Characterization of C/SiC Ceramic Matrix Composites (CMCs) with Novel Interface Fiber Coatings

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Abstract

Ceramic Matrix Composites (CMCs) are attractive candidate aerospace materials due to their high specific strength, low density and high temperature capabilities. The National Aeronautics and Space Administration (NASA) is pursuing the use of CMC components in advanced Reusable Launch Vehicle (RLV) propulsion applications. Carbon fiber-reinforced silicon carbide (C/SiC) is the primary material of interest for a variety of RLV propulsion applications. These composites consist of high-strength carbon fibers and a high modulus, oxidation-resistant matrix. For RLV propulsion applications, environmental durability will be critical. Two types of carbon fibers were processed with both standard (pyrolytic carbon) and novel (multilayer and pseudoporous) types of interface coatings as part of a study investigating various combinations of constituents. The benefit of protecting the composites with a surface sealant was also investigated. The strengths, durability in oxidizing environments, and microstructures of these developmental composite materials are presented. The novel interface coatings and the surface sealant show promise for protecting the carbon fibers from the oxidizing environment.

QSS Group, Inc.

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Introduction- Why Ceramic Matrix Composites?

NASA is pursuing the development and characterization of Ceramic Matrix Composites (CMCs) for a variety of aerospace applications including space propulsion systems.

•CMCs are being developed to provide new, high specific strength materials that can operate at higher temperatures than superalloys.

•Currently carbon fiber-reinforced silicon carbide matrix (C/SiC) composites are the primary candidates.

•Cost Reductions can be achieved by using lightweight, long-life CMC components with higher temperature capability to enable higher performance propulsion systems (increases thrust to weight).

Issue- Durability of C/SiC Ceramic Matrix Composites

Environmental Durability is Essential for Space Propulsion Applications.

•Processing of C/SiC composites leads to matrix microcracks due to the CTE mismatch between the carbon fibers and SiC matrix. Operating conditions of the component (wide range of temperatures and gases such as O_2, H_2O, H_2), allow ingress of oxygen which leads to the oxidation of the carbon fibers and strength reduction.

Possible Means of Protecting C/SiC Composites

Need to prevent oxidation of fibers and interfaces.

•Incorporate oxidation-resistant interfaces, or introduce matrix oxidation inhibitors.

•Apply oxidation resistant surface coatings to infiltrate the as-processed cracks and provide an oxidation barrier.

•Reduce operating stresses to minimize further cracking.

C/SiC Materials Examined

Novel fiber coatings (interfaces) were applied within 4 different Hyper-Therm, Inc. composites to improve oxidation resistance. The properties of these new composites were compared to the industry standard produced by Honeywell ACI.

Supplier	C Fiber	Matrix	Interface (Fiber Coating)
Honeywell ACI	T-300 (1K)	CVI SiC	PyC Coating
Honeywell ACI	T-300 (1K)	CVI/MI SiC	PyC Coating
Hyper-Therm, Inc.	T-300 (3K)	CVI SiC	Multilayer Coating (SiC and C)
Hyper-Therm, Inc.	T-300 (3K)	CVI SiC	Pseudo-Porous Coating (SiC and C)
Hyper-Therm, Inc.	IM7 (6K)	CVI SiC	Multilayer Coating (SiC and C)
Hyper-Therm, Inc.	IM7 (6K)	CVI SiC	Pseudo-Porous Coating (SiC and C)

Background: Properties and Microstructure of Typical CVI C/SiC

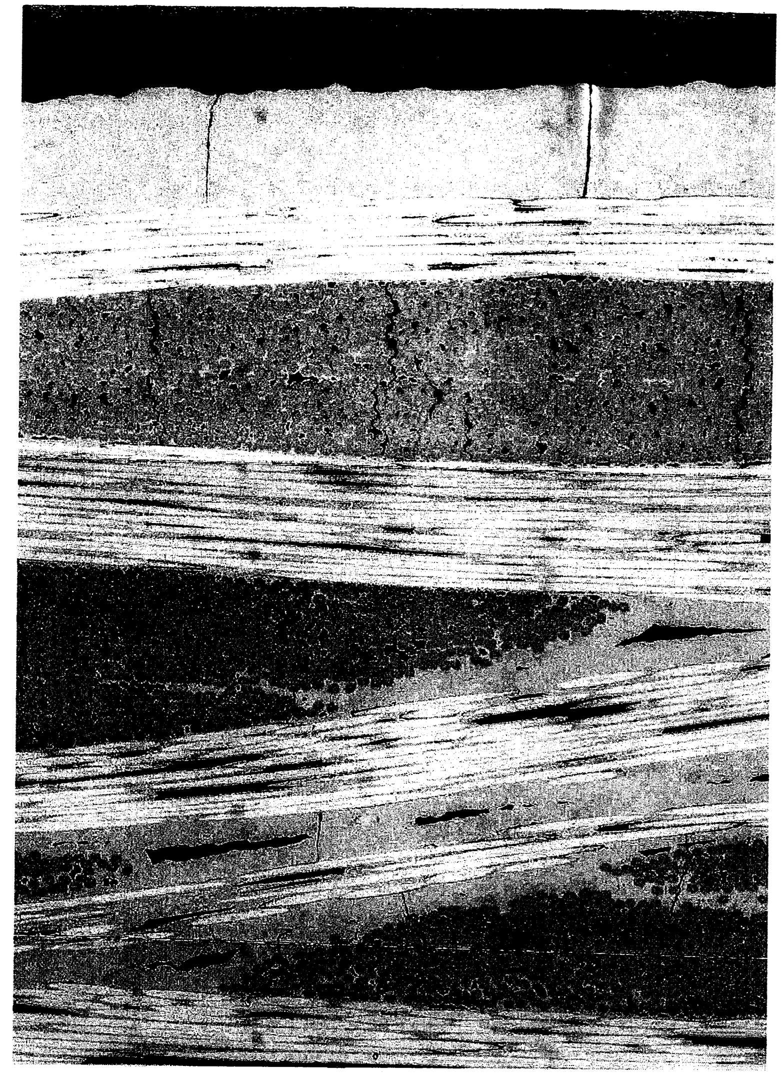
Mechanical, Physical, and Thermal Properties of Current 2-D CVI C/SiC

