Innovations in Continuous Ultrasonic Welding of Thermoplastic Composites and Evaluation for Space Applications

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Thermoplastics Development for Exploration Applications (TDEA) Project

Why Pursue Thermoplastic Composite Technology for Space Applications?

Qualitative comparison of thermoplastic composites (TPC) and thermoset composites (TSC)

Advantages:	*Disadvantages*:
• Reduced cycle time • **Processing by remelting** • **Processing that enables unitization** • Ambient material storage (no out-time) • Automated assembly (robotic welding) • Higher fracture toughness • **Welded joints with no material interface** • **Minimal outgassing** & low moisture uptake	• **Higher processing temperature and pressure required** • **Higher residual stresses (more difficult dimensional control)** • Structural and chemical properties sensitive to crystallinity • Higher melt viscosity • Crystallinity may change over lifecycle

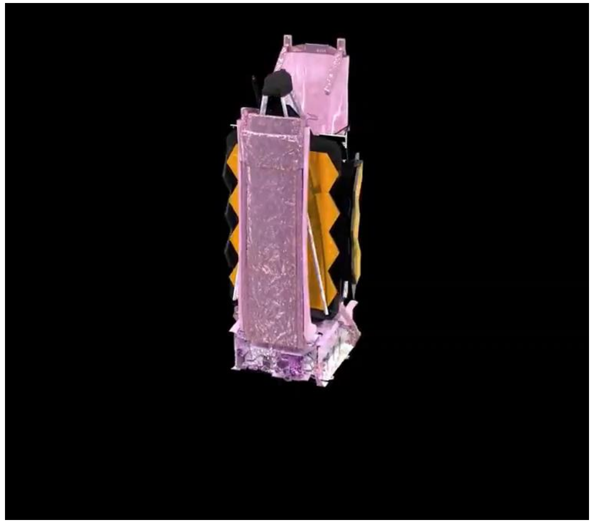
- Less complex mfg.
- Larger structures
- Fewer joints

Result: reduced cost

Welding is relatively simple and insensitive to processing conditions (vs. TS adhesive bonding)

Can new process modeling capability help mitigate associated design/ development costs via simulation?

Bolded characteristics especially relevant for space applications



- TPC can enable on-orbit assembly and manufacturing
  - NASA is already advancing in-space TP/TPC manufacturing with the OSAM missions
  - Joining TPCs in-space is a key enabler that needs further development

Benefits of TPCs for in-space manufactured/assembled structures recognized since 1980s

Now underlying TPC technology has matured sufficiently to pursue application focused developments

TDEA Technology Development Roadmap

Project Goal: To advance NASA's thermoplastic composites capabilities by developing structurally efficient joining solutions for large-scale space structures and applications to support NASA's future exploration missions.

1. State-of-the-art survey


TDEA-RPT-001
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Thermoplastic Composites as an Enabling Technology for NASA Space Applications

State of the Art Review

December 2, 20222

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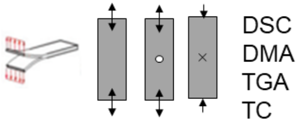
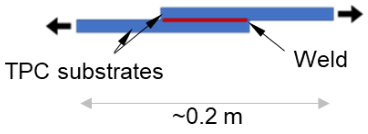
2. TPC material characterization

Material properties for material selection and model inputs



- Experiments to fill in gaps in public database of TPC material properties
- Emphasis on data required for process, material, and structural model inputs

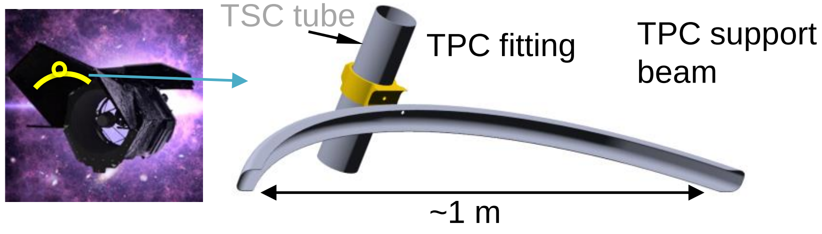
3. Welded joint pathfinder: *Foundational developments*



