Federal Aviation Administration

A Center of Excellence

Motivation and Key Issues

- Expanded use of Ceramic Matrix Composites (CMCs) in gas turbine engines and hypersonic applications
- CMCs require their own set of rules separate from more established PMCs
- No “fully approved” data in CMH-17
- Similar complexity to PMCs in terms of anisotropy, fiber architecture, high strength/stiffness fibers, and production process sensitivity and variability, they are also different in many ways such as:
    - Composite constituents
    - Degradation, damage, and failure mechanisms
    - High temperature life predictions
    - High temperature joining challenges
    - NDE challenges
    - Repairability

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Objective and Scope

- Develop a framework for the qualification of CMCs, including guidelines and recommendations for their characterization, testing, design and utilization.
- Develop and execute a test plan to evaluate the durability and long term safety of CMCs.
- Transition the CMC test data and guidelines generated in this program into shared databases

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Approach

- Generate Qualification Documents for CMCs and Perform Material Qualification
  - Material and Process Specifications
  - Test Plan
  - Statistical Analysis Report with B-Basis Allowables
- Generate Equivalency Documents for CMCs and Perform Material Equivalency
  - Test Plan
  - Equivalency Analysis Report
- Evaluate Durability and Long Term Safety of CMCs
  - Generate Test Plan
  - Perform fatigue, long term thermal exposure, and creep testing

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Ox/Ox Qualification

Fiber Source:	Weaver:	Prepreg Supplier:	Panel Fabricator:
3M	Textile Products Inc (TPI)	Axiom Materials	AC&A, Axiom
Nextel 610 Fibers **Alumina Fiber, 3K Denier, 5-Harness Satin Weave**		**AX-7800 Aluminum Silicate Slurry (Water Based)** **3 Batches**	**Autoclave Cure and Sintering**

- Documents Generated for Qualification Program:
  - Material Specification
  - Process Specification
  - Test plan – including test matrix with physical, thermal, and mechanical test requirements

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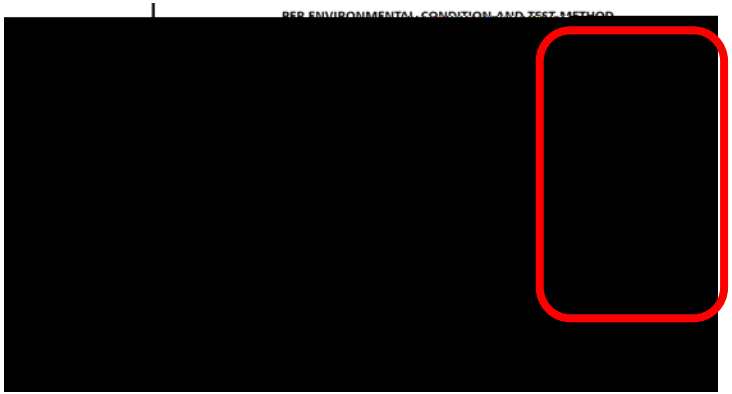
Ox/Ox Qualification

Material Specification: Complete → Process Specification: Complete → Test Plan: Complete → Panel Fabrication: Complete → **Testing: In progress, ETC Q4 2021** → **Statistical Analysis: In progress, ETC Q4 2021** → Test Reports: ETC Q1 2022 → Transition Data and Guidelines: ETC Q1 2022



Had quality issues with panels fabricated by AC&A from batch 3. Replacement panels were fabricated by Axiom Materials. Testing resumed once replacement panels were received earlier this year (testing was previously completed batch 1 and 2).

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Ox/Ox Qualification

Env	RTD	ETD	RTD	ETD
Mean	27.891	25.767	27.690	25.675
Stdev	1.793	3.481	2.067	3.974
CV	6.427	13.510	7.465	15.478
Mod CV	7.214	13.510	7.733	15.478
Min	24.932	20.343	24.969	19.889
Max	30.815	29.449	31.459	30.197
No. Batches	3	3	3	3
No. Panels	6	6	6	6
No. Spec.	18	18	18	18
B-Basis	24.352	18.111	23.609	17.878
A-Estimate	21.844	11.694	20.717	10.646
Method	Normal	Non-Parametric	Normal	Non-Parametric
B-Estimate	22.185	14.994	21.115	13.210
A-Estimate	18.284	7.617	16.620	4.681
B-Basis	23.919		23.463	
A-Estimate	21.109		20.473	
Method	Normal		Normal	
B-Basis	21.050	12.921	19.809	10.772
A-Estimac				

