MENTIS SCIENCES, INC.

Silica-Silica Mirror Substrate Fabrication Technology

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Program Overview

- Program Description
  - Mentis is working to develop a Silica-Silica composite that can be used as part of a mirror substrate
  - The material will have a low coefficient of thermal expansion which is matched in all directions.

- Projected Capabilities at conclusion of Phase I
  - Mentis will demonstrate the feasibility of silica-silica composites, along with novel manufacturing techniques developed at Mentis, as suitable method for reducing the areal cost of mirrors for NASA missions
  - Mentis will have capability to fabricate small-scale honeycomb components, suitable for mirror attachment

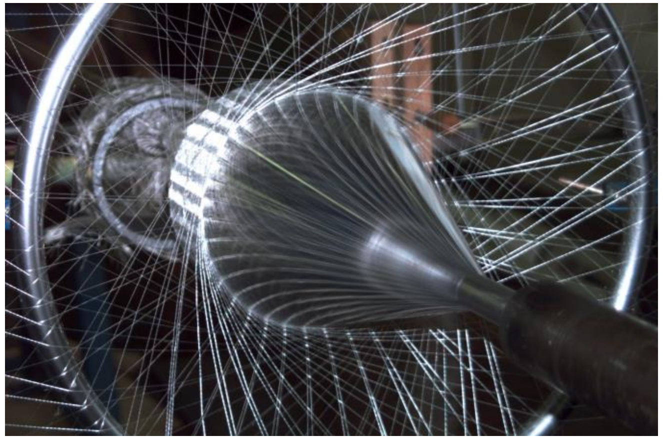
Program Overview

- Capability and Value
  - New technology and advances in preceramic polymers make the conversion process more affordable than it has been in the past
  - Mentis plans to pair the Silica-Silica material with unique fabrication processes to create honeycomb geometries that are easily scalable to different cell sizes and final configurations
  - The combination of the unique manufacturing processes, as well as low CTE matched materials, offers the potential for a high performance, lightweight mirror substrate with a lower areal cost than current fabrication techniques.

Silica-Silica Fabrication

- Preforms are made using a quartz fibers and a polysiloxane resin system.
  - In Phase I we have focused on flat panels for test coupons, and honeycomb sections to demonstrate the versatility of the concept

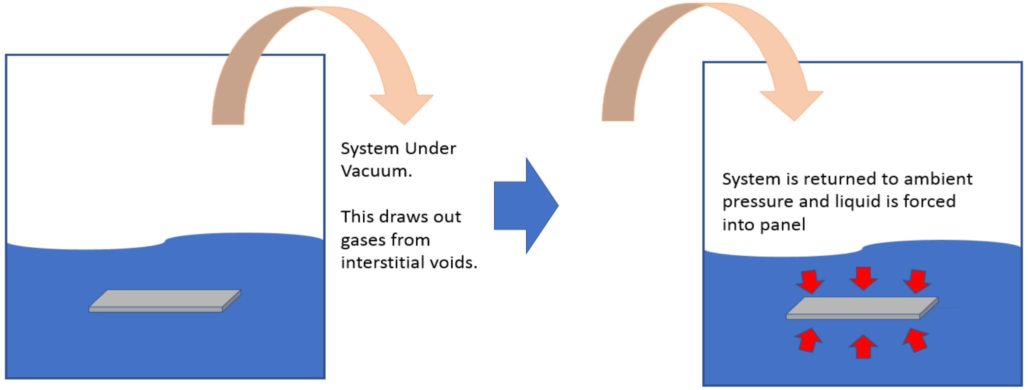
- During the fabrication process, the material is handled and processed using standard composites manufacturing techniques
  - Hand layup, braiding, filament winding are all acceptable processing methods to make preforms

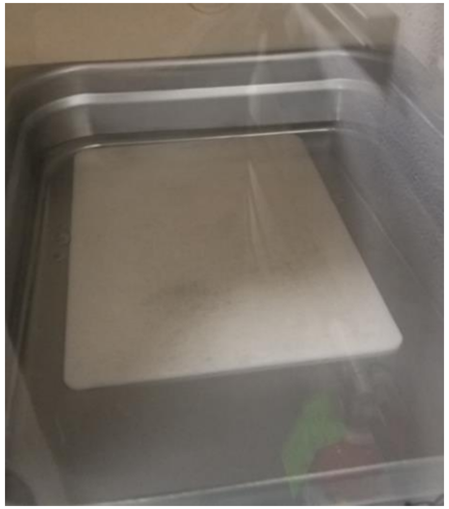


Material is compatible with traditional composite manufacturing methods

Silica-Silica Fabrication

- Parts are cured and post-cured following standard methods developed at Mentis.
- Following the standard cure and post-cure, the material is brought up to 850°C to allow organic resin constituents to burn off.
- The parts are then backfilled with a Silica precursor and heated again
  - Cycle is repeated until the desired density is achieved