- Experiments to characterize weld performance, efficiency, and robustness
- 7 material systems and 3 weld methods
- Model development and evaluation to improve weld design and sizing capabilities
- Disassembly, re-assembly feasibility

4. Thermoplastic Terrestrial Point Design (TTPD): Roman Space Telescope (RST) support beam

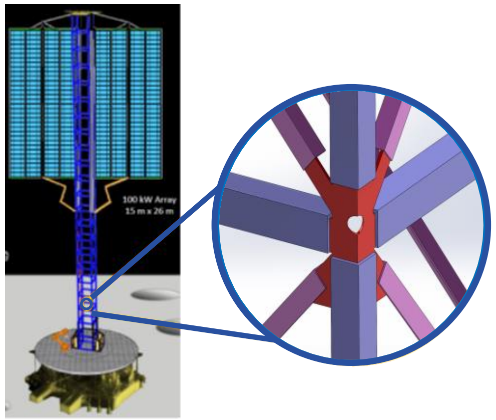
Confidence building application



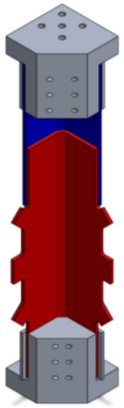
5. Thermoplastic In-Space Point Design (TSPD):

Game changing application

Tall lunar tower (TLT)

