T300HoneySiC – A New Near-Zero CTE CMC
NASA Phase II SBIR Contract NNX11CB94C

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Outline

- Honeycomb Silicon Carbide = HoneySiC™
- Additive Manufacturing
- Process Flow
- Material Properties
- Take Aways/Conclusions

Collaborators

- **Ron Eng, NASA MSFC, COTR**
- **Minority Institution and Small Business Team:**
  - Professor Mehrdad Nejhad, University of Hawaii at Manoa
  - Stan Wright, Ultracor Inc
  - Darren Welson, Starfire Systems Inc
  - Dean Szwabowski, Dean Szwabowski Professional Services
  - David Bell, Southern Research

Honeycomb Silicon Carbide

- PREMISE →If you can mold Honeycomb in prepreg state, then you can make lightweight structures with minimal machining (e.g., mirrors, optical benches, trusses, structures) very rapidly (<3 weeks), and at low cost.
- Trex T300HoneySiC™ has demonstrated feasibility
  - Technology Readiness Levels 1-5 achieved via Phase I and Phase II SBIR
- Ultra-low areal cost and ultra-low areal density (5.86 kg/m^2) mirror substrates and opto-mechanical structures.
- T300HoneySiC™ panels have a density 20% of beryllium.
- T300HoneySiC™ panels have a net production cost of $38K per square meter (unpolished), less than half of NASA's goal of $100K per square meter.
- Produced a 12-inch x 12-inch plate as demonstrator.

Additive Manufacturing

- **Trex T300HoneySiC Monolithic constructs are made in several steps**
  - **Mold and cure a prepreg consisting of T300 fabric and a pre-ceramic polymer;**
  - **Additively form complex structures (optical benches, mirror substrates, struts, etc.) using additional pre-ceramic polymer as the adhesive to join components;**
  - **Convert the cured assembly to dense, monolithic CMC via polymer-infiltration-pyrolysis (PIP).**