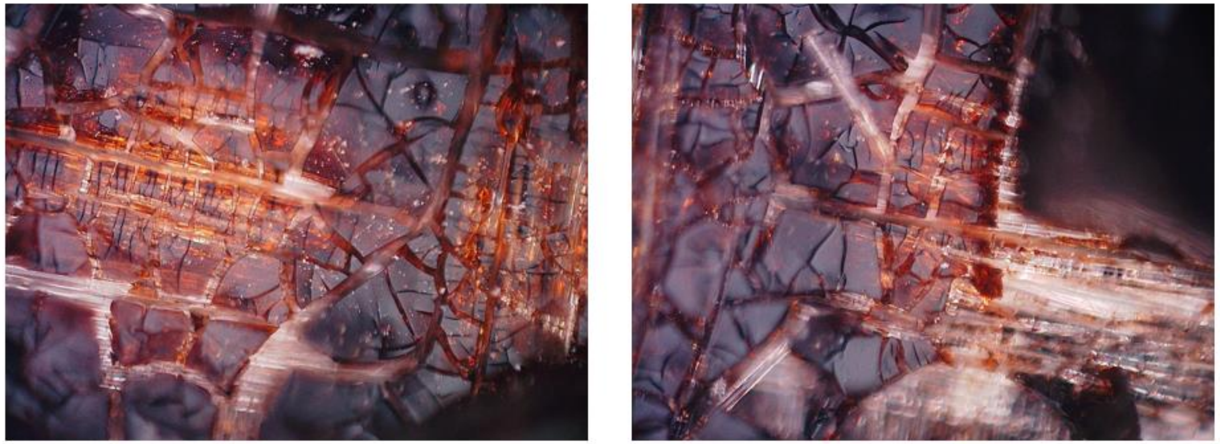




Material Selection

- Process uses fiber reinforcement, preceramic polymer resin, and backfilling agent
- Trials were conducted to identify the composite materials that were most suitable for the conversion process

Resin	Visual Inspection	Mass loss at 900°C
Resin A	No signs of charring, minimal degradation	4.54%
Resin B	some charring, minimal degradation	4.13%
Resin C	Extreme degradation and little remaining structural integrity	10.15%
Resin D	Extreme degradation and little remaining structural integrity	9.08%



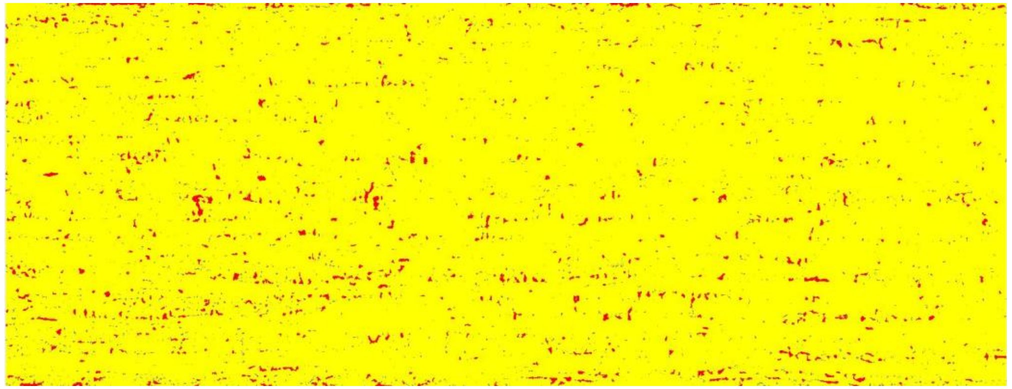
Resin C following TGA

Process Development

- Backfilling trials were conducted using different Silica precursors
- In addition, there are multiple combinations of infusion parameters possible (time, pressure, cycles)
- Starting with a higher fiber volume fraction may reduce cycle times and result in higher densities and better structural properties

