BODA RESIN™-PRIME

Technical Data Sheet

Carbon Manufacturing is Slow, Costly & Constrained

ENGINEERING AROUND LOW CARBON YIELD RESINS HAS NOT WORKED FOR >60+ YEARS

Limited Commercial Options

The advanced materials market lacks scalable, high-performance carbon precursors. All commercial options are low carbon yielding and cause procurement delays of final carbon product due to low conversion efficiency.

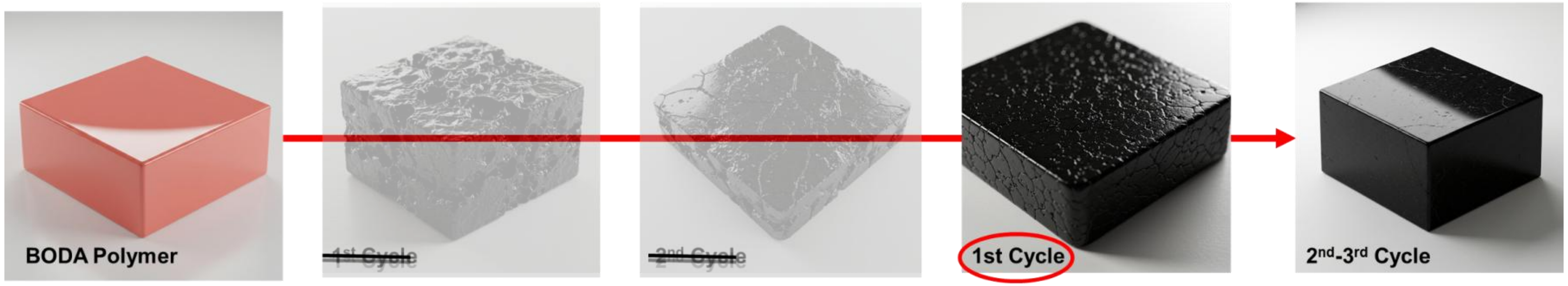
Excessive Production Timelines

For example, in carbon-carbon composite production requires 6–9 months and multiple infiltration cycles, delaying deployment of critical aerospace systems.

Low Material Efficiency

Conventional carbon precursors (phenolics, benzoxazines, etc.) yield only 30–60% carbon by weight, leading to high waste, multiple processing rounds, higher carbon footprint per unit, and greater costs.

HAND'S BODA RESIN™ PLATFORM PROVIDES GUARANTEED TIME SAVINGS



Instantly Double Carbon Production Speed

High carbon yield (>80%) BODA enables rapid carbonization in just 1–3 cycles—**cutting production time from months to weeks (50-80%),** lowering cost-per-part.

Trusted Validation and Early Demand

Structural composite integrators, materials labs, and contractors have expressed interest and have signed LOI to purchase ½ ton of resin.

Scalable Resin Chemistry

With SBIR/STTR-backed development and pilot-scale production planned by Q3-Q4 2025, HAND is on track to launch full-scale manufacturing by Q1 FY26.

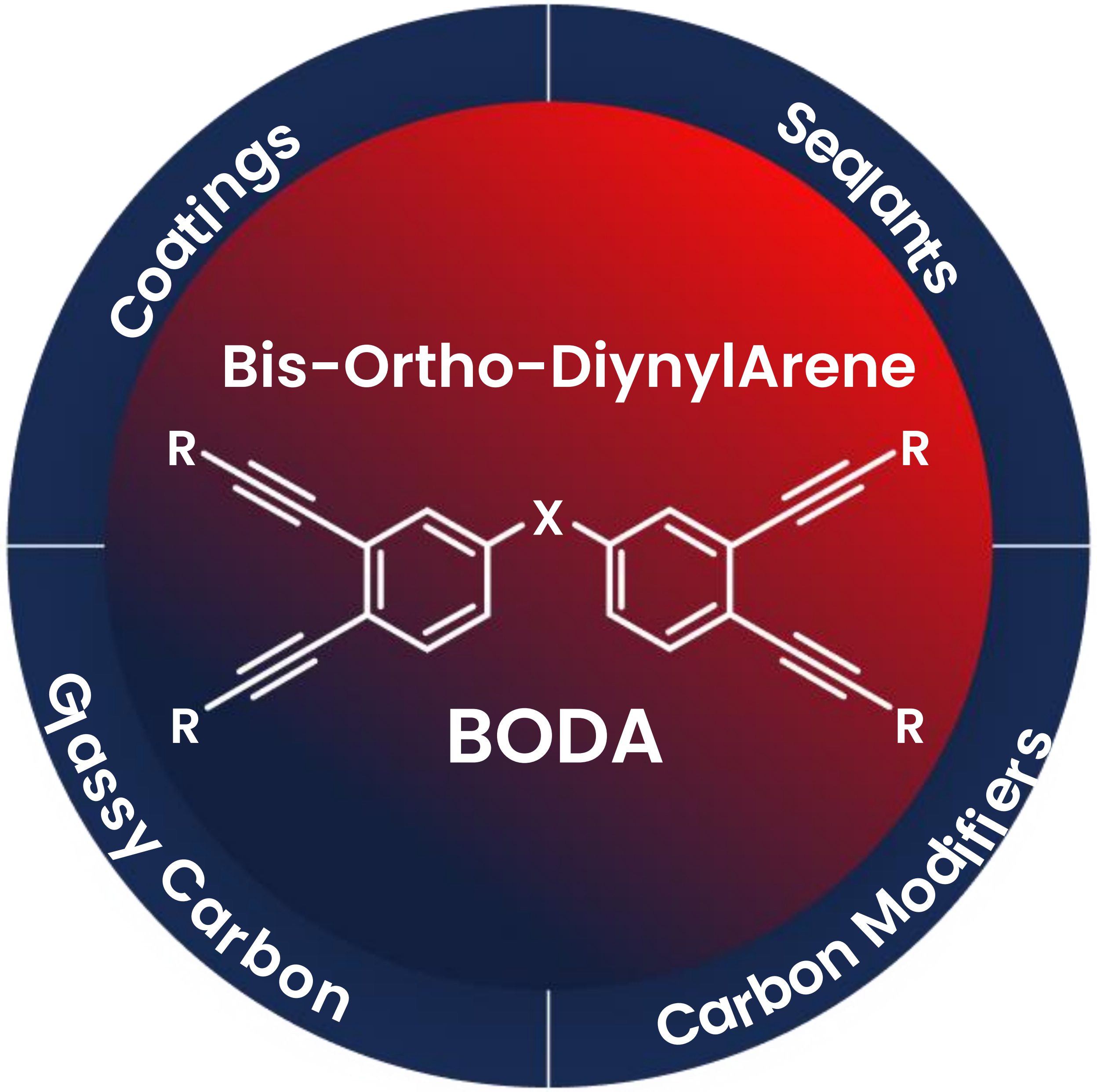
BODA RESINS CAN BE TAILORED TO YOUR NEEDS

VARIABLE PROCESSING

BODA™

BODA™

BODA™



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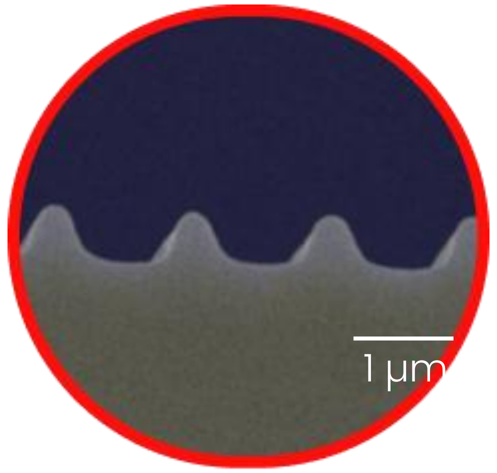
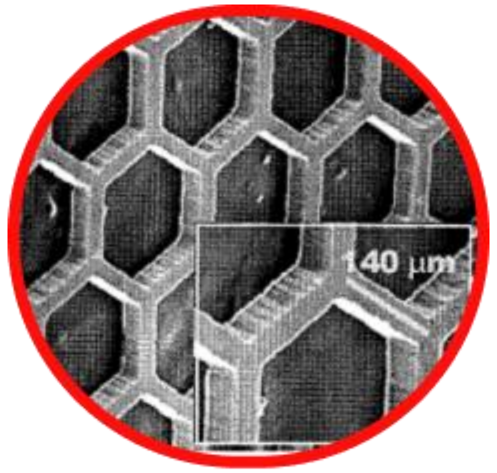
Borrego, E.I., Smith, D.W. Compos. B. Eng. 2022, (242) 110080

Borrego, E. I., Smith Jr., D.W. U.S. Patent Application US 2023/0098530 A1 March 30, 2023. (MSU).

