



Mechanical Property Testing of Thermoset and Thermoplastic Composites for Cryotank Applications

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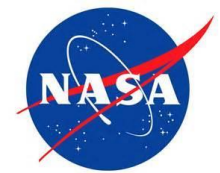
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Presentation Outline

1. Programmatic Background
2. Material Selection
3. Material Characterization
 - Coefficient of Thermal Expansion (CTE)
 - Thermal Conductivity (TC)
4. CTE-A: space applications, long term cryogen storage
 - Mechanical test matrix, temperature range from -196°C to room temp.
 - Mechanical test data
5. CHARGE: aeronautics applications, thermal cycles
 - Mechanical test matrix, room temperature test following coupon cycling between -196°C and room temp.
 - Mechanical test data



CTE-A and CHARGE Projects

Composite Technology for Exploration

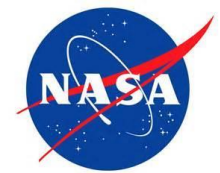
Applications (CTE-A)

- A key technology for space exploration including extended lunar missions and lunar surface systems operations is the maturation and demonstration of large-scale lightweight composite fuel storage tanks and associated support structure.
- The focus of this project was to assess the state of the art of composite materials for storage tank applications. This included screening candidate materials for lab-scale permeability and evaluating Nondestructive Evaluation (NDE) techniques for long-term storage to detect microcracking and/or permeability.

Commercially-viable Hydrogen Aircraft for Robust Growth in Efficiency (CHARGE)

- The feasibility of using of on-board cryogenic fuels systems in combination with fuel cells, high efficiency engines, and electric motors for high efficiency commercial transport aircraft is being examined at NASA in collaboration with external partners
- Development of aviation propulsion based on cryogenic fuels presents a unique fundamental challenge that has not been addressed by space technology
- The primary issues unique to commercial aviation, compared to space, include commercial transport requiring much longer service lives (5,000 – 15,000 hours) and departing at a higher take-off rate from commercial airports rather than isolated launch sites.





Material Selection

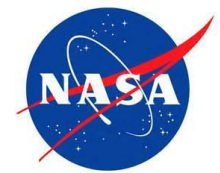
The purpose of the materials effort in each program project was to evaluate a thermosetting (TSC) and thermoplastic (TPC) composite material for a composite cryotank application.

Thermoset

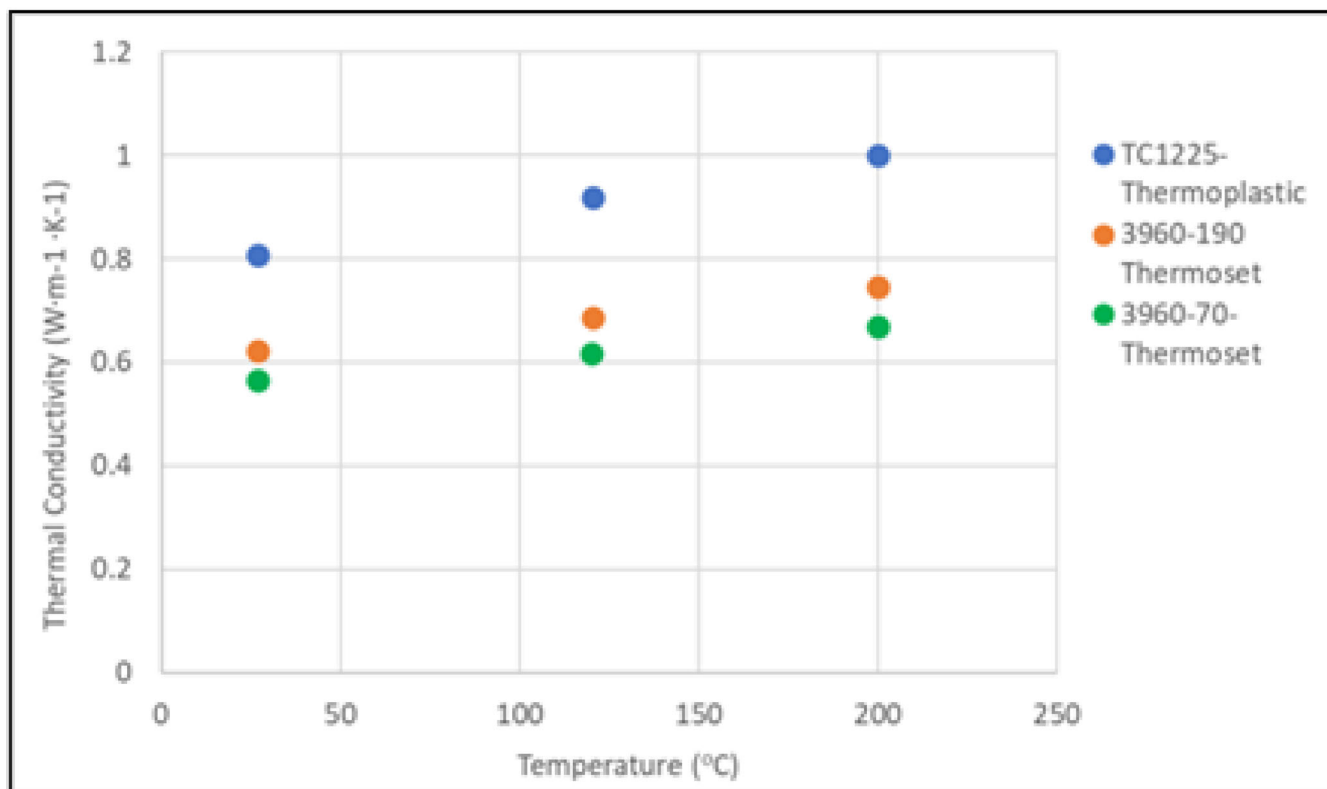
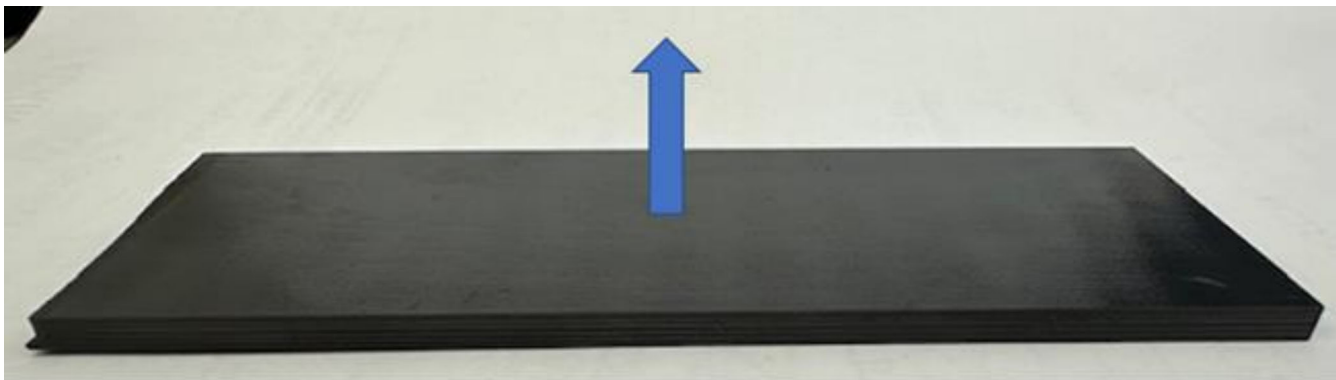
T1100/3960 toughened epoxy prepreg, 190 gsm and 70 gsm with and 34% resin content

