COMPOSITE TECHNOLOGY DEVELOPMENT, INC.

ENGINEERED MATERIAL SOLUTIONS

Testing at Cryogenic Temperatures
Engineering, Materials, and Testing Support

DOE Office of Energy Efficiency & Renewable Energy
Advanced Composite Materials for Cold and Cryogenic Hydrogen Storage Applications in Fuel Cell Electric Vehicles

By

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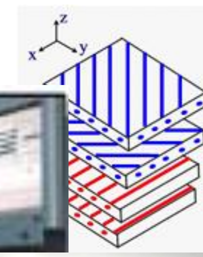
Agenda

- CTD Introduction
- CTD Cryogenic Testing Experience & Capabilities
- Cryogenic Testing Considerations
- Testing Methods and Systems
- Cryogenic Tank Testing

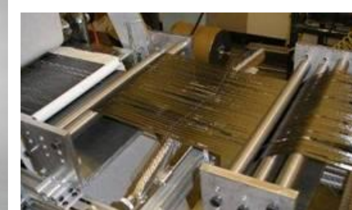
Technology and Product Development Company

- **Expertise**
  - **Material development and engineered composites**
  - **Engineered solutions for extreme operating environments**
  - **Market focus: energy, aerospace, and defense**
- **Services**
  - **Mechanical/Electrical/Thermal Testing**
  - **Engineering Design & Prototyping**
  - **Unique cryogenic capabilities**
    - **4K to 523K**
- **Commercial Materials Sales: >30 products around the world**
- **Manufacture specialty composite products**
- **Ernst & Young Entrepreneur of the Year**
  - **CTD President and Founder, Dr. Naseem Munshi named 2007 winner for excellence in innovation.**



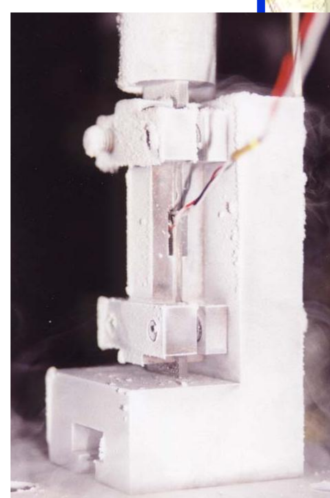





Testing History

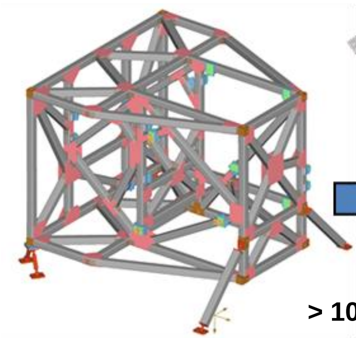
- **Performing cryogenic mechanical tests since 1989**
  - **Capabilities were developed to support superconducting magnet insulation R&D**
  - **Developed mechanical/thermal/electrical testing methods**
- **Commercial testing since 1992**
- **Expansion of testing facilities in 2003**
- **Key customers include:**
  - ***GE Healthcare***
  - ***US Navy***
  - ***NASA***
  - ***Orbital ATK***
  - ***Lockheed Martin***
  - ***Northrop Grumman***
  - ***Pratt & Whitney***



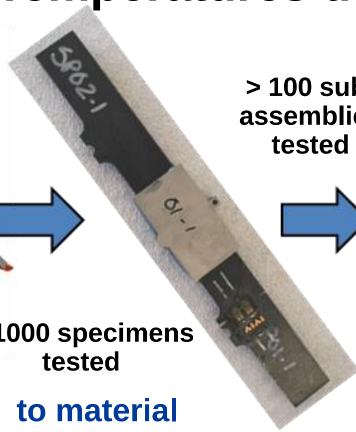
James Webb Space Telescope

Sole source facility for NASA and contractors:

- Developed test methods, temperature control and data acquisition procedures with NASA personnel
- High precision, thermally stable optical structure
- Testing of composites, composite-to-Invar joints, sub-assemblies, prototypes - Temperatures down to 15 K



