Certification of Discontinuous Composite Material Forms for Aircraft Structures – YEAR I

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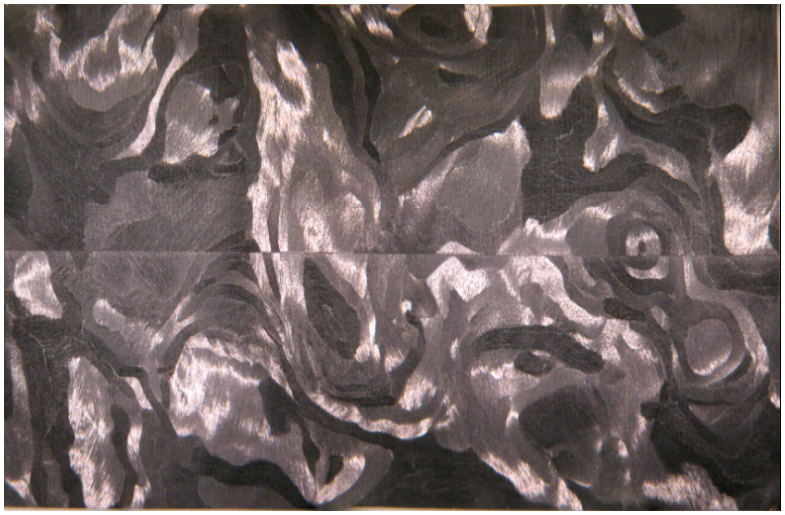

AMTAS Fall Meeting
November 2008

Certification of Discontinuous Composite Material Forms for Aircraft Structures – YEAR I

Motivation

- *New HexMC material form is behaving very differently from continuous fiber tape composites*

Benefits to Aviation

- *Streamline certification process:*
  - *possibility of TSO*
  - *increase confidence in analysis methods and move away from current certification-by-test strategy*

Objective

- *Identify physical behaviors, develop analysis methods, generate design guidelines, and summarize in certification strategy*

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Principal Investigators

- *Dr. Paolo Feraboli (AA)* *Dr. Mark Tuttle (ME)*

Students supported

- *Tyler Cleveland (MSAA/ PhD)* *Francesca Paltera (MSME/PhD)*

FAA Personnel Involved

- *Mark Freisthler, Dr. Larry Ilcewicz, and Curt Davies*

Industry Participation

- *Dr. Bill Avery (Boeing Structures Technology)*
- *Lyle Deobald, Bill Bielawski (Boeing Methods and Allowables)*
- *Dr. Patrick Stickler (Boeing Technology)*
- *Dave Barr, Bruno Boursier (Hexcel Co.)*
- *John Halpin, Hank Offermann (consultants)*

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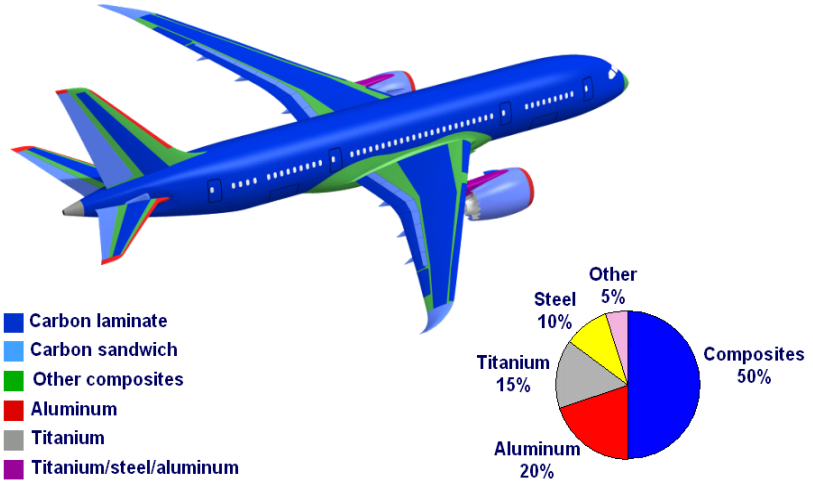
Boeing 787 out-of-autoclave components

- CFRP-intensive Boeing 787 Dreamliner: weight, rate and cost all keys to success
- Circumferential frames – Bulk resin infusion
- Aft pressure bulkhead and landing gear brace – Liquid infusion
- Moveable trailing edge, inboard flap - RTM
- Window frames – HexMC



