CMH-17 CMC Testing Working Group Meeting

November 19th, 2024

CMC Testing WG Co-chairs
Bob Zhou – GE Aerospace, yuanxin.zhou@geaerospace.com
Matt Opliger – WSU-NIAR, matthew.opliger@idp.wichita.edu

Agenda

- Introductions
- Vision and Goals
- Overview of CMC Testing WG Sections (Volume 5, Part C, Chapters 8-15)
- Review and Discuss:
  - Finished Sections Requiring Changes and/or Balloting
  - Sections Currently being Worked
  - Future Plans
- Special Topic 1: In-plane Shear Strength Characterization of MI SiC/SiC CMC
- Special Topic 2: Oversized Button Specimens for Interlaminar Tensile Properties

CMC Testing WG

Vision:

To be the primary and authoritative source for recommended/ required methods for testing characterization of CMCs & their constituents

Goals:

- To identify appropriate existing consensus standard test methods (such as ASTM Standards) for CMCs and their constituent materials
- To assist in the identification/development of appropriate standard test methods for CMCs and their constituent materials, where no such standards exist

Meetings:

- Meetings are regularly held the second Monday of the month at 12 p.m. eastern.

CMC Testing WG – Overview

Handbook Sections – Part C. Testing:

- Chapter 8 – Thermo-Mechanical-Physical Test Methods – Overview
- Chapter 9 – Material Testing & Characterization for Submission of Data to CMH-17
- **Chapter 10 – Evaluation of Reinforcements**
- **Chapter 11 – Evaluation of Matrix Materials**
- Chapter 12 – Evaluation of Interface Material
- **Chapter 13 – Evaluation of Composites**
- Chapter 14 – Subcomponent Testing – Overview of Problem
- Chapter 15 – Machining and Grinding

Chapter	Status of Sections			
	Published (Rev A)	Draft in Progress	Yellow Pages	Reserved for Future Use
8	18			18
9	110			6
10			12	
11		12		
12				1
13	4	2	5	10
14				3
15				4

17 new sections for Rev B

CMC Yellow Page Ballot Schedule

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CLOSED BALLOTS

Sp 2024 YP1:
June 14, 2024

- Fracture Toughness Testing
- Compression Testing

Sp 2024 YP2:
September 13, 2024

- Attachments to non-CMC Components (D&A)
- Creep Testing

UPCOMING BALLOTS

Fall 2024 YP1: January 10, 2025

- Axiom Material Ox/Ox Dataset (DR)
- Statistics sections updates (DR)
- Flexure Testing?
- Specific Heat Testing?
- EBC content (M&P)

Fall 2024 YP2:
March 21, 2025

If reballot is required, content may not make it in Rev. B

CMC Testing WG – Updates for Rev B

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Chapter	Section	New/Revised	Scope	Status	Priority
Chapter 10 – Evaluation of Reinforcements	10.1 Introduction	New	New section	Approved	3
	10.2 Physical Properties	New	New section	Approved	3
	10.2.1 Filament Diameter	New	New section	Approved	3
	10.2.2 Density of Fibers	New	New section	Approved	3
	10.2.3 Electrical Resistivity	New	New section	Approved	3
	10.2.4 Coefficient of Thermal Expansion	New	New section	Approved	3
	10.2.5 Thermal Conductivity	New	New section	Approved	3
	10.2.6 Specific Heat	New	New section	Approved	3
	10.3 Mechanical Testing of Fibers	New	New section	Approved	3
	10.3.1 Tensile Properties	New	New section	Balloted - Needs minor clarification	3
	10.3.2 Fiber Creep /Creep Rupture Test	New	New section	Approved	3
	10.3.3 Fiber Fatigue Test	New	New section	Approved	3
Chapter 13 – Evaluation of Composites	13.2 Fiber Volume Fraction	New	New section	Approved	1
	13.7 Compression Testing	New	New section	Approved	1
	13.10 Interlaminar Tension	New	New section	Approved	1
	13.11 Notched Testing	Revised	Add new content for OHT, including new ASTM standard for CMCs	Approved	1
	13.12 Interlaminar Fracture Toughness	New	New section	Approved	1
	13.14 Creep Testing	New	New section	Balloted - Needs minor change	1

Priority Scale

1	High
2	Medium-High
3	Medium
4	Medium-Low
5	Low

*Additionally, will align ASTM version/year referencing throughout the testing sections

CMC Testing WG – Plans for New Sections

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	Section	New/Revised	Scope	Targeted Yellow Page Ballot	Status	Contributors	Priority
	11.1 Introduction	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno	5
	11.2 Mechanical Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.1 Tensile Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.2 Compressive Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.3 Flexural Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.4 Fracture Toughness	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.5 Creep / Creep Rupture	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.2.6 Fatigue	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno, Gyanender Singh (R)	5
	11.3 Physical Properties	New	New section	Next Revision	In-Progress	Bob Zhou, Jorge Abanto Bueno	5
	11.3.1 Specific Heat	New	New section	Next Revision	In-Progress	Bob Zhou, Ken Kawanishi (R), Lilly Liu (R), Sreeramesh Kalluri (R)	5
	11.3.2 Thermal Expansion	New	New section	Next Revision	In-Progress	Bob Zhou, Ken Kawanishi (R), Lilly Liu (R), Sreeramesh Kalluri (R)	5
	11.3.3 Thermal Diffusivity and Conductivity	New	New section	Next Revision	In-Progress	Bob Zhou, Ken Kawanishi (R), Lilly Liu (R), Sreeramesh Kalluri (R)	5
*	13.3 CTE	New	New section	Next Revision	Planned	Matt Opliger, Ken Kawanishi, Merna Salama (R)	2
*	13.4 Thermal Conductivity	New	New section	Next Revision	Planned	Matt Opliger, Ken Kawanishi, Lilly Liu (R), Merna Salama (R)	2
*	**13.5 Specific Heat**	**New**	**New section**	**Fall 2024 YP1?**	**In-Progress**	**Matt Opliger, Ken Kawanishi, Merna Salama (R)**	**1**
*	**13.8 Flexure**	**New**	**New section**	**Fall 2024 YP1?**	**In-Progress**	**Lilly Liu, Bob Zhou, Allison Horner (R), Merna Salama (R)**	**1**
	13.13 Crack Growth	New	New section	TBD	Not Started	TBD	5
	13.15 Fatigue Testing	New	New section	TBD	Not Started	TBD	3
	13.16 TMF – Thermo-mechanical Fatigue	New	New section	TBD	Not Started	TBD	5
	13.17 Wear Testing	New	New section	Next Revision	Planned	Bob Zhou, Darcy Stone	5
	13.18 Bearing Testing	New	New section	TBD	Not Started	Allison Horner	3
	13.19 Biaxial Testing	New	New section	TBD	Not Started	TBD	5