Thermoplastic

T1100/TC1225 low-melt polyaryletherketone (LM-PAEK) prepreg, 145 gsm and 34% resin content.



Thermal Conductivity



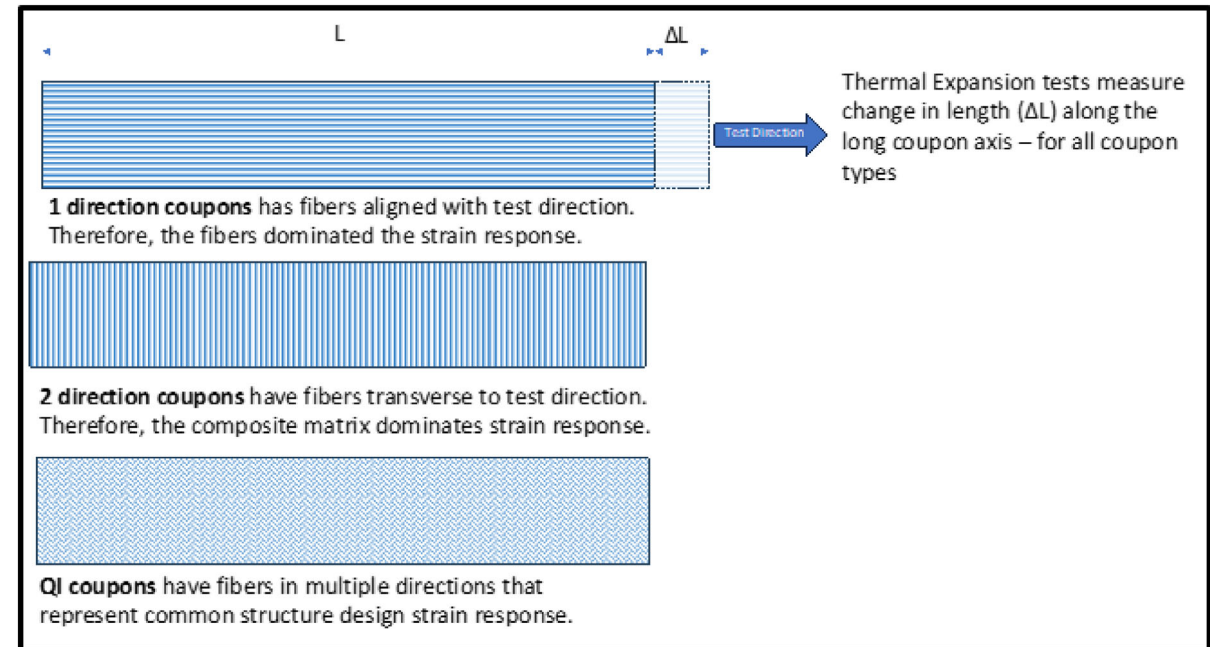
Trends in Thermal Conductivity Data

- A low TC is preferred for the tank wall material, to reduce heat transfer from the surrounding environment.
- The TC of the thermoplastic is approximately 30% higher than the thermoset.
- The thermal conductivity of the thin ply thermoset (3960-70) is approximately 10% lower than the standard thickness (3960-190) material.



