Application of High-Temperature Extrinsic Fabry-Perot Interferometer Strain Sensor

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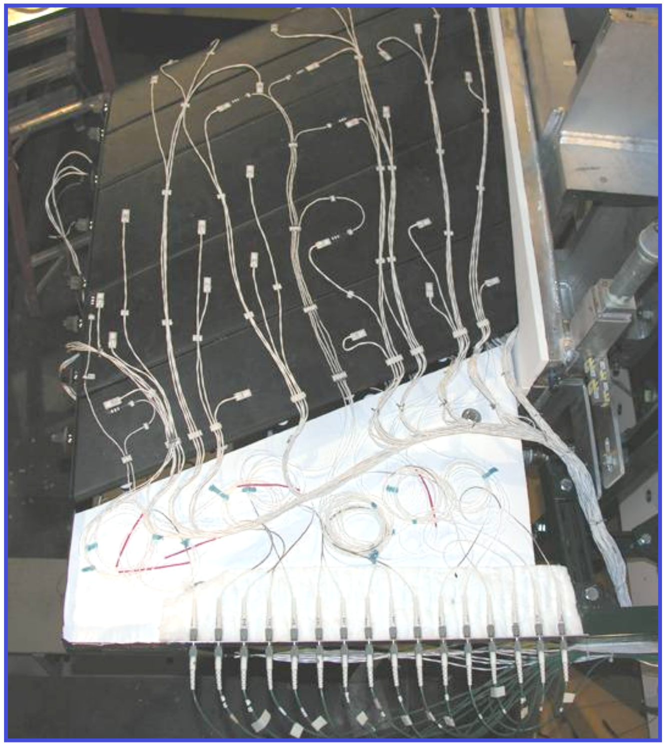
Cleared for public release

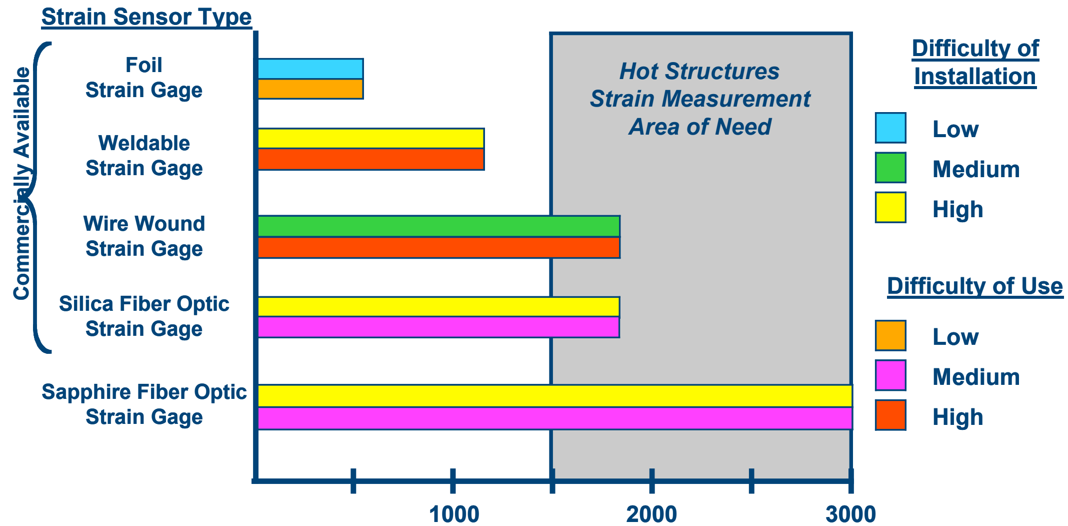
Outline

- Background
- Objective
- Sensor
- Attachment Techniques
  - Sensor Construction
  - Thermal Spray Process
- Evaluation / Characterization
- Future Fiber Optic Testing