Priority Scale

1	High
2	Medium-High
3	Medium
4	Medium-Low
5	Low

Special Topic 1: MI SiC/SiC IPS Strength

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Overview

- **Motivation and Objective**
- **In-plane shear strength testing by using 45/-45 tensile**
- **In-plane shear strength testing by using Iosipescu shear**
- **In-plane shear strength testing by using DNC**
- **Summary**

Special Topic 1: Motivation and Objective

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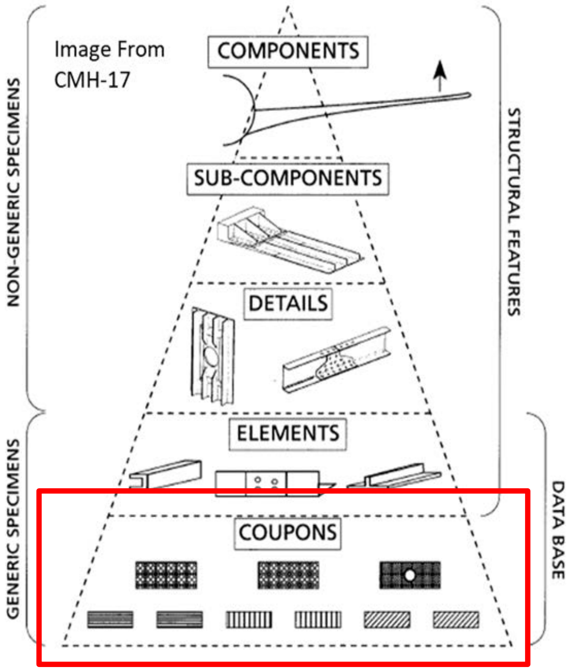
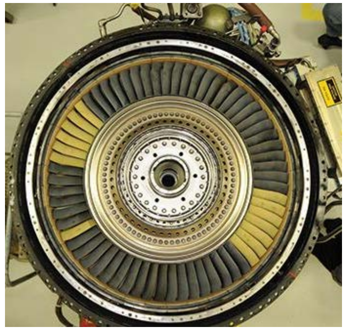
American Ceramic Society Bulletin, Vol. 98, No. 3

SiC/SiC CMCs are used for hot section components that have high use temperatures (up to 2700 °F) and require high strength. Examples include High Pressure Turbine (HPT) shrouds, seals, nozzles, vanes, and blades, combustor liners, and some potential hypersonic applications.





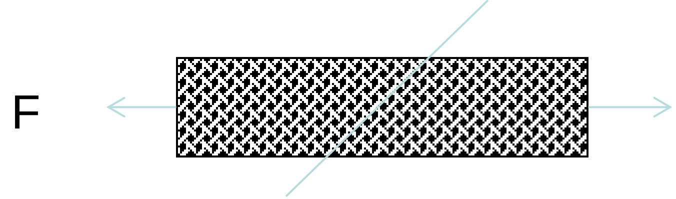
GEAEROSPACE.COM

- ❑ The first large-scale commercial use of CMCs was in high-pressure turbine (HPT) shrouds receiving FAA and EASA certification in May of 2016. These shrouds have surpassed millions of flight hours.
- ❑ Since 2016, additional CMC components have been incorporated throughout the engine hot section.
- ❖ Success application of CMC is based on fully characterization of material with Solid material database and design allowable.
- ❖ Today's presentation focused on inplane shear strength testing method of MI SiC/SiC