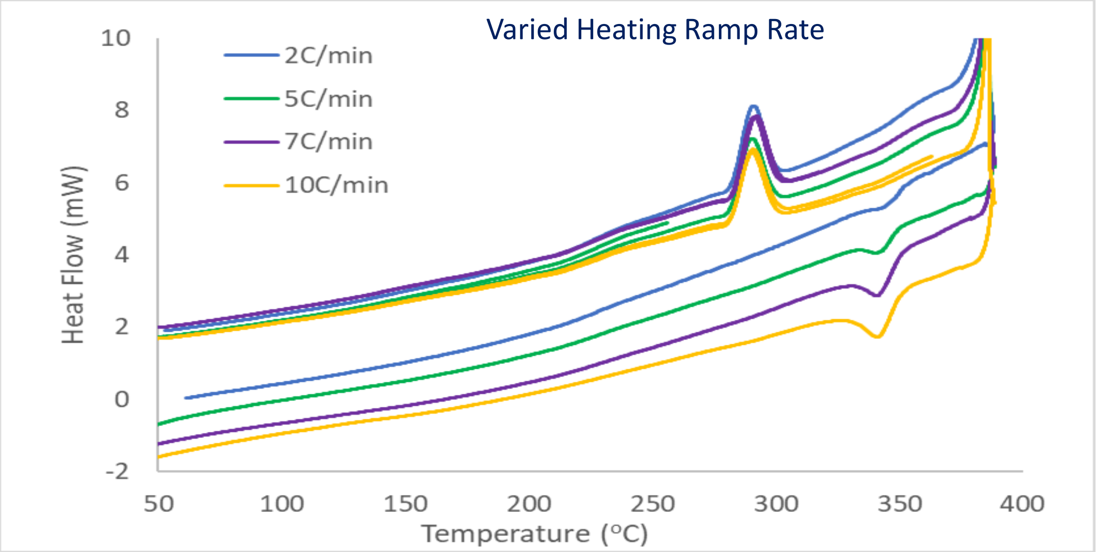


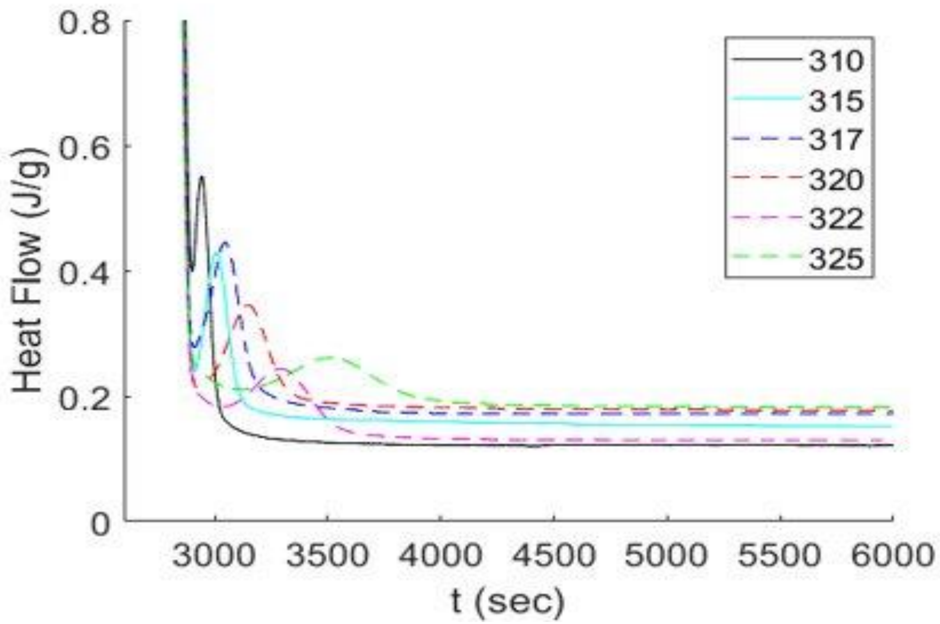
- Update existing TLT design to use all-TPC design with welded joints
- Developments for in-space welding application
- Lunar dust knockdown for welds
- Modeling to predict performance in a relevant environment

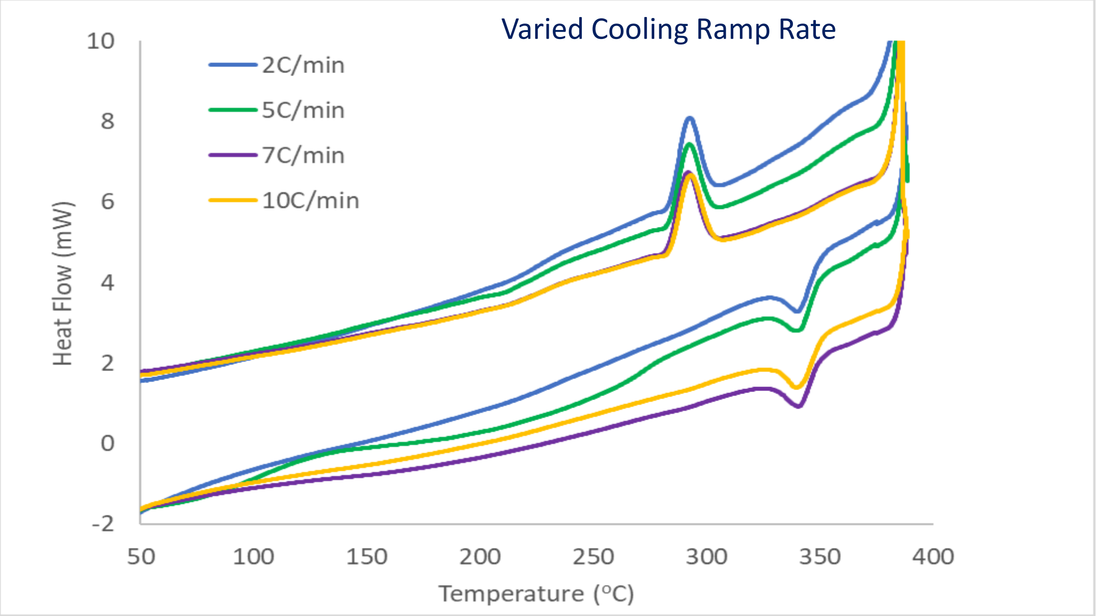


Material Characterization- Crystallization Kinetics

- Evaluate the crystallization kinetics of candidate materials as relevant to crystallization on welding.
- The DSC data (both dynamic and isothermal with post-processing) provides the melting and crystallization temperature, latent heat of melting and crystallization, and crystallization rate (Nakamura) used in the welding process model.