End-To-End Process Flow for Mirrors Deformable Mirrors Readily Achievable

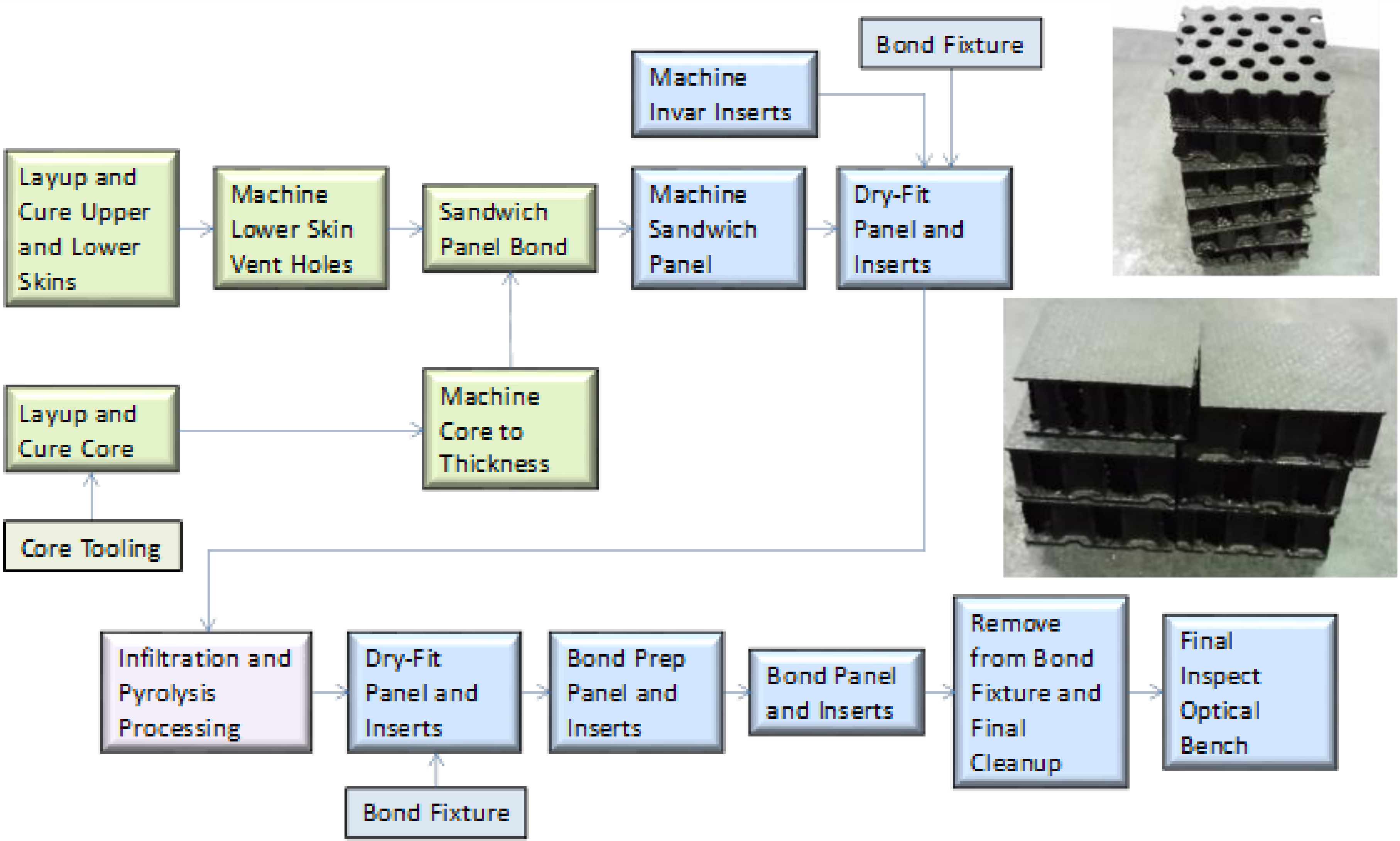
Core Overpress Tooling

Layup and Cure Upper and Lower Skins → Machine Lower Skin Vent Holes → Sandwich Substrate Bond → Machine Sandwich Substrate → Infiltration and Pyrolysis Processing → Cleanup → Inspect Mirror Substrate

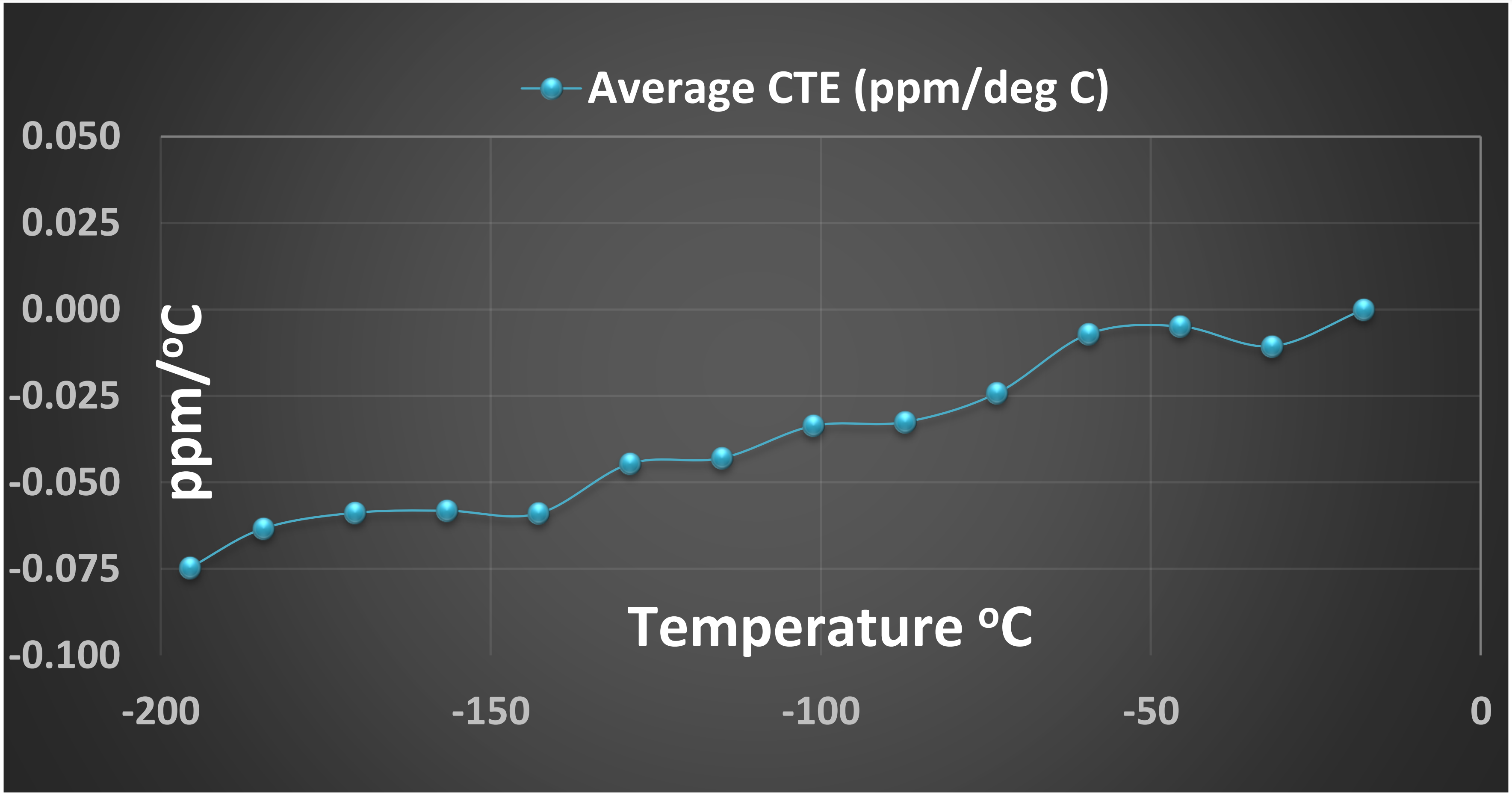
Core Tooling → Layup and Cure Core → Machine Core Shape to Thickness → Sandwich Substrate Bond