Coefficient of Thermal Expansion

Thermoplastic (T1100/TC1225)		
Lay-up	Test Direction	CTE (ppm/°C)
[0] ₂₆	1	0.09 ± 0.06
		0.4 ± 0.2
[90] ₂₆	2	44 ± 1
		45 ± 1
[45/0/-45/90] _{3s}	Q/I	2.6 ± 0.2
		2.5 ± 0.2
Thermoset (T1100/3960)		
Lay-up	Test Direction	CTE (ppm/°C)
[0] ₂₆	1	0.39 ± 0.04
		0.13 ± 0.04
[90] ₂₆	2	44 ± 1
		45 ± 1
[45/0/-45/90] _{3s}	Q/I	2.6 ± 0.2
		2.5 ± 0.2



- The CTE data represents the expansion of the composite system and can be used to predict strain on the resin at the fiber-resin interface due to mismatch of CTE between fiber and resin.
- Interfacial strain is a source of microcracking in composite cryotanks and overall, all materials yield a similar CTE in the temperature range between -175°C and 50°C.
- The small differences in CTE are unlikely to cause considerable difference in microcracking between coupons.



CTE-A: Mechanical Test Matrix

Abbr.	Test	ASTM Standard	Layup
0T	Lamina Tension	D3039	[0] ₆
90T	Lamina Tension	D3039	[90] ₈
0C	Lamina Compression	D6641	[0] ₁₄
90C	Lamina Compression	D6641	[90] ₁₄
IPS	In-Plane Shear	D3518	[+45/-45] _{4s}
UNT	Unnotched Laminate Tension	D3039	[+45/0/-45/90] _{2s}
UNC	Unnotched Laminate Compression	D6641	[+45/0/-45/90] _{3s}
OHT	Open Hole Tension	D5766	[+45/0/-45/90] _{2s}
OHC	Open Hole Compression	D6484	[+45/0/-45/90] _{3s}

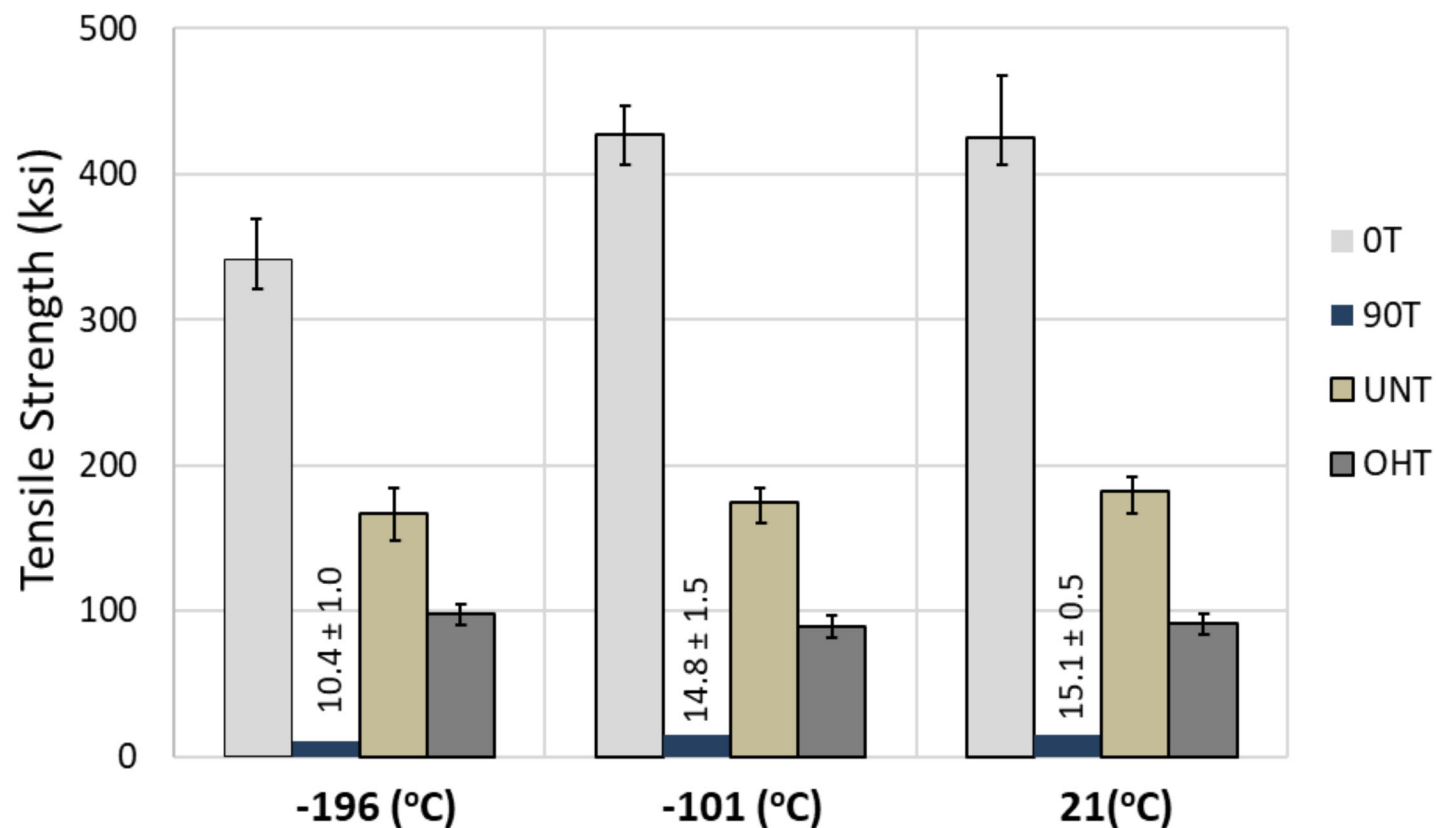
Test Temperatures: -196°C, -101°C, 21°C

Test Location: National Institute of Aviation Research (NIAR),
Wichita, KS



CTE-A: Mechanical Test Data

Tensile Strength and Modulus



Trends in Tensile Test Data

- In general, at low temperature, matrix resin contracts and molecular movement is reduced- leading to both increased fiber-matrix strength and increased molecular interaction between polymer chains.
- The net effect tends to be an increase in tensile strength and modulus at low temperature.
- In this case, little to no increase in tensile strength and modulus was observed.
- Strength decreased in uni-directional coupons.