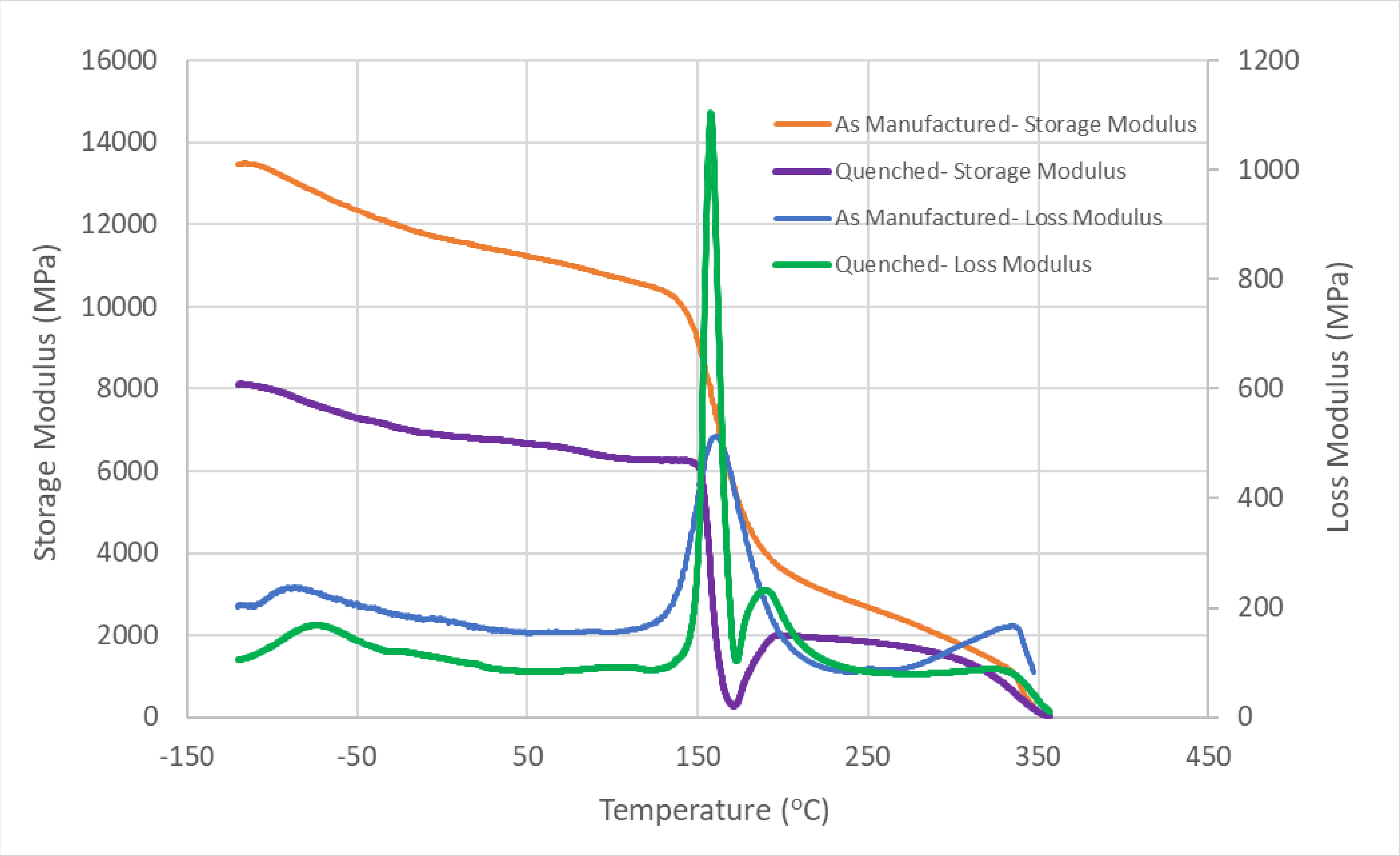






Material Characterization- Rheology

DMA was used to evaluate material transitions across wide temperature range and as a function of the degree of crystallinity



Storage Modulus:

- reduced with decreased crystallinity.
- increase in storage modulus above Tg related to cold crystallization.