From customer concept…

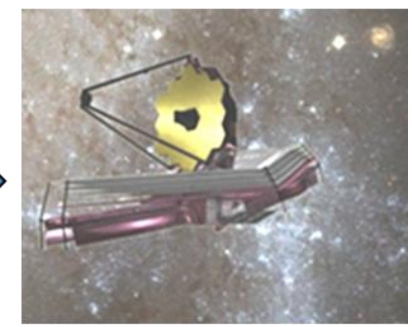


> 1000 specimens tested

to material evaluation…

> 100 sub-assemblies tested

to sub-assembly performance…



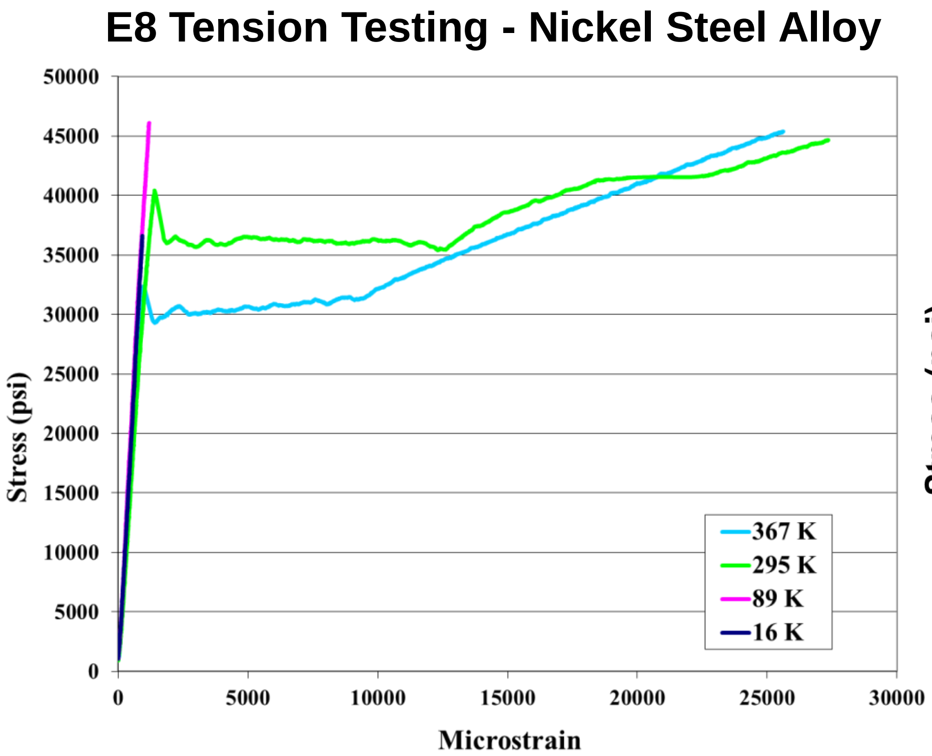
to flight!

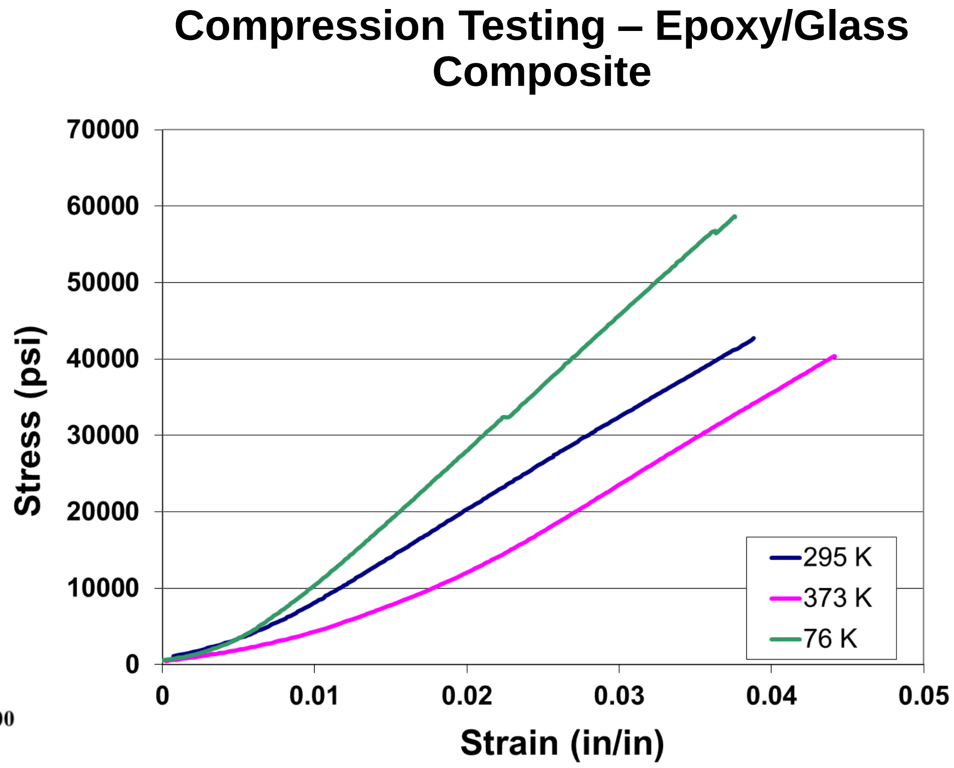
"Big part of ATK's material characterization program on the James Webb Space Telescope. Their data is extremely thorough and comprehensive." *Troy Thompson, ATK*