VARIABLE APPLICATIONS



Carbon Micrograting



Carbon MEMS

Carbon Fiber

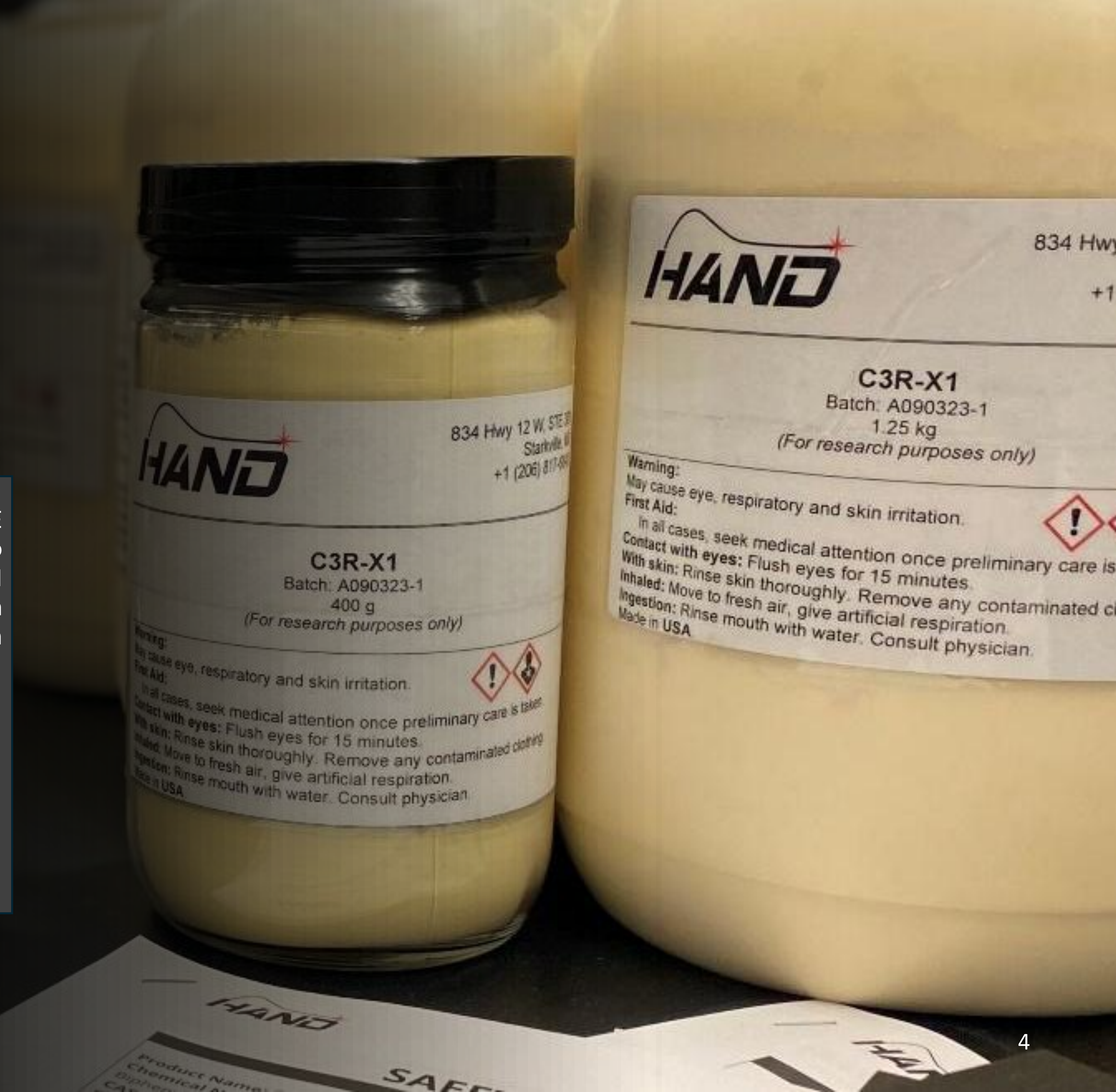
BODA-PRIME

NEAT RESIN (DRY POWDER) PROPERTIES

If you're not sure what you want, the BODA-PRIME formulation is a great starting point. This is our flagship product. Provided as a powder it is suitable for RTM processing and compression molding. In a typical Vacuum Bag mold setup this resin can shorten the redensification cycles by 50% if seeking a high density C/C composite.

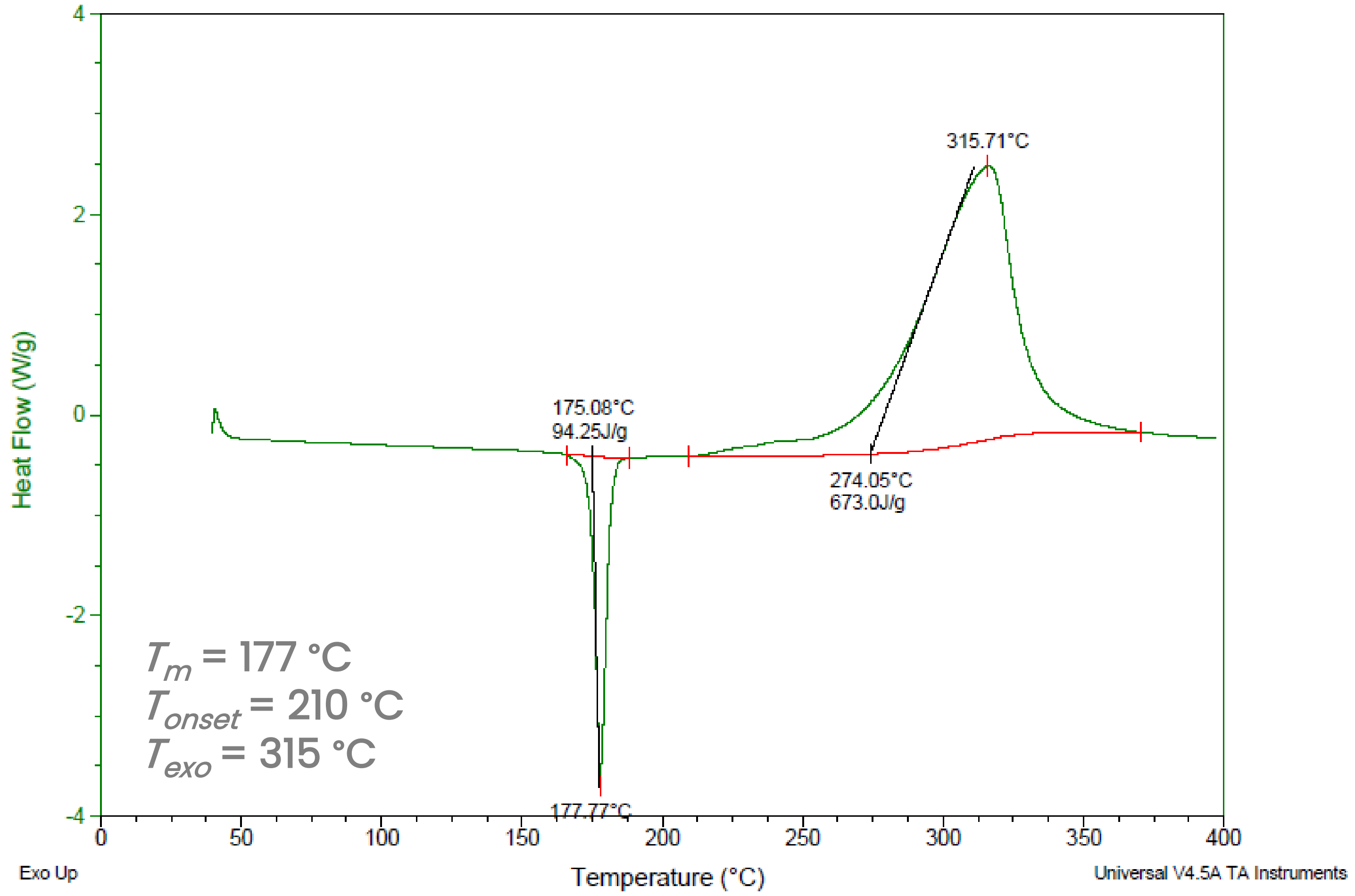
Applications:

