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Advanced Fiber Reinforced Polymer Materials Guidelines for Aircraft Design Certification Process

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Advanced Fiber Reinforced Polymer Materials Guidelines for Aircraft Design Certification Process

- Motivation and Key Issues
  - Aircraft manufacturers and airlines are investigating methods to reduce manufacturing costs and increase operational efficiency.
  - Major OEMs beginning to incorporate new processes for part manufacturing into production using advanced technologies.
  - Advances in vehicle development will likely accelerate during the next decade as new emerging technologies are applied to design and placed into production throughout the aircraft industry.
  - Research needed to prove the safety and integrity of these aircraft and advanced materials for the general public.

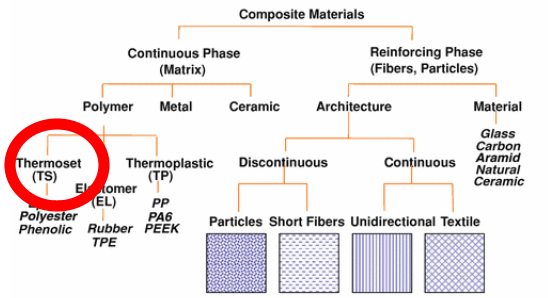

Figure 1. Composite Material Classes (Source: Friedrich, Composite Materials)

Development of Qualification Program

- **Technical Monitor**: Ahmet Oztekin

- **NIAR Contacts**: John Tomblin, Royal Lovingfoss, Rachael Andrulonis
- **Industry Partners**: TenCate, Toray, several steering committee members

- **Overall Goals**
  - Primary goal: To develop a framework for the qualification of new and innovative composite material systems including guidelines and recommendations for their characterization, testing, design and utilization.
  - Secondary goal: To transition the test data and guidelines generated in this program into shared databases, such as CMH-17.

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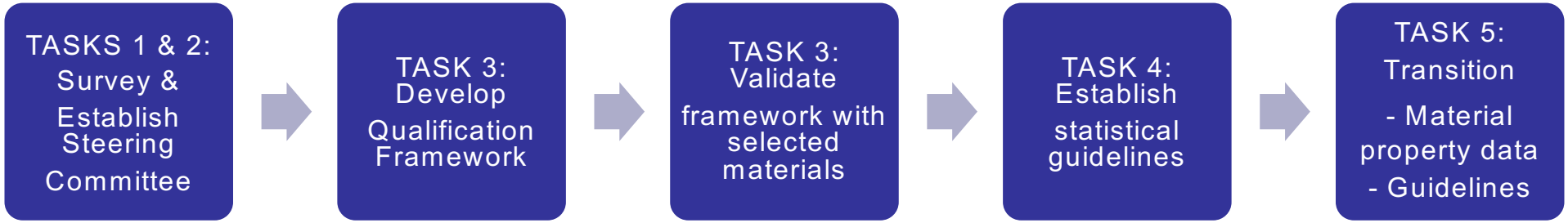
Technical Approach

- Develop a framework to advance alternative composite materials into the aerospace industry.
- Utilize the experience and framework of the NCAMP composite program as an example of process sensitive material characterization.
- Assess the validity with equivalency testing.



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Tasks 1 & 2: Survey & Steering Committee

- SURVEY
  - Administered to the composites community through Survey Monkey (Oct – Nov 2016) to generate industry driven input on the development of a qualification framework for an advanced PMC material system. 143 responses received.
  - The survey included multiple parts:
    1. Current PMC material forms and processes
    2. Future/planned material forms and processes
    3. Applications and parts
    4. Factors affecting the decision making process when considering new PMC materials
    5. Individual and company interest in serving on steering committee or contributing to CMH-17

- Industry Steering committee - Kick-off meeting held in February 2017
  - Meetings/updates as required
  - On-line portal

- Collaboration with CMH-17

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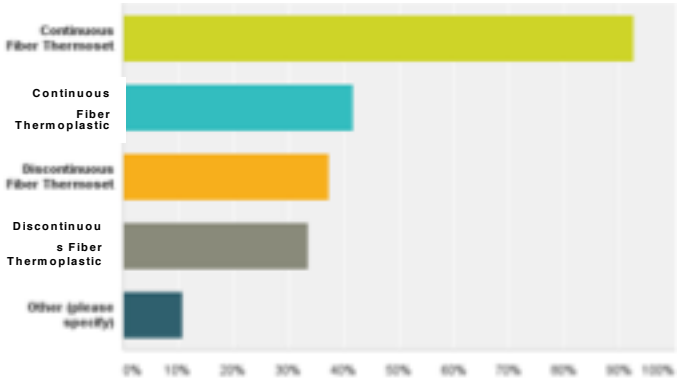
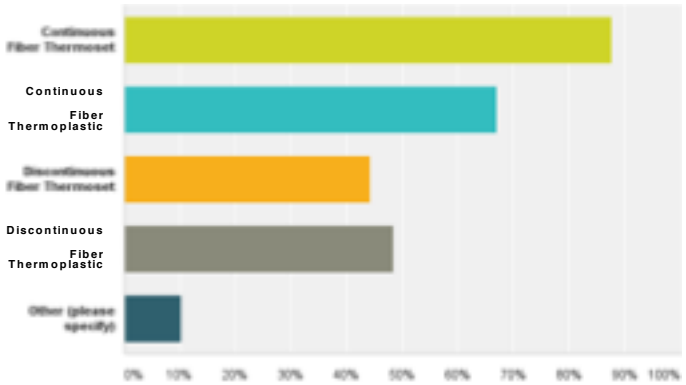
Survey Results: PMC Material Forms



Currently In Use



5 – 10 years

PMC Form	NOW [%]	5-10 Years [%]	Change
Continuous Fiber Thermoset	93	88	-5%
Continuous Fiber Thermoplastic	42	67	60%
Discontinuous Fiber Thermoset	37	44	19%
Discontinuous Fiber Thermoplastic	34	48	44%
Other	11	10	-5%

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Task 3: Development of Qualification Program

GOAL: Generate the framework for a qualification test program including material and process specifications, test matrices, and documentation requirements.