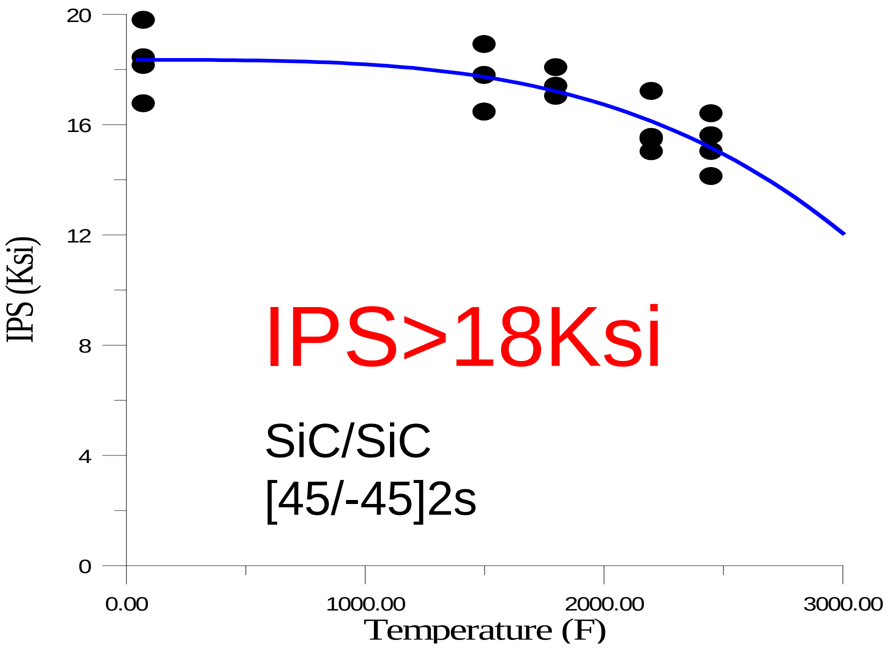
Special Topic 1: [45/-45] Tension Data

ASTM D3518: **Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate**

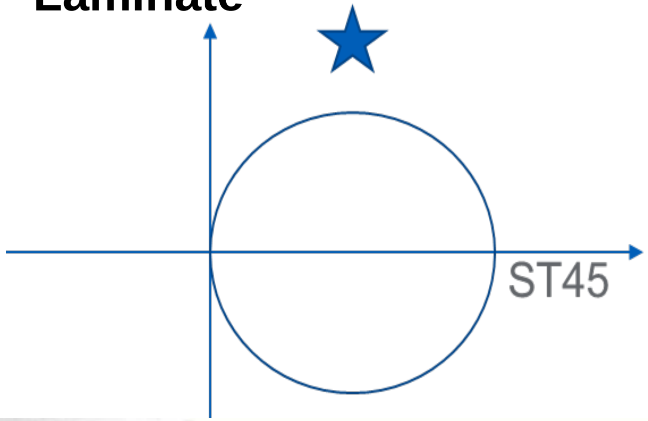
- ❖ RT and high temperature
- ❖ Modulus and strength

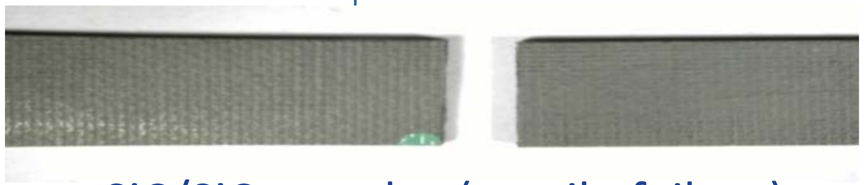


$$\tau = \frac{P}{2A}$$

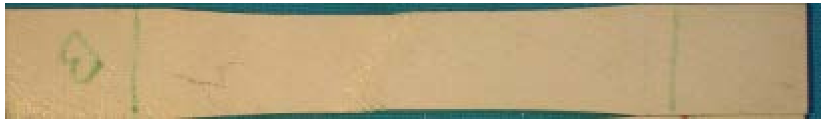


Specimen did not fail in shear





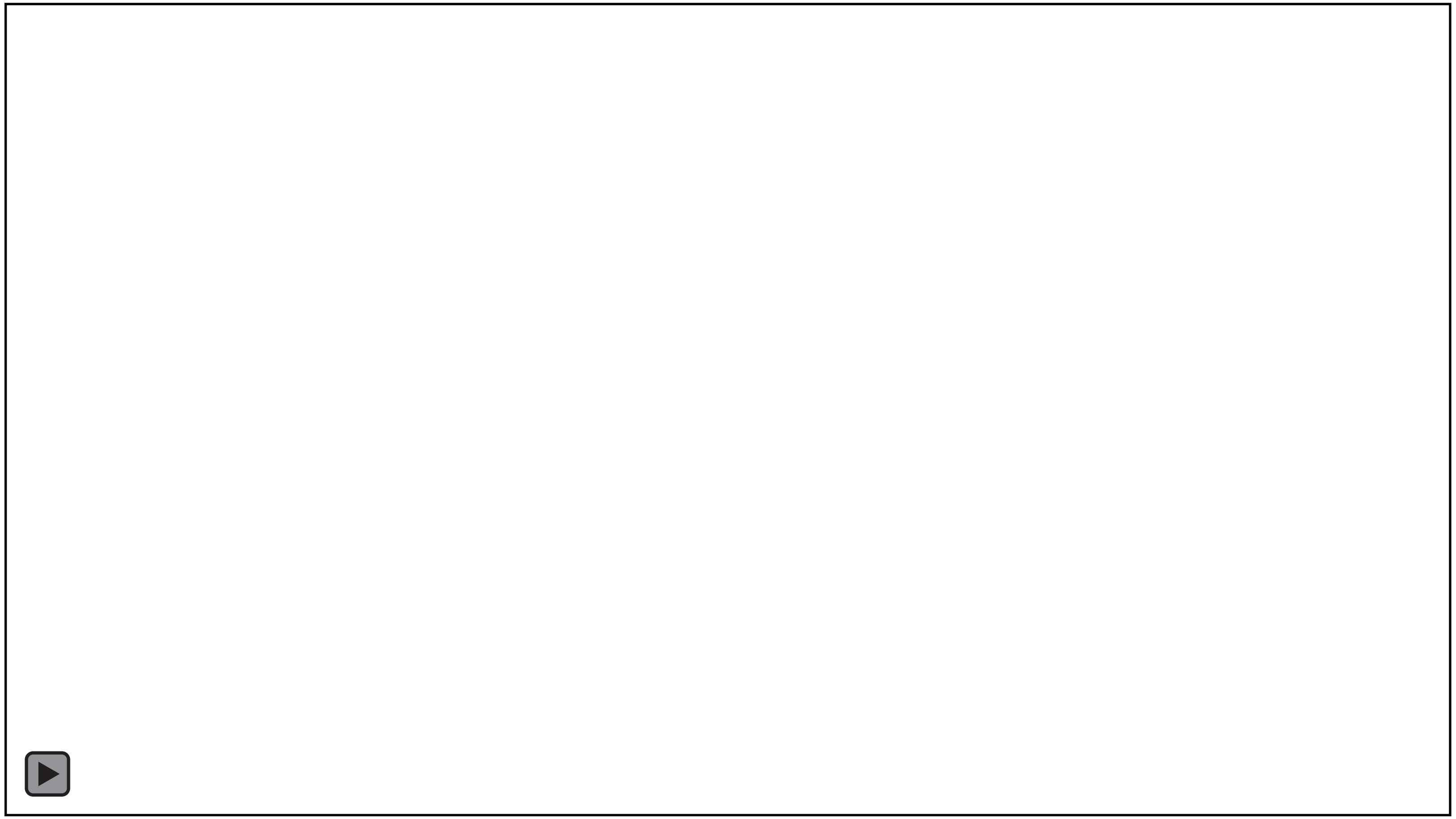
SiC/SiC samples (tensile failure)