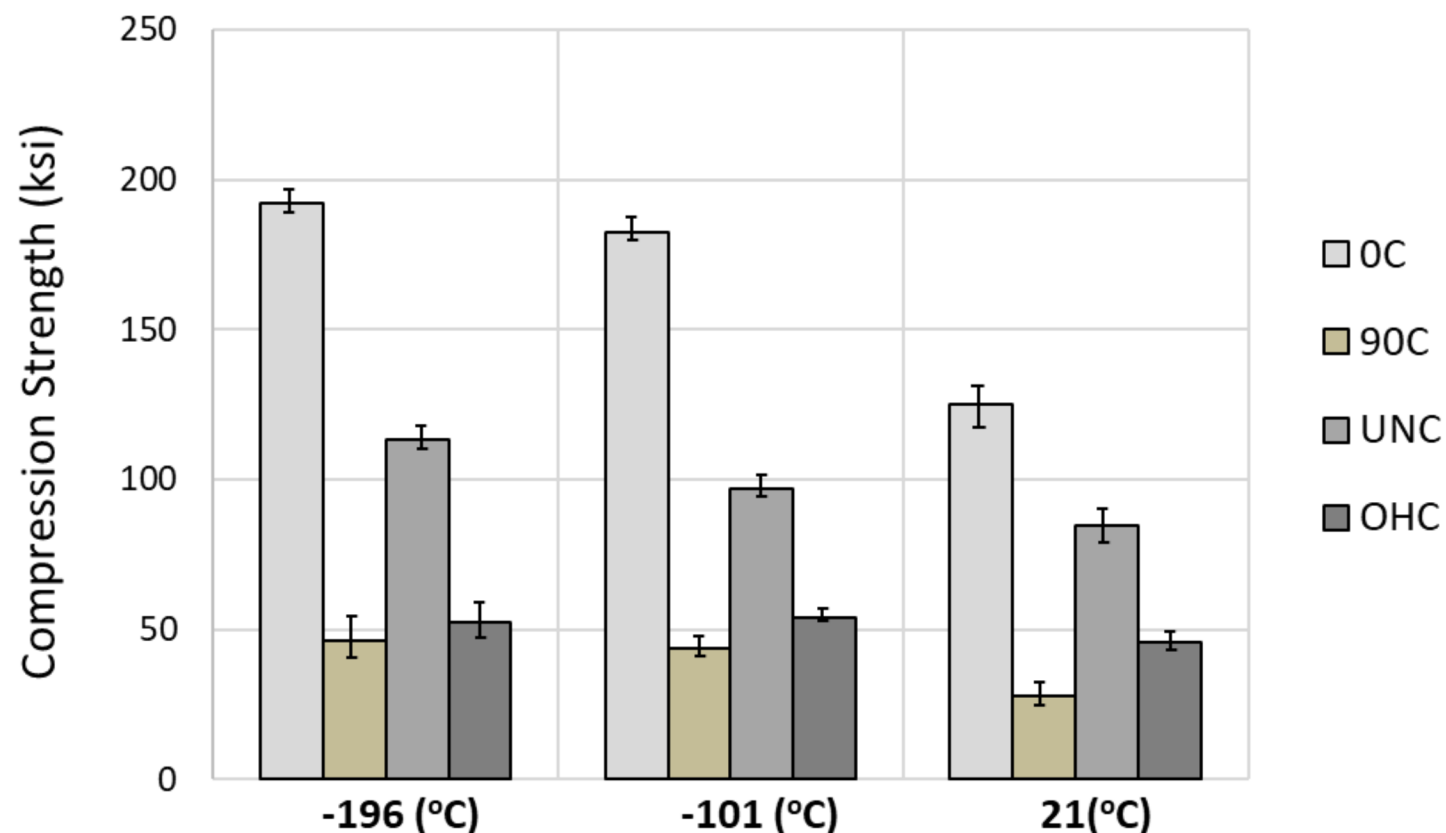
Modulus

Temp	0T	CoV (%)	90T	CoV (%)	UNT	CoV (%)	OHT	CoV (%)
-196°C	25.1 ↑	1	1.7 ↑	1.7	9 ↑	3	9.3 ↑	1.9
-101°C	24.1 ↑	1.6	1.7 ↑	11.8	8.8 ↑	3.6	9.2 ↑	4.2
21°C	24.7 ↑	2.5	1.4 ↑	1.2	8.7 ↑	2.7	9 ↑	2.4



CTE-A: Mechanical Test Data

Compression Strength and Modulus



Modulus

Temp	0C	CoV (%)	90C	CoV (%)	UNC	CoV (%)	OHC	CoV (%)
-196°C	22.8	4.1	1.7	3	8.2	0.3	8.1	1.4
-101°C	22.1	1.6	1.5	1	8.1	2.5	8.5	1.6
21°C	21.8	0.8	1.4	1.8	7.9	2.7	8.9	2