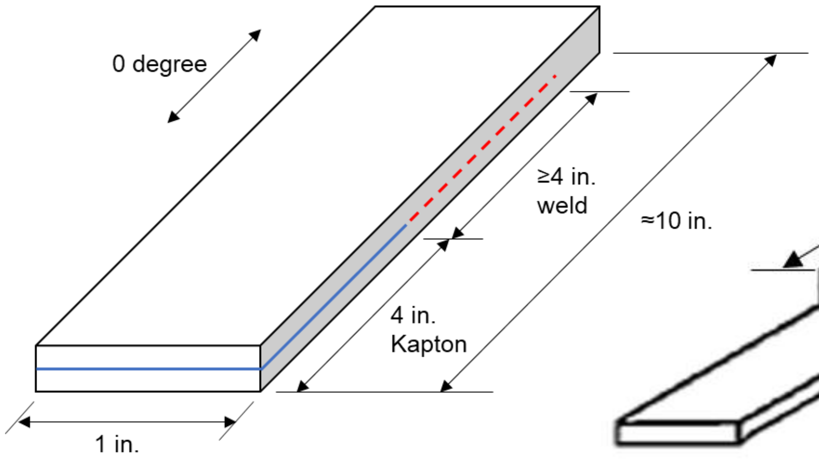
Loss Modulus:

- Transition observed above Tg related to crystallization
- Transition at -75°C observed in both coupons.

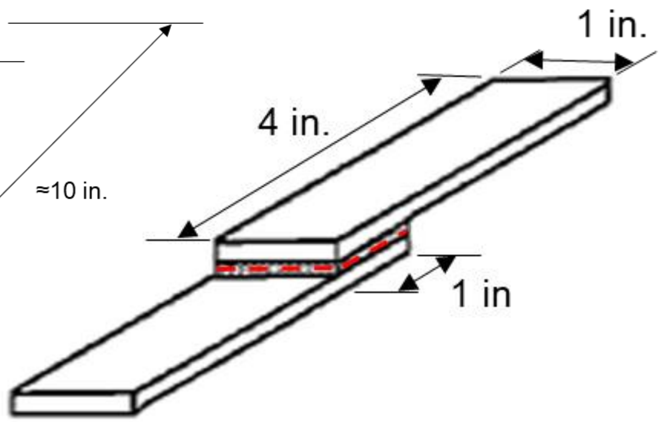
Ultrasonic Welding Trials

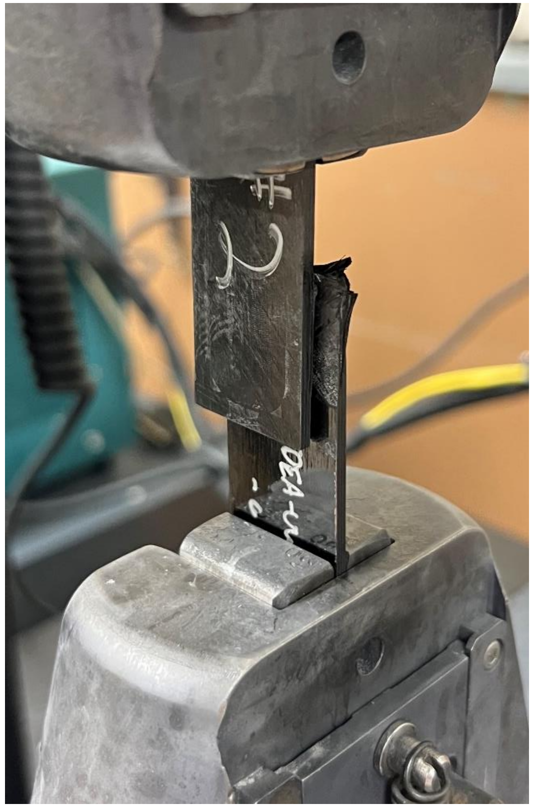
Material System	SLS	DCB
AS4/PEEK (TC1200)	12	6
AS4/PEI (Solvay)	12	6
T700/LM-PAEK (TC1225)	12	6
AS4/PPS (TC1100)	12	6
M30S/PEKK (thin ply)	12	6

Double Cantilever Beam



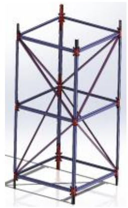
Single Lap Shear





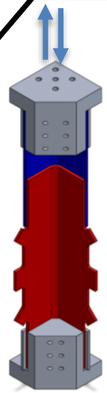
TSPD Building Block Effort

Elements



Repeating unit cell (RUC) manufacturing demo

Sub-elements

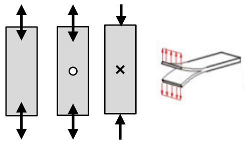


Vertical joint

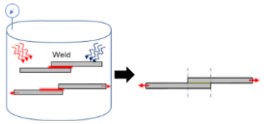
Goal: Advance an ultrasonic welding approach toward future lunar surface assembly applications by manufacturing the TSPD vertical joint and characterizing its structural behavior under tension and compression.