- Carbon Matrices
- Reinfusion agent
- C/C Rapid Prototyping
- C/C healing & recovery

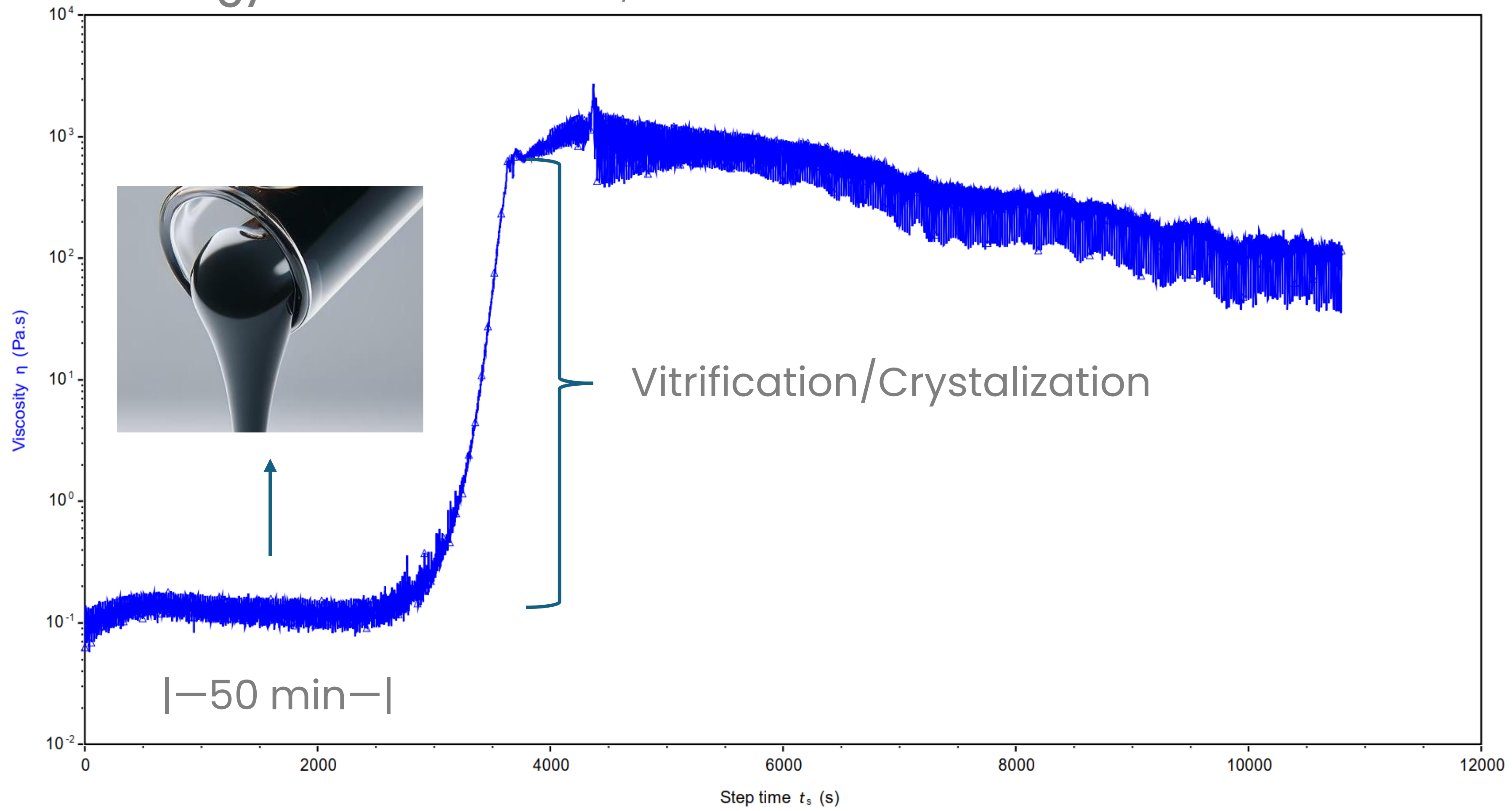


Thermal Processing Properties - DSC and Rheology

DSC 10 °C /min → 400°C, (N_2-25 ml/min)



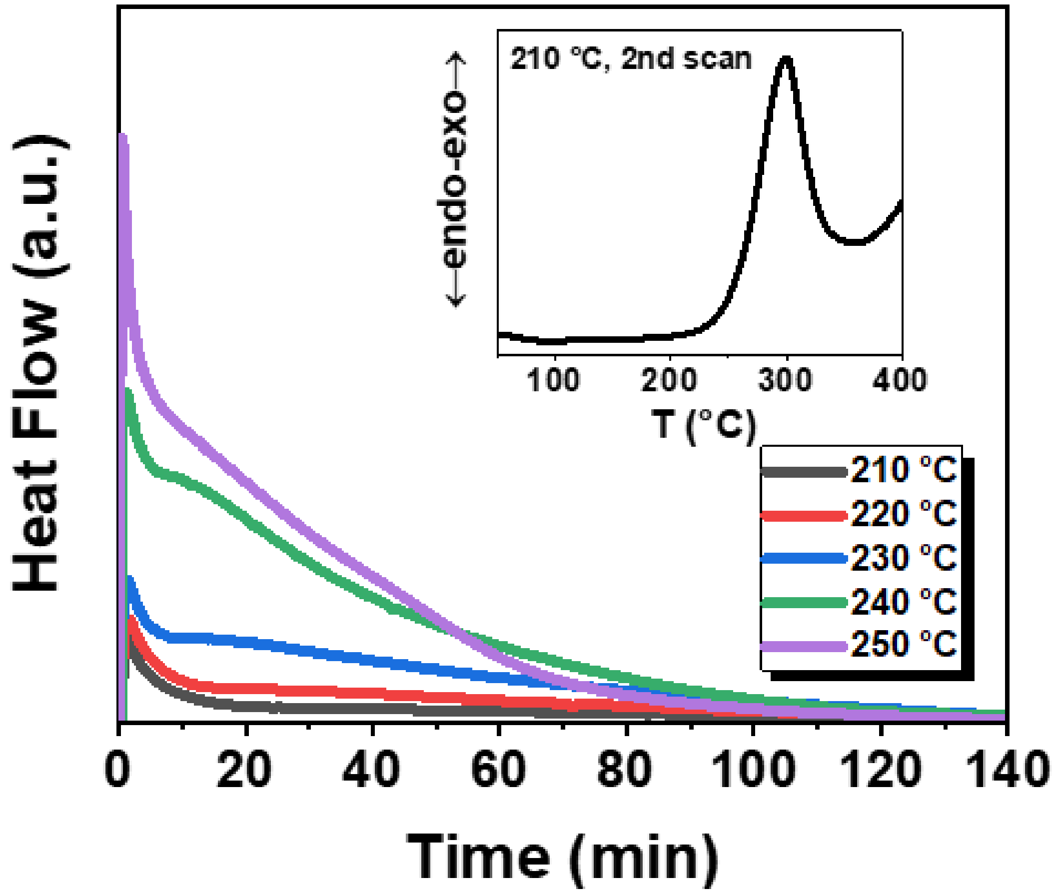
Rheology Isothermal 180 °C, Shear rate: 10 s⁻¹