Objectives:

- Select advanced fiber PMC material and process to initially develop this framework. The material was selected with input from the steering committee.
- Address quality aspects of the manufacturing process and the framework for a quality assurance program.
- Draft material and process specifications for selected material.
- Develop a test matrix including required physical and mechanical data.
- Generate substantial mechanical property test data necessary for development of statistical guidelines using accepted test standards for the selected material.

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Project Status

- **Material Selection**
  - TenCate - TC1225 (PAEK) unidirectional tape (semi-crystalline engineered polyarlyetherketone resin)
  - Fiber form – originally AS4D → now changed to T700 due to acquisition by Toray
- **Current Activity**
  - Screening Studies → for development of test matrix
  - Documentation – material and process specifications (initial release – update required)
  - Test Plan (initial release – update required)
  - Qualification Production
    - Audit at TenCate (December 2017) – signed and complete (update required)
    - Panels to be fabricated by TenCate Netherlands facility

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Material Specification

- Scope – form, application, classification
- Applicable Documents
- Technical Requirements
  - Detail specification
  - Constituent Material Requirements
  - Prepreg physical and chemical requirements
- Quality Assurance
- Preparation for Delivery

Table 1 – Prepreg Physical and Chemical Properties

Property	Product Form	Test Method(1)	Number of Replicates
Fiber Areal Weight	Prepreg	ASTM D3776 or SACMA SRM 23R-94	Each Lot/Batch(2)
Resin Content	Prepreg	ASTM D3171	Each Lot/Batch(2)
Differential Scanning Calorimetry (DSC) Glass Transition Temperature Melt Temperature Crystallization Temperature	Prepreg	ASTM D3418 or SACMA SRM 25R-94	Each Lot/Batch(3)

(1) Specific procedures should be identical to those used in the original material qualification program.
(2) Three specimens minimum should be taken across the width of each prepreg lot.
(3) Three specimens minimum should be taken for each prepreg lot.

TABLE 2 - Molded Laminate Physical Properties

Property	Test Method	Number of Replicates
Molded Ply Thickness	ASTM D3171-11	10 measurements per panel
Laminate Density	ASTM D792-08	2 per batch/lot minimum
Fiber Volume, % by Volume	ASTM D3171-11	2 per batch/lot minimum
Resin Content, % by Weight	ASTM D3171-11	2 per batch/lot minimum
Void Content, % by Volume	ASTM D3171-11	2 per batch/lot minimum
DSC (dry) - Glass transition Temp(1) - Melt Temperature - Crystallization Temperature	ASTM D3418-15	2 per batch/lot minimum

(1) Optional to use either method. Specific procedures should be identical to those used in the original material qualification program.

TABLE 3 - Required Molded Laminate Tests for Mechanical Properties (Class 1 Only)

Property	Test Temperature	Test Method(1)	Number of Replicates
0° Tension Strength and Modulus	RT	ASTM D3039	5
90/0° Compression Strength	RT	ASTM D6641	5
90 Flex Strength	RT	ASTM D790-5	5
SBS Strength	RT	ASTM D2344	5

(1) Specific procedures should be identical to those used in the original material qualification program

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Process Specification (NPS 81225)

- Scope
- Applicable Documents
- Materials
- Test Laminate Fabrication (compression molding)
- Quality Assurance

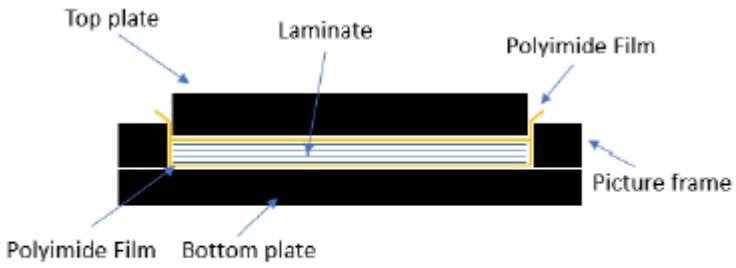

Figure 1. Molding Test Panels Schematic for TC1225

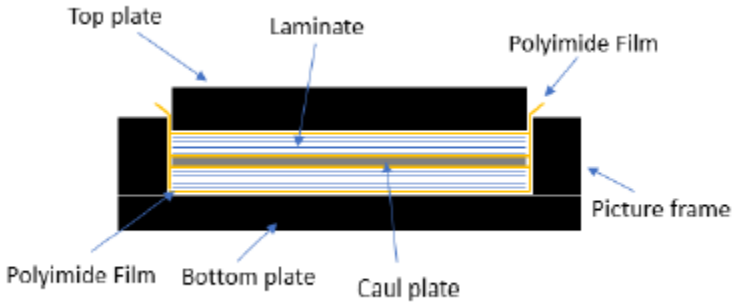

Figure 2. Molding Test Panels Schematic for TC1225 (Multiple panels)

Test Matrix – typical thermoset

Layup (warp direction)	Test Type and Direction	Property	Number of Batches x Number of Panels x Number of Test Specimens			
			Test Temperature/Moisture Condition			
			CTA	RTA	ETA1	ETW
$[0]_8$	ASTM D3039 0° Tension	Strength, Modulus, and Poisson's Ratio	3x2x3	3x2x3 (4)		3x2x3
$[0]_{20}$	ASTM D6641 0° Compression	Modulus	3x2x3	3x2x3 (1)(4)	3x2x3	3x2x3 (3)
$[90°]_{16}$	ASTM D3039 90° Tension	Strength and Modulus	3x2x3	3x2x3 (4)		3x2x3
$[90°]_{20}$	ASTM D6641 90° Compression	Strength and Modulus	3x2x3	3x2x3 (1)(4)	3x2x3	3x2x3 (3)
[90/0]4s	ASTM D6641 0° Compression (5)	Strength and Modulus	3x2x3	3x2x3	1x2x3	3x2x3 (3)
$[\pm45°]_{4s}$	ASTM D3518 In-Plane Shear	Strength and Modulus	3x2x3	3x2x3 (4)		3x2x3
$[90°]_{16}$	ASTM D790 Flex	Strength	3x2x3	3x2x3		3x2x3
$[0]_{34}$	ASTM D2344 Short Beam	Strength	3x2x3	3x2x3	3x2x3	3x2x3