OX/OX sample (shear failure)

PMC IPS failure

Special Topic 1: DIC of 45 Degree Tensile



No Shear band was formed during 45/-45 tensile
Specimen failed due to 45 degree tensile

Special Topic 1: [45/-45]2s Degree Tensile

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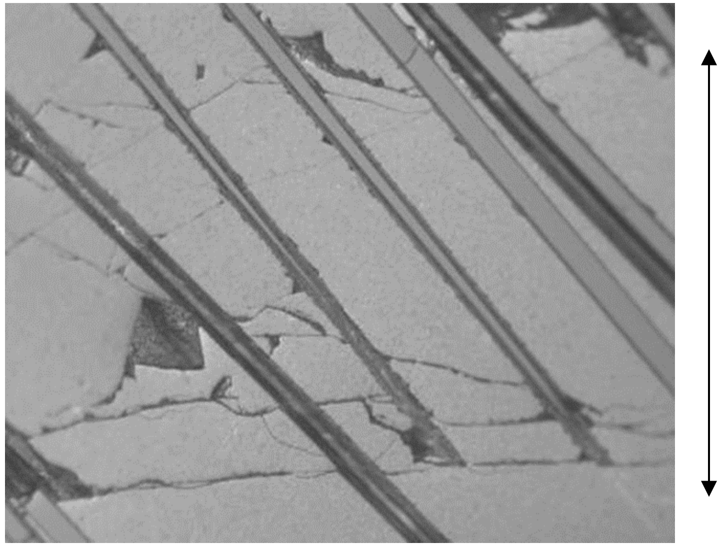
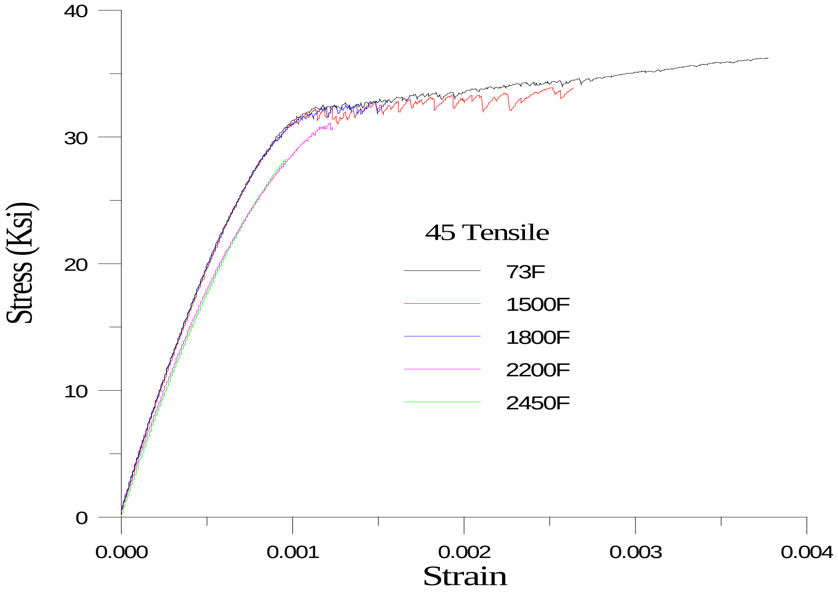
Tensile direction





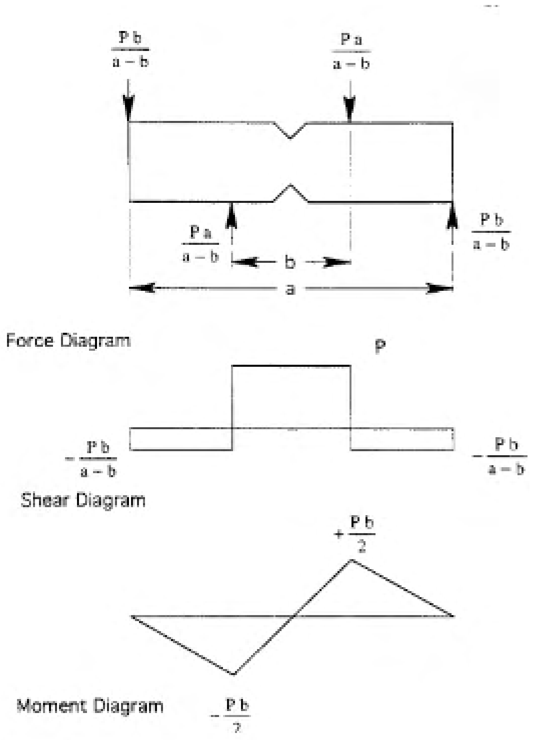
- Microcracks in matrix propagated normal to the tensile direction
- No crack propagated along fiber/matrix interface
- Some cracks progagated through fiber
- Some crack circumvents fiber
- Fiber also failed in tensile mode

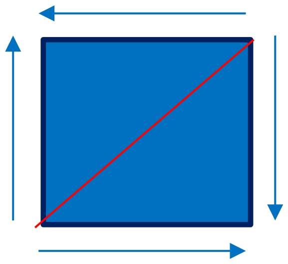
No typical inplane shear failure mode was observed. Stress-strain curves can be regarded as 45 degree tensile results. It is due to high shear modulus of SiC matrix.