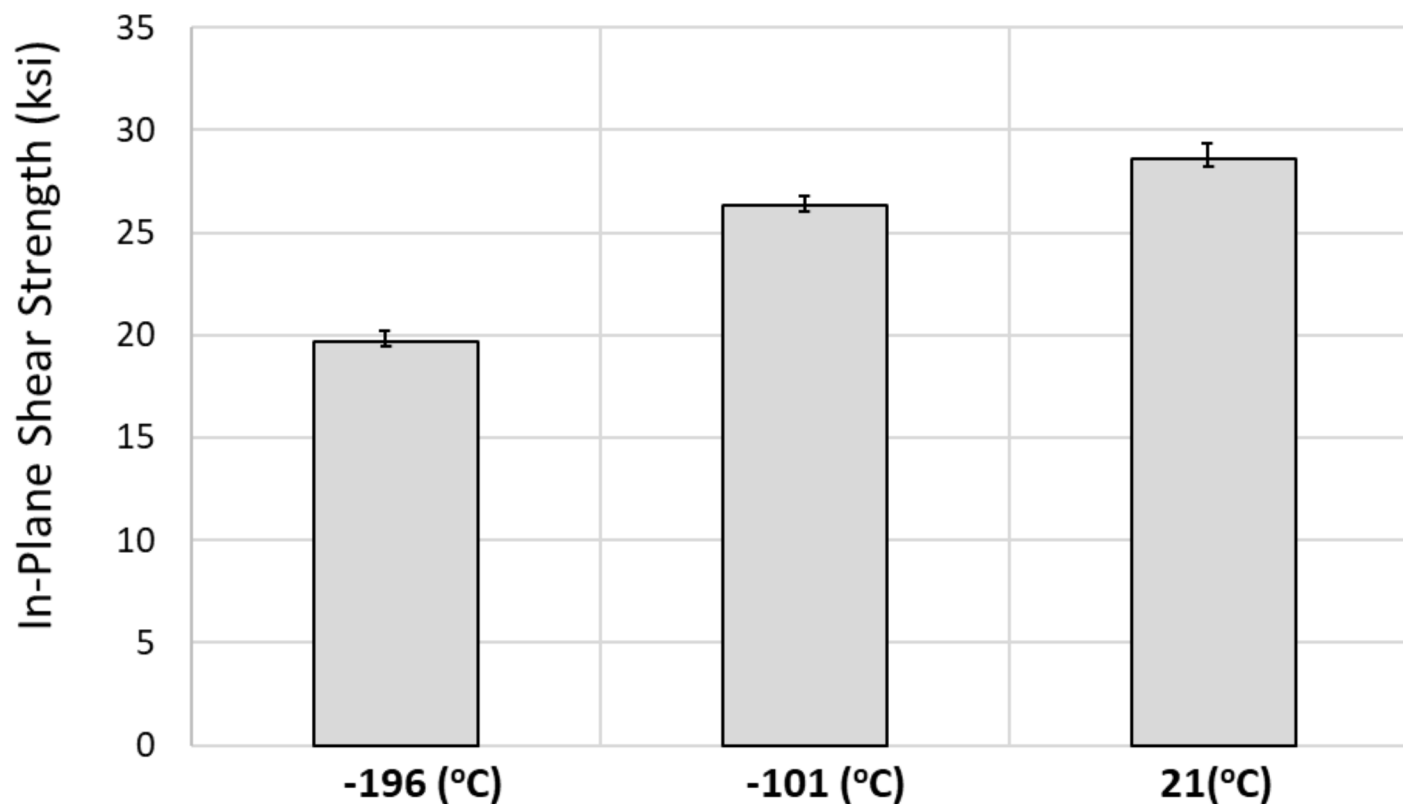
Trends in Compression Test Data

- As with tensile tests, a reduction in test temperature generally leads to increased compression strength and modulus.
- Compression data followed this trend, with the exception of open hole compression, where strength was unchanged and modulus was reduced.
- Overall, the effect of test temperature on material modulus was small.



CTE-A: Mechanical Test Data

Shear Strength and Modulus



Trends in Shear Test Data

- The increased matrix stiffness leads to reduced strain to failure and a reduction in IPS strength.
- The modulus data for IPS tests shows a 38% increase in modulus at -196°C when compared to the room temperature test.

Modulus

Temp	IPS	CoV (%)
-196°C	0.83	0.34
-101°C	0.75	1.8
21°C	0.6	1.94

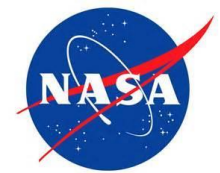


CHARGE: Mechanical Test Matrix

Abbr.	Test	ASTM Standard	Layup
OT	Lamina Tension	D3039	[0] ₆
UNT	Unnotched Laminate Tension	D3039	[+45/0/-45/90] _{2s}
OC	Lamina Compression	D6641	[0] ₁₄
UNC	Unnotched Laminate Compression	D6641	[+45/0/-45/90] _{3s}
IPS	In-Plane Shear	D3518	[+45/-45] _{4s}
TTF	Tension-Tension Fatigue	D3479	[+45/0/-45/90] _{2s}