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Ox/Ox Equivalency

Unnotched Tension Strength Equivalency Criteria					
		Normalized		As-measured	
	Env	RTD	ETD	RTD	ETD
Grade A or Grade B	CMH17 Minimum Equivalency Criteria forStrength (n=8, alpha = 5%)				
	Mean	26.674	23.404	26.287	22.976
	Minimum	23.051	16.368	22.109	14.945
Grade C	CMH17 Mod CV Minimum Equivalency Criteria for Strength (n=8, alpha = 5%)				
	Mean	26.525	NA	26.236	NA
	Minimum	22.459		21.909	
Grade G	Generic Equivalency Criteria for Strength (n=8, alpha = 5%)				
	Acceptance Limit for Mean	23.823	18.128	23.004	16.813
	Maximum Sample Standard Deviation	4.185	7.860	4.822	9.118

SiC/SiC Qualification

Fiber Source: Ube Industries Ltd.

Tyranno ZMI SiC Fiber

Fiber Coating Source: IHI Corporation

Boron Nitride Coating

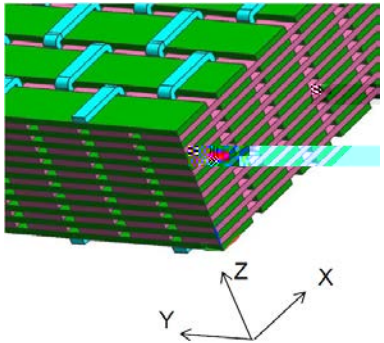
Weaver: Shikibo Ltd.

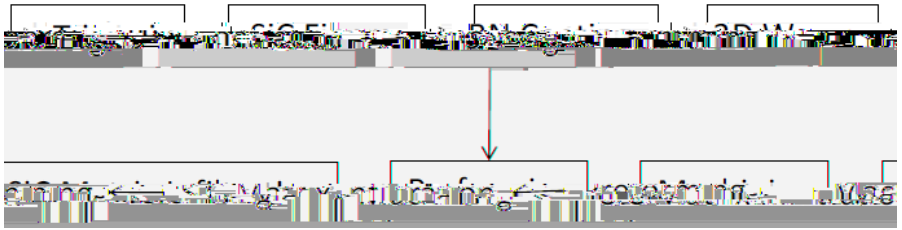
3D Orthogonal Woven Preform

Panel Fabricator: IHI Corporation

Chemical Vapor Infiltration (CVI) and Polymer Infiltration and Pyrolysis (PIP) Hybrid Process

3 Batches





Watanabe, F., Manabe, T., “Engine Testing for the Demonstration of a 3D-Woven Based Ceramic Matrix Composite Turbine Vane Design Concept,” ASME Turbo Expo 2018: Turbomachinery Technical Conference and Exposition, Oslo, Norway, June 11-15, 2018

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Durability and Long Term Safety

Notional Fatigue Test Matrix

- The target for “low” cycle fatigue is on the order of 1×10^4 to 5×10^4 cycles.
- The target for “mid” cycle fatigue is on the order of 5×10^4 to 2×10^5 cycles.
- The target for “high” cycle fatigue is on the order 2×10^5 to 1×10^6 cycles.
- Specimens which do not fail will be run for at least 10^6 cycles (runout), and residual strength tested.
- Stress levels to target low, mid, and high cycle fatigue stress will be identified during the scoping trials and better defined ranges will be established for low, mid, and high cycle failures.

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Durability and Long Term Safety

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Durability and Long Term Safety

High Temperature Creep Test Matrix

- Testing will be conducted at 1650°F.
- Relative applied stress is defined as a percentage of either the ultimate stress or peak stress, as appropriate, as determined by static testing on the same batch of material.
- One set of coupons for each test type will be reserved for either testing at an additional stress level or testing at an identical stress level but a higher or lower temperature. This will be determined based on preliminary creep testing results.

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Technical Publications

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