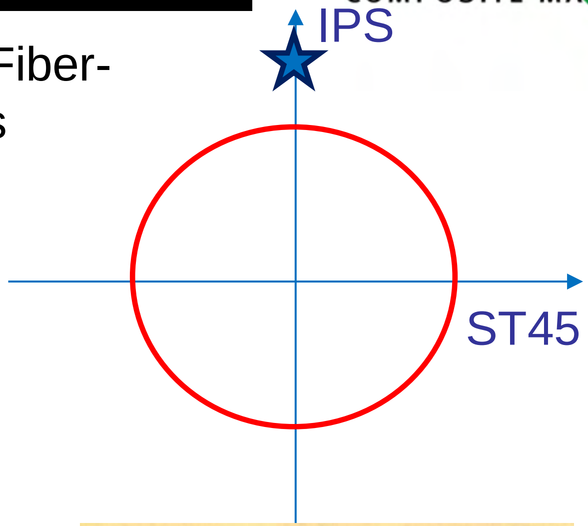
Special Topic 1: Iosipescu In-plane Shear Test

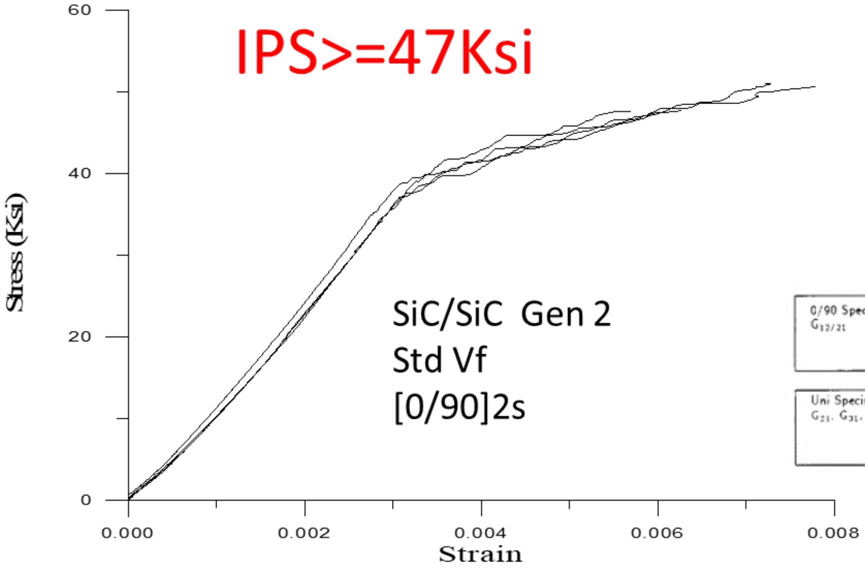
ASTM C1292: Standard Test Method for Shear Strength of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperatures

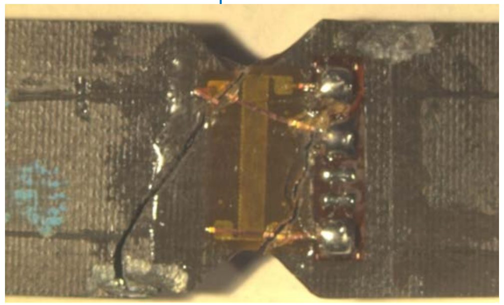
- RT only
- Modulus and Strength











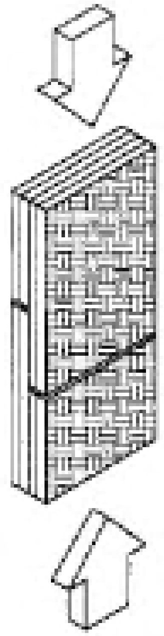
Acceptable failure mode

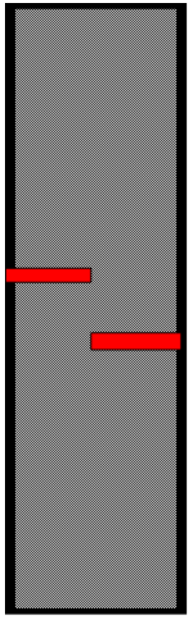
Specimen did not fail in shear

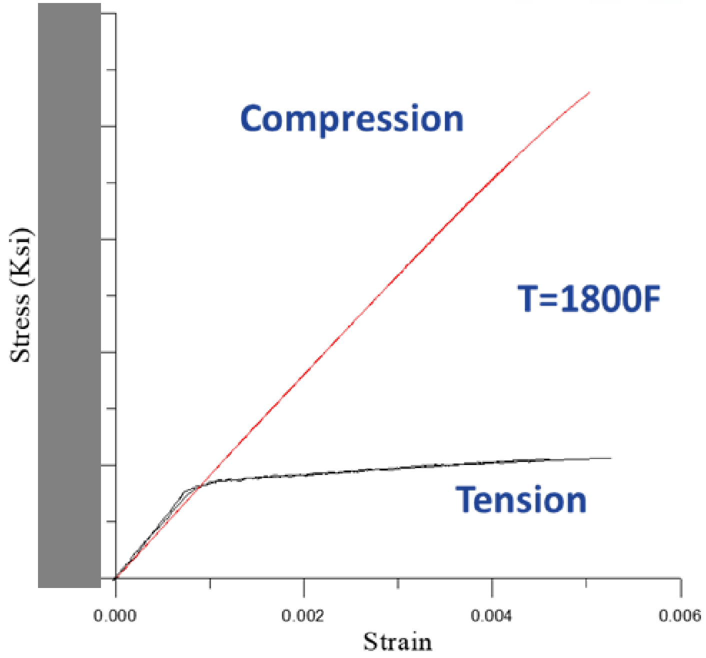
Special Topic 1: Double Notch Samples for IPS Test