(%0°/%±45°/%90°) Actual Test Type	Test Type and Layup (5)	Property	Number of Batches x Number of Panels x Number of Test Specimens		
			Test Temperature/Moisture Cond		
			CTA	RTA	ETW
(25/50/25 - QI) UNT1	ASTM D3039 Un-notched Tension [45/0/-45/90]2S	Strength & modulus	3x2x3	3x2x3 (7)	
(10/80/10) UNT2	ASTM D3039 Un-notched Tension [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength & modulus	3x2x3	3x2x3 (7)	3x2x3
(50/40/10) UNT3	ASTM D3039 Un-notched Tension [0/45/0/90/0/-45/0/45/0/-45]S	Strength & modulus	3x2x3	3x2x3 (7)	3x2x3
(25/50/25 - QI) UNC1	ASTM D6641 Un-notched Compression [45/0/-45/90]3S	Strength & modulus		3x2x3 (4&7)	3x2x3 (6)
(10/80/10) UNC2	ASTM D6641 Un-notched Compression [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength & modulus		3x2x3 (4&7)	3x2x3 (6)
(50/40/10) UNC3	ASTM D6641 Un-notched Compression [45/0/90/0/-45/0/45/0/-45/0]S	Strength & modulus		3x2x3 (4&7)	3x2x3 (6)
(25/50/25 - QI) SBS1	ASTM D2344 Short Beam [45/0/-45/90]3S (specimens may be taken from panels of similar layup)	Strength		3x2x3	3x2x3
(25/50/25 - QI) OHT1	ASTM D5766 Open Hole Tension (1) [45/0/-45/90]2S	Strength	3x2x3	3x2x3	3x2x3
(10/80/10) OHT2	ASTM D5766 Open Hole Tension (1) [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength	3x2x3	3x2x3	3x2x3
(50/40/10) OHT3	ASTM D5766 Open Hole Tension (1) [0/45/0/90/0/-45/0/45/0/-45]S	Strength	3x2x3	3x2x3	3x2x3
(25/50/25 - QI) FHT1	ASTM D6742 Filled Hole Tension (2) [45/0/-45/90]2S	Strength	3x2x3	3x2x3	3x2x3
(10/80/10) FHT2	ASTM D6742 Filled Hole Tension (2) [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength	3x2x3	3x2x3	3x2x3
(50/40/10) FHT3	ASTM D6742 Filled Hole Tension (2) [0/45/0/90/0/-45/0/45/0/-45]S	Strength	3x2x3	3x2x3	3x2x3
(25/50/25 - QI) OHC1	ASTM D6484 Open Hole Compression (1) [45/0/-45/90]4S	Strength		3x2x3 (4)	3x2x3
(10/80/10) OHC2	ASTM D6484 Open Hole Compression (1) [45/-45/0/45/-45/90/45/-45/45/-45]2S	Strength		3x2x3 (4)	3x2x3
(50/40/10) OHC3	ASTM D6484 Open Hole Compression (1) [0/45/0/90/0/-45/0/45/0/-45]2S	Strength		3x2x3 (4)	3x2x3
(25/50/25 - QI) FHC1	ASTM D6484 Filled Hole Compression (2) [45/0/-45/90]4S	Strength		3x2x3	3x2x3
(10/80/10) FHC2	ASTM D6484 Filled Hole Compression (2) [45/-45/0/45/-45/90/45/-45/45/-45]2S	Strength		3x2x3	3x2x3
(50/40/10) FHC3	ASTM D6484 Filled Hole Compression (2) [0/45/0/90/0/-45/0/45/0/-45]2S	Strength		3x2x3	3x2x3
(25/50/25 - QI) SSB1	ASTM D5961 Single Shear Bearing (3) [45/0/-45/90]2S	Strength & Deformation		3x2x3	3x2x3
(10/80/10) SSB2	ASTM D5961 Single Shear Bearing (3) [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength & Deformation		3x2x3	3x2x3
(50/40/10) SSB3	ASTM D5961 Single Shear Bearing (3) [0/45/0/90/0/-45/0/45/0/-45]S	Strength & Deformation		3x2x3	3x2x3
(100/0/0) ILT	ASTM D6415 Interlaminar Tension Strength [0]30 (note: curved panel)	Strength	1x1x6	1x1x6	1x1x6
(25/50/25 - QI) CAI1	ASTM D7136 & D7137 Compression After Impact (1500 in.lb/in) (4) [45/0/-45/90]4S (8)	Strength		1x1x6	

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Screening Studies

- QUESTIONS:
  - Does moisture uptake affect strength properties significantly? *If not, consider removing ETW from test matrix.*
  - What elevated temperature(s) should be selected for qualification testing? *Full 3 batch or single batch recommendations.*

- Test Temperatures:
  - Phase 1: 180°F, 250°F, and 350°F.
  - Phase 2: 200°F, 225°F, 275°F
  - Phase 3: 400°F and 450°F

- Mechanical Properties:
  - IPS – $[+45/-45]_{4S}$
  - SBS – $[0]_{34}$
  - OHC – $[+45/0/-45/90]_{3S}$

