Structural Nanocomposites for Aerospace Applications

NASA/Orbital ATK Technical Interchange Meeting

Mia Siochi
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NASA Structural CNT Team

- Computational Materials
  * NASA LaRC
    * Kris Wise
    * Ben Jensen
  * Universities
    * Greg Odegard – MTU
    * Adri van Duin – PSU

- Synthesis
  * NASA GRC
    * Sandi Miller
    * Tiffany Williams
    * Marisabel Lebron-Colon
    * James Baker
  * NASA LaRC
    * John Connell
    * Joe Smith
    * Yi Lin
  * Material Suppliers
    * Nanocomp Technologies
    * General Nano
  * Universities
    * University of Cincinnati
    * Rice University

- Processing
  * NASA LaRC
    * Brian Grimsley
    * Bert Cano
    * Dennis Working
    * Sean Britton
    * Hoa Luong
    * Jae-Woo Kim
    * Godfrey Sauti
  * NASA GRC
    * Sandi Miller
    * Tiffany Williams
  * Universities
    * FSU
    * University of Cincinnati

- Materials Characterization/Testing
  * NASA LaRC
    * Buzz Wincheski
    * Mike Czabaj
    * James Ratcliffe
    * Jae-Woo Kim
    * Yi Lin
    * Godfrey Sauti
    * Jennifer Carpena

- Structural Mechanics & Design
  * NASA LaRC
    * Steve Scotti

- Systems Analysis
  * NASA LaRC
    * Mark McMillin

Collaborative Partner:
AFOSR –Low Density Materials Program
PM: Dr. Joycelyn Harrison
Why Structural Nanomaterials?

Harris, Shuart, Gray, NASA TM 211664, 2002
Highlights from Early Work: 1999 – 2008

Measured Electrical Conductivity and Percolation Modeling

Observed Differences in Nanocomposite Solution Stability

Fast Fourier Transform of HRSEM Image

“Poly-transparent” Imaging

$y = -5.9882 + 1.4801x \quad R = 0.99968$

$\log(\sigma)$

$\log(c/f)$

$\sigma$
Potential System Weight Savings

Two Stage to Orbit Launch Vehicle Concept

- **Baseline Mass Fractions**
  - typical for existing cryogenic pump and pressure fed stages

- Weight savings applied to pressurized structures only

- Including other structures and subsystems may show increased benefit

- Low tech pressure fed systems show greatest benefit from reduced structures weight
Project has adopted a comprehensive approach involving modeling, materials development, testing and characterization, and component level demonstration to accelerate materials development and mission transition.
Nano to Macro Challenge

Available materials have starting mechanical properties inferior to other SOA materials.
Bundle Failure

- True Stress (GPa/(g/cm$^3$))
- True Strain

Graph showing stress vs. strain for different materials:
- Total
- Am-C
- CNTs
Calculated Mechanical Properties in Context

**Modeling CNT Based Structural Materials**

- **Q-I M46/7714A**
- **Q-I IM7/8552**
- **Aluminum**
- **M46J Fiber**
- **IM7 Fiber**
- **Modeling CNT/a-C Axial**
- **Modeling CNT/a-C Transverse**

* SWNT Modulus and Strength unscaled due to ambiguity in density
CNT Composite Procedure

1. Stretched
2. Clamped
3. Cured while Clamped
4. Coated with Resin Solution
CNT Composite Tensile Testing
Influence of Post-Processing on CNT Sheet Composite Properties

Specific Strength [Mpa/(G/cm³)]

- PE
- R
- I
- S
- T
- I
- N
- E

Specific Modulus [GPa/(cm³)]

- PE
- F
- S
- +
- EB
- +
- SS
- PP
- +
- FF
- +
- BMI Resin Properties

Pristine: Pristine CNT sheet (Lot#70044-Acetone treated)
EB: EB (40 min)
EB: EB (90 min)
F: m-CPBA Functionalized
F + EB: m-CPBA Functionalized + EB (90 min)
S: Stretched (41%)
S + EB: Stretched (49%) + EB (90 min)

S + P: Stretched (46%) + purified
S + P + EB: Stretched (33%) + purified + EB (90 min)
S + F: Stretched (43%) + m-CPBA Functionalized
S + F + EB: Stretched (43%) + m-CPBA Functionalized + EB (90 min)
S + P + F: Stretched (46%) + purified + m-CPBA Functionalized
S + P + F + EB: Stretched (33%) + purified + m-CPBA Functionalized + EB (90 min)
CNT Yarn to CNT COPV

CNT Yarn

Solution Infiltration and Wet Winding of CNT Yarn

CNT Yarn Composite Wound Rings

Variable Temperature Mechanical Testing

Commercial Scale Winding

CNT Yarn COPV
Characterization of Wound CNT Composites

Kim97593, Wet Wound, 50%, .55lbf, 66 turns

Kim97715, Wet Wound, 70%, 1lbf, 66 Turns

Kim97771, Wet Wound, 70%, 3.35lbf, 66 Turns

Kim97774, Wet Wound 70%, > 5 lbf, 66 Turns
Status – End of FY 14

Project Objective

Specific Modulus (GPa/g/cc)

Specific Strength (GPa/g/cc)

- M46J Fiber
- IM7 Fiber
- Q-I M46/7714A
- Q-I IM7/8552
- Aluminum
- CNT Sheet Composite (2012)
- CNT Sheet Composite (2013)
- CNT Yarn Composite (2012)
- CNT Yarn Composite (2014)
- Modeling CNT/a-C axial
- Modeling CNT/a-C transverse
- Theoretical SWNT

- Aluminum
- CNT Sheet Composite (2012)
- CNT Yarn Composite (2012)
- CNT Yarn Composite (2014)
- M46J Fiber
- IM7 Fiber
- Q-I M46/7714A
- Q-I IM7/8552
- Specific Modulus (GPa/g/cc)
- Specific Strength (GPa/g/cc)
How is Structural Nano Different?

[Graph showing specific modulus and specific strength for various materials, including IM7/8552, Uni IM7/8552, M46J Fiber, IM7 Fiber, CNT Sheet Composite, CNT Yarn Composite, Q-I M46/7714A, Aluminum, and Lightly Doped CNT Composite.]
Peak of Inflated Expectations

Slope of Enlightenment

Plateau of Productivity

Trough of Disillusionment

High Strength CNT Yarns

Early CNT Powders

Commercial CNT Sheets

CNT Fibers

Technology Expectations

Technology Maturation

Innovation Trigger


CNT Sheet Composite Publication (2010)
• **OBJECTIVE:** Reduce the mass and improve the fatigue resistance of power and data cables

• **APPROACH:** Utilize carbon nanotube conductors and ultralightweight aerogel insulation to reduce cable mass and improve fatigue resistance
  – Employ intercalation chemistries to enhance electrical properties
  – Develop processing methods to apply aerogel insulation
  – Characterize electrical and thermal properties and cable durability

• **IMPACT:**

> 70% reduction in data cable mass
> 50% reduction in power cable mass

• **FY2014 MAJOR ACCOMPLISHMENTS:**
  ✓ Improved electrical conductivity of CNT wires to 98 kS/cm
  ✓ Demonstrated dip coating of polyimide aerogels onto CNT wires

Use of carbon nanotube conductors and ultralightweight polymer aerogel insulation could reduce the mass of data cables by >70%.
Accelerate Technology Maturation with Multidisciplinary Approach