Property (Units)	Value
RT Tensile Strength (ksi)	75
2200 °F (1200°C) Tensile Strength (ksi)	79
Interlaminar Shear (ksi)	5.0
Density (g/cc)	2.05
RT Thermal Conductivity (Btu/hr•ft•°F)	3.8

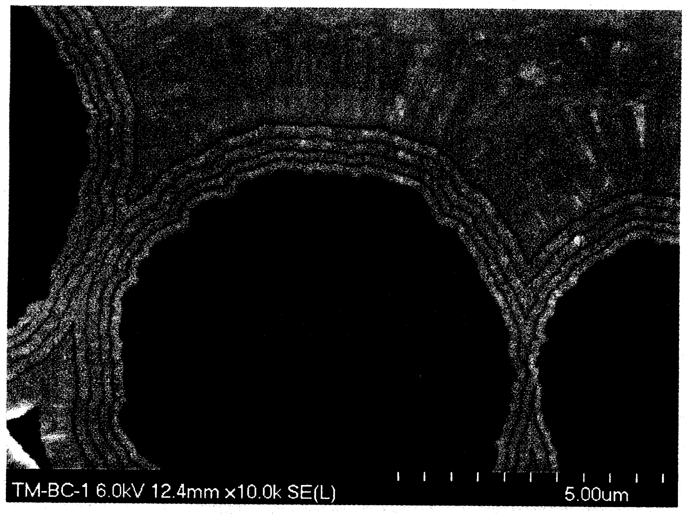
- Utilizes T-300 fiber
- Plain weave (PW) fabric
- Pyrolytic carbon (PyC) interface
- 45 v/o fiber

Source: Honeywell Advanced Composites, Inc.
now General Electric Power Systems Composites

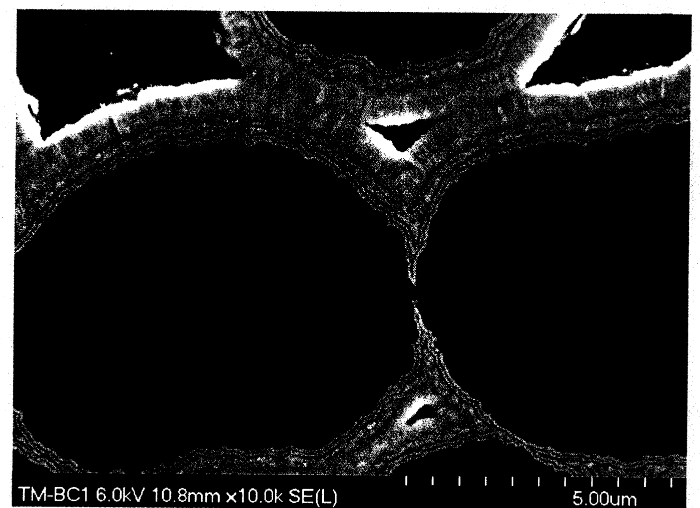
Microstructure of 2-D CVI C/SiC



C/SiC: T-300 (3K) Fiber, CVI SiC Matrix, Multilayer Coating (SiC and C)