Background

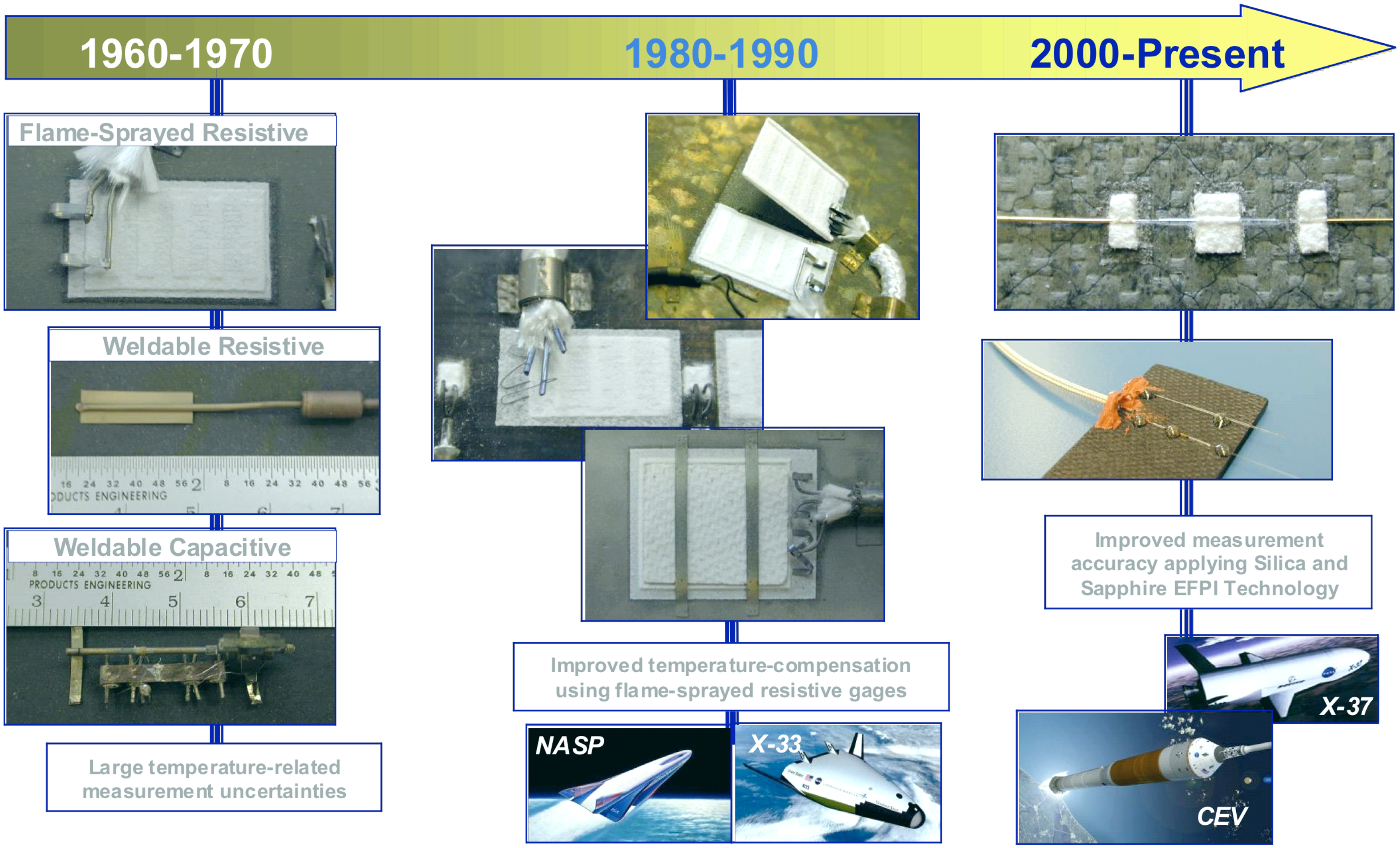
Sensor Development Motivation



- **Lack of Capability**
  - TPS and hot structures are utilizing advanced materials that operate at temperatures that exceed our ability to measure structural performance
  - Robust strain sensors that operate accurately and reliably beyond 1800°F are needed but do not exist
- **Implication**
  - Hinders ability to validate analysis and modeling techniques
  - Hinders ability to optimization structural designs

Background

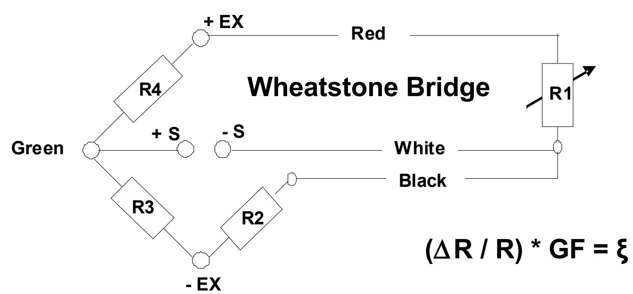
Strain Sensor Maturation



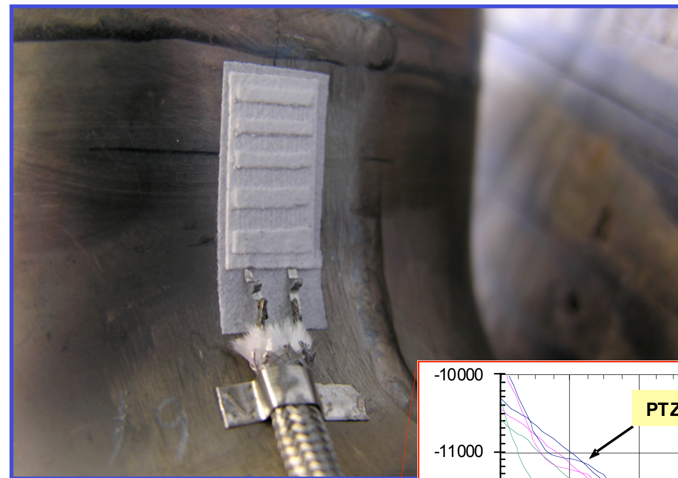
Background

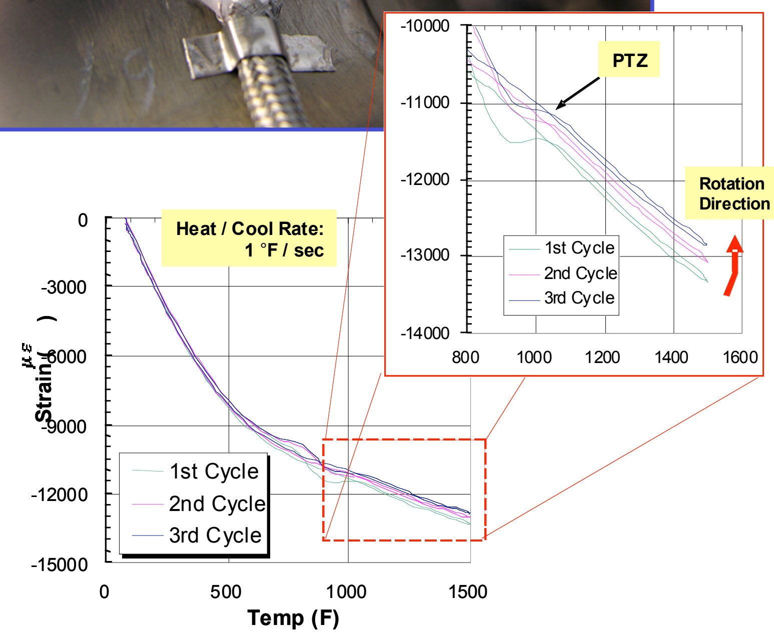
Electrical Resistive Strain Gage

High-Temp Quarter-Bridge Strain Gage



$(\Delta R / R) * GF = \xi$





<u>Pro's</u>

- Sturdy / rugged thermal sprayed installation and spot-welded leadwire stakedown
- Available high sample rate DAS, usually AC coupled to negate large ξapp

<u>Con's</u>

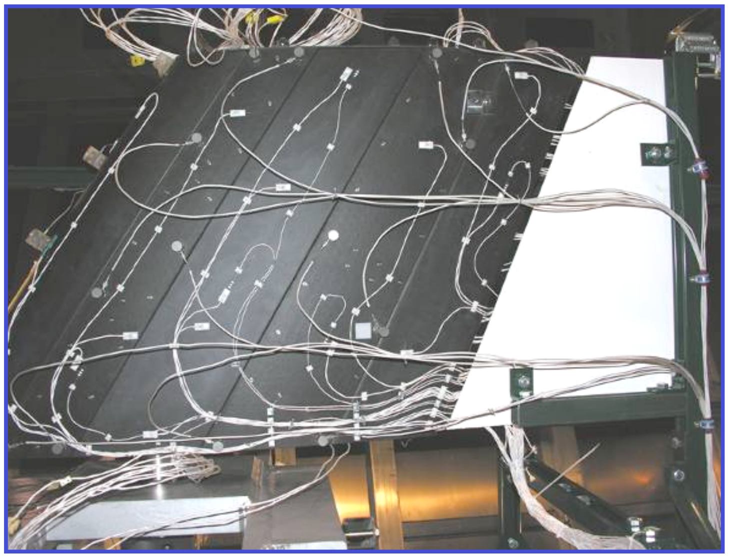
- Large magnitude ξapp primarily due to wire TCR, slope rotates cycle-to-cycle
- Sensitivity (GF): Function of temperature

$$\xi_{app} = [TCR_{gage} / GF_{set} + (\alpha_{sub} - \alpha_{gage})] * (\Delta T)$$