- Physical Properties: DSC/DMA were evaluated

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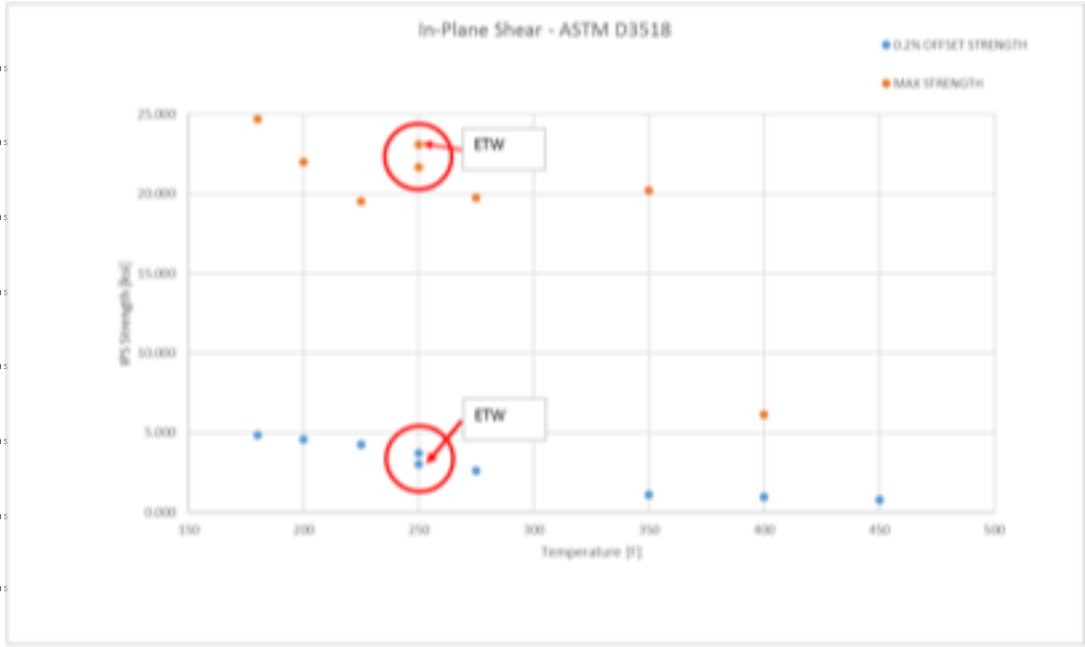
Screening Results - IPS

2-5 coupons @ each condition

ASTM D 3518
IN-PLANE SHEAR RESPONSE OF POLYMER MATRIX COMPOSITE MATERIALS BY TENSILE TEST OF A ±45° LAMINATE

		0.2% offset [ksi]	5% Strain [ksi]	Max [ksi]	Modulus [Msi]	
180	Average	4.859	7.598	24.710	0.514	5 specimens
	CV	2.234	4.792	10.431	1.519	
200	Average	4.585	7.042	21.994	0.491	5 specimens
	CV	3.415	6.982	8.357	1.704	
225	Average	4.263	6.724	19.546	0.462	5 specimens
	CV	2.103	2.622	4.662	1.615	
250	Average	3.727	6.031	21.661	0.404	5 specimens
	CV	1.663	2.003	4.502	1.250	
250 Wet	Average	3.030	5.749	23.104	0.302	4 specimens
	CV	8.477	10.140	6.399	7.981	
275	Average	2.625	4.753	19.753	0.258	5 specimens
	CV	7.252	5.905	7.386	4.490	
350	Average	1.132	2.637	20.200	0.091	5 specimens
	CV	15.415	11.157	8.259	17.393	
400	Average	0.977		6.118	0.071	4 specimens
	CV	8.246		9.995	8.124	
450	Average	0.806			0.058	4 specimens
	CV	0.697			2.427	



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Screening Results - SBS

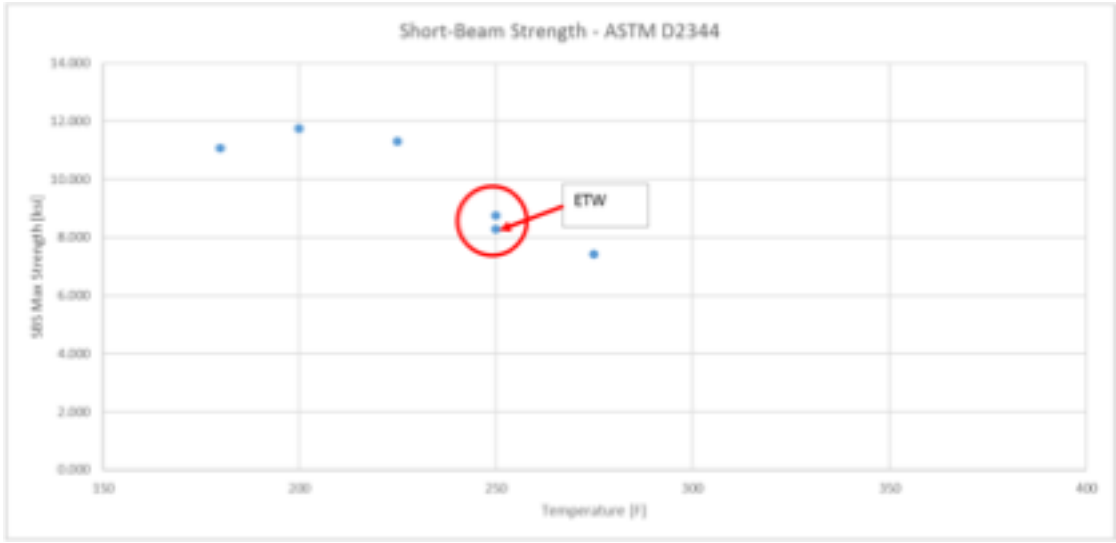
2-5 coupons @ each condition

ASTM D2344

SHORT-BEAM STRENGTH OF POLYMER MATRIX COMPOSITE

MATERIALS AND THEIR LAMINATES

		Max [ksi]	
180	Average	11.064	5 specimens
	CV	2.970	
200	Average	11.753	5 specimens
	CV	2.579	
225	Average	11.296	5 specimens
	CV	2.382	
250	Average	8.755	5 specimens
	CV	3.270	
250 WET	Average	8.273	5 specimens
	CV	5.660	
275	Average	7.431	3 specimens
	CV	4.731	