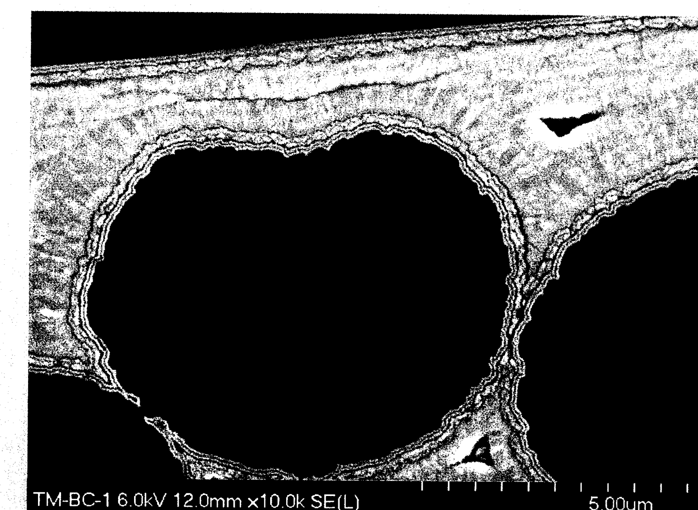


Surface of Composite, Surface of Tow



Surface of Composite, Center of Tow

Center of Composite, Surface of Tow



Between Surface / Center, Surface of Tow

Fiber Coating: SiC with interspersed thin C layers, emulating unbonded SiC layers. Significant change in fiber coating thickness and appearance from surface of the composite to the interior.

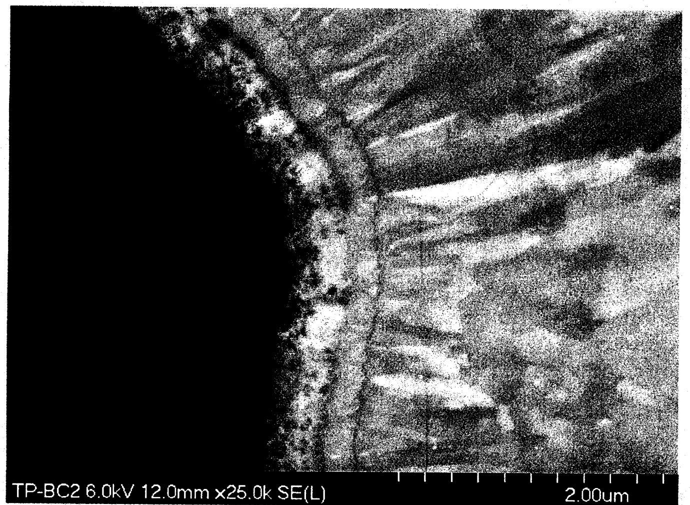
Fiber Loading: 48 v/o

Density: 2.07 g/cm^3

RT Strength: 27 ksi

Ult. Strain: 0.28%

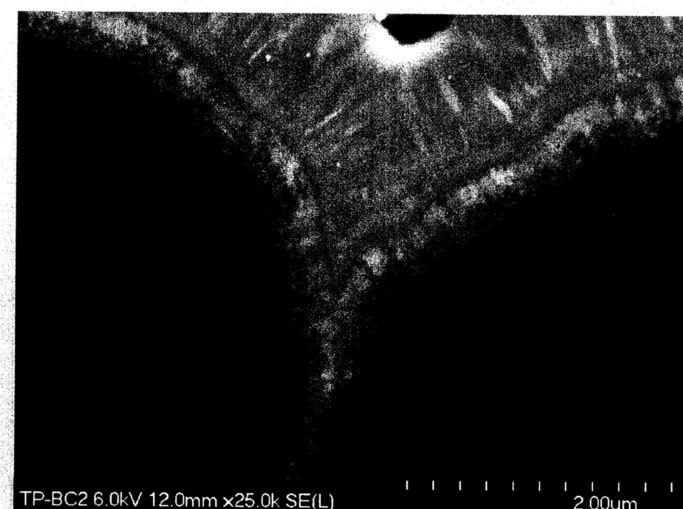
C/SiC: T-300 (3K) Fiber, CVI SiC Matrix, Pseudo-Porous Coating (SiC/C)



Surface of Composite, Surface of Tow

Surface of Composite, Center of Tow

Center of Composite, Surface of Tow



Between Surface / Center, Surface of Tow

Fiber Coating: SiC and C are co-deposited. The C is supposed to emulate porosity. C-rich portion of the fiber coating: fairly uniform to a depth of 1/4 the sample thickness.

