ADVANCED
Silicon Carbide
MATERIALS

ADVANCED
Silicon Carbide
MATERIALS

SBIR Phase II for Contract No. NNX17CM08C

“Ultra-stable Zero-CTE HoneySiC™ and H^2CMN Mirror Support Structures”

Dr. William Fischer
Principal Investigator
Office: 808-245-6465
Cell: 570-899-4191
wfischer@ascmtech.com

ASCM's Primary Technologies

- Manufacturer of both CVC and CVD SiC
  - Capability to process other materials
- Honey SiC ceramic-ceramic composite materials family
- Radiation hard reflective coatings

Patent Pending Transparent/ Translucent CVC SiC

- Transparent SiC is available commercially.
- We have a patent pending technology that would allow for production of transparent/translucent CVC SiC with equivalent optical clarity while
  - Retaining our optical surface finish capability
  - Improving our high temperature capability
  - Retaining our high thermal conductivity
  - Maintaining our cost/size/scale, near net shape capability, capacity, and fast delivery advantages

- Suitable for both Missile and Hypersonic applications, as well as several other advanced technology areas

Transparent/Translucent CVC SiC (cont.)

- Allows for unique design and functional optimization of missile and hypersonic design/geometric windows and optical telescopes etc.
- Similar process technology as standard grade of CVC SiC
  - Same Industrial capacity and equipment with minor modifications
- TRL level not as mature at this point.
- Several potential chemistry and process options to evaluate and characterize performance.

SiC Window

SiC Wafers

Technical Solution: HoneySiC™

- **HoneySiC™: ASCM's innovative, additively manufactured, ceramic matrix composites**
  - HoneySiC – T300 carbon fiber reinforced SiC CMC
  - H^2CMN – hybrid hierarchical ceramic matrix nanocomposite with CNTs
- Program effort addresses the need for stable, strain-free, precision optical structures under the influence of dynamic and thermal stimuli, specifically whiffle plates, delta frames and backplane
- Traceable to the needs of Cosmic Origins for UVOIR, Exo and FIR telescopes
- Maturation of this technology will allow NASA and ASCM to develop a method to create large aperture optical support structures and assemblies via deployment, assembly or active control
- HoneySiC additive manufacturing process significantly minimizes cost and schedule associated with post-production fabrication steps (machining, polishing, metrology).

ADVANCED Silicon Carbide MATERIALS

HoneySiC™ Features

ADVANCED Silicon Carbide MATERIALS

- **Rapid Prototyping** - Extremely rapid additive manufacturing process with all assets under a single roof.
  - Large complex mirrors/structures could be produced in a matter of weeks.
  - Web thickness < 1mm, core geometries (pocket depth, pocket size) easily tailored.
  - Minimizes machining, recurring/non-recurring costs; cost is 100X < beryllium.
- **Low Areal Cost** - Cost of raw materials ~\$38K/m^2 for unpolished HoneySiC, which already meets NASA's goal of \$100K/m^2 -> ~100X reduction in mirror cost based on current cost of \$4-\$6 million/m^2.
- **Low Areal Density**
  - Face sheet density ~same as beryllium
    - Sandwich constructions further reduce areal density.
  - 95% light weighting w.r.t. bulk silicon carbide.
  - Areal density of first panel made: 5.86 kg/m^2.
  - Estimated weight and areal density of a 255-mm mirror: 0.35 kg and 7.0 kg/m^2, respectively.
  - Estimated mass of 305-mm optical bench with inserts: 0.94 kg.

HoneySiC™ Features

- **Extreme dimensional stability** - CTE of HoneySiC confirmed to be near-zero with a variation of only -91 to -146 ppb/°C from -196°C to 0°C in testing at Southern Research Institute.
- **Carbon fiber or SiC reinforced SiC structure**
  - Thermal conductivity "supercharged" by addition of CNT
  - No coefficient of moisture expansion (CME)
  - Low Z for nuclear survivability
  - Electrically conductive for dissipating static charge build-up
  - ~2X higher fracture toughness than pure SiC, estimated ~4.6 MPa-$m^{0.5}$
- **Nuclear and Space Survivable** - Precursor carbon-carbon honeycomb is flying on >100 spacecrafts.