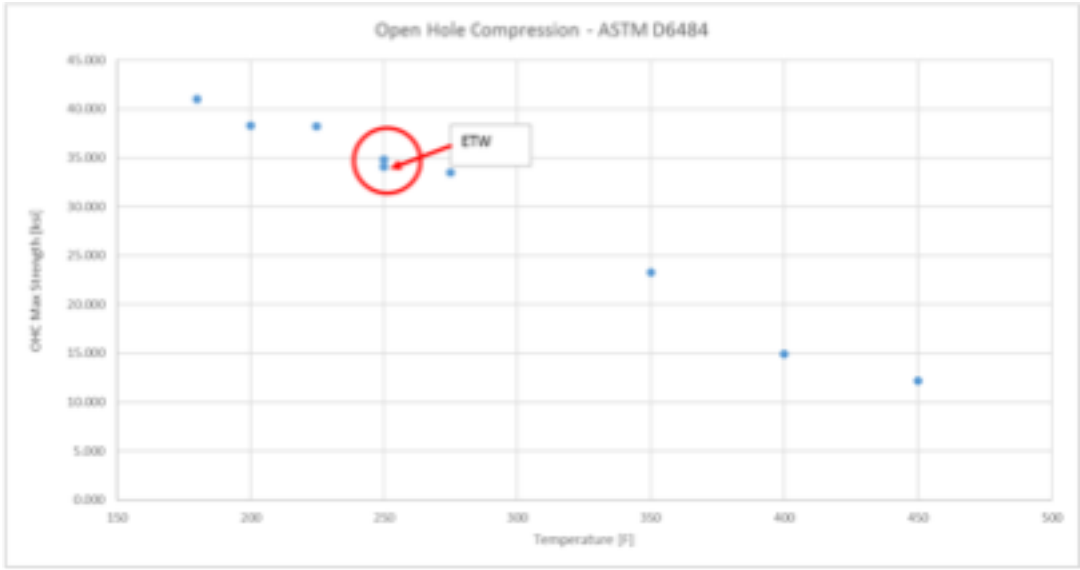


Screening Results – OHC

2-4 coupons @ each condition

ASTM D6484 (PROCEDURE A)
OPEN HOLE COMPRESSIVE STRENGTH OF POLYMER MATRIX COMPOSITE LAMINATES

		Max [ksi]				
180	Average	41.004				2 specimens
	CV	8.95%				
200	Average	38.291				2 specimens
	CV	1.603				
225	Average	38.206				2 specimens
	CV	8.483				
250	Average	34.823				3 specimens
	CV	1.24%				
250 WET	Average	34.100				1 specimen
275	Average	33.475				3 specimens
	CV	1.719				
350	Average	23.310				2 specimens
	CV	8.45%				
400	Average	14.942				4 specimens
	CV	5.56%				
450	Average	12.179				3 specimens
	CV	6.71%				



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Test Plan

- Test Methods
- Panel and Specimen Identification
- Prepreg and Resin Testing
- Molded Laminate Physical Testing
- Molded Lamina and Laminate Mechanical Property Testing
- Inspection, conformance, witnessing, shipping
- Data reduction and reporting

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Lamina Test Matrix

Table 3 Lamina Level Tests

Layup	Test Type and Direction	Property	Number of Batches x Number of Panels x Number of Test Specimens				
			Test Temperature/Moisture Condition				
			CTA	RTA	ETA1	ETA2	ETW
$[0]_8$	ASTM D3039 0° Tension	Strength, Poisson's Ratio, and Modulus	3x2x3	3x2x3 (4)	3x2x3 (4)	1x2x3 (4)	1x2x3
$[0]_{20}$	ASTM D6641 0° Compression	Poisson's Ratio and Modulus	3x2x3	3x2x3 (1)(4)	3x2x3 (1)(4)	1x2x3 (1)(4)	1x2x3 (3)
$[90°]_{16}$	ASTM D3039 90° Tension	Strength and Modulus	3x2x3	3x2x3 (4)	3x2x3	1x2x3 (4)	1x2x3
$[90°]_{20}$	ASTM D6641 90° Compression	Strength and Modulus	3x2x3	3x2x3 (1)(4)	3x2x3	1x2x3 (1)(4)	1x2x3 (3)
[90/0]4s	ASTM D6641 0° Compression (5)	Strength and Modulus	3x2x3	3x2x3 (1)(4)	3x2x3	1x2x3	1x2x3 (3)
$[+45/-45°]_{4s}$	ASTM D3518 In-Plane Shear	Strength and Modulus	3x2x3	3x2x3 (4)	3x2x3	1x2x3 (4)	1x2x3
$[0°]_{22}$	ASTM D790 Flex	Strength	3x2x3	3x2x3	3x2x3	1x2x3	1x2x3
$[0]_{34}$	ASTM D2344 Short Beam	Strength	3x2x3	3x2x3	3x2x3	1x2x3	1x2x3

Test environments are defined as:
CTA = -65±5°F, ambient
RTA = 70±10°F, room temperature ambient
ETA1 = 275±5°F, ambient
ETA2 = 400±5°F, ambient
ETW = 275±5°F, wet (equilibrium moisture content per section 6.1)