Objective

Provide strain data for validating finite element models and thermal-structural analyses

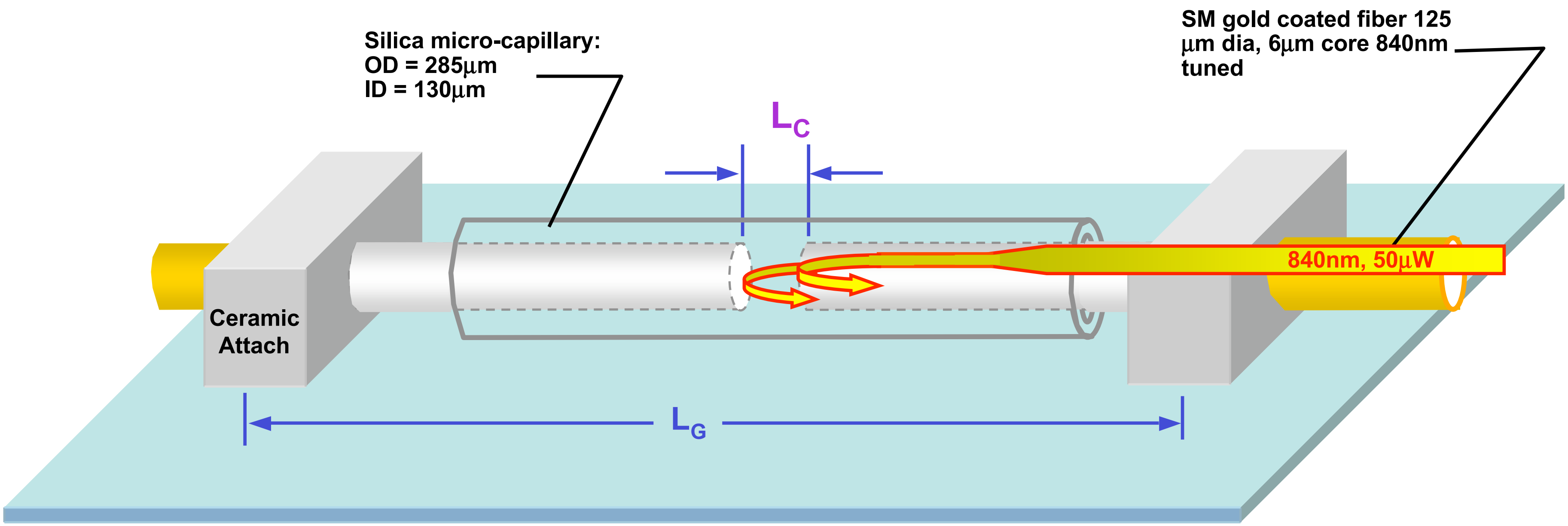
- Develop sensor attachment techniques for relevant structural materials
- Perform laboratory tests to characterize sensor and generate corrections to apply to indicated strains
- Instrument large scale hot-structures test articles



EFPI Strain Sensor

Static Measurement

Extrinsic Fabry-Perot Interferometer (EFPI)



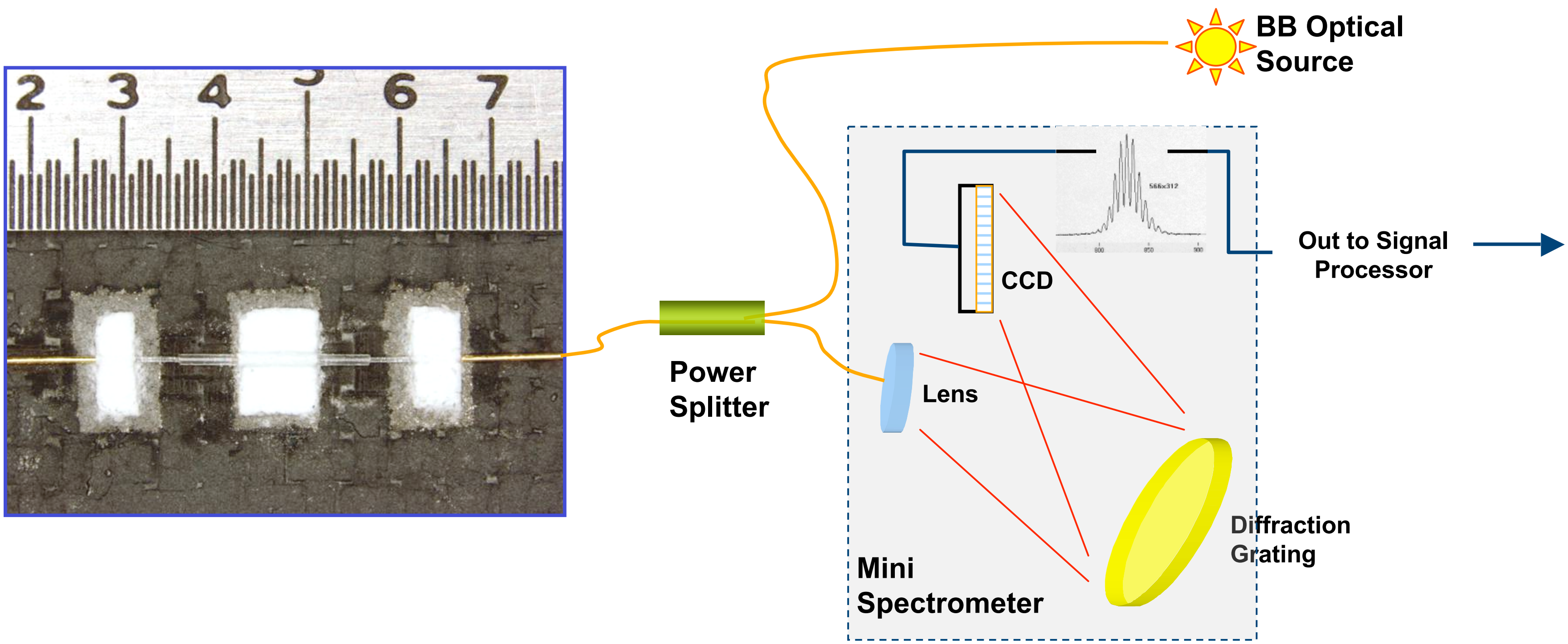
Strain = $\Delta L_C / L_{G\ (initial)}$, where sensitivity = L_G