Phase I Progress

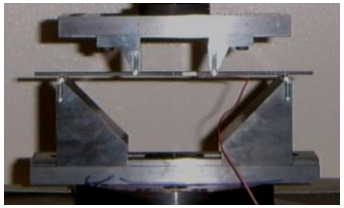
ADVANCED Silicon Carbide MATERIALS

- ASCM would produce HCMC and H²CMN coupons for flexural strength and CTE measurements.
- Flexure testing would be performed by Professor Nejhad at the University of Hawaii using a 4-point flexure test set up. Properties to be determined: strength, strain/deflection, stiffness and toughness.
- In-plane coefficient of thermal expansion (CTE) testing would be performed at Southern Research Institute (SoRI) at the University of Alabama using a linear variable differential transformer (LVDT). Test temperature range: -196°C to RT.
  - LVDT measures change in length as a function of temperature
  - A dial gauge would be used to provide additional expansion data and validate the LVDT measurements.

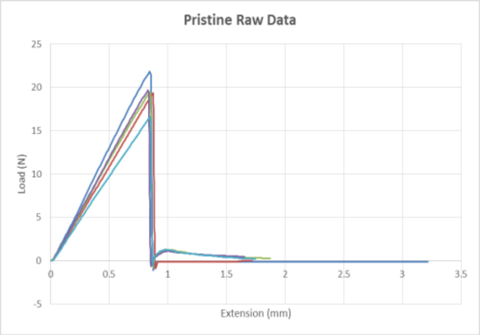
ADVANCED Silicon Carbide MATERIALS

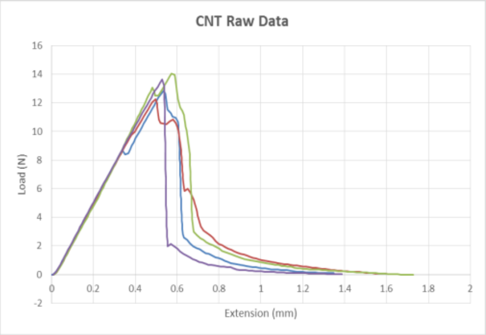
Phase I Results – Flexure Testing

- **Flexure testing was performed by Professor Nejhad. Specimens are shown on the left, test fixture is shown on the right.**



- **Raw load-deflection curves for Pristine (HCMC) and CNT (H^2CMN) samples are shown below.**



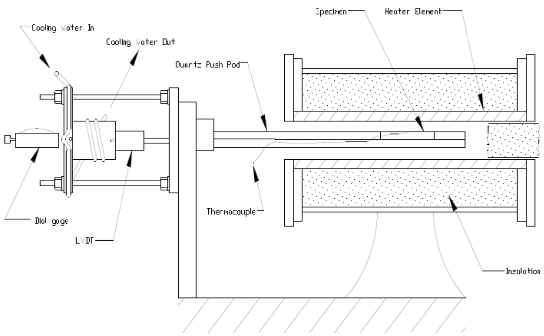


- **The generated stress-strain data was used to deduce strength, toughness, modulus/stiffness and strain-at-failure.**