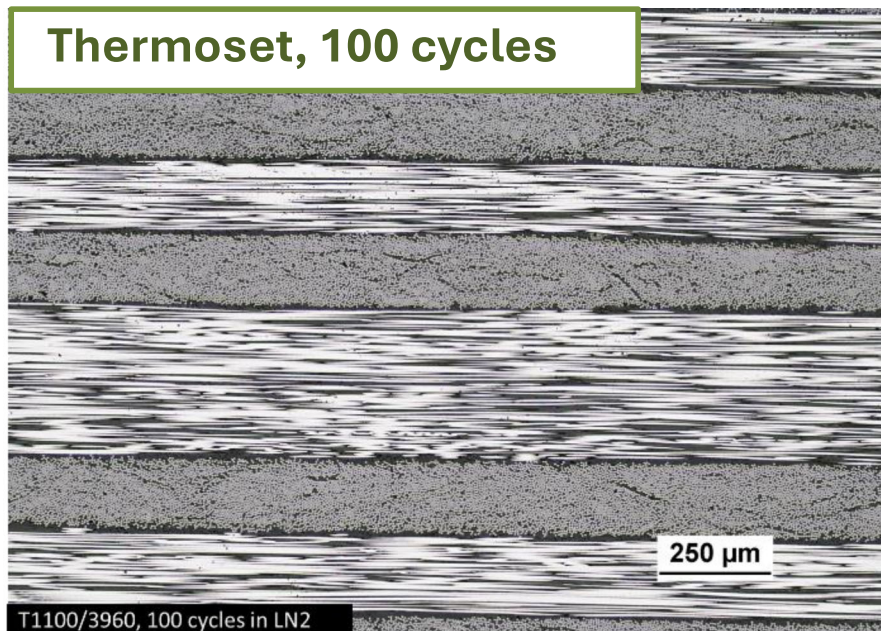
Test Temperatures: 21°C, baseline and 100 cycles in LN2