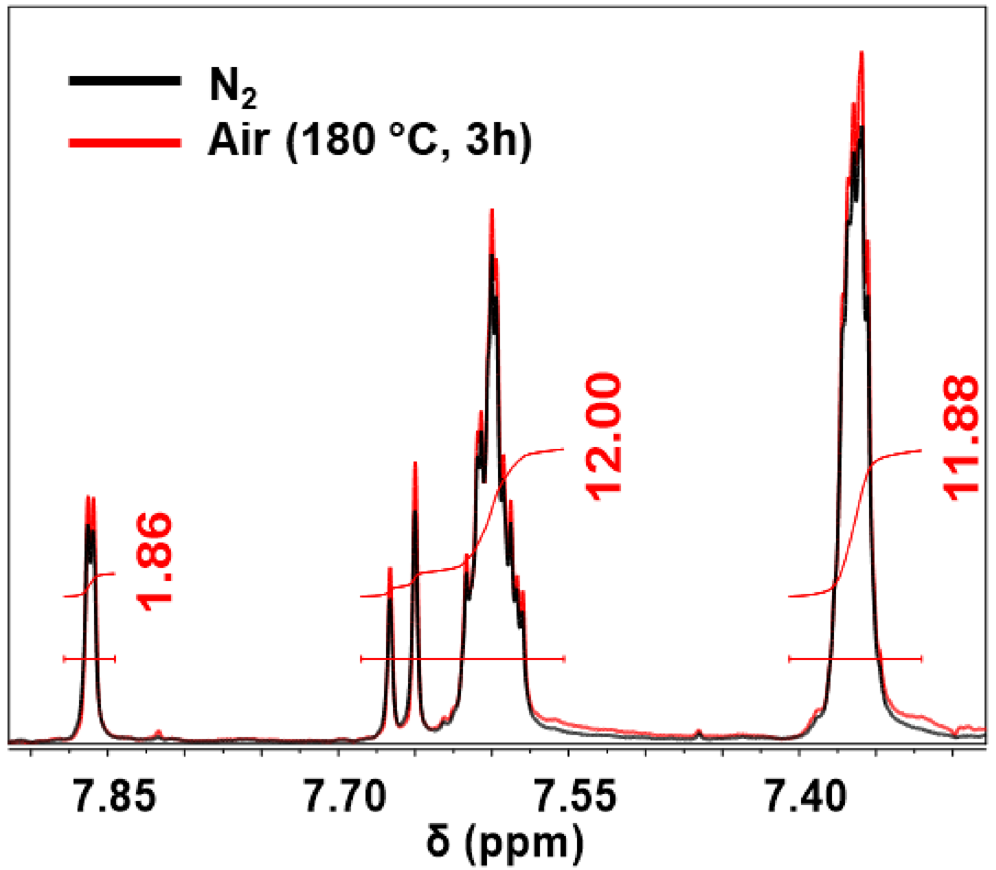
DSC
- Melt temperature (T_m) is 177 °C. Recommended set-temperature for melt-infusion is 190 °C to ensure the resin is at T_m.
- Dwelling at the onset temperature (T_{onset} = 210 °C) the resin begins to polymerize slowly over the span of a few hours.
- Dwelling at temperatures approaching T_{exo} = 315 °C (i.e. >230 °C) the resin begins to polymerize and vitrify quite rapidly.

Rheology
- Upon melting, the neat resin has a low melt viscosity, ~0.2 Pa·s or 200 cP.
- Viscosity will increase at 2800 s (~50 min) and gradually stabilize at 4000 s (66 min).
- Increase in viscosity is due to vitrification (or re-crystallization at low temperatures) not curing.
- Melting (to low viscosity ~200cP) can be re-achieved by raising the temperature further.
- Vitrification window at 210-220 °C is 3 h.

Thermal Processing Properties – Exothermic and Oxidative Processing



Isothermal DSC at various temperatures, inset showing the second heating scan after holding isothermally at 210·°C