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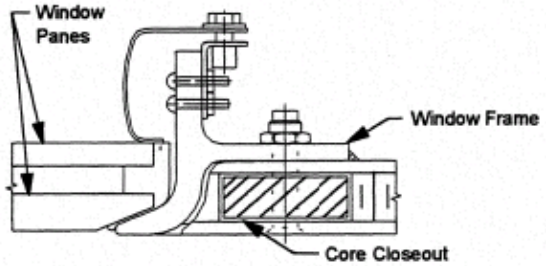
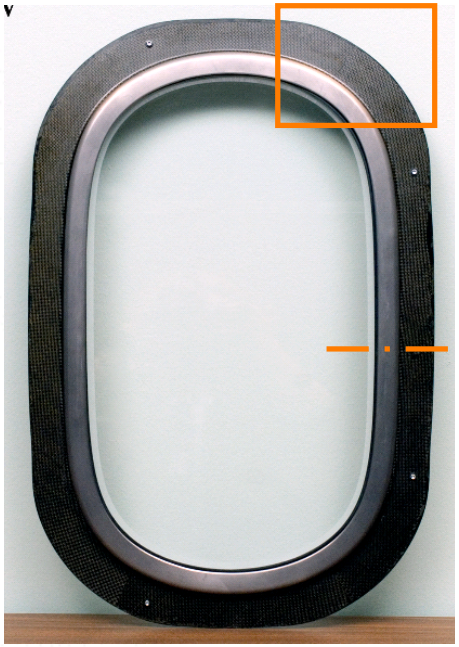
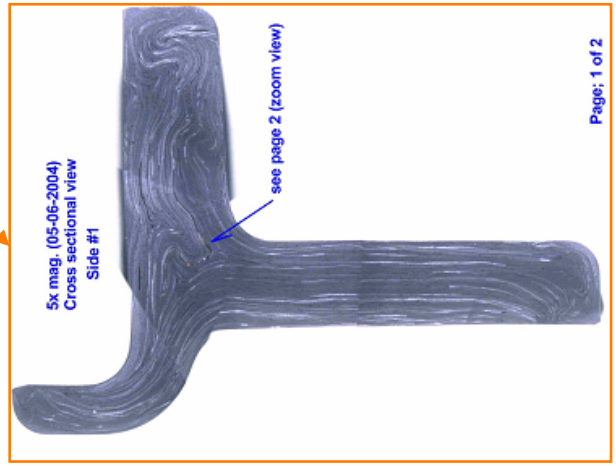
787 HexMC window frames

- Discontinuous carbon/ epoxy prepreg tape

  AS4/ 8552 chopped and rolled into sheets
- 50 mm long x 8 mm wide chips
- Compression molded







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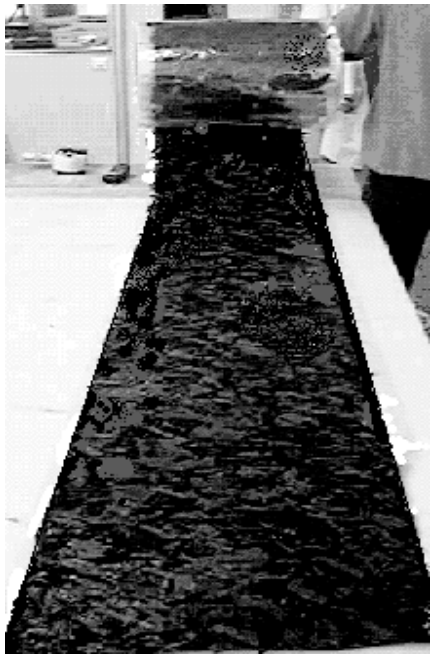
HexMC chip characteristic

- Prepreg chips 2.0 in. x 0.33 in.
- High grade fibers/ resins
- Unidirectional tape
- Per-ply thickness 0.065 in.
- Compression molding process
- RC ~40% by weight

HexMC laminate characteristic

- Quasi-isotropic properties
- Per-ply thickness 0.055 in.
- RC ~32-34% by weight



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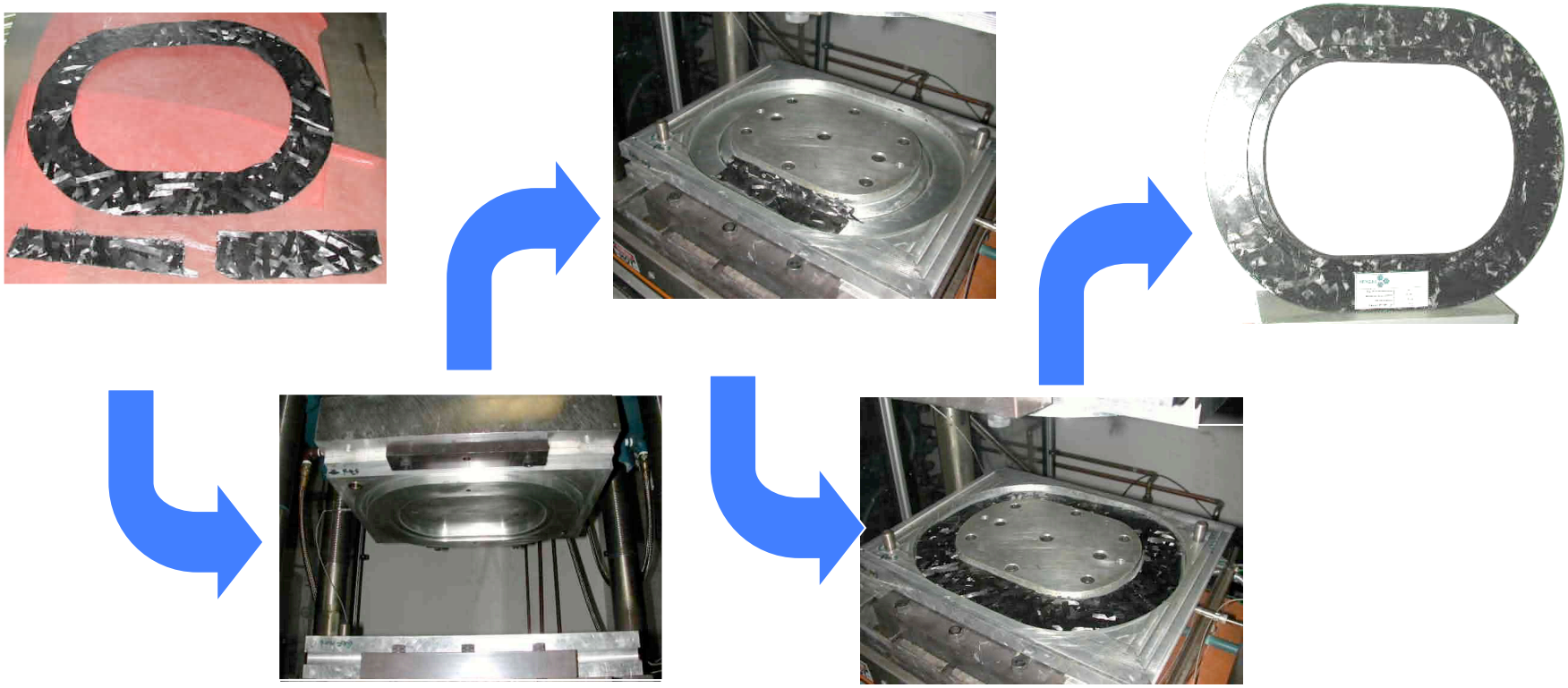
Low-flow molding vs. High-flow molding