Density change during processing of Panel ID DSS-19

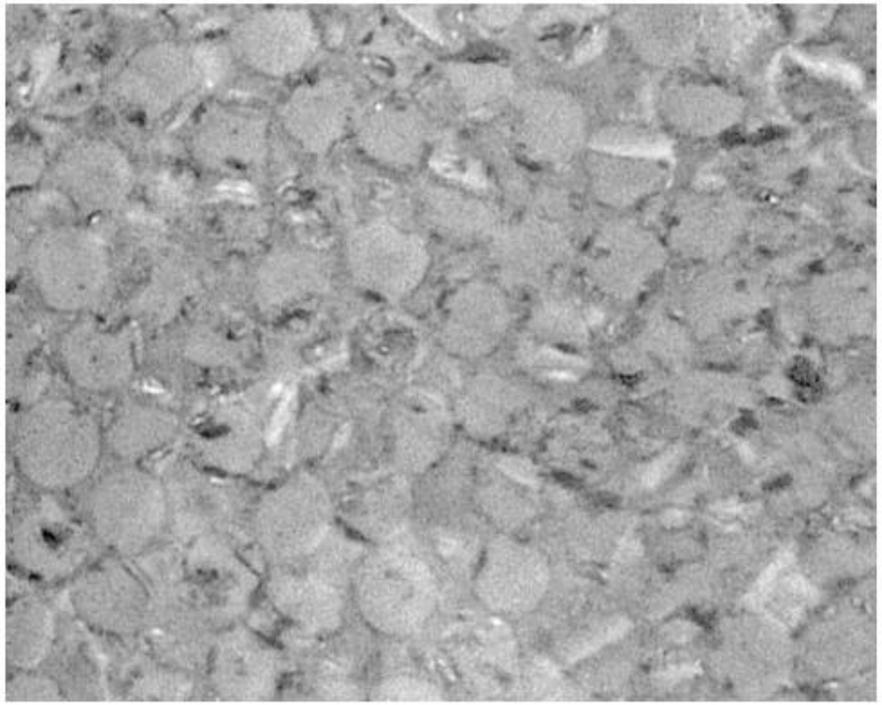
Post cure	1.72	g/cc
Following bake out	1.58	g/cc
Following Infusion Series	1.67	g/cc



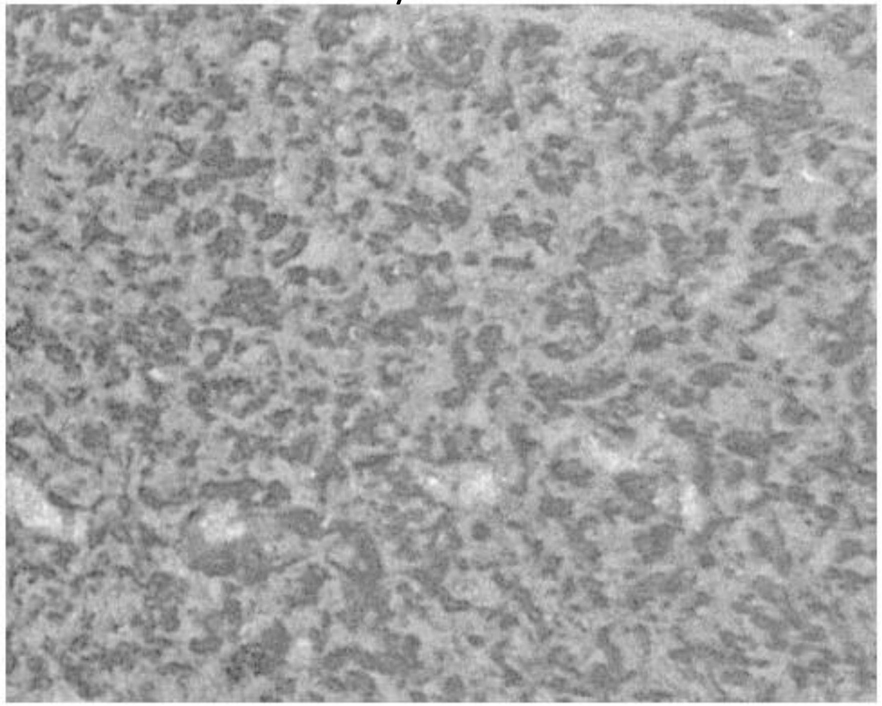
Porosity (shown in red) of cross section of DSS-19 after infusion trials. Porosity is at 2.09%