Coupons

Material properties

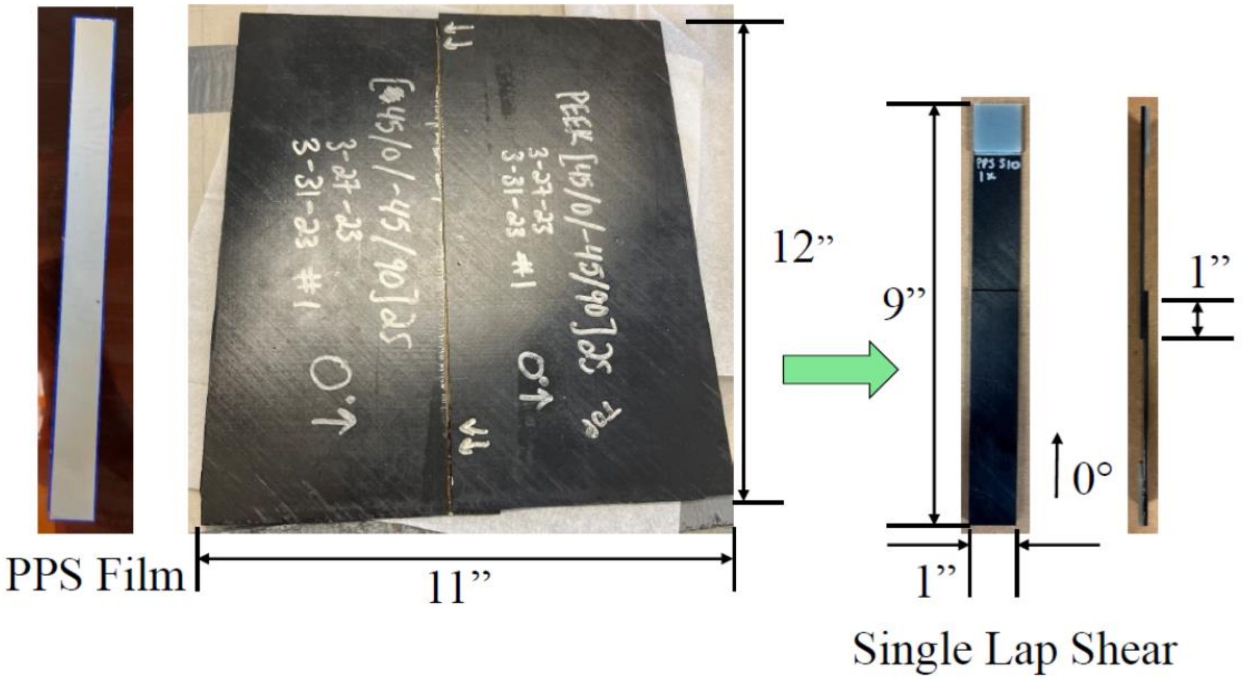


Weld knockdowns relevant environment



Joint Disassembly and Re-assembly

- The manufacturing and bonding of thermoplastic composites can be leveraged to advance space exploration applications
- Objective → Evaluate feasibility of disassembly and reassembly of thermoplastic composite joints
  - Bond line film: thermoplastic (PPS, LM-PAEK)
  - Composite material: Toray Cetex® TC1200 PEEK
    - PEEK: T_g = 143°C, T_m = 343°C, T_p = 370-400°C
    - PPS: T_g = 90°C, T_m = 280°C, T_p = 300-330°C
    - LM-PAEK: T_g = 147°C, T_m = 305°C, T_p = 340-385°C
    - Allows melting of interlayer while keeping the PEEK substrate below melting



- Quantitively study the quality of joint:
  - Shear strength (single lap shear)
  - Debonding at tip of flange (modified 3-pt bend)
- Test at room temp (RT, ~23°C) and elevated temp (ET, 121°C/250°F)
- Bond film material, thickness, and failure mode studied