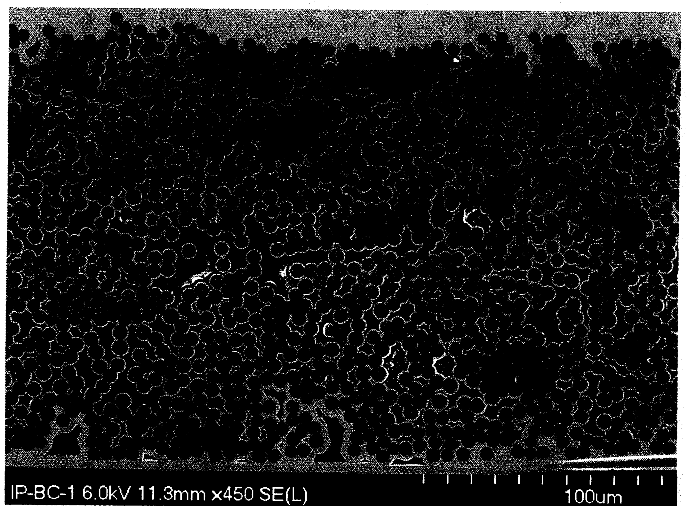
Fiber Loading: 46 v/o

Density: 1.96 g/cm^3

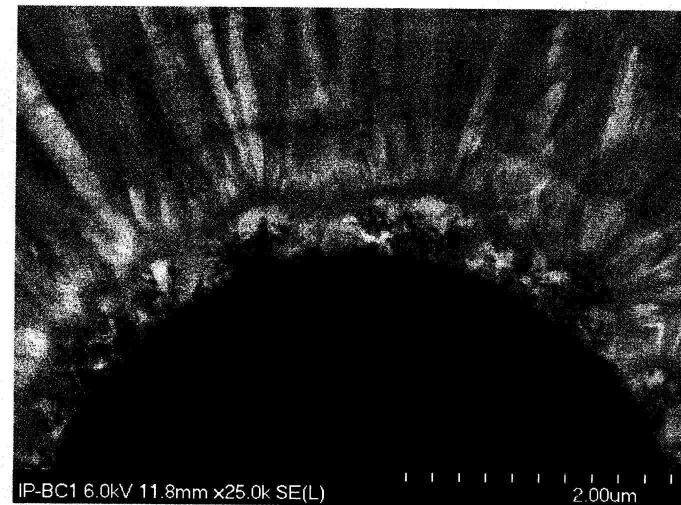
RT Strength: 28 ksi

Ult. Strain: 0.33%

C/SiC: IM7 (6K) Fiber, CVI SiC Matrix, Pseudo-Porous Coating (SiC/C)

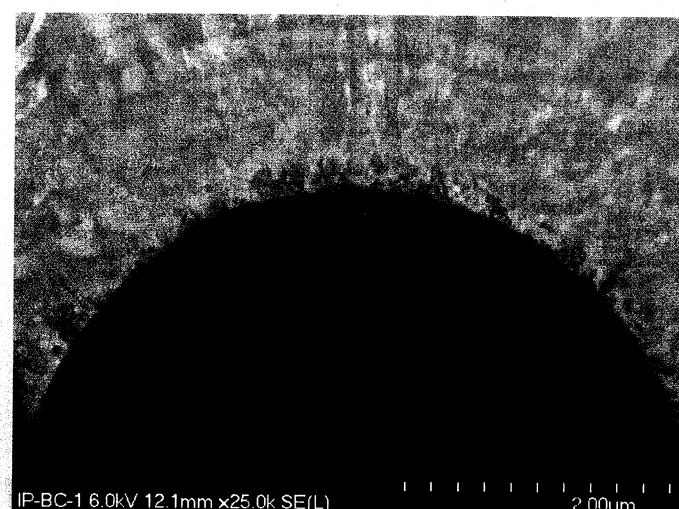


Surface of Composite, Tow Cross Section



Surface of Composite, Surface of Tow

Surface of Composite, Center of Tow



Center of Composite, Surface of Tow

Fiber Coating: SiC and C are co-deposited. The C is supposed to emulate porosity. Coating is less distinct than pseudo-porous coating on T-300 fibers.

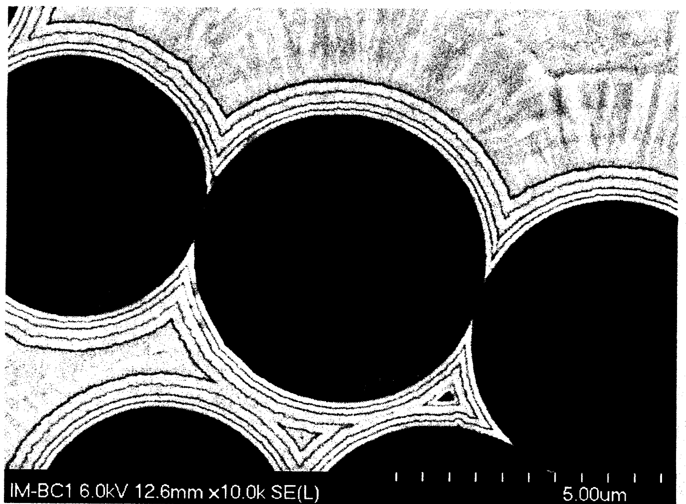
Fiber Loading: 43 v/o Tows are quite large, and fiber packing within the tows is variable.