Apparent Strain (ξapp) = $(\alpha_{sub} - \alpha_{fiber}) * \Delta T$

EFPI Strain Sensor

Static Measurement

Single Mode Interferometer Signal Conditioning



Attachment Techniques

Develop sensor attachment techniques for relevant structural materials

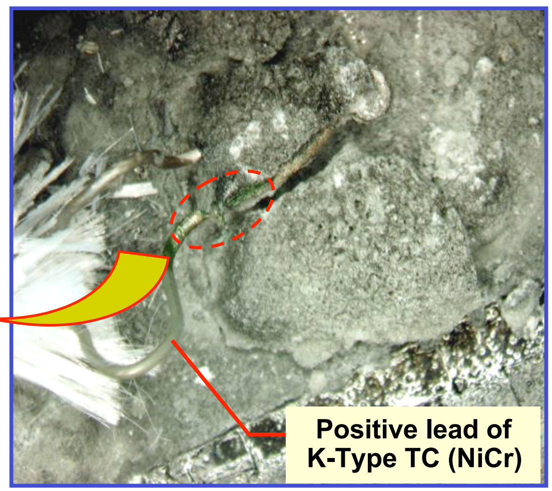
- Derive surface prep and optimal plasma spray parameters for applicable substrate
  - powder media / type, power level, traverse rate, and spraying distance
- Or, optimize / select cement that best fits application
- Improve methods of handling and protecting fragile sensor during harsh installation processes

Attachment Techniques

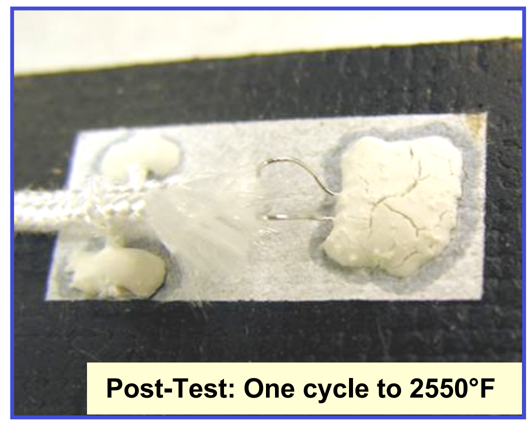
Thermal Spray vs. Cement

Thermal sprayed attachments are preferred even though cements are simpler to apply

- Tests indicate increased gage-to-gage scatter on first cycle
- Cements are often corrosive to TC or strain gage alloys
  - Si / Pt, NaF / Fe-Cr-Al alloys, alkali silicate / Cr
- Cements are more prone to bond failure due to shrinkage and cracking caused when binders dissipate



Positive lead of K-Type TC (NiCr)



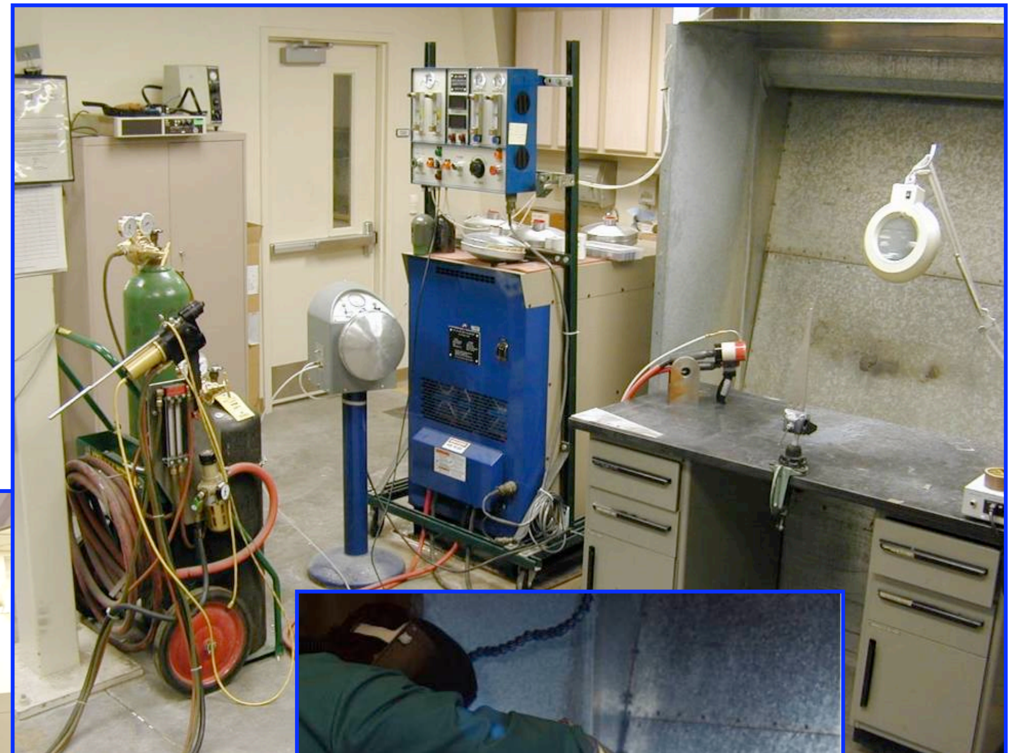
Post-Test: One cycle to 2550°F

Attachment Techniques

Thermal Spray Equipment

Thermal Spray Room

- 80KW Plasma System
- Rokide Flame-Spray System
- Powder Spray System
- Grit-Blast Cabinet
- Micro-Blast System
- Water Curtain Spray Booth