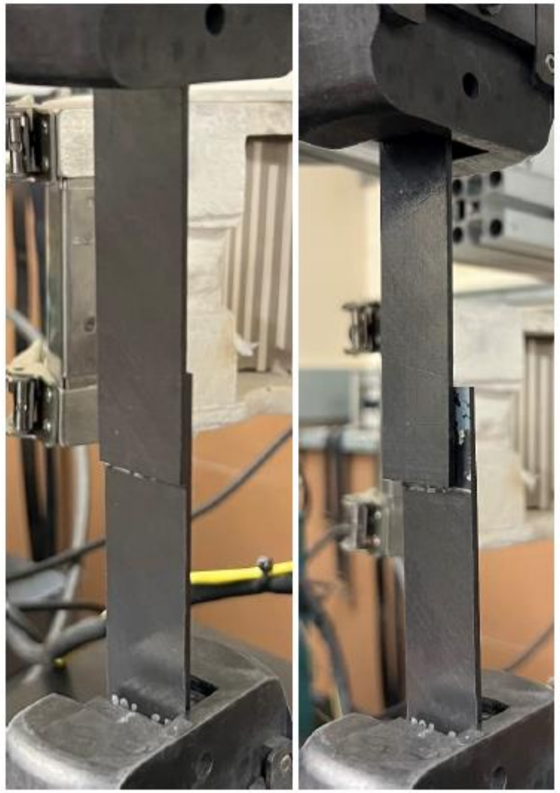
Joint Disassembly and Re-assembly

SLS – PPS Film Results

*Bonded coupons were tested in single lap shear configuration to determine disassembly force

- 1.3 mm/min displacement rate
- PPS interlayer thickness (nominal): 0.10-0.12 mm
- Performed at room temperature (23°C) and 121°C (above T_g of PPS)

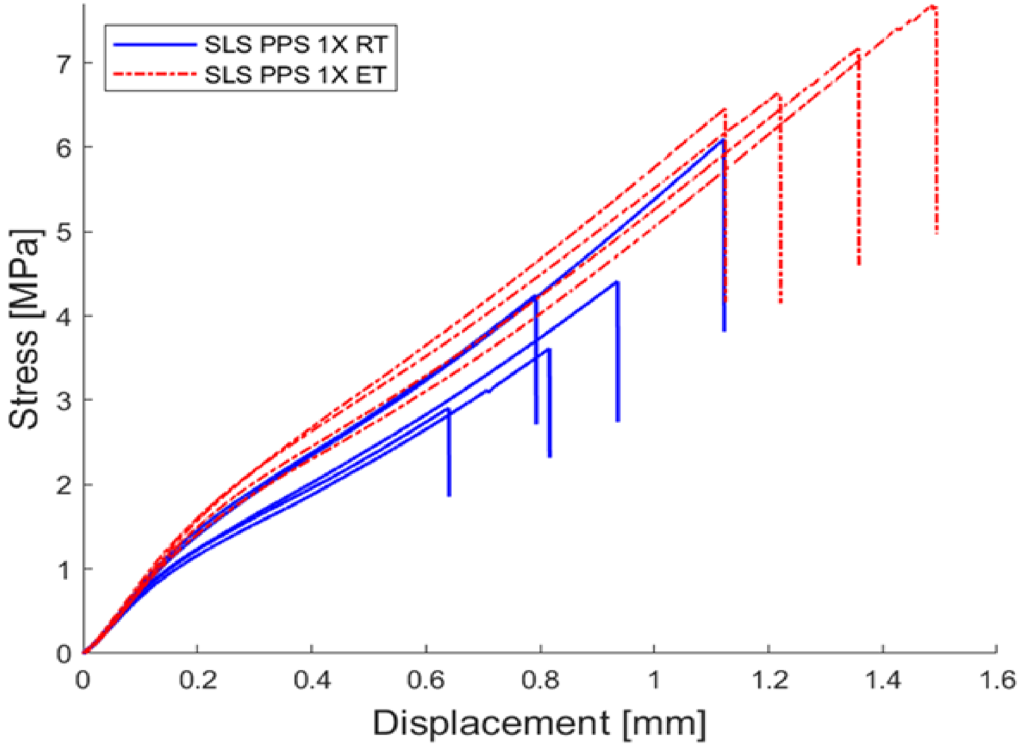
*66% increase in maximum stress to failure at elevated temperature



SLS test setup before (left) and after (right) failure.