Test Location: NASA Glenn Research Center

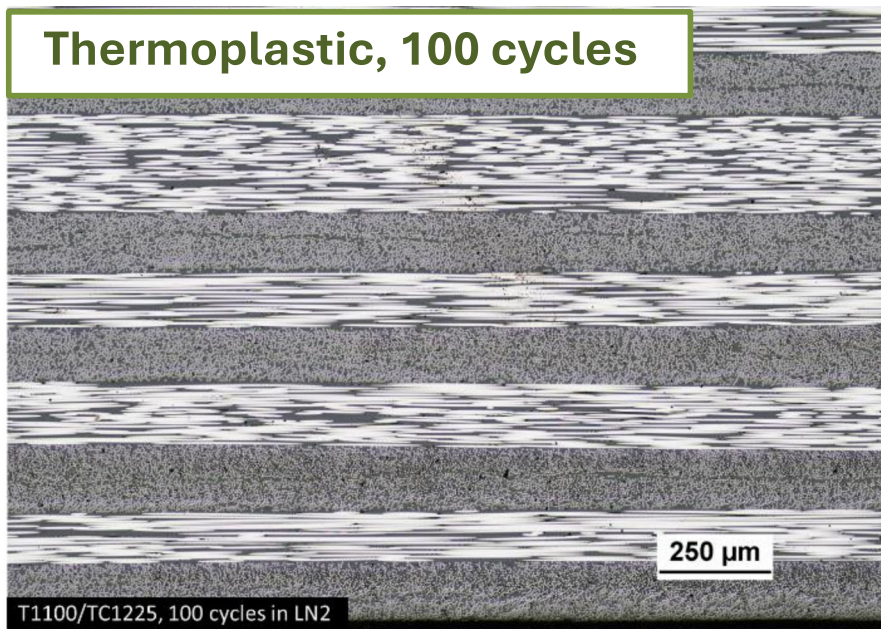


CHARGE- Thermal Cycling and Photomicroscopy

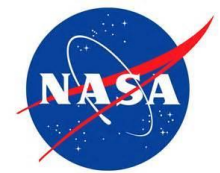
Thermoset, 100 cycles



Thermoplastic, 100 cycles

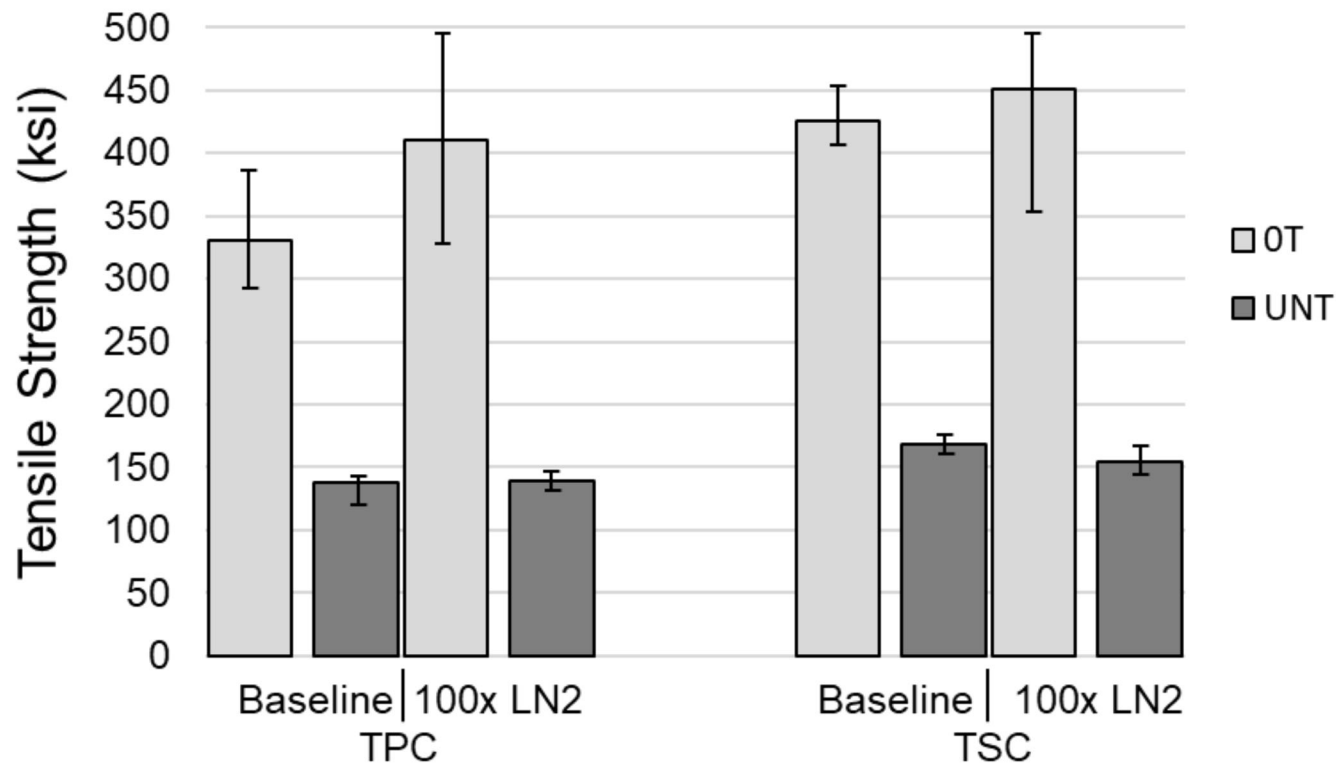


Specimen immersion in LN2



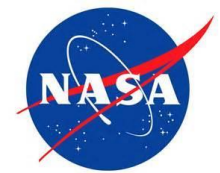
CHARGE: Mechanical Test Data

Tensile Strength



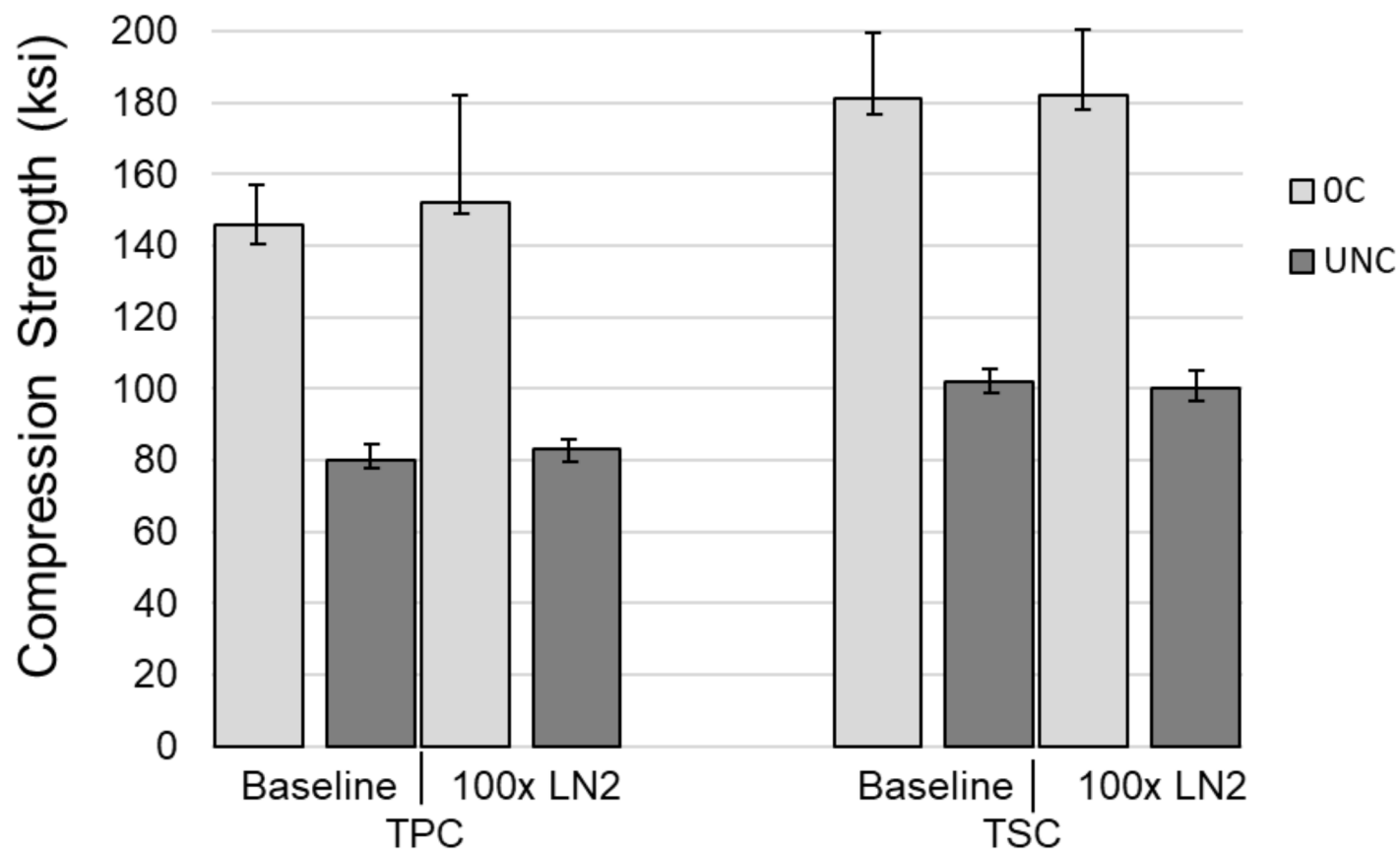
Trends in Tensile Test Data

- The influence of thermal cycling on the thermoplastic and thermosetting material was a small increase in OT and a small decrease in UNT strength.
- All strength measurements were within the scatter.