NASA report: NASA/TM—2000-210608
ASTM D3846

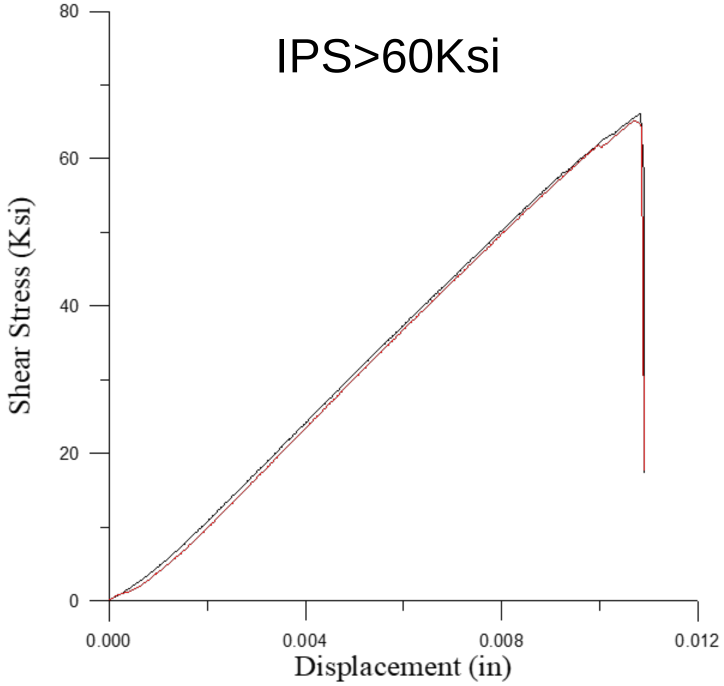
- Cut 4 0.5”X3.18” straight bar (same size as DNC samples)
- Cut 2 notch half through width (not half thickness, different with DNC)
- Perform compression test the same way as DNC

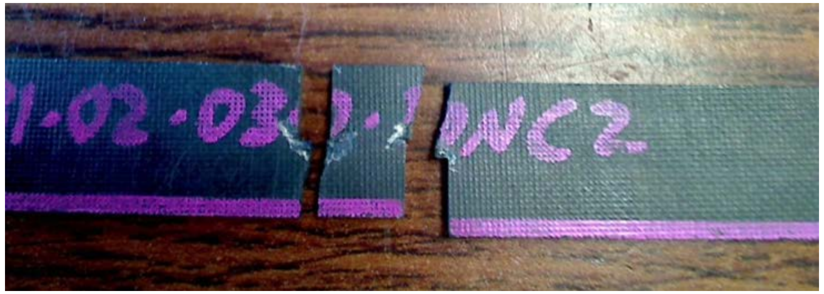




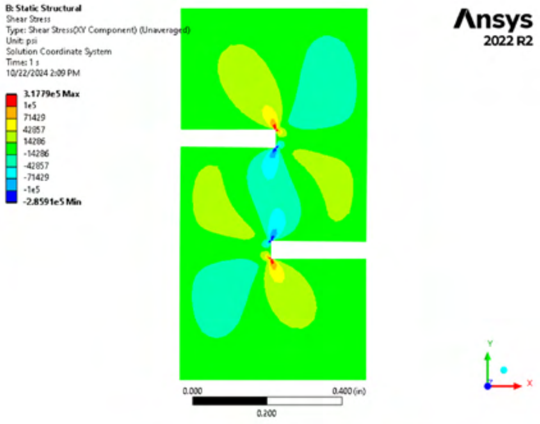


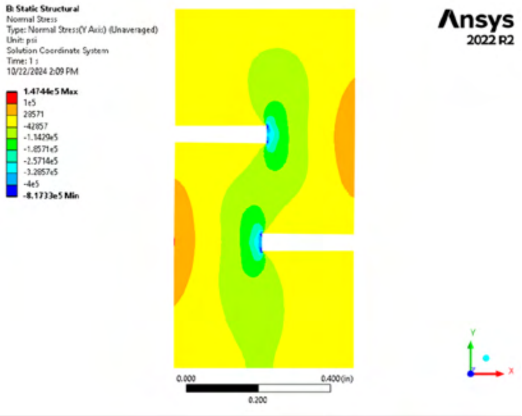
Special Topic 1: Double Notch Samples for IPS Test