Microstructural Analysis

Panel cross section at 3500X magnification prior to infusion

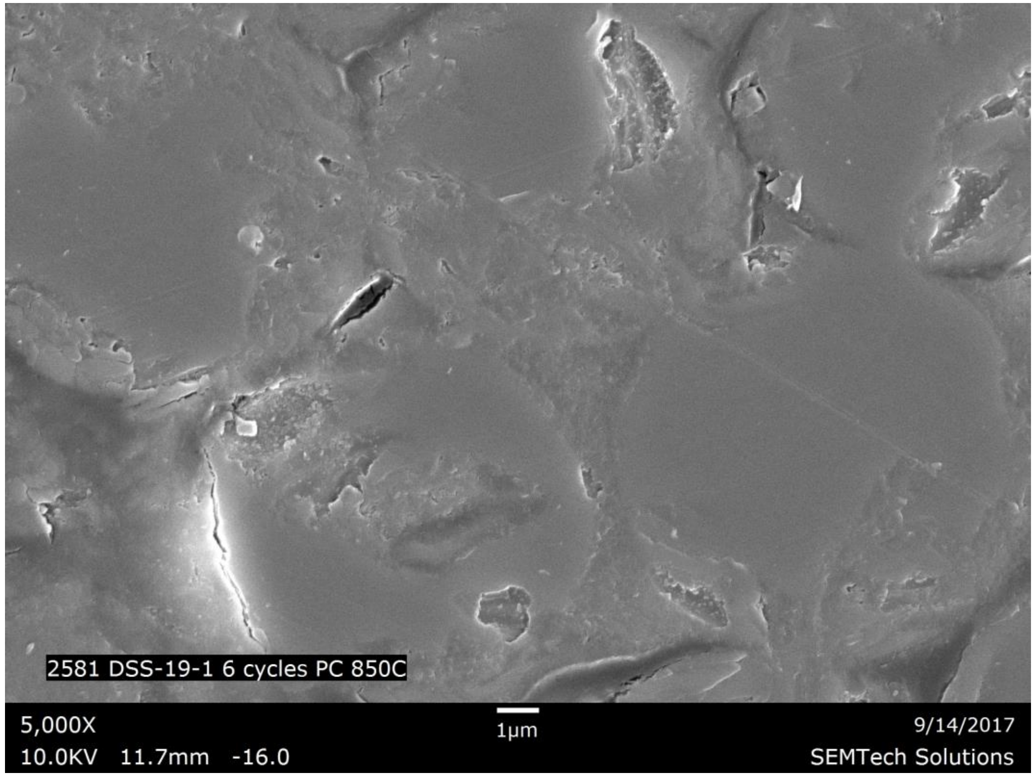


Panel cross section at 3500X after five infusion cycles

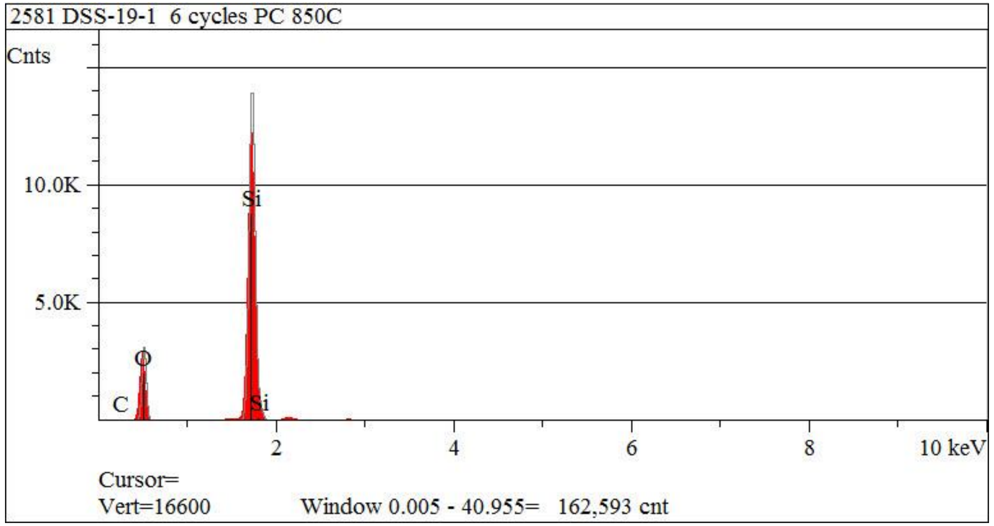


Note that the individual quartz fibers are still round and have definition on the left. After the infusion process, the fibers have lost their round shape and definition, indicating that conversion is happening