Worked with NASA to validate the process and build confidence in the testing approach

Material Properties at Cryogenic Temperatures

Materials behave differently at cryogenic temperatures

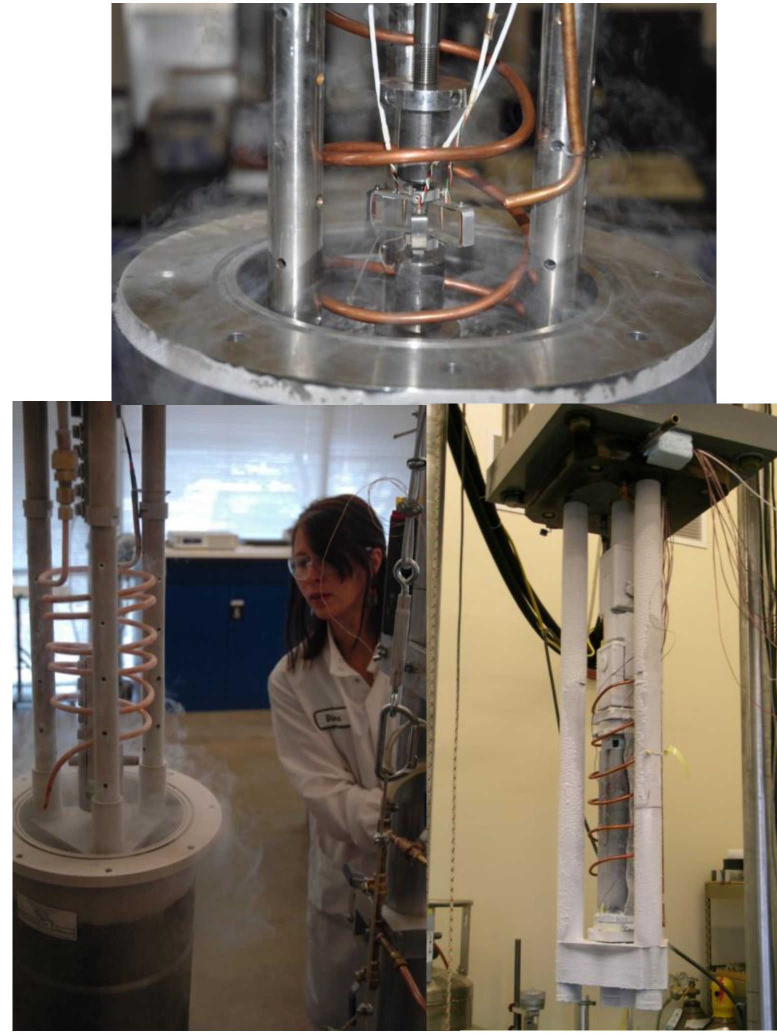




CTD has characterized both metallic and composite/polymers through a wide range of temperatures

Cryogenic Testing Considerations

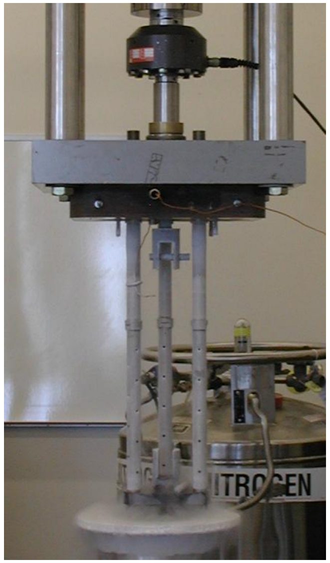
- **Most mechanical test methods can be adapted to cryogenic temperatures**
- **Key points to consider:**
  - **Equipment Capability**
  - **Fixture Design**
  - **Temperature/Environmental Controls**
  - **Specimen Design/Behavior**
  - **Instrumentation & Data Acquisition**
- **Only one ASTM test standard is specifically for cryogenic temperature testing**
  - **ASTM E1450 – Standard Test Method for Tension Testing of Structural Alloys in Liquid Helium**
  - **This specification is not for composite materials**