- Yields highest performance - only one of interest in this activity



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Desirable behaviors

- Material is quasi-isotropic in the plane, and strength variation is ~9%
- Material retains high strength in presence of holes, notches
- Material is highly resistant to moisture and temperature
- Material has same modulus as quasi-isotropic continuous tape
    - Material is ideal for stiffness driven designs, as well as for applications where the loading or geometry is complex

Undesirable behaviors

- Best suitable for non-minimum gage parts
- Nearly 50% of specimens with ¼ in. diameter holes fail away from the hole
- Unusually high variation in the modulus measurements
    - All traditional analysis methods (semi-empirical or FEA) and related allowables are no longer valid.

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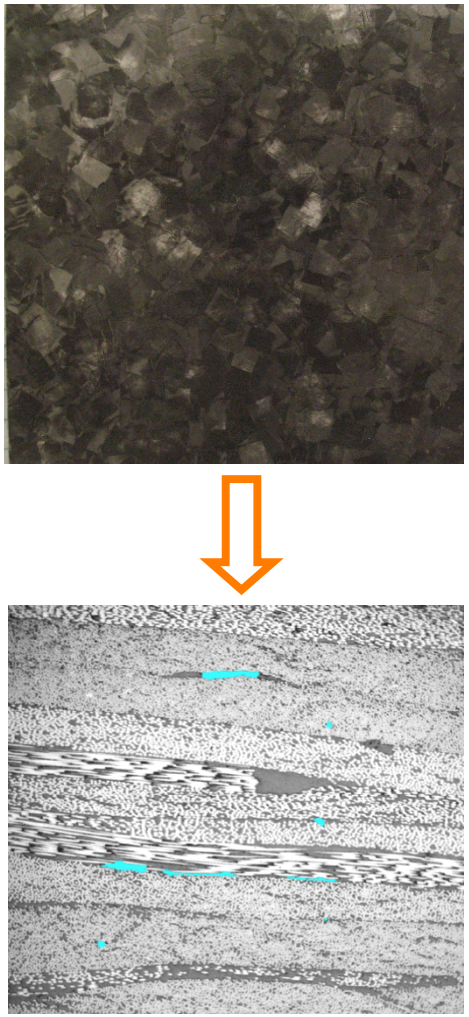
Background research

- 3-year (Feb 2006-Dec 2008) Boeing 787 Technology Program
- PI Paolo Feraboli and Boeing POC Patrick Stcikler
- Contributions from Eleof Peitso (MSAA June 2008), Dr. John Halpin, Dr. Al Miller
- Partial focus on HexMC
- Prepreg can be slit and chopped in the lab to make HexMC-like systems (similarly to Halpin+ Kardos research from 1970's)
- Voids are present as concentrated unwetted areas (air pockets) rather than diffused porosity