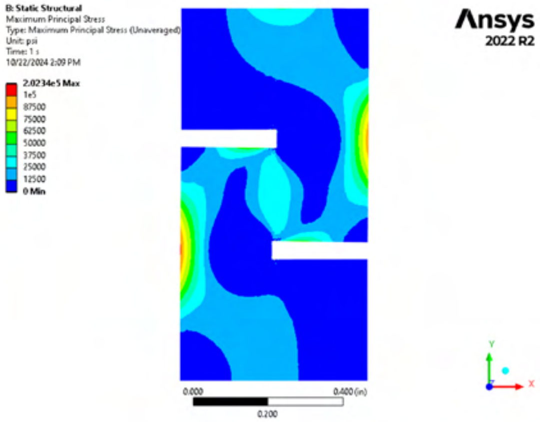




0.25 Notch Distance DNC sample did not fail in shear



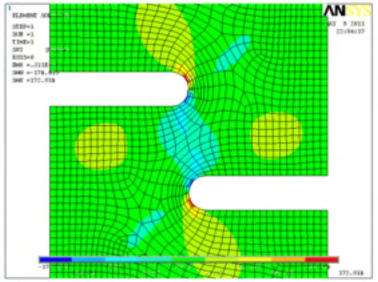


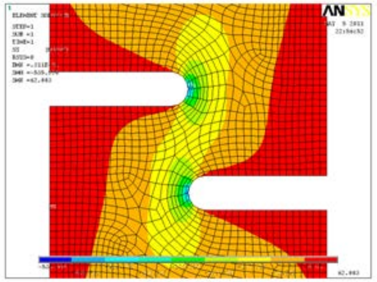


Special Topic 1: Double Notch Samples for IPS Test

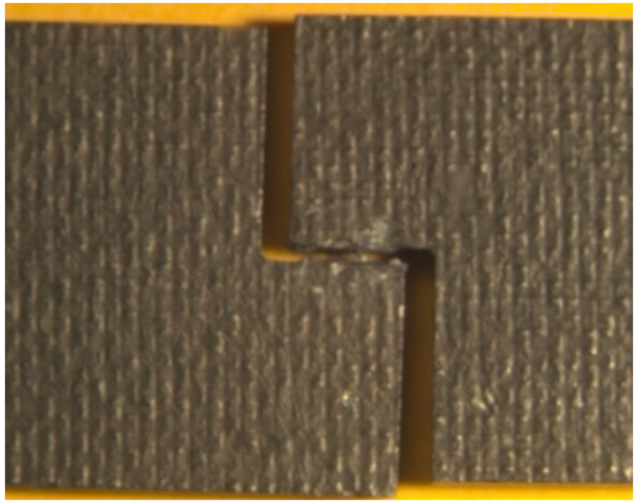
IPS distribution

Y direction stress distribution

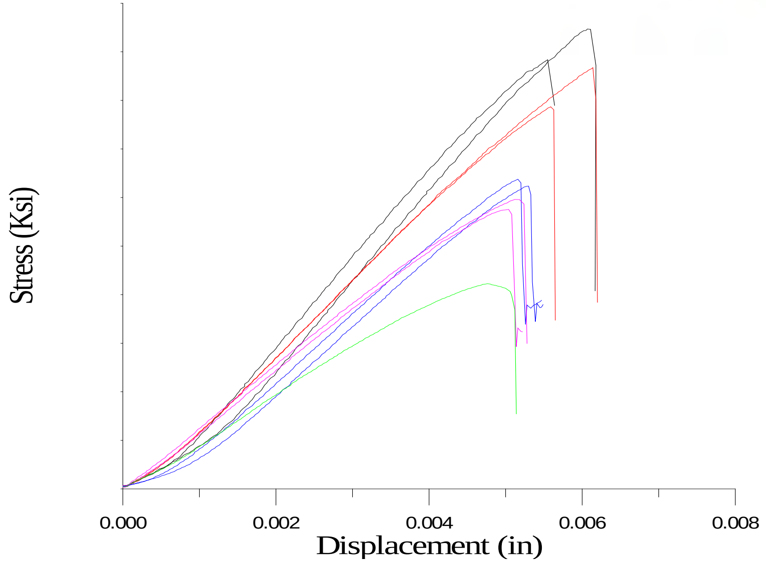


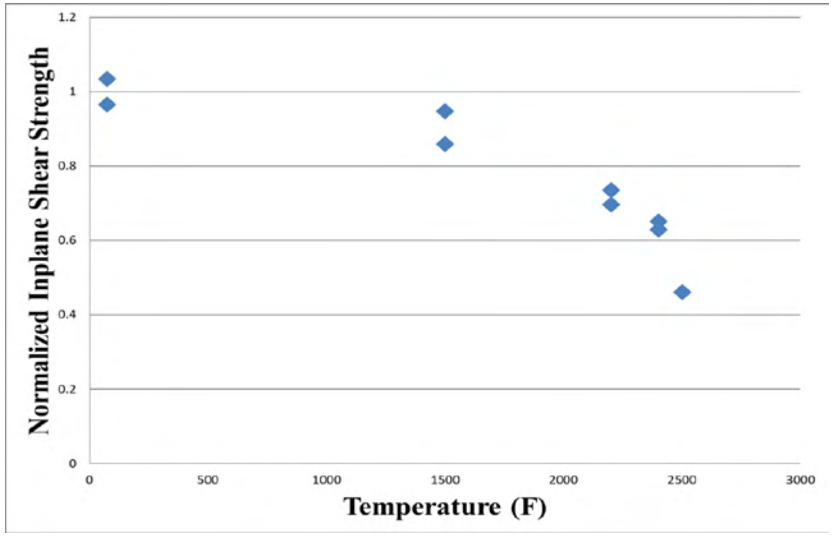


Based on FEM model, notch distance was reduced to 0.1” to make shear stress is much greater than Y direction stress



0.1 Notch Distance DNC sample Specimen failed in shear





Special Topic 1: Summary

- If CMC matrix shows high modulus and low porosity , In-plane shear strength (IPS) may higher than 45 degree tensile strength of CMC.
- In this case, ASTM 45/-45 degree tensile or Iosipescu shear test can't generate desired in-plane shear failure mode.
- In-plane double notch compression (DNC) test may be used to evaluate IPS capability of material.
- High in-plane shear strength of MI SiC/SiC may brining new application for high temperature bolt or pin.