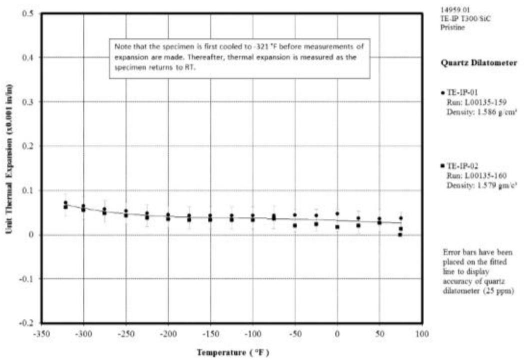
Sample	Avg. Flexure Strength (MPa)	Avg. Real Toughness (KJ/m³)	Avg. E Modulus (MPa)	Avg. Flexure Strain at Failure (mm/mm)
HoneySiC™	63.96	44.55	53,116.96	0.00139
H^2CMN	40.87	18.49	54,281.89	0.00090
Notes	CNT had ~36% less strength	CNT had ~59% less toughness	CNT had ~2% higher stiffness	CNT had ~35% less strain at failure

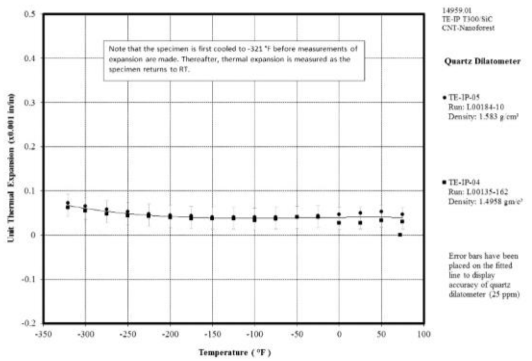
Phase I Results – CTE Testing

- **LVDT test set up for in-plane CTE measurements shown below.**



- **Tabulated data is shown below for Pristine (HCMC, left) and CNT samples (H^2CMN, right). Error bars represent the accuracy of the quartz dilatometer (25 ppm)**





Phase I Conclusions

ADVANCED
Silicon Carbide
MATERIALS

- **Mechanical Measurements**
  - The powder impregnation process during SMP-730 pre-pregging allowed sufficient infiltration into HCMC samples, but ineffective for H2CMN since the CNT growth requires a viscous matrix to penetrate the nanoforest.
  - It is believed the CNT matrix wet-outs were incomplete and interlaminar bonding was relatively weak, leading to reduced mechanical performance in strength, toughness and strain-at-failure.
  - H^2CMN elastic modulus increased slightly due to the sandwich-type structure.
  - It is believed that the advantages of CNTs will be realized if a less viscous pre-pregging matrix (SMP-10) is used as the initial pre-pregging matrix. This will be explored in Phase II.
- **CTE Measurements**
  - Both HoneySiC materials exhibited relatively zero expansion in the in-plane direction from -196°C to RT.
  - Negative expansion was observed between -196°C and -128°C.

Phase II Effort

- Collaborate with NASA MSFC, GSFC, JPL and Northrop Grumman Aerospace Systems (NGAS) to design a prototype whiffle plate, delta frame or tube structure to be made using HoneySiC or H^2CMN materials that will support space-based telescope applications.
- Supplement the suite of HCMC and H^2CMN material properties measurements as requested by NASA and NGAS.
- Produce HCMC and H^2CMN prototype(s) for demonstration of the technology.
- Characterize the prototype via mechanical property testing.
- Demonstrate superior performance to the incumbent material (M55J cyanate ester), which is an organic material and subject to outgassing, dimensional instability under temperature and environmental fluctuations.

Phase II Progress

- Material procurement for technology demonstration prototypes HCMC and H^2CMN prototype(s)
- Planning for manufacturing of one or more of the following:

Figure 1. Latch, mounting bracket, struts, whiffle plate, delta frame

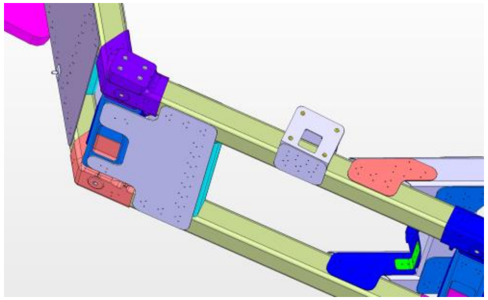


Figure 2. Composite tube structure (yellow)