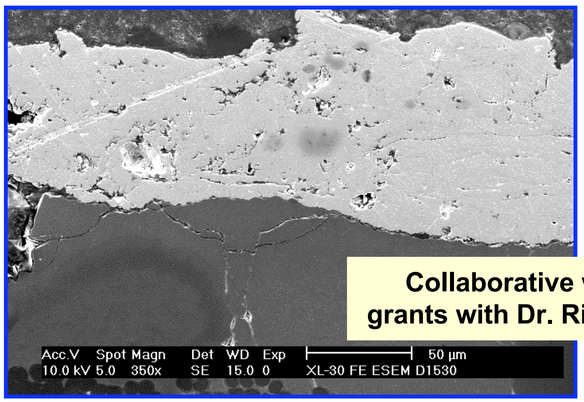


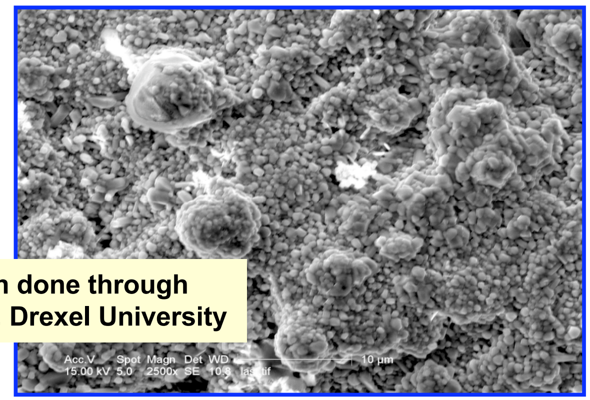
Attachment Techniques

Thermal Spray

Arc-plasma sprayed base coat

- Metallic Substrates: Used to transition high expansion substrate metal with low expansion sensor attachment material (Al_2O_3)
- CMC Substrates (inert testing): High melting-point ductile transitional metals (i.e. Ta, TiO_2, & Mo) more conducive for attachment to smooth surfaces like SiC





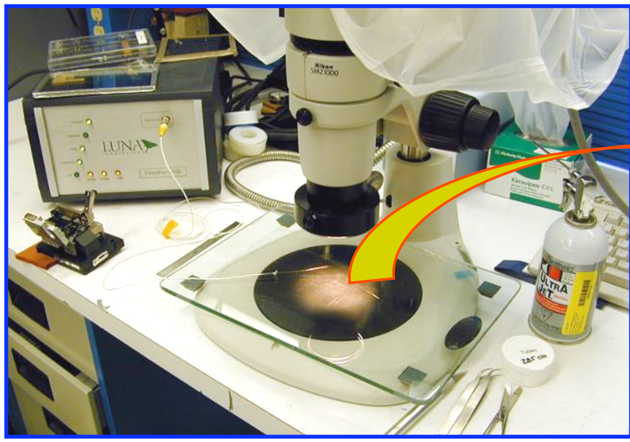
Collaborative work has been done through grants with Dr. Richard Knight, Drexel University

Rokide flame-sprayed sensor attachment

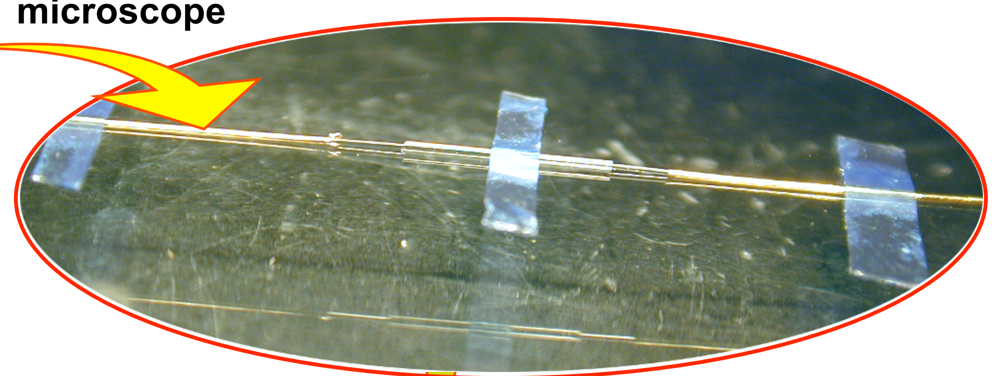
- Applies a less dense form of alumina than plasma spraying
- Electrically insulates (encapsulate) wire resistive strain gages

Attachment Techniques

Fiber Optic EFPI Installation

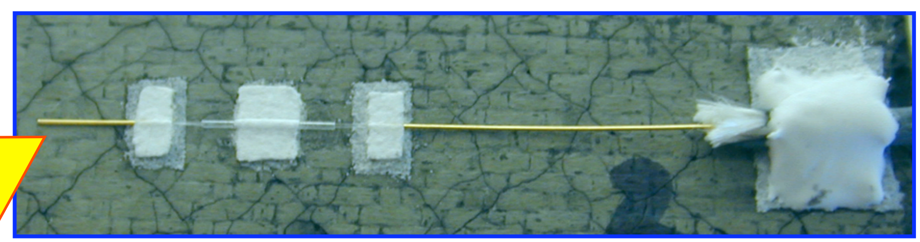


Fabricate sensor under microscope



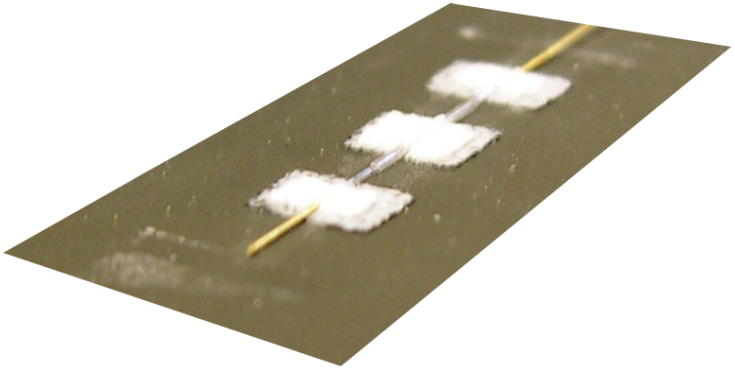
Transfer to thermal sprayed base coat using carrier tape