Special Topic 2: Oversized Button Specimens for ILT Properties

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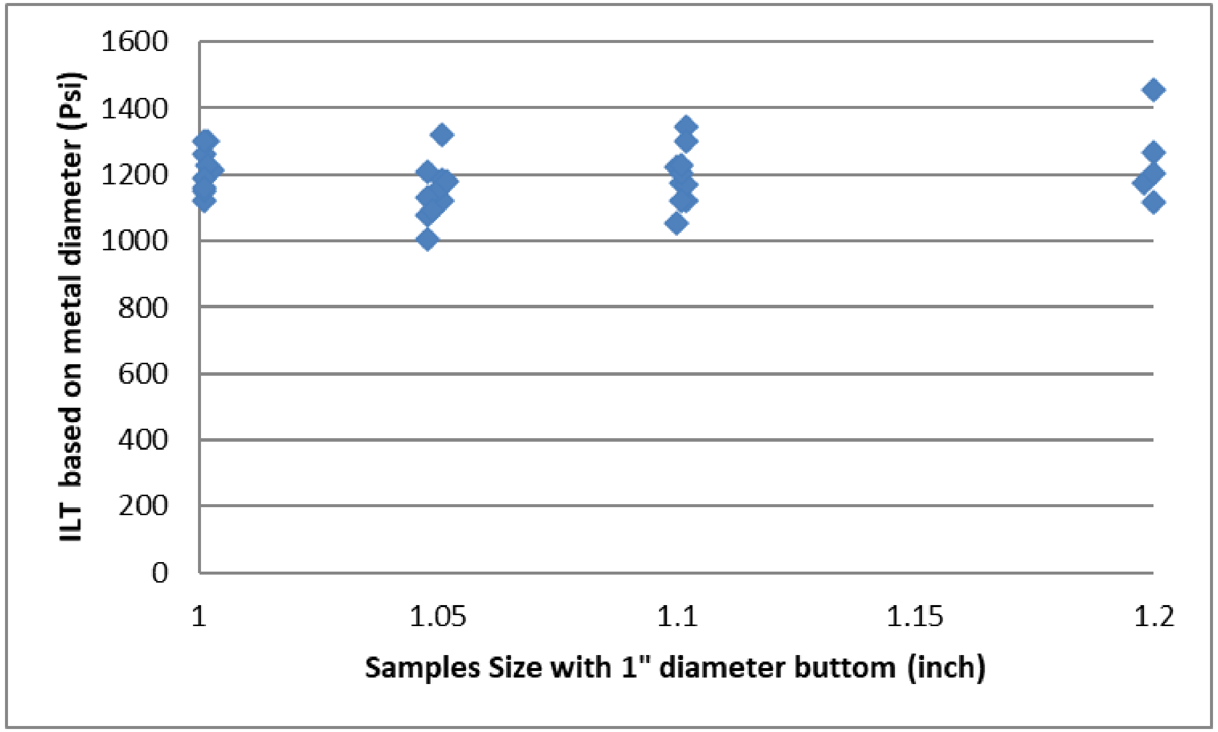
Oversized sample of OX/OX



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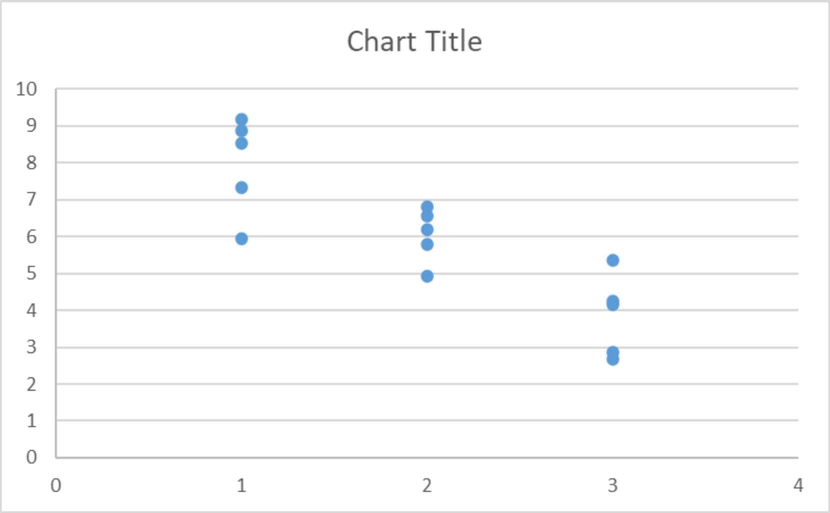
Oversize Sample Study

Adhesive	Specimen ID	Diameter in	FWT Strength ksi
FM1000 Adhesive, 350°F for 1.5 h	15495-ILT1	1.002	5.95
FM1000 Adhesive, 350°F for 1.5 h	15495-ILT4	0.996	9.18
FM1000 Adhesive, 350°F for 1.5 h	15495-ILT7	1.001	7.33
FM1000 Adhesive, 350°F for 1.5 h	15495-ILT10	1.003	8.53
FM1000 Adhesive, 350°F for 1.5 h	15495-ILT13	1.002	8.88
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT2	1.001	5.78
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT5	1.001	6.55
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT8	1.002	6.18
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT11	1.003	6.8
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT14	1.003	4.94
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT3	0.947	5.35
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT6	0.946	2.67
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT9	0.947	2.86
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT12	0.947	4.26
EA9394 Adhesive, 150°F for 2.0 h	15495-ILT15	0.947	4.17



Special Topic 2: Oversized Button Specimens for ILT Properties

Failure Mode