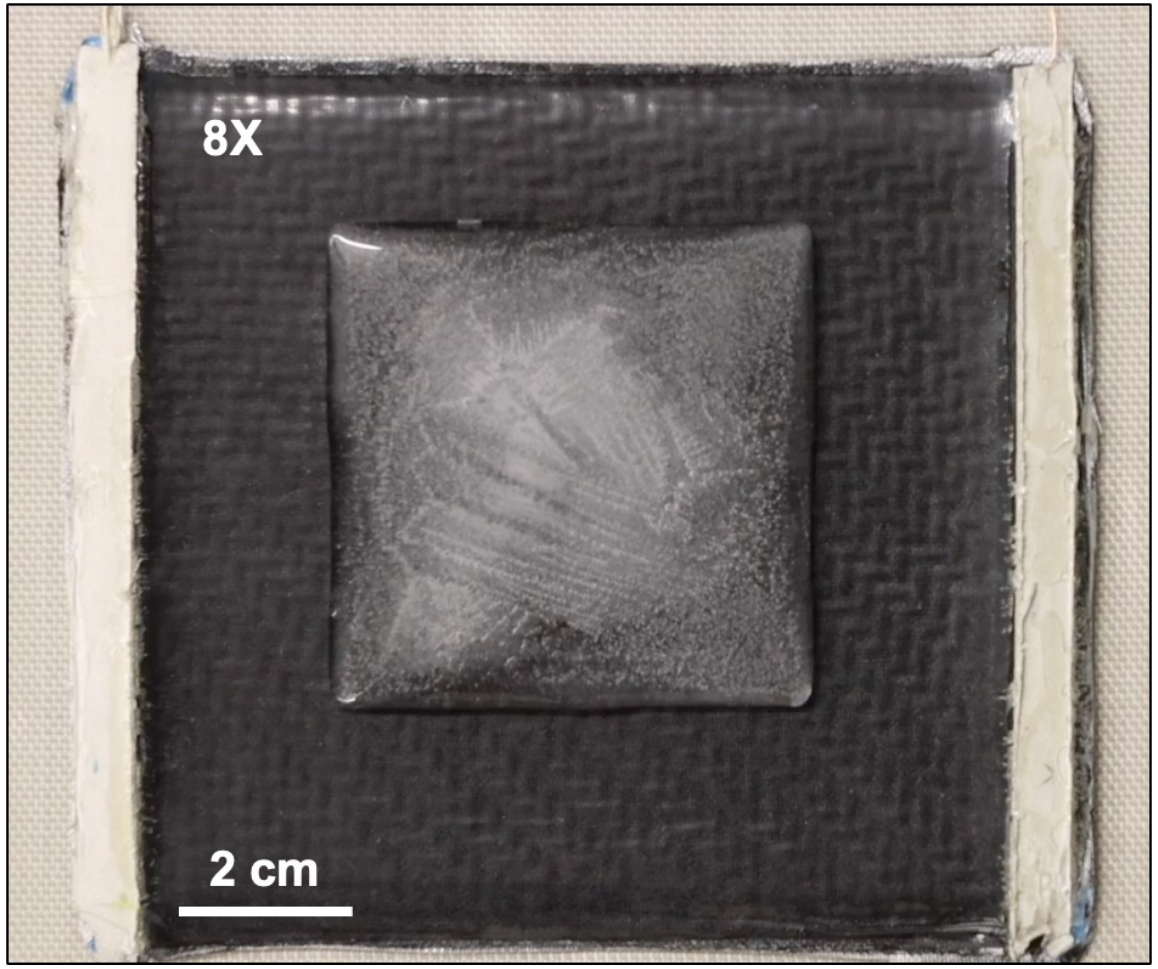
De-icing Demonstration

- Complete melting of a 50 × 50 × 3 mm^3 cube of ice within 3 min
- Power requirement: 6 W/in^2



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Summary

- Through-thickness heating enables frontal curing of composites within 5 min, irrespective of part size
- 100 and 100,000 times reduction in cure time and energy input, respectively
- High degree of cure in produced composite panels
- Eliminating the need for expensive equipment and reducing periodic maintenance costs
- Reduced weight and cost of composite structures
- Demonstrated de-icing functionality in produced composites