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Laminate Test Matrix

Table 4 Laminate Level Tests

(%0°/%±45°/%90°) Actual Test Type	Test Type and Layup (5)	Property	Number of Batches x Number of Panels x Number of Test Specimens				
			Test Temperature/Moisture Condition				
			CTA	RTA	ETA1	ETA2	ETW
(25/50/25 - QI) UNT1	ASTM D3039 Un-notched Tension [45/0/-45/90]2S	Strength & modulus	3x2x3	3x2x3 (7)	3x2x3 (7)	1x2x3	1x2x3
(10/80/10) UNT2	ASTM D3039 Un-notched Tension [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength & modulus	3x2x3	3x2x3 (7)	3x2x3 (7)		
(50/40/10) UNT3	ASTM D3039 Un-notched Tension [0/45/0/90/0/-45/0/45/0/-45]S	Strength & modulus	3x2x3	3x2x3 (7)	3x2x3 (7)		
(25/50/25 - QI) UNC1	ASTM D6641 Un-notched Compression [45/0/-45/90]3S	Strength & modulus		3x2x3 (4&7)	3x2x3 (4&7)	1x2x3	1x2x3 (6)
(10/80/10) UNC2	ASTM D6641 Un-notched Compression [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength & modulus		3x2x3 (4&7)	3x2x3 (4&7)		
(50/40/10) UNC3	ASTM D6641 Un-notched Compression [0/45/0/90/0/-45/0/45/0/-45]S	Strength & modulus		3x2x3 (4&7)	3x2x3 (4&7)		
(25/50/25 - QI) SBS1	ASTM D2344 Short Beam [45/0/-45/90]3S (specimens may be taken from panels of similar layup)	Strength		3x2x3	3x2x3	1x2x3	1x2x3
(25/50/25 - QI) OHT1	ASTM D5766 Open Hole Tension (1) [45/0/-45/90]2S	Strength	3x2x3	3x2x3	3x2x3	1x2x3	1x2x3
(10/80/10) OHT2	ASTM D5766 Open Hole Tension (1) [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength	3x2x3	3x2x3	3x2x3		
(50/40/10) OHT3	ASTM D5766 Open Hole Tension (1) [0/45/0/90/0/-45/0/45/0/-45]S	Strength	3x2x3	3x2x3	3x2x3		
(25/50/25 - QI) FHT1	ASTM D6742 Filled Hole Tension (2) [45/0/-45/90]2S	Strength	3x2x3	3x2x3	3x2x3	1x2x3	1x2x3
(10/80/10) FHT2	ASTM D6742 Filled Hole Tension (2) [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength	3x2x3	3x2x3	3x2x3		
(50/40/10) FHT3	ASTM D6742 Filled Hole Tension (2) [0/45/0/90/0/-45/0/45/0/-45]S	Strength	3x2x3	3x2x3	3x2x3		
(25/50/25 - QI) OHC1	ASTM D6484 Open Hole Compression (1) [45/0/-45/90]4S	Strength		3x2x3 (4)	3x2x3 (4)	1x2x3	1x2x3
(10/80/10) OHC2	ASTM D6484 Open Hole Compression (1) [45/-45/0/45/-45/90/45/-45/45/-45]2S	Strength		3x2x3 (4)	3x2x3 (4)		
(50/40/10) OHC3	ASTM D6484 Open Hole Compression (1) [0/45/0/90/0/-45/0/45/0/-45]2S	Strength		3x2x3 (4)	3x2x3 (4)		
(25/50/25 - QI) FHC1	ASTM D6484 Filled Hole Compression (2) [45/0/-45/90]4S	Strength		3x2x3	3x2x3	1x2x3	1x2x3
(10/80/10) FHC2	ASTM D6484 Filled Hole Compression (2) [45/-45/0/45/-45/90/45/-45/45/-45]2S	Strength		3x2x3	3x2x3		
(50/40/10) FHC3	ASTM D6484 Filled Hole Compression (2) [0/45/0/90/0/-45/0/45/0/-45]2S	Strength		3x2x3	3x2x3		
(25/50/25 - QI) SSB1	ASTM D5961 Single Shear Bearing (3) [45/0/-45/90]2S	Strength & Deformation		3x2x3	3x2x3	1x2x3	1x2x3
(10/80/10) SSB2	ASTM D5961 Single Shear Bearing (3) [45/-45/0/45/-45/90/45/-45/45/-45]S	Strength & Deformation		3x2x3	3x2x3		
(50/40/10) SSB3	ASTM D5961 Single Shear Bearing (3) [0/45/0/90/0/-45/0/45/0/-45]S	Strength & Deformation		3x2x3	3x2x3		
(100/0/0) ILT	ASTM D6415 Interlaminar Tension Strength [0]30 (note: curved panel)	Strength	1x1x6	1x1x6	1x1x6	1x1x6	1x1x6
(25/50/25 - QI) CAI1	ASTM D7136 & D7137 Compression After Impact (1500 in.lb/in) [45/0/-45/90]4S (8)	Strength		1x1x6	1x1x6	1x1x6	1x1x6

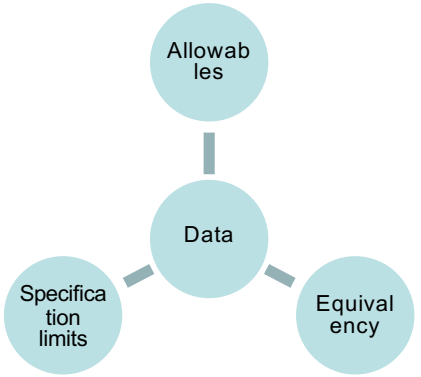
(1) Open-hole configuration: 0.25" hole diameter, 1.5 inch width.
(2) Filled-hole test configuration: 0.25" diameter, see section 2 for fastener callout, 1.5" width.
(3) Single shear bearing test configuration: 0.25: hole diameter, 1.5" width, see section 2 for fastener callout, e/D=3, ASTM D5961/D5961M-17 Procedure C.

Test environments are defined as:
CTA = -65±5°F, ambient
RTA = 70±10°F, room temperature ambient
ETA1 = 275±5°F, ambient
ETA2 = 400±5°F, ambient
ETW = 275±5°F, wet (equilibrium moisture content per section 6.1)

Task 4: Development of statistical guidelines

GOAL: Understanding of how parameters interact and affect variability as well as final allowables.

- Establish qualification statistical requirements. The factors affecting variability will be assessed during this task.
- Establish equivalency requirements including specification minimums for acceptance.



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Task 5: Guidelines and Recommendations

GOAL: To provide guidelines to industry for the collection of statistically meaningful critical data that designers need to utilize thermoplastic composite materials potentially including:

- Creation of a shared database to include material test data, material and process specifications and analysis methods.
- Development of handbook data and guidelines for CMH-17.
- Transition specification to SAE P-17.