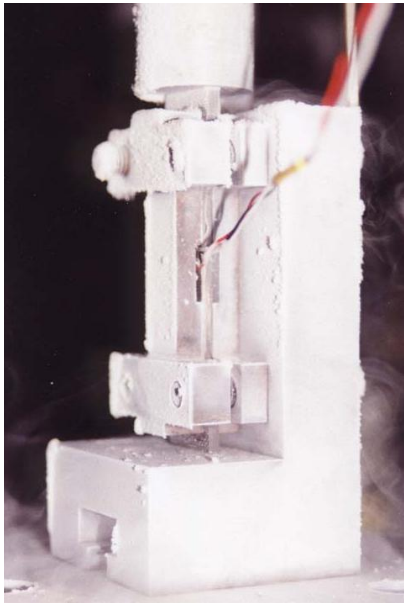
Equipment and Fixturing

Test equipment & fixturing must be capable of surviving the extreme temperatures

- **Grips**
  - **No hydraulic, all mechanical**
  - **Amount of force that can be applied is limited**
  - **Cooling and heating rates need to be reviewed**
- **Fixturing**
  - **Mechanical threads are notch sensitive and can fracture at cryogenic temperatures**
  - **Certain materials not suited for extended use**
  - **Failure loads are typically higher, so fixturing gets larger, increases thermal mass**
- **Load cells need to be separated from the cryogen**
- **Automation becomes more challenging at cryogenic temperatures (i.e. valve operation)**



Instrumentation & Environmental Controls

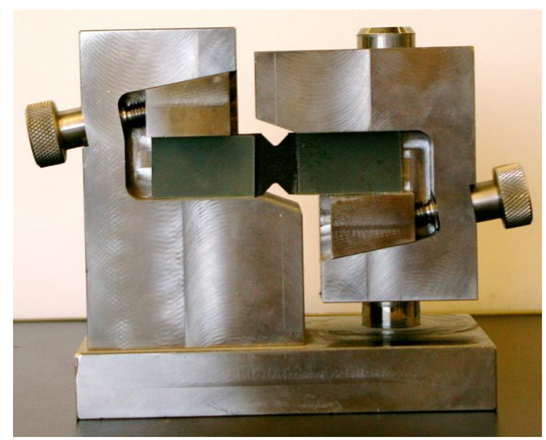


- **Strain gages/extensometers**
  - Overall strain capability is limited
  - Must be able to calibrate at specific test temperature for accuracy
- **Temperature sensors**
  - TC operation can be problematic
  - Silicon diodes very reliable, but must be calibrated and need specific control units to read temperatures
- **Can't visually watch what is happening**
  - Specimen, fixturing, etc. typically contained inside a cryogenic dewar
- **Temperature control at intermediate temperatures (between LHe and LN2) is more challenging**
  - Difficult to automate
  - Expensive cryogenic controllers
  - Specimen size dictates dewar and cryogen volume

ASTM Tests Commonly Performed at Cryogenic Temperatures

- **Tension**
  - D3039 Composite
  - D638 Neat Resin
  - D5766 Open Hole
- **Compression**
  - D695 Composite (SACMA SRM-1)
  - D3410 In-plane (IITRI)
  - D6484 Open Hole
- **Shear**
  - D2344 SBS
  - D3518 ±45° Tensile mode
  - D5379 V-Notched
- **Other**
  - C273 Core Shear
  - C297 Flatwise Tension
  - D5961 Shear Bearing
- **Experience in non-standard, mock-ups, sub-assemblies, and prototypes**