^{1}H-NMR, 600 MHz, $CDCl_3$

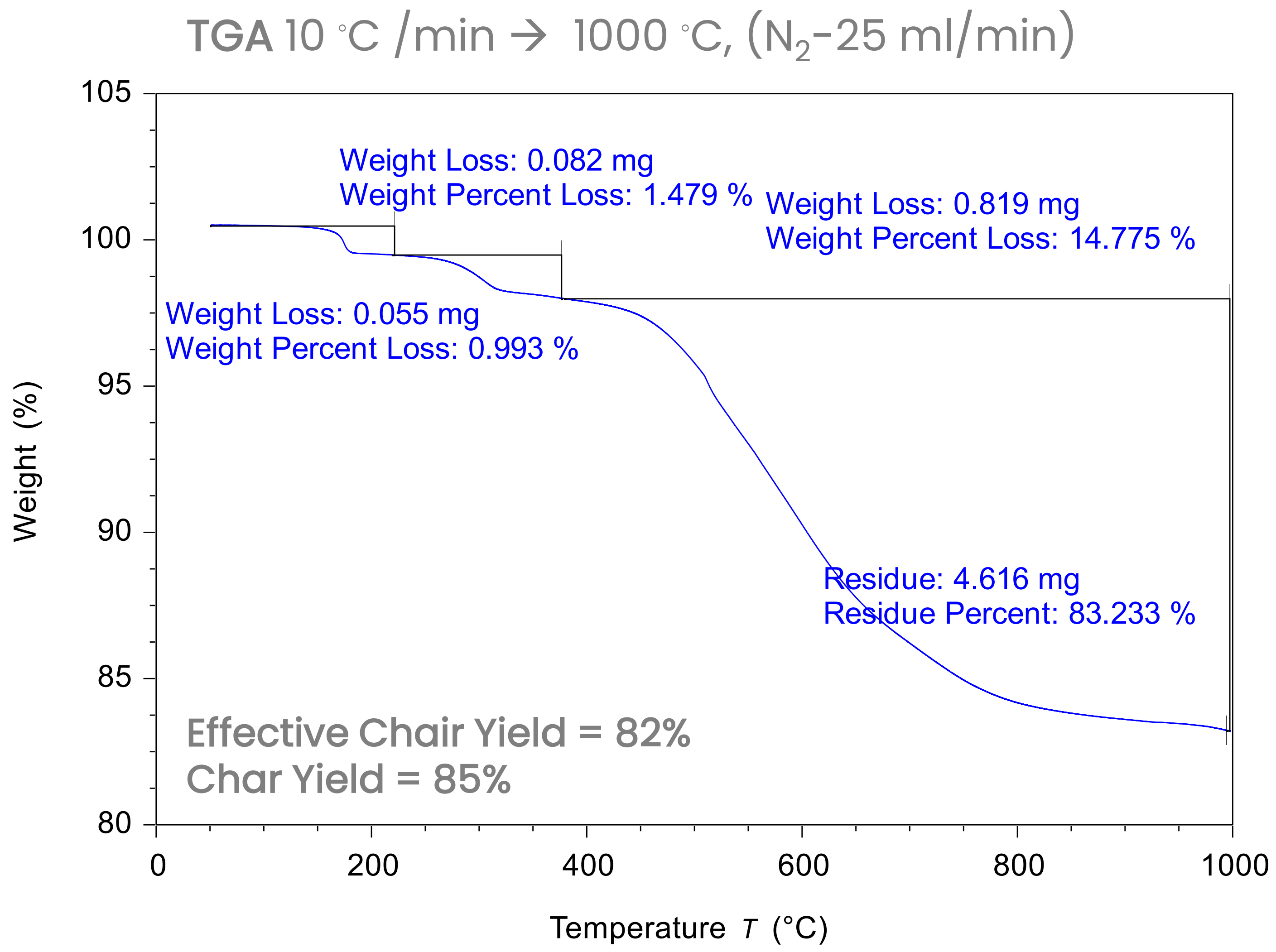
Isothermal DSC

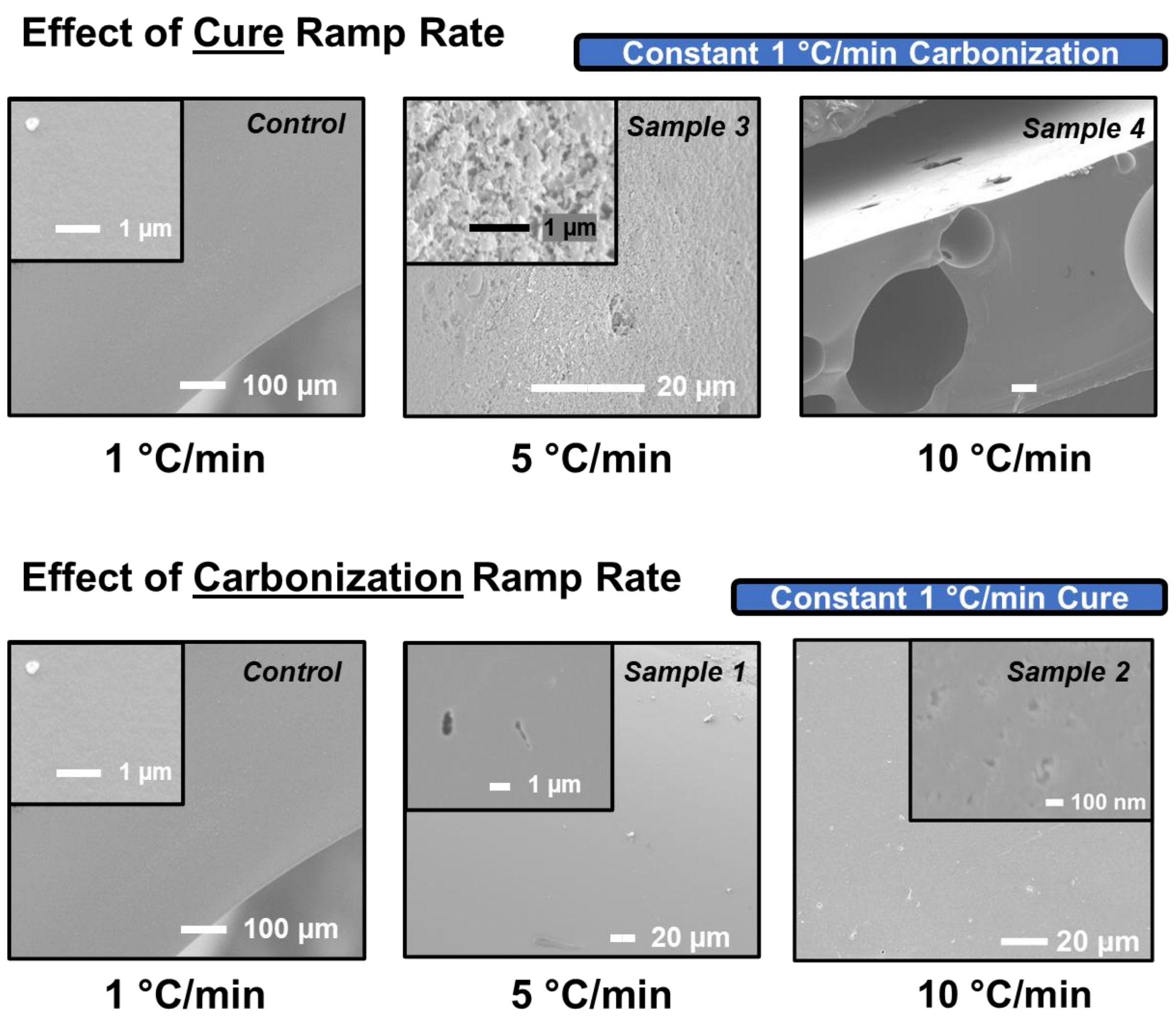
- Maximum heat release occurs upon reaching dwell temp and is thereafter reduced, with no signs of sustained reaction.
- BODA RESIN™ (PRIME) therefore exhibits non-autocatalytic curing behavior, with minimal chance for runaway reaction.
- When mixed with other materials, e.g. T300 carbon fiber, the energy released throughout the entire cure (~700J/g) will be mostly absorbed and dissipated by the T300 fibers.
- *Disclaimer:* When mixed alone, in quantities >10g, processing systems with poor heat control and localized hot spots can initiate an exotherm.

^{1}H-NMR

- Comparative NMR of BODA RESIN™ (PRIME) post-melt processing in N_2 and air illustrates the general oxidative stability for the melt-infusion process at 180 °C. No change in molecular structure occurs. Common behavior amongst the BODA RESIN ™ family.