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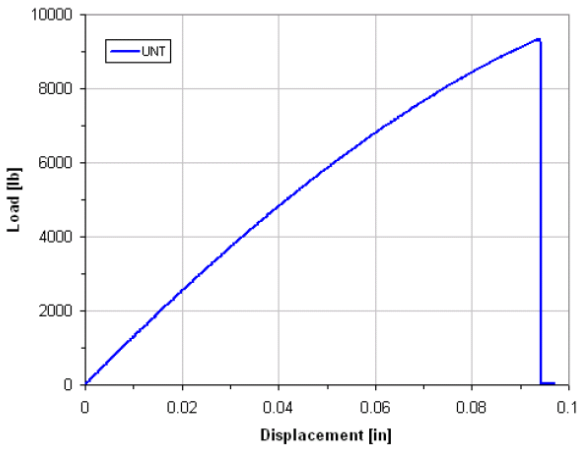
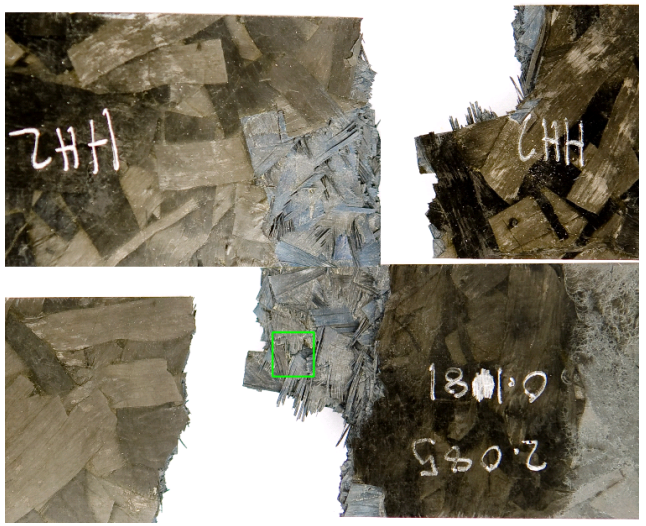
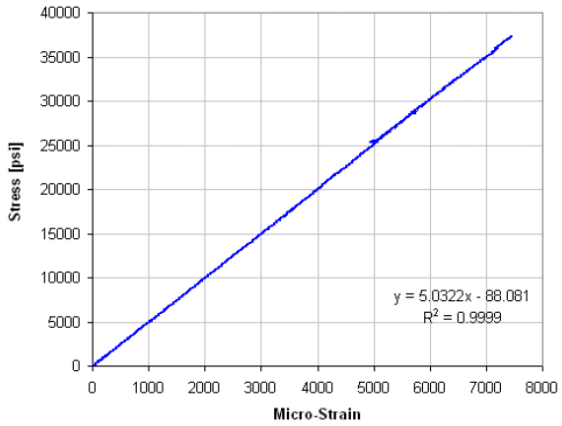
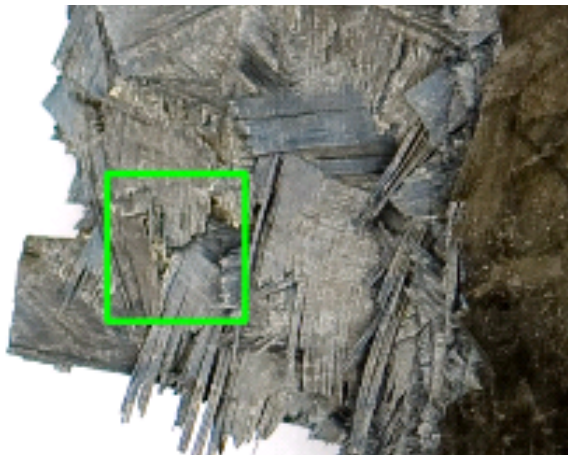
Tension failure

- Linear stress-strain curve
- Extensive fiber breakage observed









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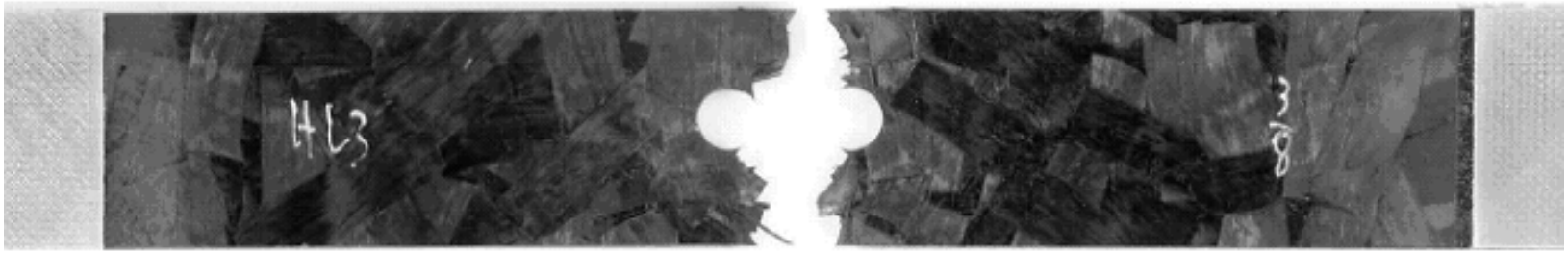
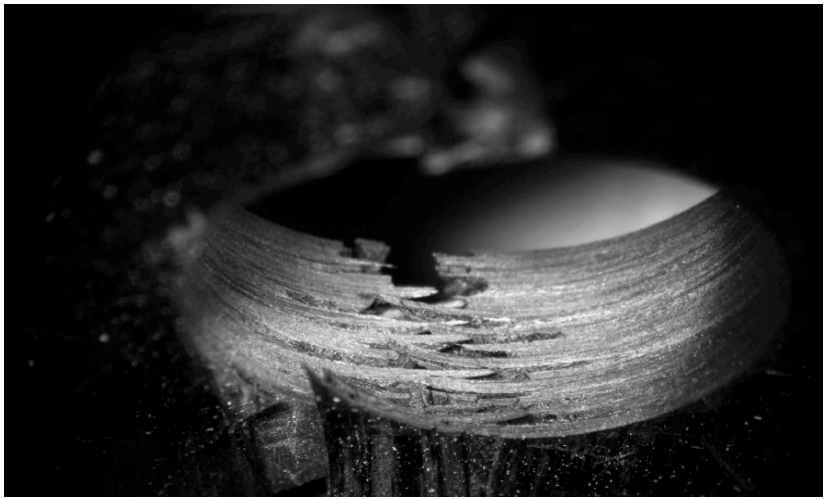
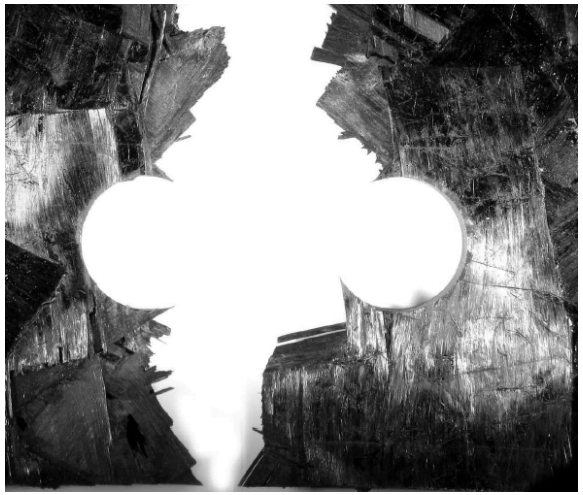
Open-hole tension net-section failure