Density: 1.99 g/cm^3

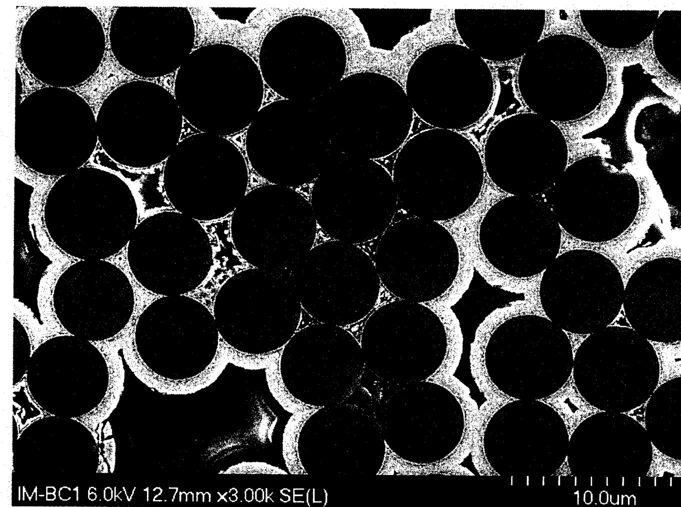
RT Strength: 25 ksi

Ult. Strain: 0.23%

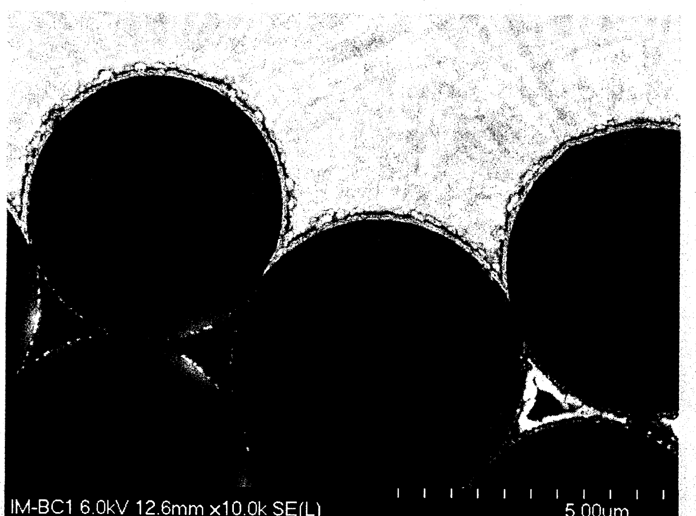
C/SiC: IM7 (6K) Fiber, CVI SiC Matrix, Multilayer Coating (SiC and C)



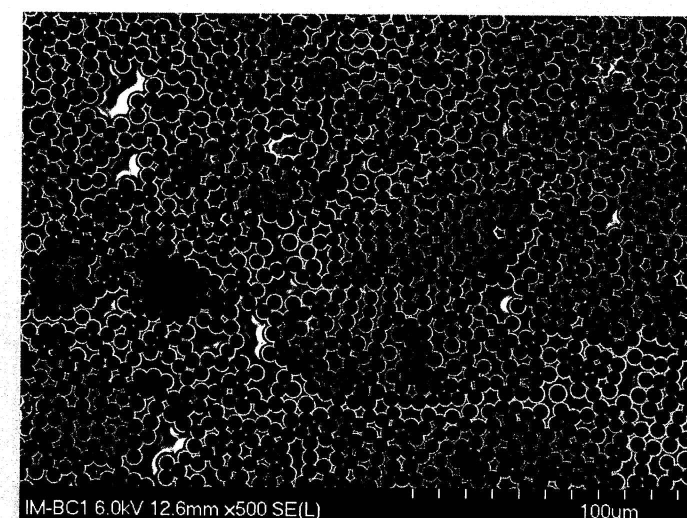
Surface of Composite, Surface of Tow



Surface of Composite, Center of Tow



Center of Composite, Surface of Tow



Center of Composite, Center of Tow

Fiber Coating: SiC with interspersed thin C layers, emulating unbonded SiC layers. Significant change in fiber coating thickness and appearance from surface of the composite to the interior.