Scanning Electron Microscopy



Energy Dispersive X-ray Spectroscopy



Elt.	Line	Intensity (c/s)	Atomic %	Conc	Units	
C	Ka	3.65	5.162	2.986	wt.%	
O	Ka	255.95	53.704	41.379	wt.%	
Si	Ka	1,593.94	41.134	55.635	wt.%	
			100.000	100.000	wt.%	Total

kV 20.0

Takeoff Angle 35.0°

Elapsed Live time 75.9 seconds

Initial Properties for the 1311 Material

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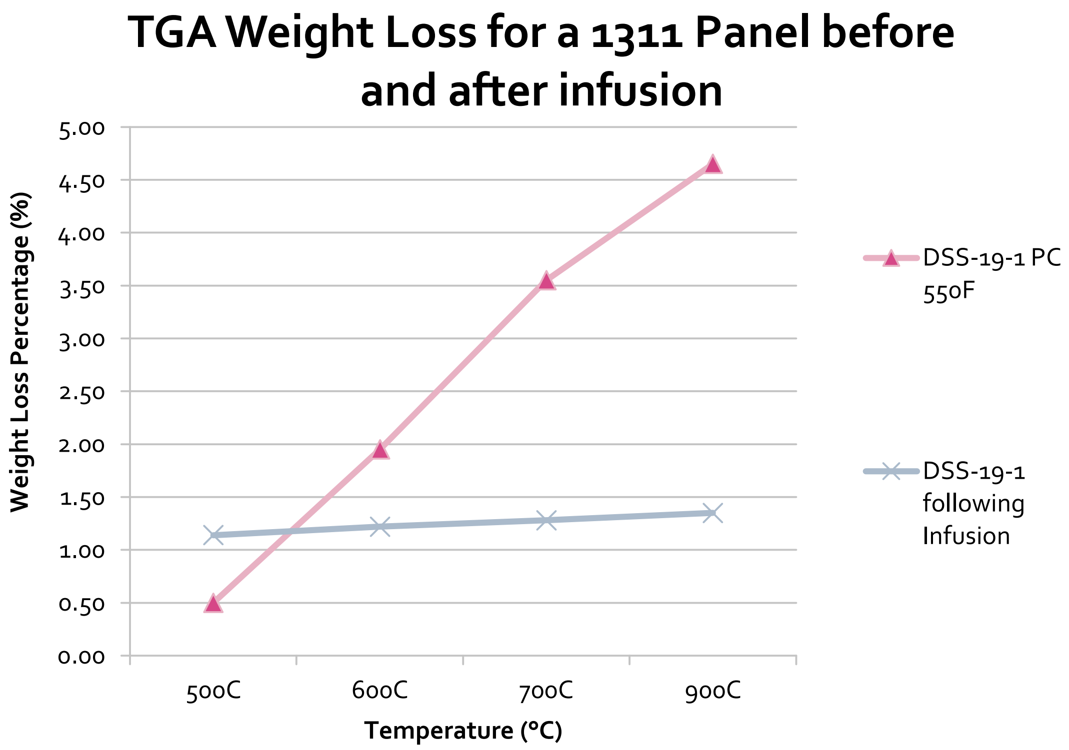
- Bulk Modulus in the z-direction, for the 1311 Material
- The weight loss at temperature was monitored for the material at different stages in the processing

Bulk Modulus	
Material	**GPa**
1311 Following Cure	14.8
1311 Fully Processed	29.2



Following infusion, the weight loss is greatly reduced, indicating that organic constituents have largely been removed

Initial Properties for the 1311 Material

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- Phase one testing includes:
  - Coefficient of Thermal Expansion over a temperature range of -60 °C to 300°C (ASTM E831)
    - Testing in progress
  - Flexure testing in the X and Y direction to determine laminate modulus (ASTM C1341)
    - This will change with the specific laminate design, in Phase one we are evaluating a 0-90 layup
    - Testing in progress
  - Thermal Conductivity in the Z direction from 20°C to 185°C (ASTM C518)
    - Preliminary results show thermal conductivity of 0.33 W/mK