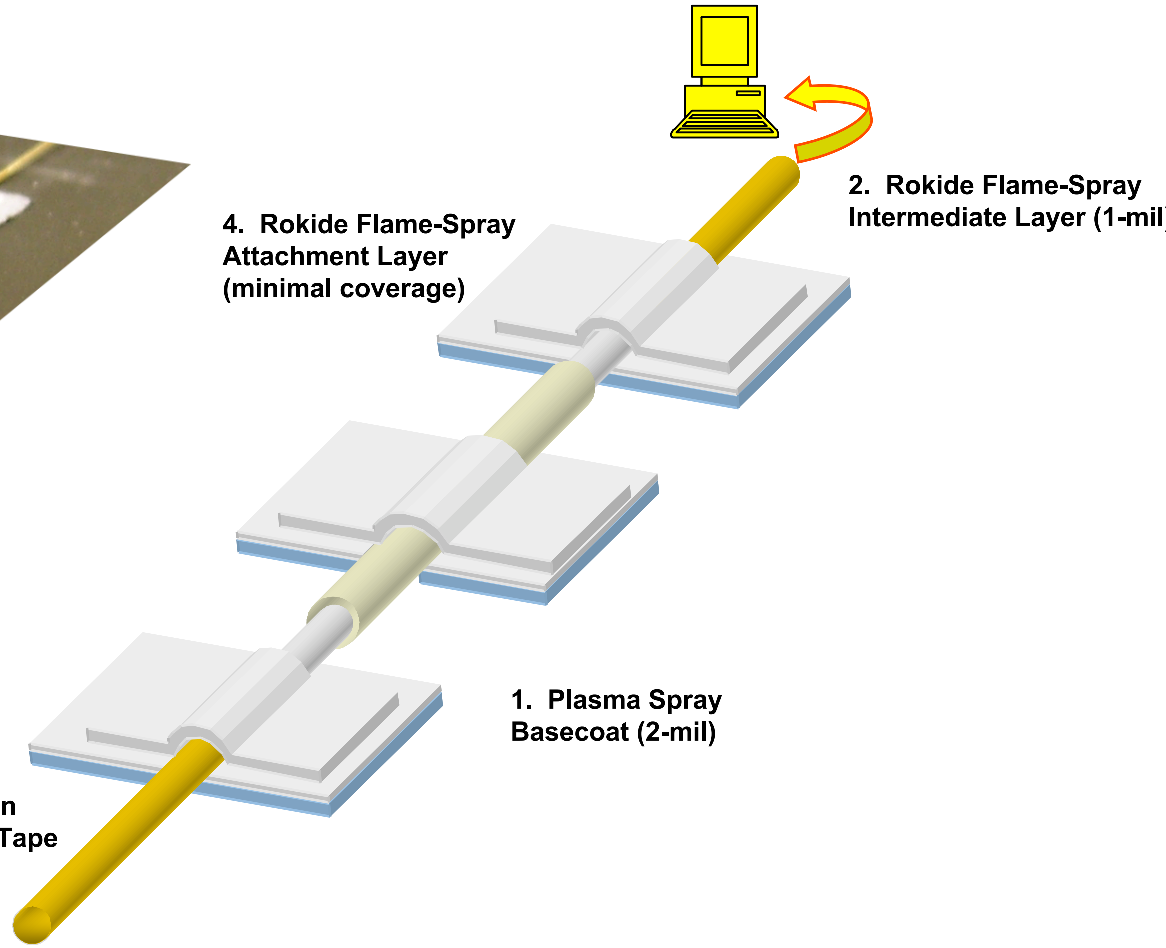
Flame-spray sensor attachment



Attachment Techniques

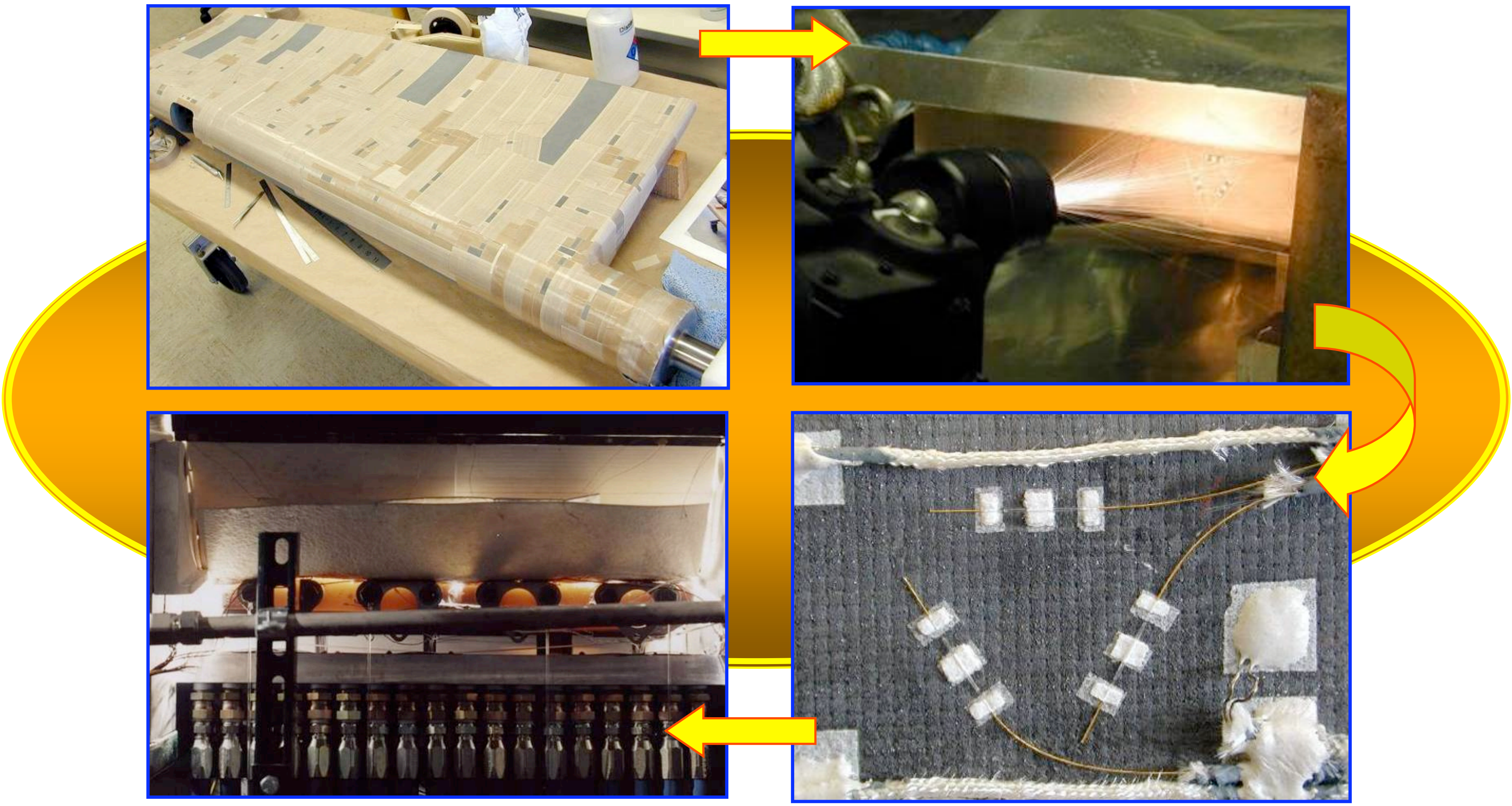
Fiber Optic EFPI Installation





Attachment Techniques

Large-Scale Structures



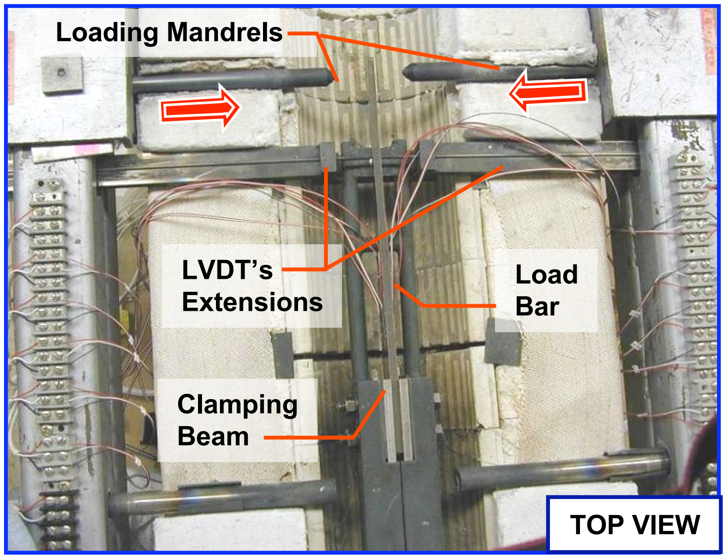
Evaluation / Characterization

Validate and characterize strain measurement

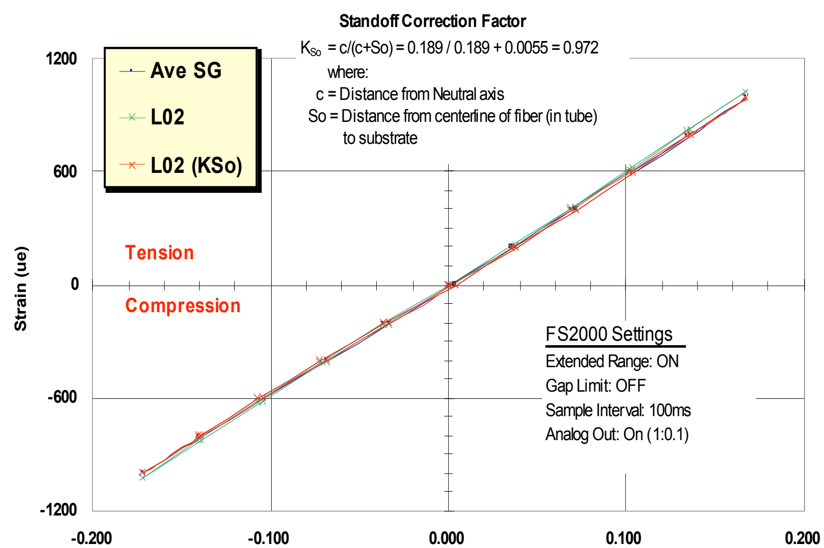
- Base-line / characterize high-temperature strain sensors on monolithic Inconel specimens
  - Known material spec's isolate substrate from inherent sensor traits prior to testing on more complex composites