- Open-hole failure modes identical to unnotched
- 3/8 in. diameter hole







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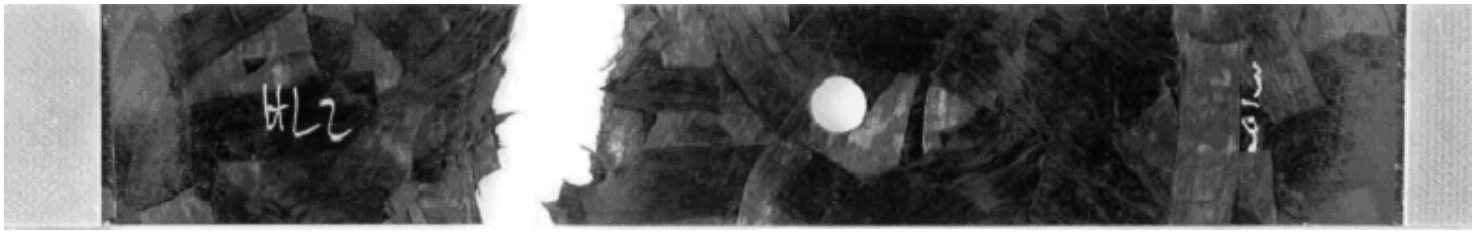
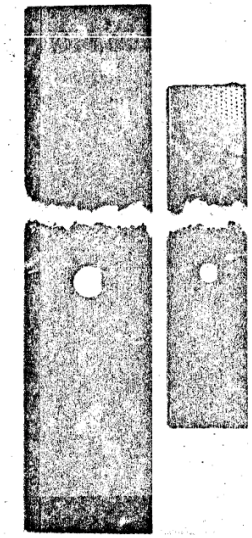
Open-hole tension gross-section failure

- Same 3/8 in diameter hole
- Similar observation by Kardos and Halpin in 1970 report for Navy





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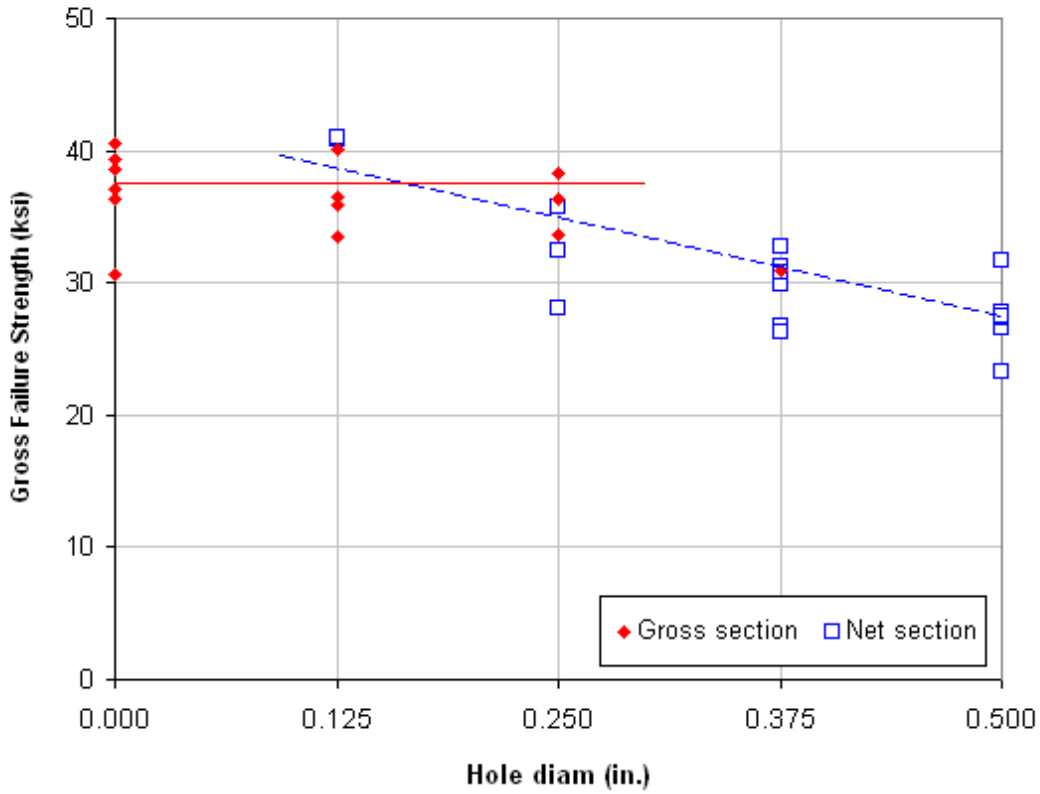
Gross-section strength