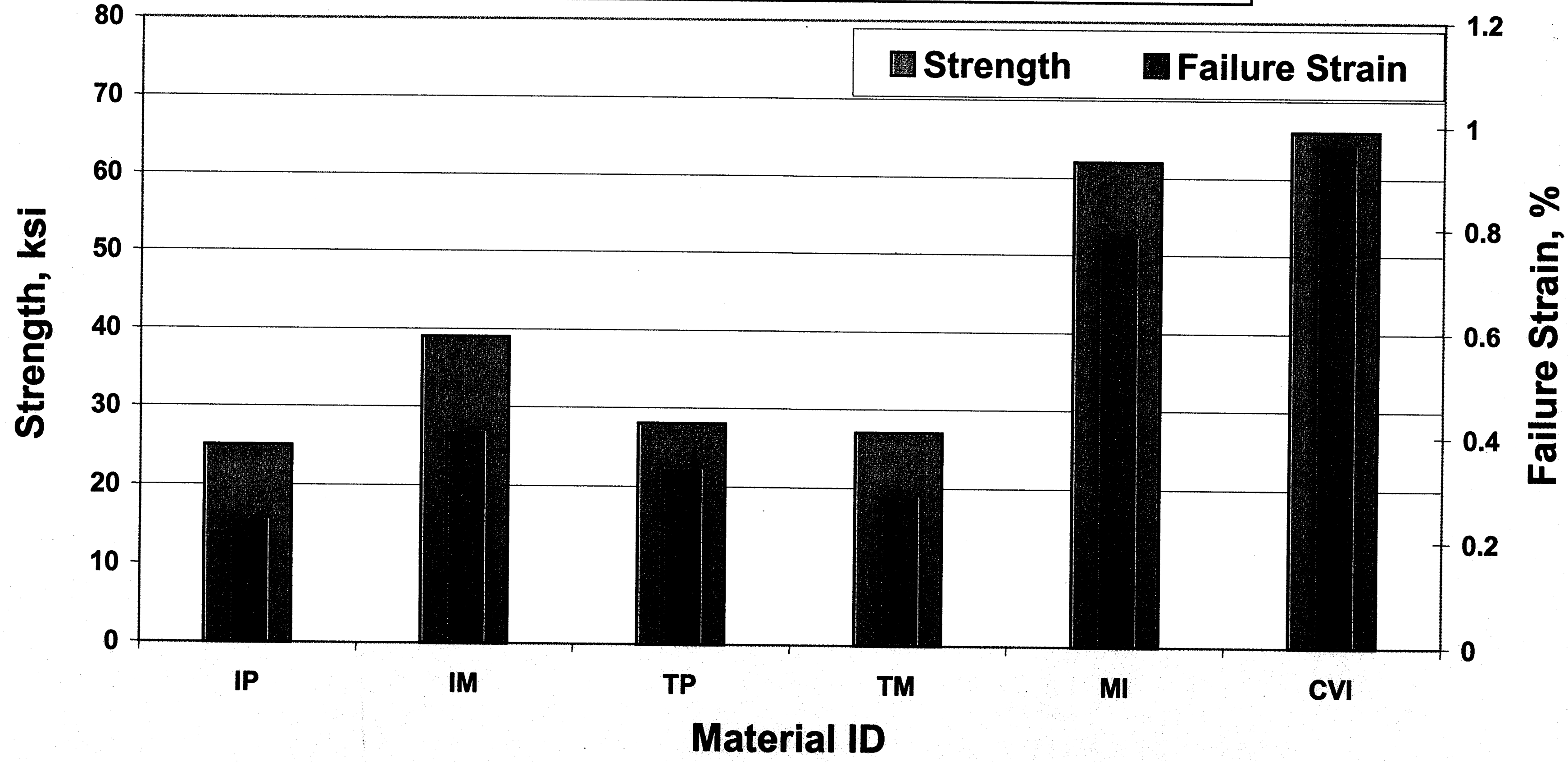
Fiber Loading: 44 v/o **Density:** 1.97 g/cm^3