TIMELINE – Based on FY2017 Deliverables

	Activity	Completion Date	Milestone / Deliverable	Complete?
1.1	Survey - Develop survey questions and administer to PMC community - Collect survey results and analyze for input on material selection	11/30/2016	Deliverable	✓
1.2	Industry Steering Committee - Establish group of participants - Create online portal for document sharing and data repository	12/1/2016	Milestone	✓
1.3	Preliminary drafts of qualification framework - Material and process specifications - Test plan - Conformity documentation	6/30/2017	Deliverable	✓

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TIMELINE – Based on FY2017 Deliverables

	Activity	Target Date	Milestone / Deliverable	Complete?
1.1	Trial / Screening Studies (ongoing) - Perform thermal and mechanical tests to assist in test matrix development and selection of elevated test temperature - Present data to FAA, Industry Steering Committee, NCAMP Partners	12/31/2017	Milestone	✓
1.2	Qualification Material - Site audit complete (scheduled for 12/7-12/8/2017) - ✓ - Panels built and delivered to NIAR (see next slide)	10/29/2018	Milestone	
1.3	Qualification Testing - Perform physical and mechanical testing on qualification panels. – Generate test data for qualification program.	4/30/2019	Milestone	
1.4	Develop Statistical Guidelines based on qualification data	5/31/2019	Milestone	
1.5	NCAMP Reports on Qualification Data - Material technical report - Statistical analysis technical report	6/30/2019	Deliverable	
1.6	CMH-17 - Submit content, data, and protocols to Composite Materials Handbook 17 (CMH-17)	8/31/2019	Deliverable	
1.7	Final Report - Final Technical Report on the Guidelines for Thermoplastic Continuous Fiber PMC Qualification	8/31/2019	Deliverable	

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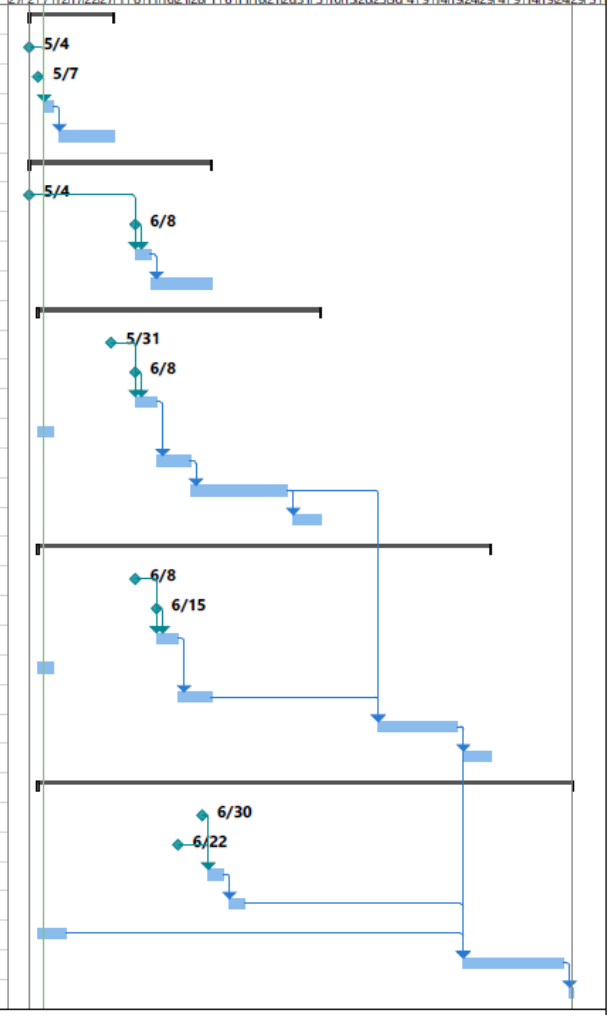
TenCate/Toray Schedule

NCAMP TC1225 (LMPAEK) T700 Qualification Schedule

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		**TP1 Screening Run**	**20 days**	**Fri 5/4/18**	**Thu 5/31/18**		
2		Receive Fiber Batch 1	0 days	Fri 5/4/18	Fri 5/4/18		
3		Receive Polymer Batch 1	0 days	Mon 5/7/18	Mon 5/7/18		
4		Produce material	3 days	Wed 5/9/18	Fri 5/11/18	2,3	
5		Test material	14 days	Mon 5/14/18	Thu 5/31/18	4	
6		**TP4 Screening Run**	**42 days**	**Fri 5/4/18**	**Mon 7/2/18**		
7		Receive Fiber	0 days	Fri 5/4/18	Fri 5/4/18		
8		Receive Polymer	0 days	Fri 6/8/18	Fri 6/8/18		
9		Produce material	3 days	Fri 6/8/18	Tue 6/12/18	7,8	
10		Test material	14 days	Wed 6/13/18	Mon 7/2/18	9	
11		**Production Run 1 (TP1)**	**67 days**	**Mon 5/7/18**	**Tue 8/7/18**		
12		Receive Fiber	0 days	Thu 5/31/18	Thu 5/31/18		
13		Receive Polymer	0 days	Fri 6/8/18	Fri 6/8/18		
14		Produce Material	5 days	Fri 6/8/18	Thu 6/14/18	12,13	
15		Test material	5 days	Mon 5/7/18	Fri 5/11/18		
16		Send Material to Nijverdal	7 days	Fri 6/15/18	Mon 6/25/18	14	
17		Produce Laminates	24 days	Tue 6/26/18	Fri 7/27/18	16	
18		Ship Laminates to NIAR	7 days	Mon 7/30/18	Tue 8/7/18	17	
19		**Production Run 2 (TP4)**	**107 days**	**Mon 5/7/18**	**Tue 10/2/18**		
20		Receive Fiber	0 days	Fri 6/8/18	Fri 6/8/18		
21		Receive Polymer	0 days	Fri 6/15/18	Fri 6/15/18		
22		Produce Material	5 days	Fri 6/15/18	Thu 6/21/18	20,21	
23		Test material	5 days	Mon 5/7/18	Fri 5/11/18		
24		Send Material to Nijverdal	7 days	Fri 6/22/18	Mon 7/2/18	22	
25		Produce Laminates	20 days	Mon 8/27/18	Fri 9/21/18	24,17	
26		Ship Laminates to NIAR	7 days	Mon 9/24/18	Tue 10/2/18	25	
27		**Production Run 3 (TP4)**	**126 days**	**Mon 5/7/18**	**Mon 10/29/**		
28		Receive Fiber	0 days	Sat 6/30/18	Sat 6/30/18		
29		Receive Polymer	0 days	Fri 6/22/18	Fri 6/22/18		
30		Produce Material	5 days	Mon 7/2/18	Fri 7/6/18	28,29	
31		Test material	5 days	Mon 7/9/18	Fri 7/13/18	30	
32		Send Material to Nijverdal	7 days	Mon 5/7/18	Tue 5/15/18		
33		Produce Laminates	25 days	Mon 9/24/18	Fri 10/26/18	32,25,31	
34		Ship Laminates to NIAR	1 day	Mon 10/29/1	Mon 10/29/	33	