- Variation of strength with hole diameter
- For constant W, there is a given D for which failure transitions to pure net section
- Strength decrease is linear and mild, unlike continuous laminates



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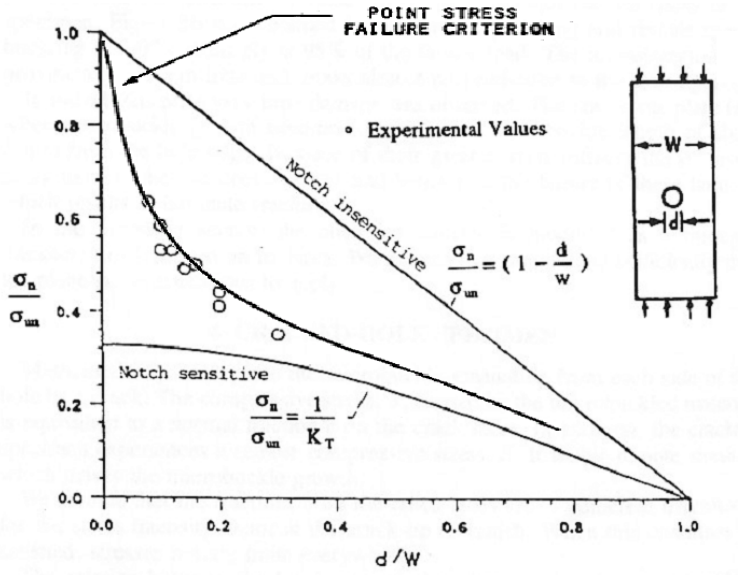
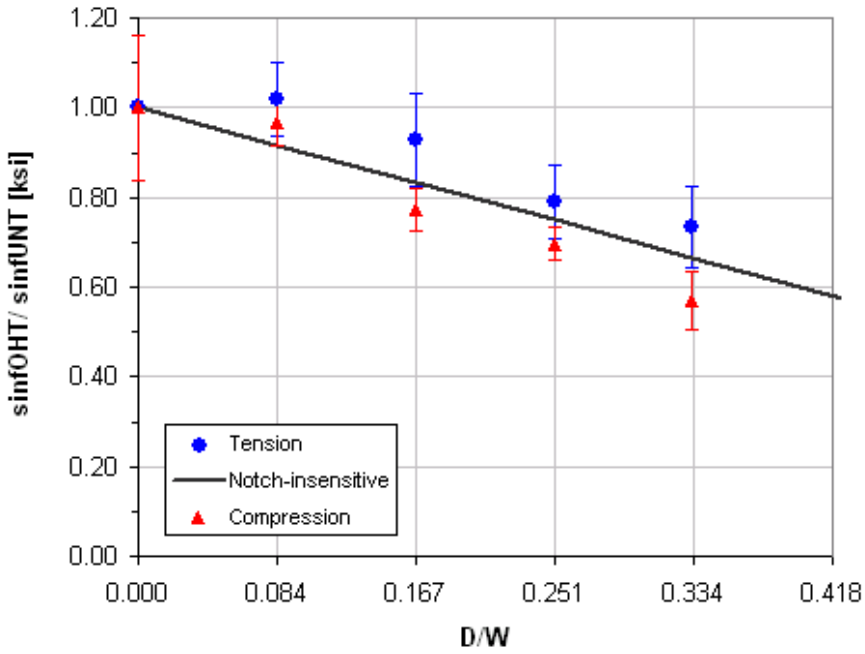
Open-hole strength vs. D/W ratio

- This material form appears to be “notch-insensitive”
- 1:1 line shifted to the right: built-in stress concentration **(inherent material K_t)** due heterogeneous nature