Achieving an Optimally Dense BODA Carbon– Carbonization Behavior





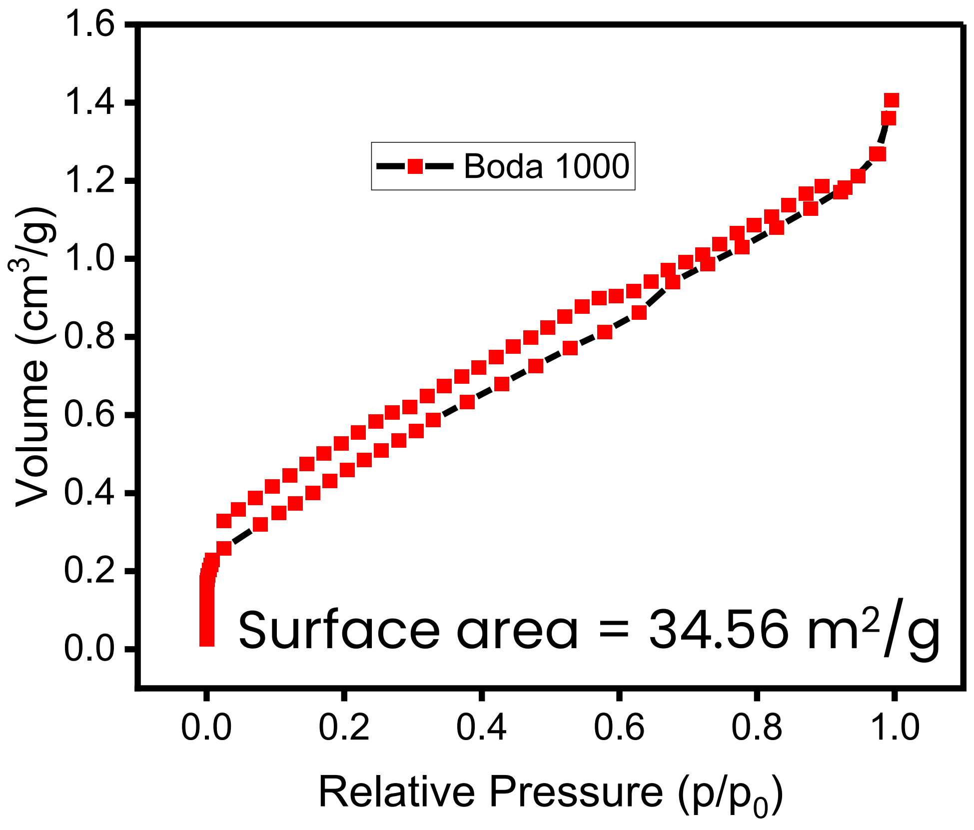
Thermogravimetric Analysis

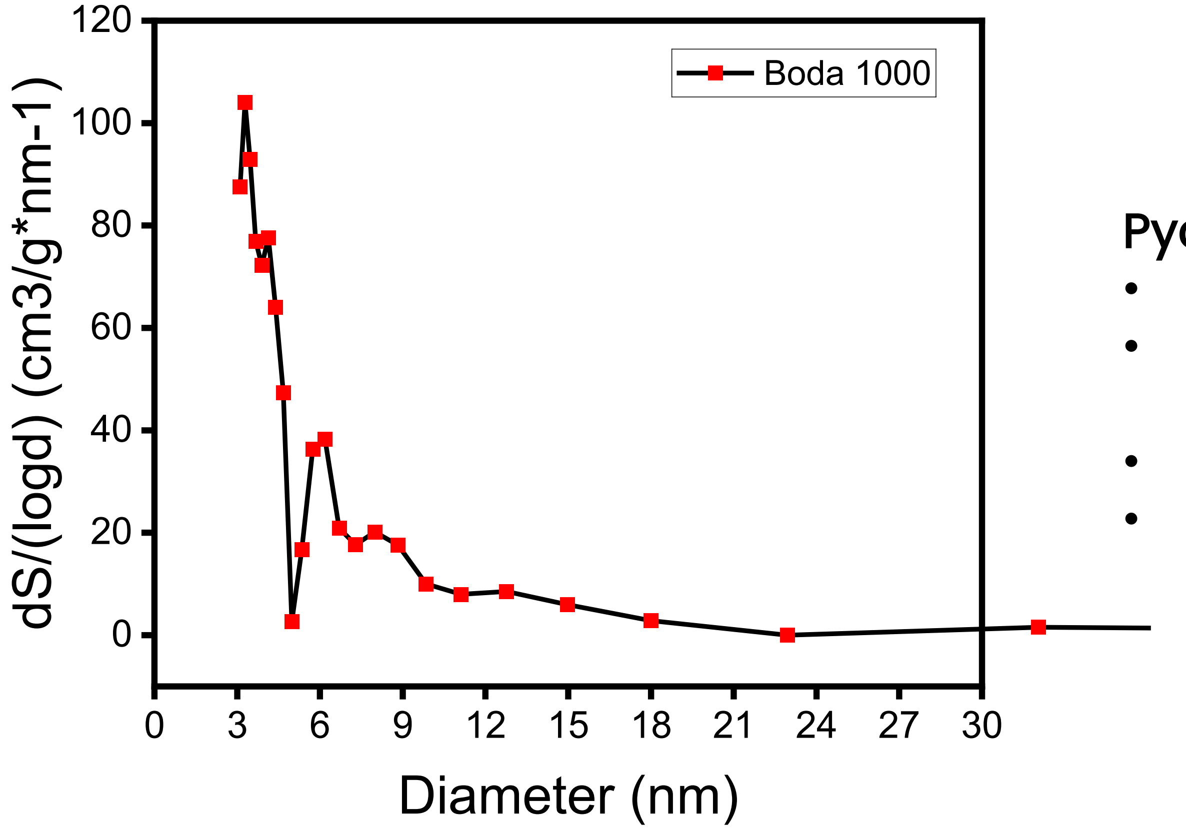
- The BODA thermoset obtained after 300-400 °C has a **char yield of 85%** and exhibits great dimensional stability during pyrolysis.
- Prior to curing, as the temperature advances to >210 °C volatilization will occur (see TGA, ~2-3% between 200-400 °C).

Effect of Cure & Carbonization Rate on Carbon Density/Porosity

- The key to getting an optimally dense BODA carbon is getting an optimally dense BODA thermoset first.
- Volatilization (at >180 °C) is negligible under atmospheric pressure but almost constant under vacuum.
- An intermediate cure (~220 °C, >2h) after infusion (190-210 °C) will stabilize volatilization and minimize pore formation.
- We recommend a final cure of 230 °C for >3h or up to 250 °C for at least 2 h. Higher temperatures preferred for first use.
- Optimizing these infusion and curing conditions for your process is critical to forming a BODA carbon with minimal porosity.
- Once an optimally dense BODA thermoset is achieved, the carbonization/pyrolysis conditions (e.g. ramp rate) has little effect on generating pores. See figure on the top right. Fast carbonization to 1000 °C does little to generate pores after an optimized cure.

Carbon Microstructure





Pycnometry Data

- The surface area (34.56 m^2/g) is low.
- From the plot, we have type 4 hysteresis loop which is a strong identifier of a slit shaped pore.
- Pore distribution around 3 to 8 nm.
- The pores are slit shaped with 4 nm average size.

T_{onset} (°C)	HTT (°C)	CTE α ($\times 10^{-6}$ °C^{-1})	Std. Dev. ($\times 10^{-6}$ °C)	CTE Range (°C)
575	1000	6.92	0.68	20-1000

Carbonized **BODA RESIN-PRIME** were then reheated from ambient to 1000 °C at 10 °C/min to determine their CTE. The CTE (a) was determined by linear graphical regression using the equation $a = (1/L_0)(\Delta L/\Delta T)$, where L_0 is the initial sample length, ΔL is the change in length from ambient to elevated temperature, and ΔT is the change in temperature from ambient. Measurements were taken in triplicate for each sample and are reported as an average. STM measurements were performed by a Digital Instruments Nanoscope III.

Summary of Notes for Composite Processing

For Powder Melt-Infusion

- Recommended infusion temperature is 190 °C.
- Under high vacuum, some volatilization is expected during the infusion.
- Dwelling at 230 °C for 1.5 h between the infusion and cure will B-stage the resin, increasing its viscosity and boiling point sufficiently that volatilization is minimized and proper degassing for the matrix at high vacuums can begin.
- Recommended cure temperature is 250-300 °C for >2 h.

For Pre-Pregging

- HAND can provide its resins in the form of B-staged solutions (see example in slides 11-13).
- The solvent choice can be varied according to customer needs.
- Processing notes will be specific to the formulation, i.e. resin conc., solvent, etc.
- A B-staged solution may be sought for tailoring the infusion temperature or pre-pregging.
- Furthermore, prior B-staging minimizes volatilization under high vacuum, once solvent is removed.

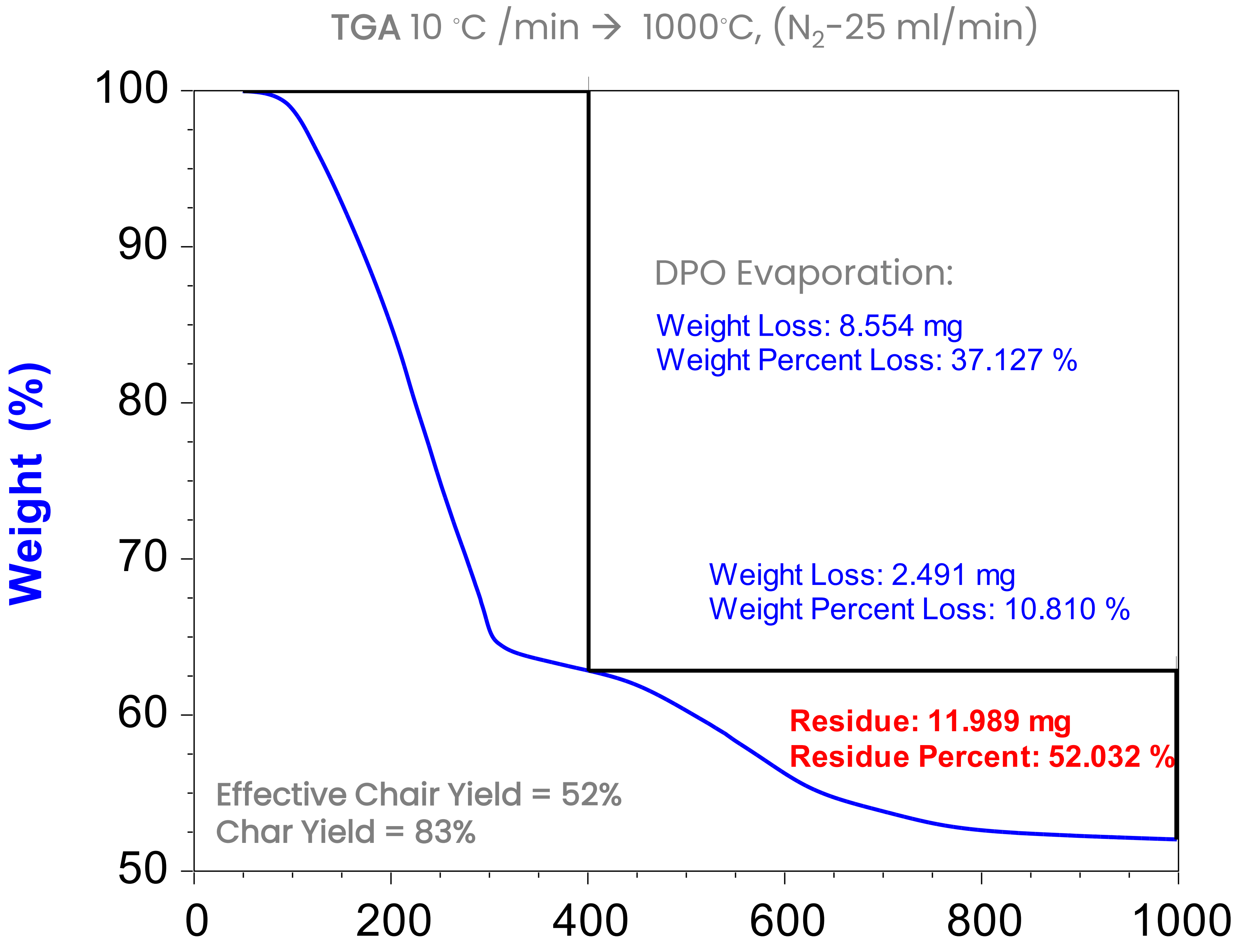
For R&D Use Only. These guidelines serve as a starting point. Users should expect to optimize processing conditions to achieve maximum material performance within their specific equipment.