Apply Polishing Layer to Optical Surface → Coat Optical Surface

End-To-End Process Flow for Optical Bench/Structures



SoRI Data – Can this be? Near Zero CTE!
The UNITS are in PPM/deg C



Average instantaneous CTE for T300HoneySiC. The slope of the curve over the temperature range is only 0.42 ppb/°C/°C!

SUMMARY DATA
Laminate and Panels

Facesheet Elastic Modulus, Tension	61.0 -67.57+/- 8.96 GPa	8.85-9.80 +/- 1.3 Msi
Facesheet Gravimetric Density	1.873 +/- 0.05 g/cm^3	116.93 +/- 3.12 lb/ft^3
Facesheet Ultimate Stress, Tension	172.53 +/- 12.85 MPa	25,024 +/- 1864 psi
Facesheet Elastic Modulus, Compression	58.78 +/- 2.0 GPa	8.525 +/- 0.29 Msi
Facesheet Ultimate Stress, Compression	244.72 +/- 16.55 MPa	35,494 +/- 2400 psi
Facesheet Gravimetric Density, Compression	1.670+/- 0.027 g/cm^3	104.26+/- 1.69 lb/ft^3
Honeycomb Panel Gravimetric Density	0.376 +/- 0.005 g/cm^3	23.473 +/- 0.31 lb/ft^3
Honeycomb Panel Compressive Modulus	1.444 +/- 0.30 GPa	209.5 +/-43.4 ksi
Honeycomb Panel Ultimate Stress, Compression	11.204 +/- 1.04 MPa	1625 +/- 151 psi
Honeycomb Panel Areal Density	**5.86 kg/m^2**	**0.0083 lb/in^2**

Take Aways for T300 HoneySiC™

- **Rapid Prototyping→ Extremely rapid additive manufacturing process w/vertical integration**
  - Large complex mirrors/structures could be produced in a matter of weeks
  - Web thickness <1-mm, core geometries (pocket depth, pocket size) easily tailored
  - Minimizes machining, recurring/non-recurring costs, cost→ 100X < beryllium

- **Ultra-low areal cost→ Raw materials on the order of $38K/square meter**
  - Projects to 100X reduction in mirror cost based on current cost of $4-$6 million/square meter

- **Ultra-low areal density→ Facesheet density of beryllium metal, Sandwich a fraction of Be density**
  - 255-mm mirror: mass= 0.35 kg, areal density= 7.0 kg/m^2.
  - 305-mm optical bench with inserts: mass= 0.94 kg.
  - Maximizes light weighting and stiffness→95% lightweighting w.r.t. bulk silicon carbide

- **Extreme dimensional stability→ CTE measured to be near-zero**
  - variation of only 0.42 ppb/^{o}C/^{o}C from -200 ^{o}C to 0^{o}C.

- **Carbon fiber reinforced SiC structure→**
  - Low CTE/high thermal conductivity for stability better than ULE
  - Low Z for space effects environment
  - Electrically conductive for dissipating static charge build-up
  - ~2X higher fracture toughness than pure SiC, estimated ~4.6 MPa-m$^{0.5}$
  - High stiffness honeycomb panel construction

Conclusions

- **We have a process that is amenable to current facilities and practice.**

- **With optimized process and equipment, large, lightweight CMC parts could be turned out in weeks, and at dramatically lower cost.**

- **CMC with Near-Zero CTE from -196 to +24 deg C**
  - "How Low can you go?" Need to test at NASA MSFC down to 25 K

- **C/SiC is also High Temperature Material**
  - Likewise, "How High can you go?"

- **Several $M Additional R&D funding would lead to a Big Payoff.**
  - We have already demonstrated incorporation of U of H nano-technologies to dramatically improve properties.

- **Would like to discuss partnering and licensing.**

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