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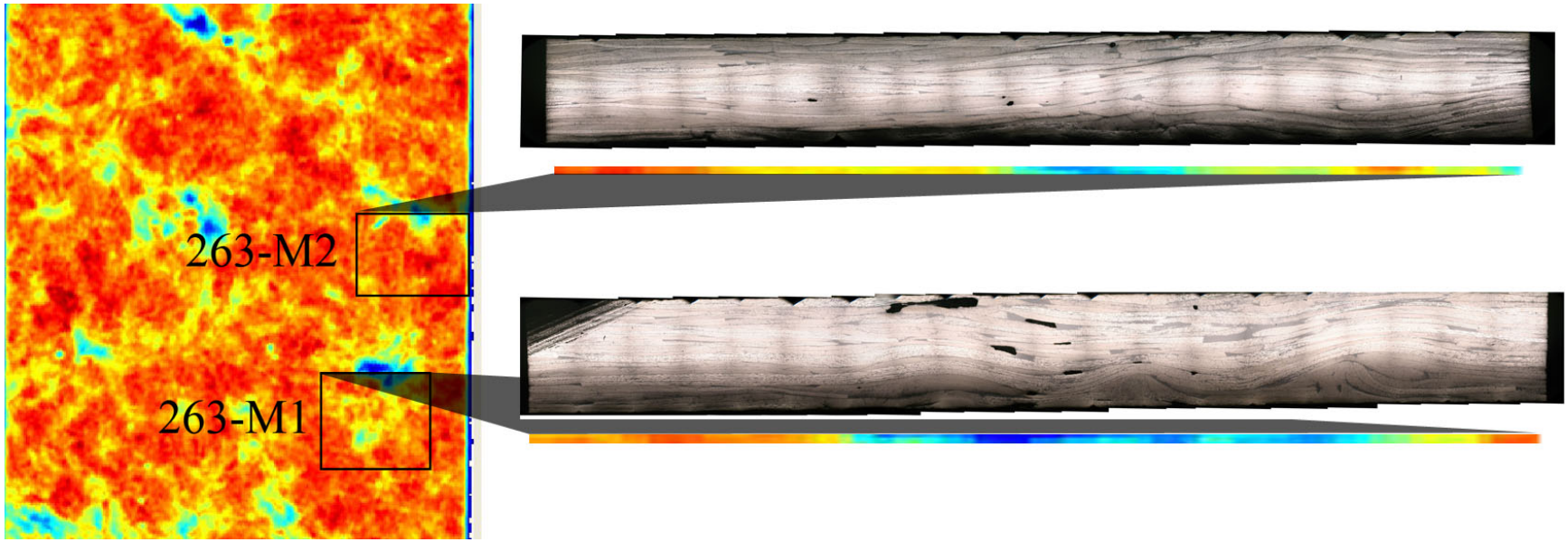
Ultrasonic inspection

- C-scans reveal presence of areas of signal attenuation
- Large “hot-spots” can be due to large entrapped air (macro-voids)



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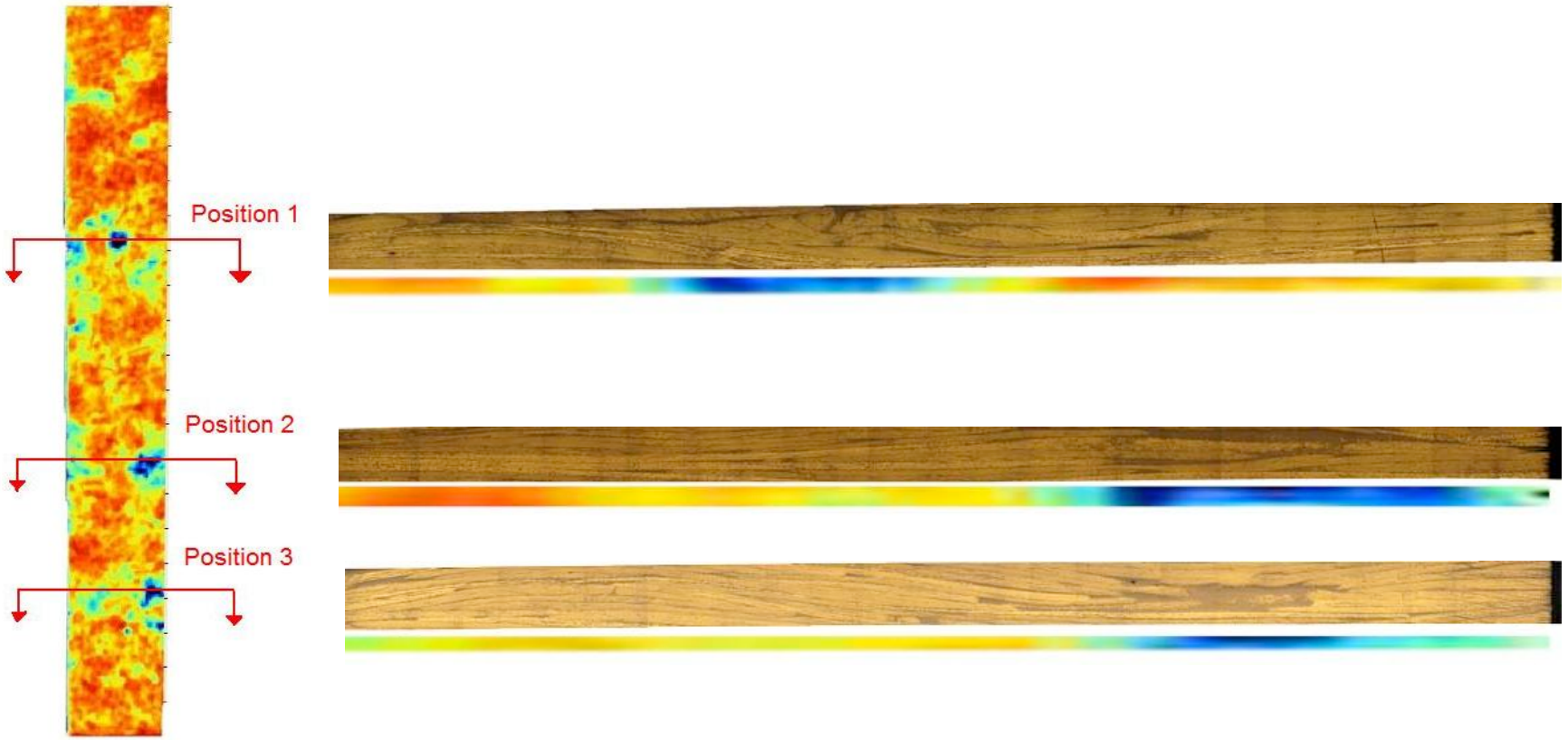
Microsections at hot-spot locations