RT Strength: 39 ksi

Ult. Strain: 0.40%

Room Temperature Tensile Properties of Different C/SiC Materials

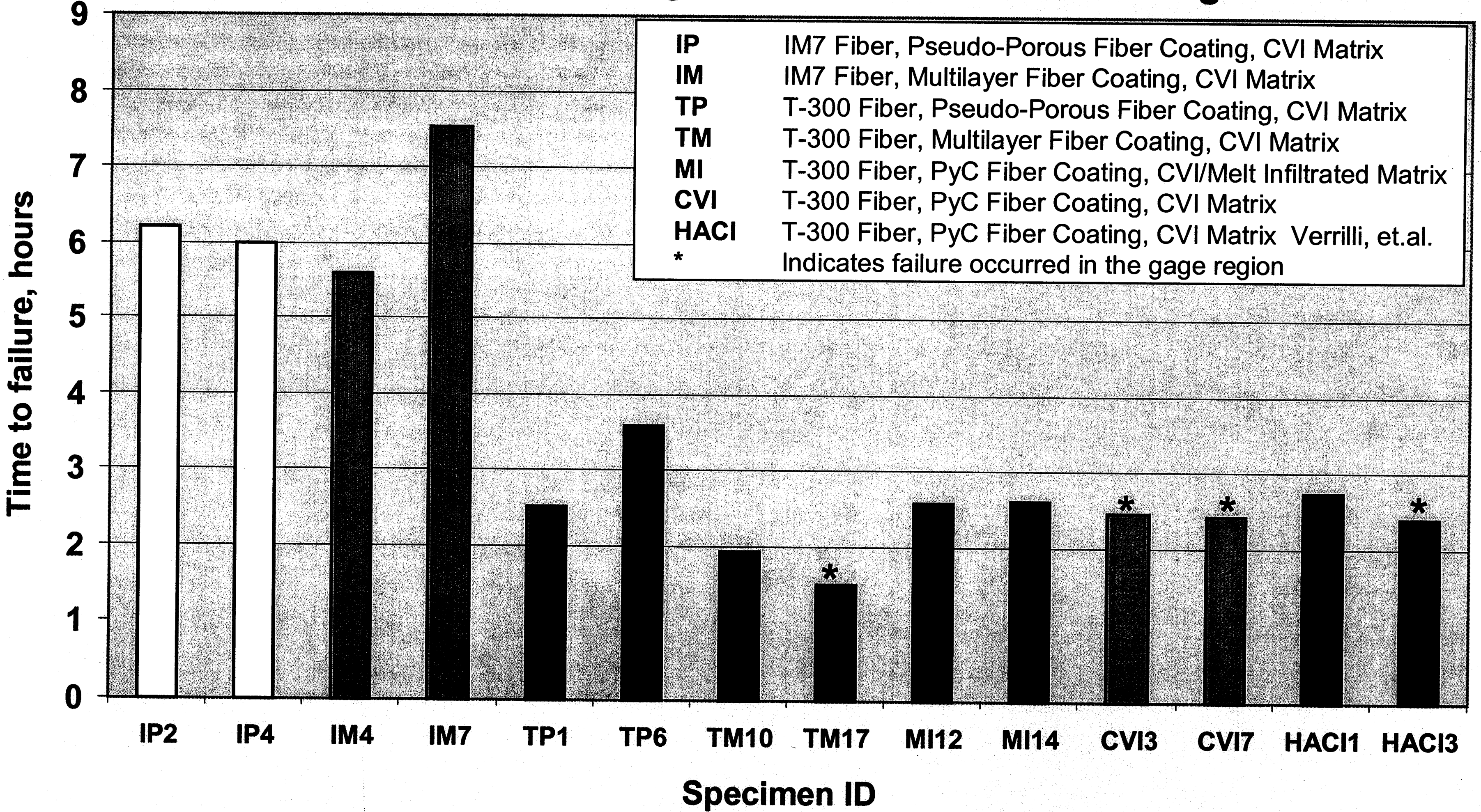
IP	IM7 Fiber, Pseudo-Porous Fiber Coating, CVI Matrix
IM	IM7 Fiber, Multilayer Fiber Coating, CVI Matrix
TP	T-300 Fiber, Pseudo-Porous Fiber Coating, CVI Matrix
TM	T-300 Fiber, Multilayer Fiber Coating, CVI Matrix
MI	T-300 Fiber, PyC Fiber Coating, CVI/Melt Infiltrated Matrix
CVI	T-300 Fiber, PyC Fiber Coating, CVI Matrix



- **C/SiC composites with T-300 C fiber reinforcement and PyC interfaces have best room temperature tensile properties.**

Stress-Rupture Lives of Different C/SiC Materials
(1200°C, 10 ksi in air)

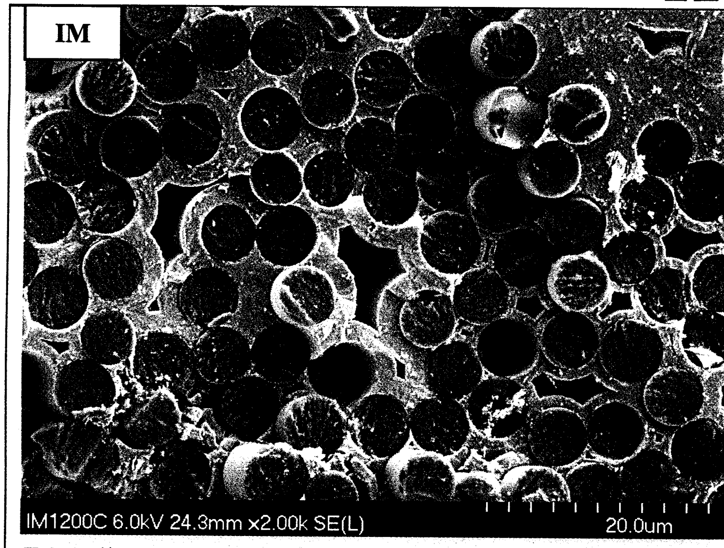
C/SiC composites containing IM7 fibers exhibited the longest lives



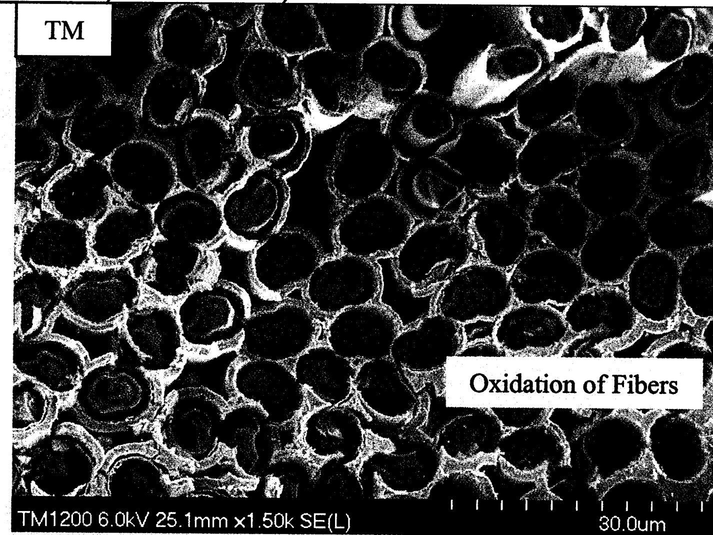
- **C/SiC composites with T-300 C fiber reinforcement and PyC interfaces have lives of approximately 2.5 hours under these conditions.**