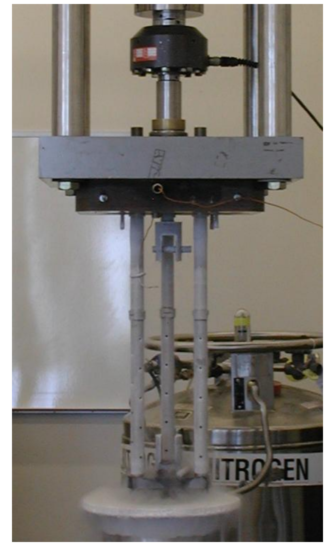
D638 Neat Resin Tension

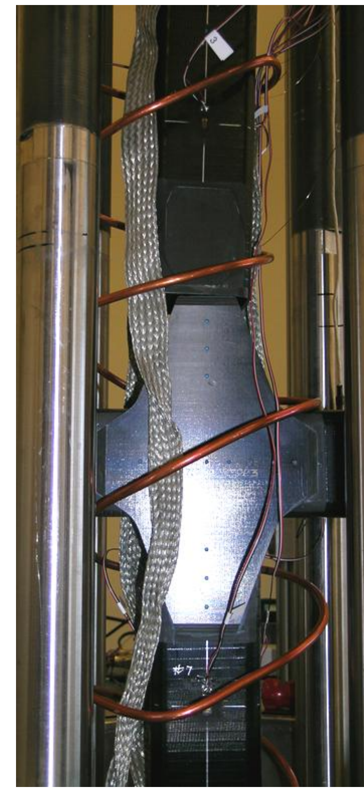


D5379 V-Notched Shear

Mechanical Test Systems

- **Servo-Hydraulic load frames outfitted for cryogenic and elevated temperatures**
  - **1,000 lbs(5 kN) to 100,000 lbs (500 kN)**
  - **Temperatures from 4 K to 523 K (250ºC)**
- **Electro-mechanical load frame with environmental chamber**
  - **10 lbs (50 N) to 1,000 lbs (5 kN)**
- **10 sensor channels available for specimen temperature monitoring**
- **15 Strain channels available with data acquisition rates up to 10 kHz**
- **Maximum specimen envelope of 48” long by 6.5” in diameter at cryogenic temperatures**
  - **Typical test temperatures**
  - **4 K, 20 K, 30 K, 77 K, 90 K, 170 K, RT, 100ºC, 120ºC, 200ºC, and 250ºC**

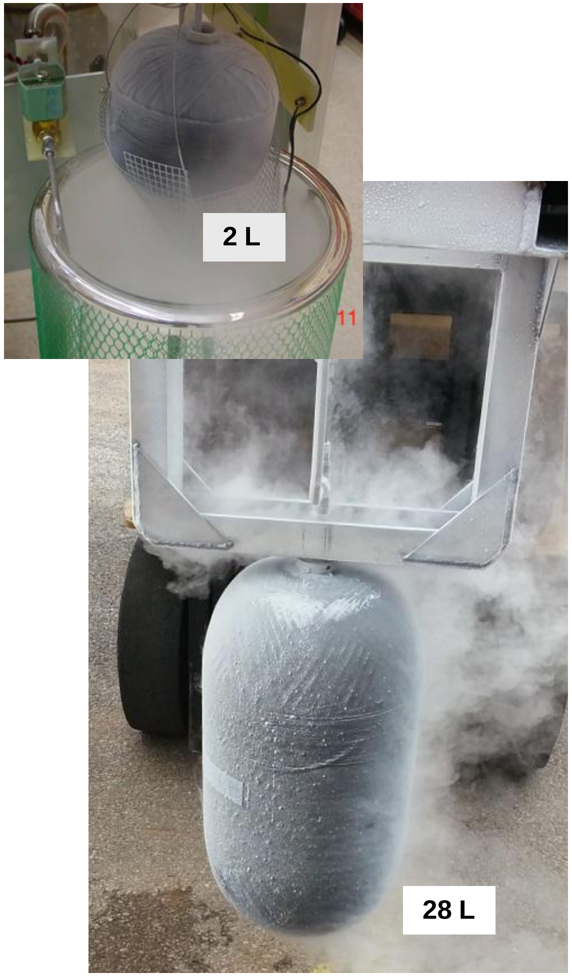




Cryogenic Tank Testing

Hydrostatic pressure testing tanks at low temperatures is equally challenging

- Tanks typically filled with cryogen (LN2)
- Pressurization control during fill and testing much more involved
  - Computer controlled
  - Remote pressurization for safety
- Insulated containment system required
- Testing at temperatures below LN2 becomes even more expensive
  - Insulation systems efficiency must be increased
  - LHe typically requires control systems upgrades
- Instrumentation needs to be cryogenic compatible



Testing Summary

- **Extensive material testing experience at cryogenic and elevated temperatures.**
- **Experience with design, development, fabrication, and testing of composite pressure vessels**
- **Services include test plan development, specimen and mock-up design, engineering analysis, specimen fabrication, and cost effective testing**
- **CTD's broad test experience and composite material knowledge adds value to our customers programs.**