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Looking forward

- Benefit to Aviation
  - Framework for characterization of thermoplastic continuous fiber composites
  - Understanding of ETW and ETA2 properties compared to typical ETA
  - Process specification for a thermoplastic – key process parameters required
  - Material specification for a thermoplastic – key mechanical properties for spec minimums
- Future needs
  - Other thermoplastic material forms
  - Discontinuous PMCs – test matrix and processing spec considerations

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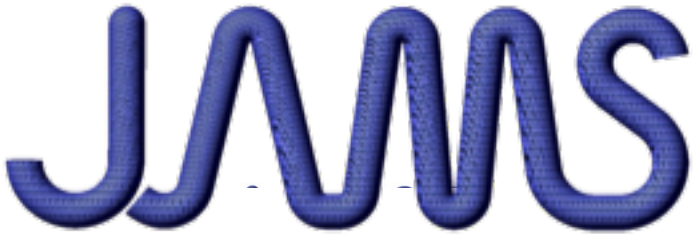
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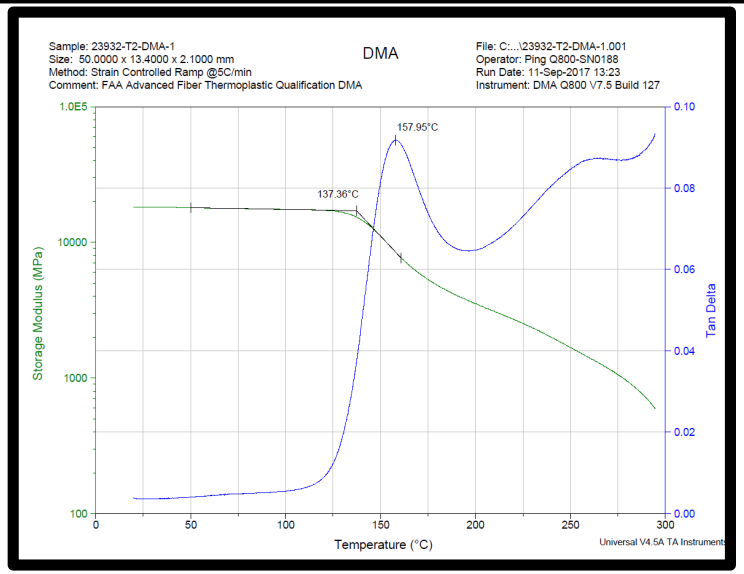
Screening Results – DSC and DMA

ASTM D7028

DMA Results

FAA Advanced Fiber Thermoplastic Qualification DMA

Sample #	Onset Storage Modulus T_g [°C]	T_g [°F]		T_g [°F]	Peak of Tangent Delta T_g [°C]	T_g [°F]		T_g [°F]
23932-T2-DMA-1	137.36	279.25	Average	278.94	157.95	316.31	Average	316.08
23932-T2-DMA-2	136.98	278.56			157.75	315.95		
23932-T2-DMA-3	137.22	279.00	St. Dev.	0.35	157.77	315.99	St. Dev.	0.20

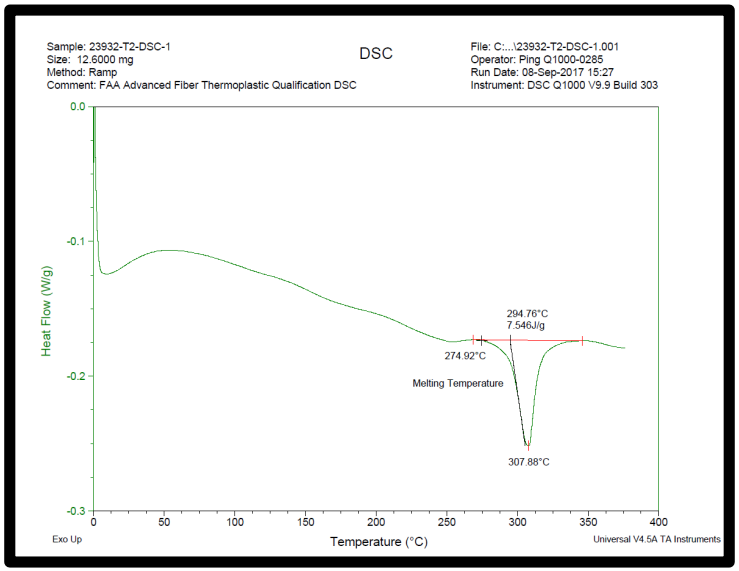


ASTM D3418

DSC Results

FAA Advanced Fiber Thermoplastic Qualification DSC

Sample #	Melting Temperature T_g [°C]	T_g [°F]	Onset Temperature of Endotherm T_{eic} [°C]	T_{eic} [°F]	Peak Temperature of Endotherm T_{pc} [°C]	T_{pc} [°F]	Heat of Reaction of Endotherm Delta H [J/g]
23932-T2-DSC-1	274.92	526.86	294.76	562.57	307.88	586.18	7.546
23932-T2-DSC-2	269.36	516.85	294.24	561.63	307.36	585.25	7.418
23932-T2-DSC-3	272.90	523.22	294.14	561.45	307.00	584.60	7.568
Average	272.39	522.31	294.38	561.88	307.41	585.34	7.511
St. Dev.	2.81	5.07	0.33	0.60	0.44	0.80	0.081



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