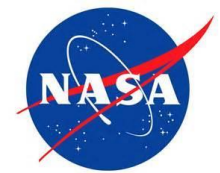
CHARGE: Mechanical Test Data

Compression Strength



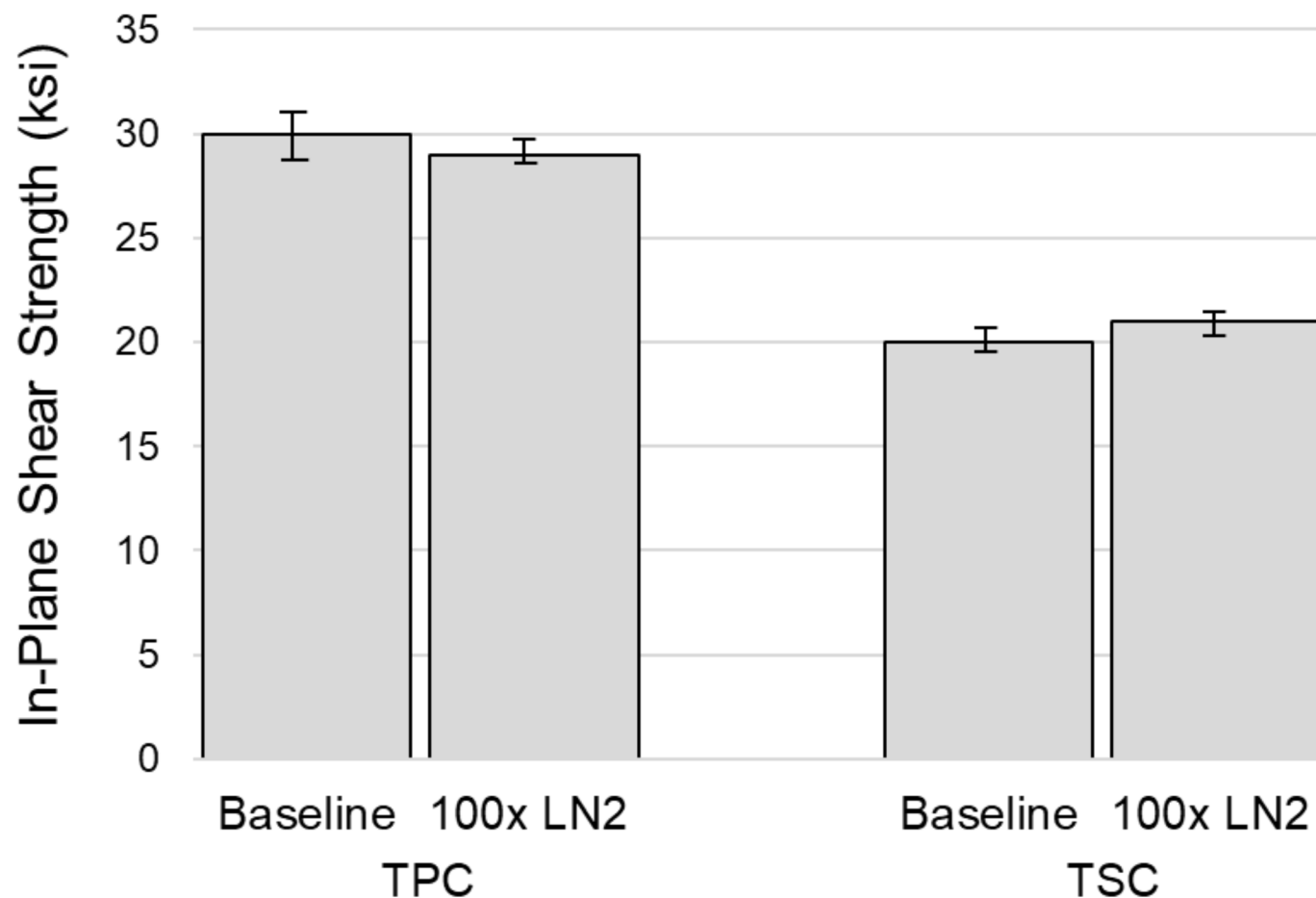
Trends in Compression Test Data

- Compression strength values, of LN2 cycled coupons remain unchanged, following the trend observed in cold temperature tests.



CHARGE: Mechanical Test Data

Shear Strength



Trends in Shear Test Data

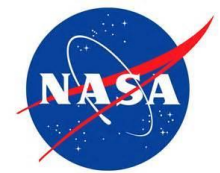
- Unlike coupons that were tested at LN2 temperature, the IPS strength of cycled coupons was unchanged relative to the baseline.
- The cycled coupons were tested at room temperature and therefore the reduction in matrix strain to failure observed during cold temperature testing was not a factor in the strength of the cycled coupons.



CHARGE: Mechanical Test Data

Modulus

	Condition	0T (Msi)	UNT (Msi)	0C (Msi)	UNC (Msi)	IPS (Msi)
TPC	Baseline	23.7	8.4	22.4	8	0.52
	100x LN2 Cycles	25	8.4	21.8	8.4	0.48
TSC	Baseline	24.9	9	22.2	8.6	0.71
	100x LN2 Cycles	23.9	8.9	21.7	8.5	0.66



Summary

- Data presented in this study provided trends in strength and modulus for a TPC and TSC material when tested from room temperature to -196°C , and following thermal cycles from room temperature to -196°C .
- Trends in strength and modulus were similar for both materials evaluated.
- Photomicroscopy following thermal cycling did not show evidence of matrix microcracking with 100 thermal cycles in LN2.
- While panel data can provide important strength and modulus values as needed for design and model development, further material characterization will be required.
- We anticipate manufacturing demonstrations to identify manufacturing constraints, in particular for the thermoplastic tank. Leak testing following fill-drain cycles as well as burst test data when combined with coupon data and manufacturing pathfinder information will allow for materials selection for scale-up and further development.