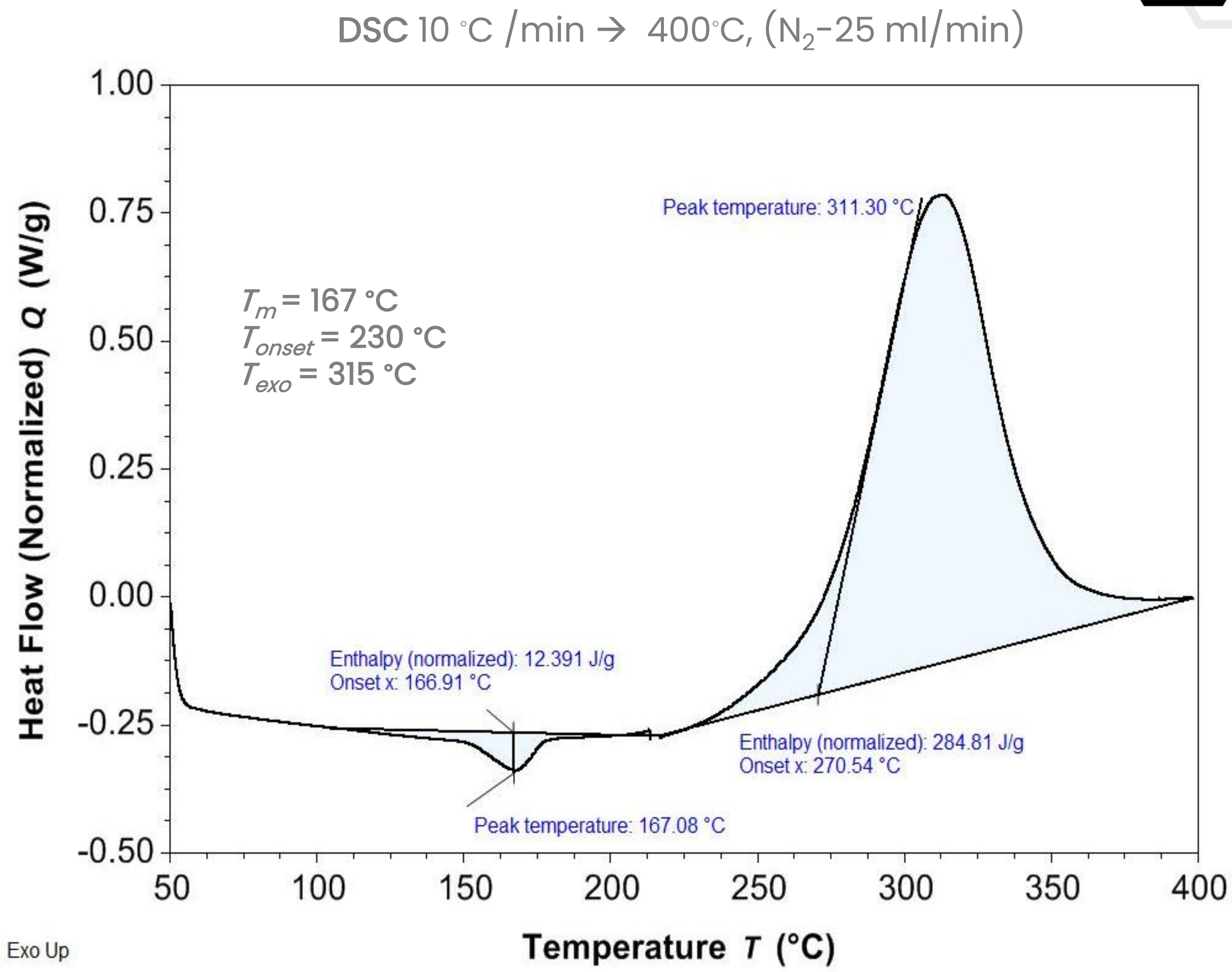
BODA-PRIME

B-STAGED SOLUTION PROPERTIES (IN DIPHENYL OXIDE)

This BODA-PRIME formulation can be provided in a few different solutions according to your needs. It is ideal for pre-pregging and low temperature infusions.