Stressed Oxidation Fractography Study

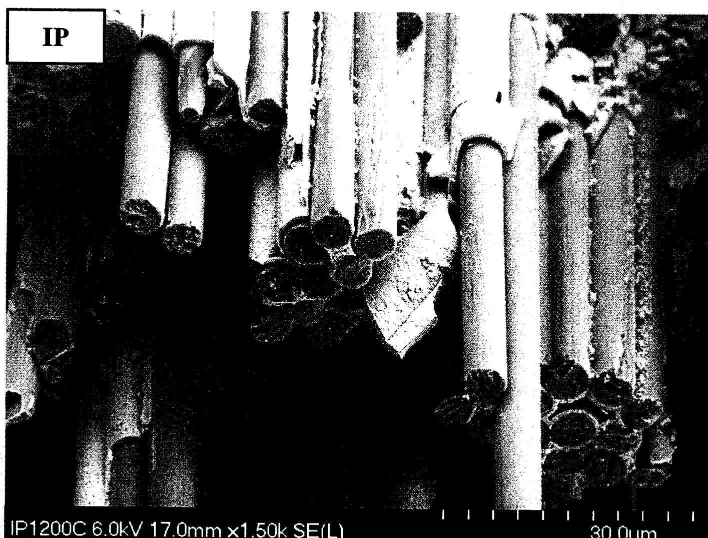
1200°C, 10ksi, in air



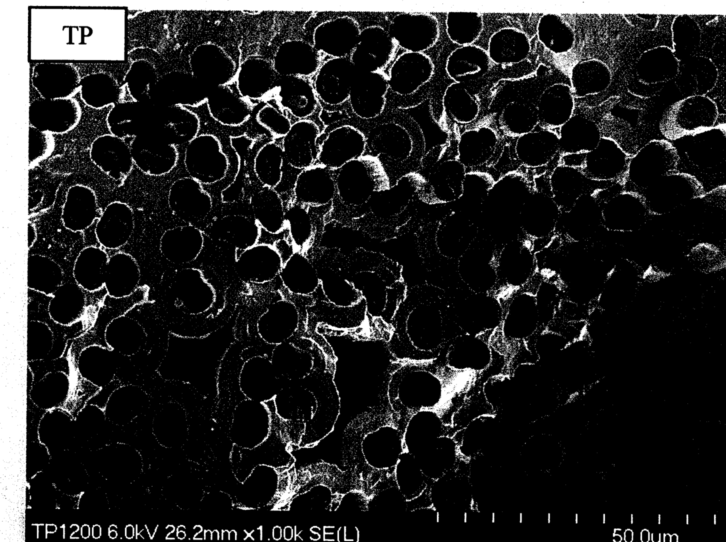
IM- Failure was outside of gage section. Image was taken at center center of composite.



TM- Failure was within the gage section. Image was taken between edge and center of composite.



IP- Failure was outside of gage section. Image was taken at center of composite.



TP- Failure was outside of gage section. Image was taken between the edge and center of composite.

Note that IM, TM, and TP exhibited large regions of brittle failure more typical of a monolithic ceramic material. The IP material exhibited more fiber pullout and exhibits a more typical composite behavior. Both composites made with the IM7 fiber showed longer lives at 1200C. In areas exhibiting pullout in each of these composites the novel fiber coating remained with the matrix as the cracks advanced, and did not add any further protection to the carbon fiber. Theoretically, debonding at the coating-matrix interface would lead to to a more durable material at these temperatures.

Summary and Future Work

- Six C/SiC composites comprising different ceramic matrices, fibers, and interfaces are currently being evaluated. Initial microstructural characterization and mechanical property results have been obtained.

- C/SiC CMCs with PyC fiber coatings and T-300 C fiber reinforcement exhibited the highest room temperature strength.

- Developmental C/SiC materials reinforced with IM7 fiber exhibited better durability in stressed oxidation tests in spite of interface (fiber coating) non-uniformity and lower room temperature strengths/strain to failure.

- The examination of the fracture surfaces indicate that the IM7 fiber may lead to more graceful composite failures in stress-rupture testing, however there is a need to evaluate the fracture occuring within the gage section. Additional samples are being coated with a CBS (carbon-boron-silicon) coating by GEPSC (General Electric Power Systems Composites). This coating should lead to failures within the gage section and also improve the high temperature properties. Samples with these coatings will also be tested at higher temperatures (2650°F) and stresses (25 ksi).

- CVI C/SiC specimens with IM7 (6K) fibers and PyC interfaces will be fabricated and tested.