Honeycomb Construction Concept

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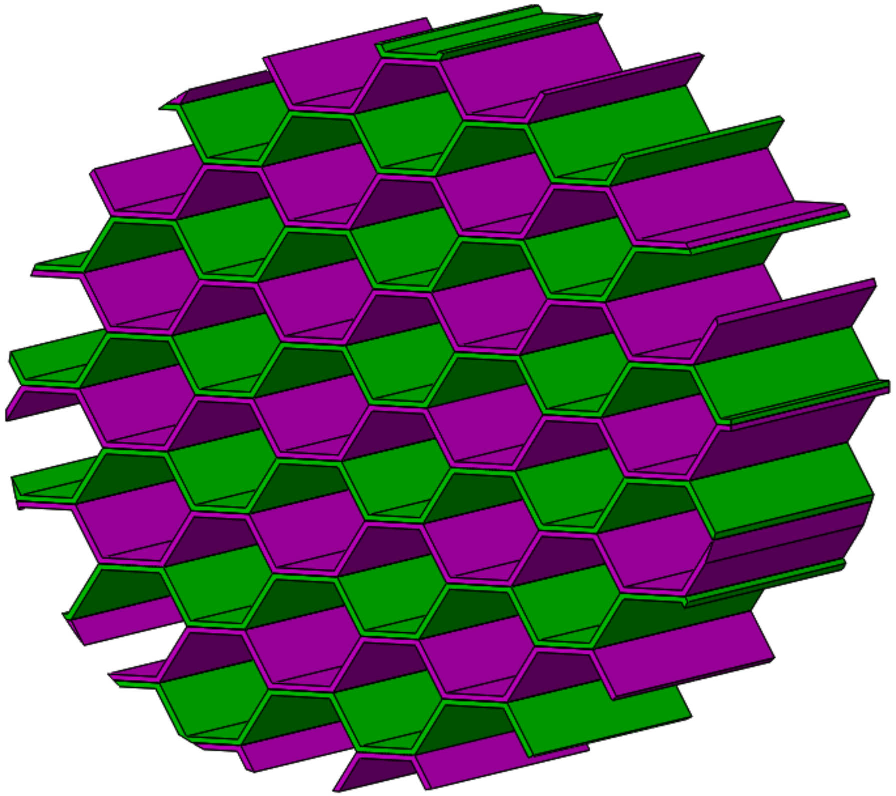
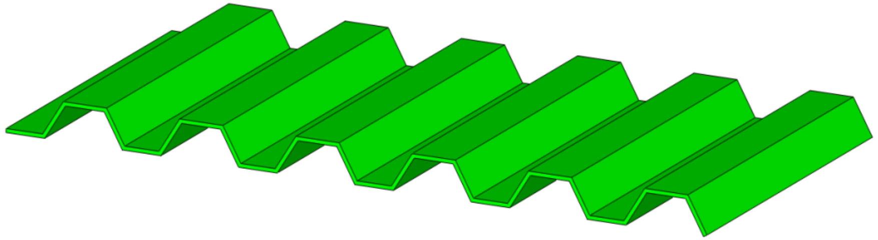
- Precision and Accuracy
  - Consistent cell shape
  - Consistent wall thickness
  - Single Stage Cure – including overwraps,
- Thin walls
  - Under 0.010”
- No additional adhesives
- Versatility
  - Compatible with many materials and processes
  - Cell size and wall thickness can be adjusted
  - Opportunity for engineered laminates