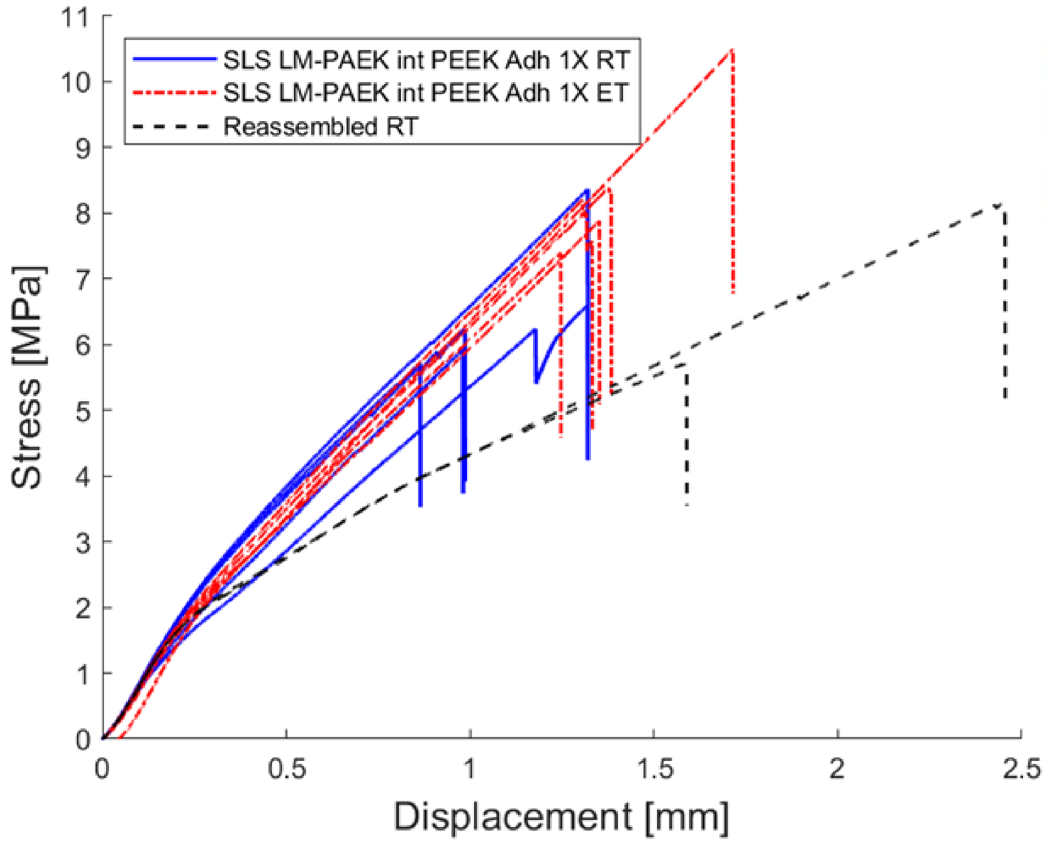
	Interlayer Material	
	PPS - 1x thick	
	RT (~23°C)	ET (~121°C)*
Max Stress [MPa]	4.23 ± 1.19	7.04 ± 0.49
Displacement at Failure [mm]	0.86 ± 0.18	1.29 ± 0.14

*Note: Temperature within ± 3°C, and values reported with ± one st. deviation.



Joint Disassembly and Re-assembly

	PEEK Adherend	
	LM-PAEK Interlayer	
	RT (~23°C)	ET (~121°C)*
Max Stress [MPa]	6.56 ± 1.07	8.47 ± 1.19
Displacement at Failure [mm]	1.09 ± 0.21	1.4 ± 0.18



Future Work

Ultrasonic Welding

- Evaluate ultrasonic welding in relevant environment
  - Under vacuum
  - Cold Temperature
  - Dust Additive

Disassembly and Reassembly

- Evaluate ultrasonic welding for disassembly and reassembly
- Evaluate bond-line materials to facilitate joining