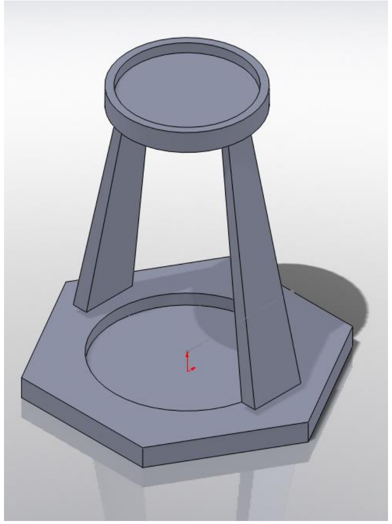


Figure 3. Cassegrain telescope structure

NASA Applications

ADVANCED **Silicon Carbide** MATERIALS

- **NASA sees potential for HoneySiC™ as an affordable technology for large observatories and future astrophysics missions[5] for:**
  - The Formative Era, answering such questions as “What are exoplanets like?”
    - Characterizing planet forming disks and planetary atmospheres with the LUVOIR Surveyor.
    - Searching for life using the LUVOIR Surveyor to obtain full-disk images and spectra of pale blue dots.
    - Making longitudinal maps and detecting seasonal variations on exoEarths.
    - Searching for signs of habitability and evidence of biological activity on exoEarths.
  - The Visionary ERA, searching for life using an ExoEarth Mapper to produce resolved maps and spectra of “New Earth”, confirming surface water and identifying possible life.

Task Summary Timelines

- **H²CMN Validation (19 weeks)**
  - Prepare coupons using SMP-10 as the initial pre-pregging matrix.
- **HCMC and H²CMN Prototype Definition (10 weeks)**
  - A prototype design will be collaboratively designed by ASCM, NASA, NGAS and Professor Nejhad
- **Prototype Design and Engineering (16 weeks)**
  - FEM will be used to define design and performance requirements.
  - Design concepts will be refined and optimized for HoneySiC™; not a redesign of the original component.
  - ICDs, preliminary and final manufacturing drawings will be generated.

Summary of Tasks

ADVANCED
Silicon Carbide
MATERIALS

- **Joint Specimen Production and Testing (27 weeks)**
  - Full scale specimens of the intended prototype joint will be produced to replicate the design, application and use of fasteners/hardware for mechanical testing (or other testing deemed appropriate by NGAS and NASA).
  - We anticipate there will be several candidate designs.
- **Prototype Definition (28 weeks)**
  - An HCMC or H^2CMN prototype will be produced based on the D&E and joint specimen testing in Tasks 5 and 7.
  - Tentative plan is to make a scaled-down version of whiffle plate, delta frame or tube structure. Scaling ratio will depend on the selected component relative to UH's furnace workspace (13"x13"x14").
  - Estimated task time includes procurement of materials.

Summary of Tasks

- **Prototype Testing (5 weeks)**
  - Mechanical testing will be performed.
- **Phase II-E Application and Plan (12 months into POP)**
  - ASCM intends to apply for a P2-E.
  - The proposed scope of work is as follows:
    - Additional material characterization of HoneySiC™ materials. Specifically:
      - Thru-thickness CTE
      - In-plane CTE at ppb level (optional)
      - Thermal conductivity
      - Volume resistivity
      - BRDF using visible and single line laser sources
    - Development of 3D printing processes for HoneySiC™ material systems
    - Design and fabricate a meter-class telescope front structure
- **Task 11: Phase III Plan**
  - ASCM and NASA will develop a preliminary and strategic plan for Phase III and transition to commercial production.

SBIR Phase II for Contract No. NNX17CM08C

"Ultra-stable Zero-CTE HoneySiC™ and H^2CMN Mirror Support Structures"

Dr. William Fischer

Principal Investigator

Office: 808-245-6465

Cell: 570-899-4191

wfischer@ascmtech.com