Honeycomb Construction Methodology

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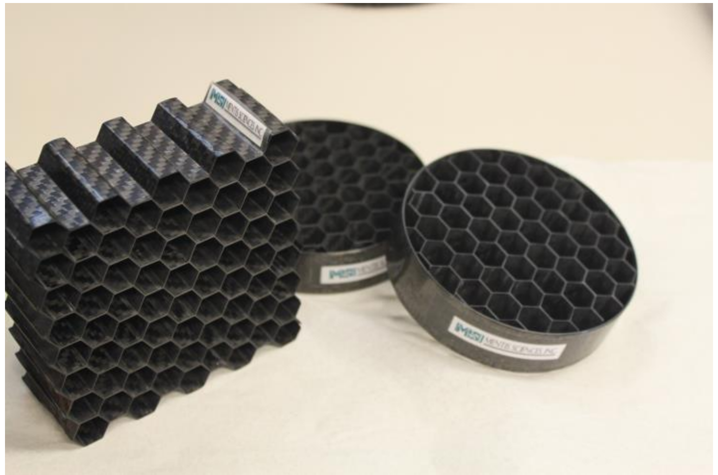
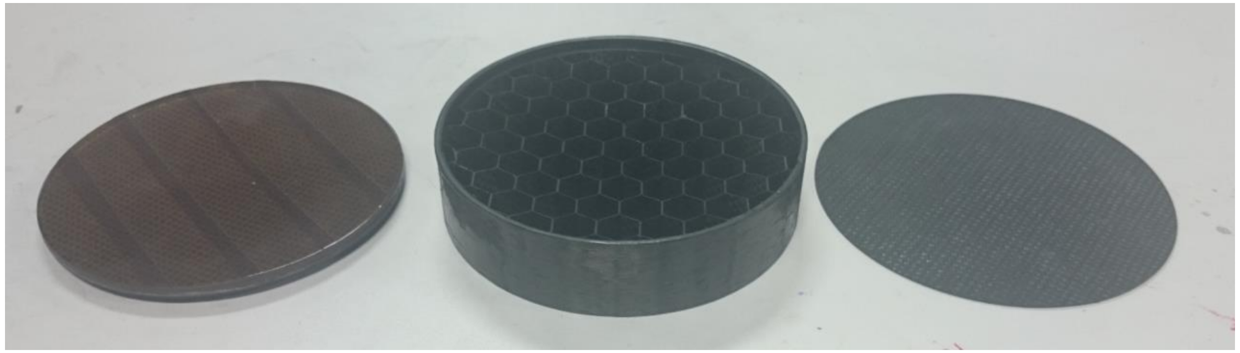
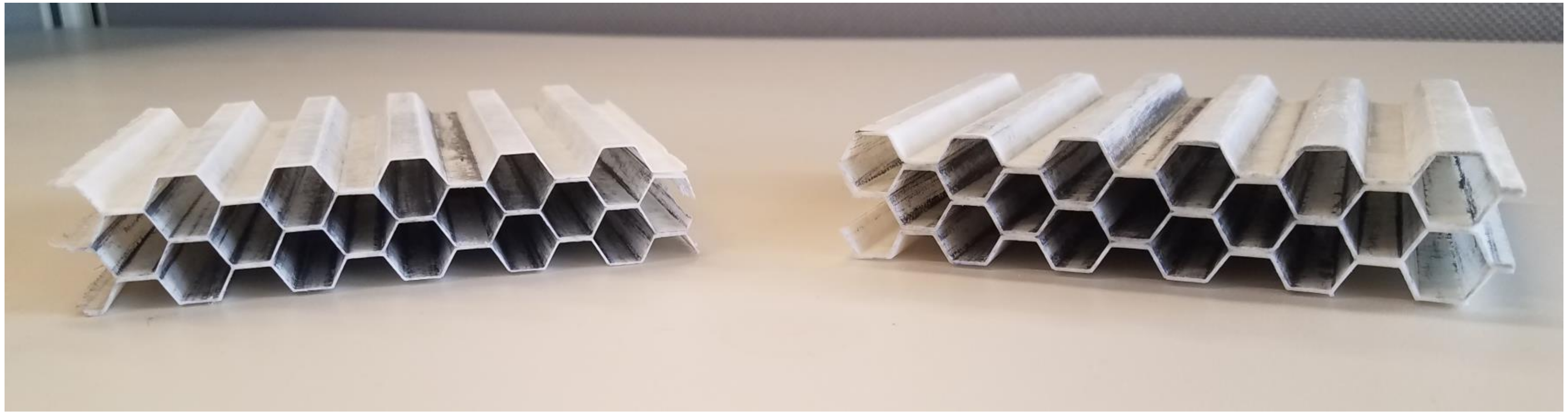
- Until now the technology has been used mostly on Carbon Fiber components