- Evaluate / characterize sensitivity (GF) of strain sensors on ceramic composite substrates using laboratory combined thermal / mechanical load fixture
- Generate apparent strain curves for corrections on relevant ceramic composite substrates

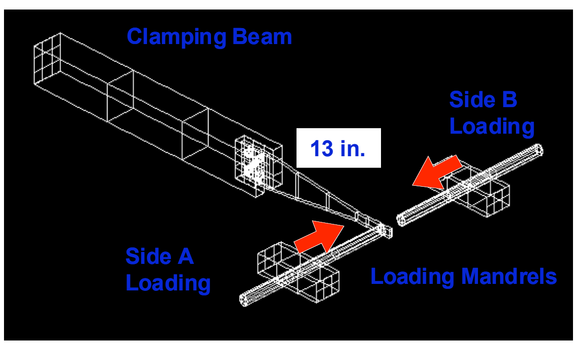
Evaluation / Characterization

Combined Thermal / Mechanical Loading (Obsolete)



EFPI Combined Loading on IN625



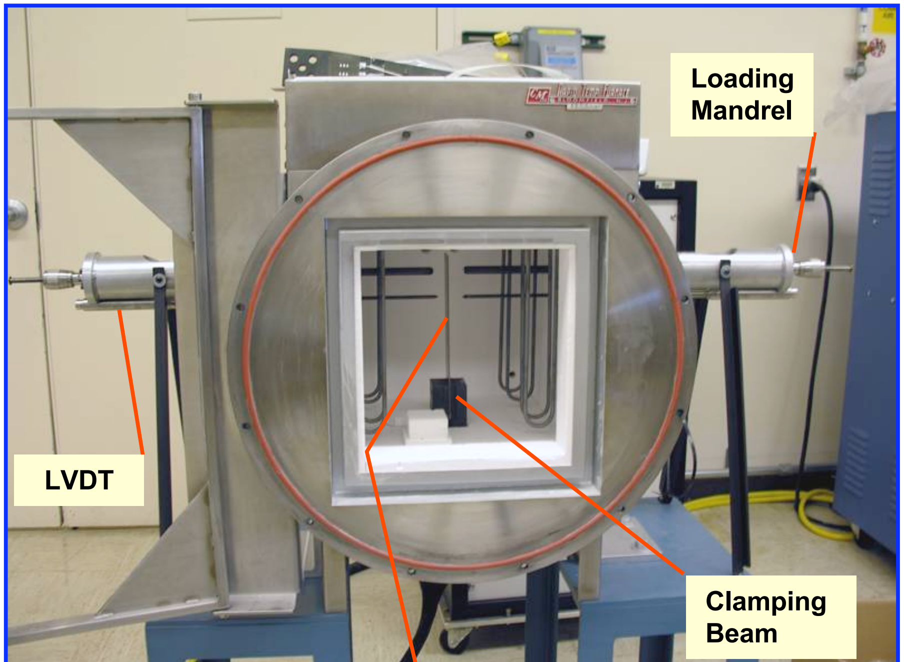


Thermal / Mechanical Cantilever Beam Testing of EFPI's

- Excellent correlation with SG to 550°F (3%)
- Very little change to 1200°F
- Slight drop in output slope above 1200°F
- Maximum gap readability uncertain at upper range temperatures on high expansion material