Thermal Processing Properties – TGA and DSC





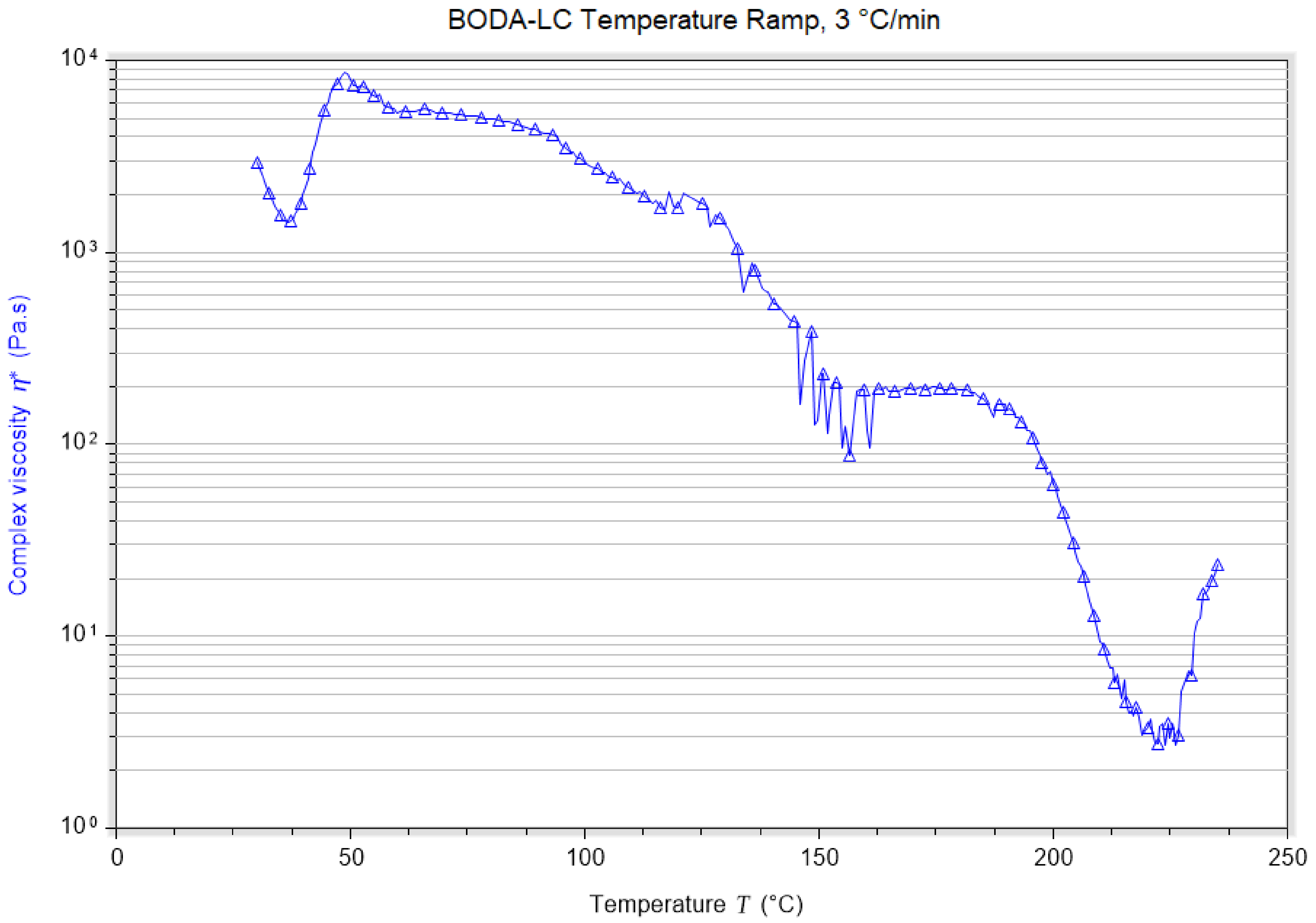
Thermogravimetric Analysis

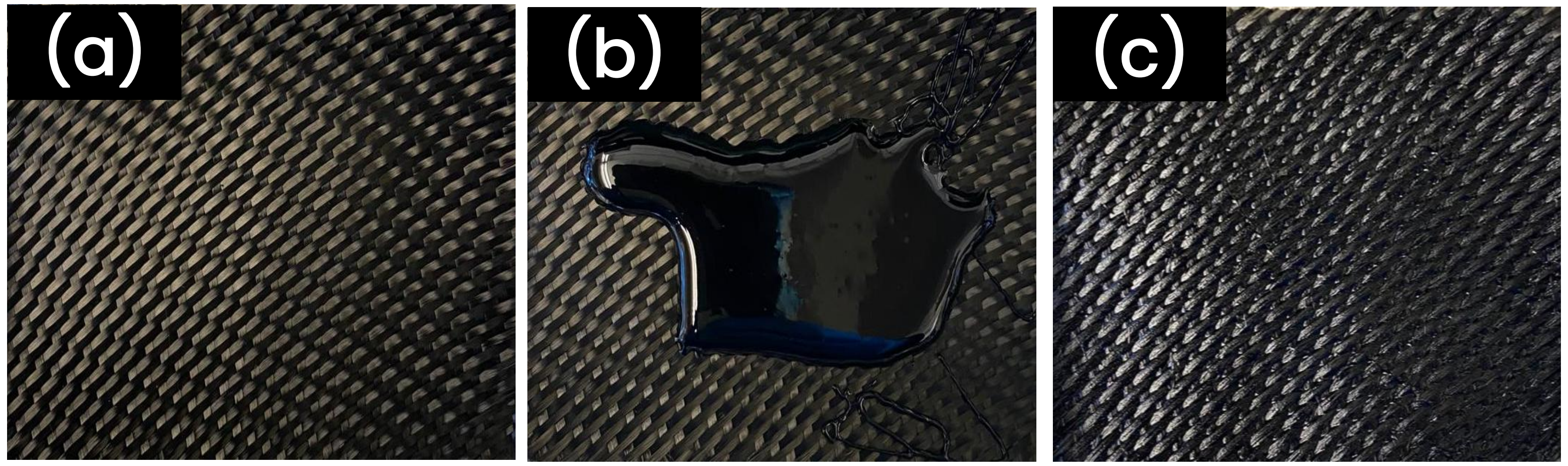
- TGA of BODA RESIN™-PRIME shows a weight loss (~ 37-40%) after 200 °C due to volatilization of DPO.
- After DPO volatilization, BODA RESIN™-PRIME thermoset has a **char yield of 83%** and exhibits great dimensional stability during pyrolysis.

DSC

- Note: DPO was removed at 150 °C under vacuum (-29 inHg) prior DSC analysis.
- Softening point is observed at 167 °C.
- Dwelling at the onset temperature (T_{onset} = 230 °C) the resin begins to polymerize slowly over the span of a few hours.
- Dwelling at temperatures approaching T_{exo} = 311 °C the resin begins to polymerize and vitrify quite rapidly.

Rheology and Prepreg test





Prepreg

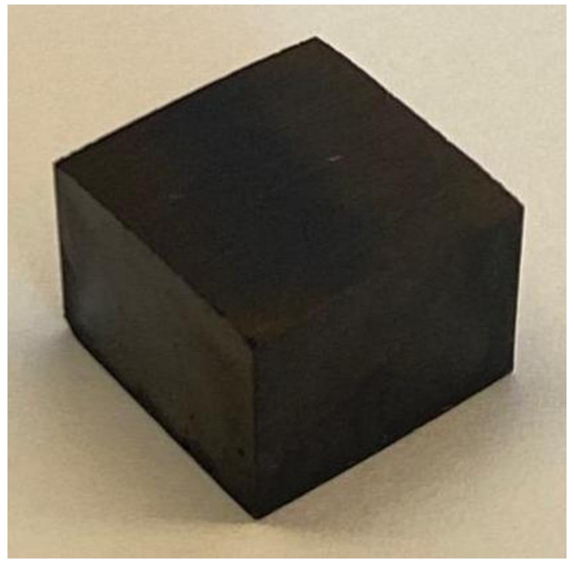
(a) Carbon fiber.
(b) BODA RESIN™-PRIME deposited on carbon fiber at 100 °C.
(c) BODA RESIN™-PRIME impregnated into carbon fiber at 130 °C.

Rheology

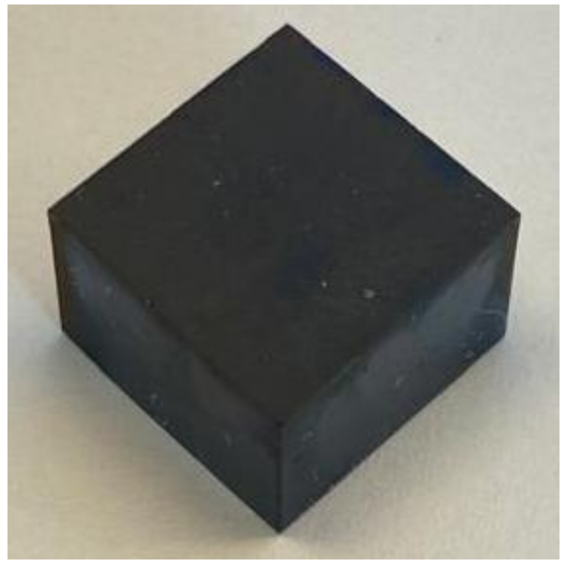
- The viscosity gradually decreases from approximately 10,000 Pa·s to below 10 Pa·s (10,000,000 cP down to 10,000 cP) within the temperature range of 50 °C to 230 °C.
- At around 230 °C, the viscosity increases again due to polymerization and curing processes.

Carbonization (Neat Resin)

Temp. (ºC)	Parameter	BODA RESIN™-PRIME	B-staged BODA RESIN™-PRIME
240	Dimensions (mm)	9.68x12.84x12.99	7.94x12.79x12.92
	Volume (cm^3)	1.61	1.31
	Envelope density	1.12	1.12
	Archimedes density	1.150	1.148
400	Dimensions (mm)	9.46x12.87x12.99	7.90x12.83x12.70
	Volume (cm^3)	1.58	1.29
	Envelope density	1.12	1.10
	Archimedes density	1.118	1.128
1000	Dimensions (mm)	8.52x11.37x11.47	6.95x11.31x11.20
	Volume (cm^3)	1.11	0.88
	Envelope density	1.36	1.34
	Archimedes density	1.412	1.392
1700	Dimensions (mm)	8.42x11.30x11.36	6.75x11.19x11.12
	Volume (cm^3)	1.08	0.84
	Envelope density	1.32	1.33
	Archimedes density	1.322	1.390



Carbon block from
BODA RESIN™-PRIME



Carbon block from
B-staged
BODA RESIN™-PRIME

Carbon yield and density are not affecting by prior B-staging or processing in solvent.

- **Why would I buy a more expensive resin??**
    - BODA resins are a premium solution to instantly eliminate 50% of the production time for Carbon/Carbon composites.
    - Industry cost analysis shows that in an RTM process, the current price of BODA is slighty cheaper than phenolic with these time savings.
    - BODA is not competing on cost savings per unit. The unit gross margin economics are nearly neutral but BODA promises an instant doubling of production capacity, <u>with zero capital expenditure</u>. BODA competes on time, capacity, development speed, market reach, profits, equipment ROI, etc.

- **Is the price of the resin coming down?**
    - Our current prices reflect our pre-production prices, with scale price will come down.
    - HAND does provide other grades of BODA that may be more suitable for your business needs.

CONTACT US

Custom Resin Formulation/ Resin Processing / SBIR-STTR Partnerships

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