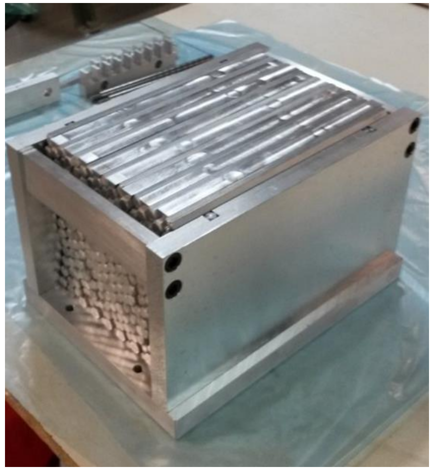
Mirror Substrate Proof-of-concept

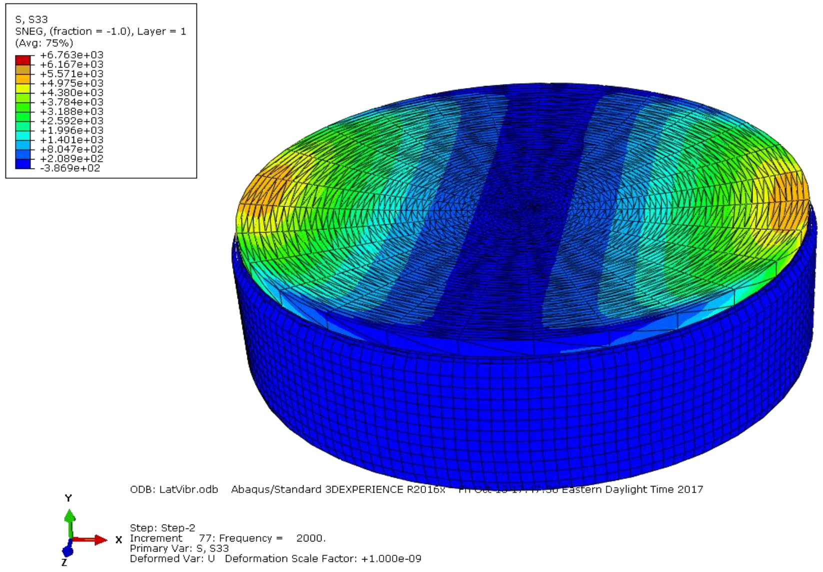
- Honeycomb segments shown below were fabricated using existing tooling
- Larger sections are being processed now
- Planning to attach face sheets and perform conversion as a phase 1 deliverable
- Section on the right is example of component that could eventually serve as overwrap or covering for edges of substrate



Feasibility Studies

- Manufacturing Technology
  - Current Capacity for Honeycomb is approximately 8” x 8”
  - Will need larger equipment – presses, ovens, infusions centers to make parts of a size that useful to NASA
- Production Rates and costs
  - Top-level estimates of material requirements and labor hours to make 1 meter honeycomb substrate are being calculated
  - Mirror finishing not included
  - Goal of reducing current mirror cost of space mirrors ($4-$6 million per areal meter) by 5-50 times
- Performance Analysis
  - We are in the process of comparing performance of mirrors using several popular materials against the Silica-Silica composites. The model will leverage a model completed for a separate development effort
  - Waiting on the test results to complete the preliminary material model for Silica-Silica





Phase II Plans

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- Continue refining the material manufacturing processes
  - Shorten processing time
  - Improve material properties
  - Expand database of material properties
- Scale manufacturing capacity to be more in line with NASA needs
  - Current tooling limits the size of honeycomb that can be produced
  - Scale to larger size components more representative of a NASA system
- Mirror Design
  - Identify parameters for mirror or segment to be fabricated Optimize mirror structure using for use with Silica-Silica materials
- Fabricate and Evaluate the mirror
  - Build a mirror or mirror segment and evaluate the performance of the completed component in a laboratory setting
- Transition
  - Specific Applications within NASA
  - Department of Defense uses
  - Private Space and Satellite Companies

Projected Capabilities and Results from Phase I

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Identify and Refine the manufacturing process for a Silica-Silica Composite

- Developed initial processing steps
- Identification of areas where process can be improved to result in shorter cycle times, improved material properties or

Preliminary Quantification of Material properties important to mirror design

- CTE
- Modulus
- Thermal Conductivity

Demonstrate Economic and technological Feasibility for the mirror fabrication concept

- Top Level Economic Assessment of scale-up costs and estimate of mirror surface finishing
- Finite Element Model based analysis comparing performance of Silica-Silica to other common mirror substrates

Fabricate a silica-silica composite sandwich panel as a deliverable

- Proof of concept Silica-Silica honeycomb with face sheet manufactured

Concluding Remarks

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- The development of the processing steps required to make the Silica-Silica has been successful.
- Silica-Silica material works very will with honeycomb substrate manufacturing techniques. Net shape manufacturing will reduce costs further along in the process
- All processing steps can be easily scaled to produce larger substrates
- Still waiting on some test results that will help demonstrate the structural properties of the material