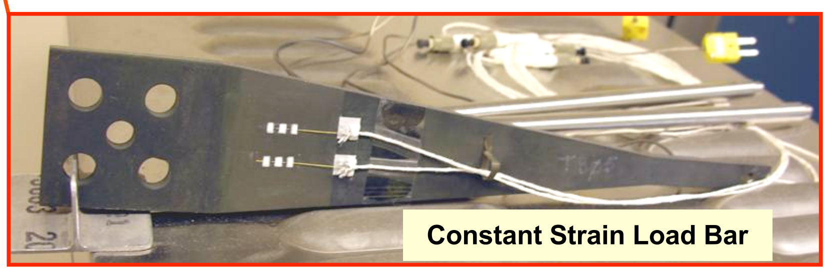
Evaluation / Characterization

Combined Thermal / Mechanical Loading (Current)



Furnace / cantilever beam loading system for sensitivity testing

- Air or inert (3000°F max)
- 12-in^3 inner furnace with Molydisilicide elements
- Micrometer / mandrel side loading
- LVDT displacement measurements
- POCO Graphite hardware for inert environment testing of ceramic composites
- IN625 hardware for metallic testing in air
- Sapphire viewing windows



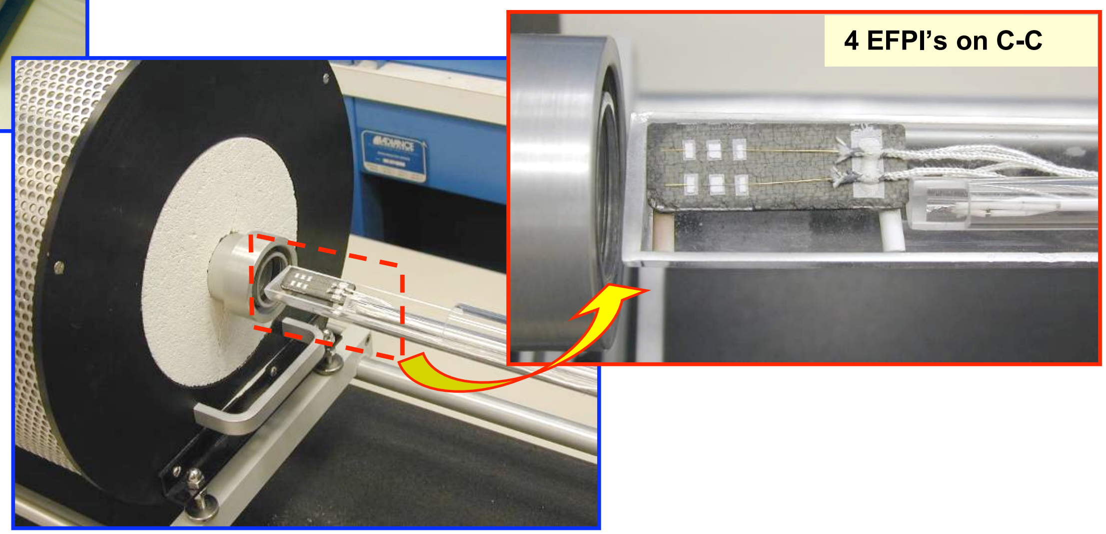
Evaluation / Characterization

Dilatometer Testing

Sensor Characterization

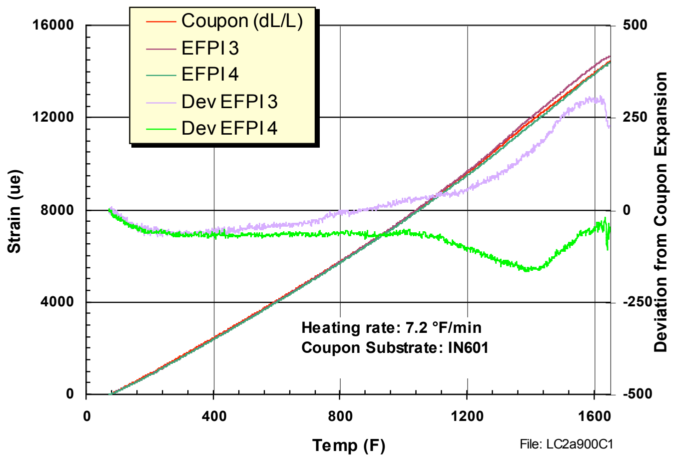
Air or inert (3000°F max)

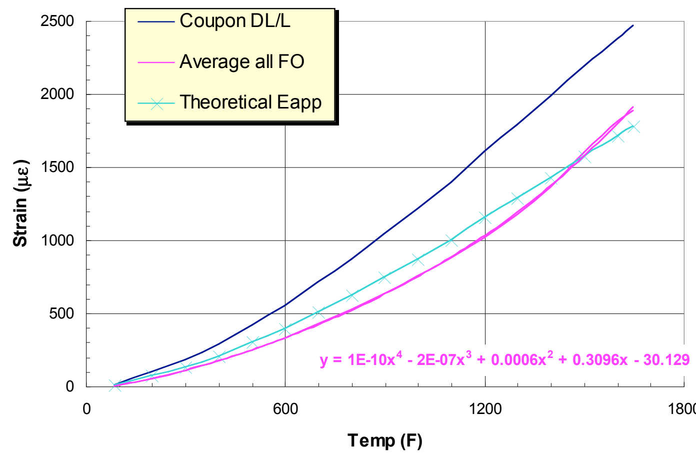
- Evaluate bond integrity
- Generate ξapp correction curves
- Evaluate sensitivity and accuracy
- Evaluate sensor-to-sensor scatter, repeatability, hysteresis, and drift



Evaluation / Characterization

EFPI Apparent Strain





ξ_{app} Correction: The removal of inherent sensor traits and substrate expansion from indicated strain to acquire true applied strains or thermal stresses

$$\xi_{true} = \xi_{indicated} - \xi_{app}, \text{ where } \xi_{app} = (\alpha_{sub} - \alpha_{fiber}) * \Delta T$$

- Inconel (LH chart): Expansion ratio between IN and Si so large no sensor correction *required* (output primarily substrate expansion, CTE * ΔT)
- CMC (RH chart): Small CTE ratio between C-SiC and Si requires a correction for the growth in fiber (lessening cavity gap) verses the expansion of the substrate
- Graphs demonstrate how well actual ξapp curves followed theoretical

Future Fiber Optic Testing

- Test single-mode silica EFPI's in combined thermal / mechanical load fixture on C-C and C-SiC substrates
- Develop Sapphire strain sensor (multi-mode)
  - Keep precise parallel gap faces aligned throughout process
    - Develop precision transfer method (i.e. temporary alignment fixture)
  - Test in laboratory thermal / mechanical loads fixture to > 2500°F
- Test and evaluate high-temperature fiber Bragg Gratings for use as strain and temperature sensors
- Attach and evaluate high-temperature heat flux gage
- Evaluate weldable (shim) EFPI strain sensor on Inconel