- Resin-rich areas or chip swirls occur at the location of the hot spots



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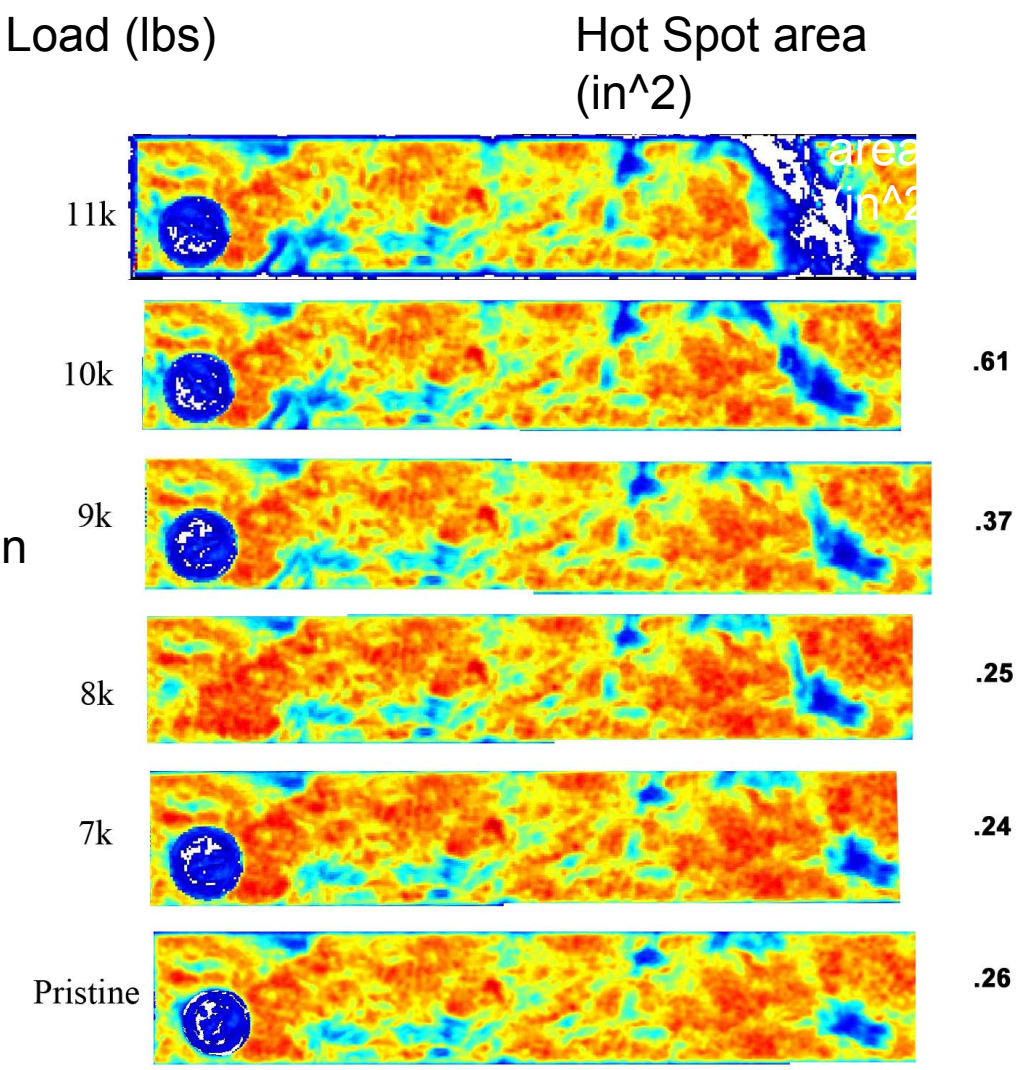
UNT Incremental loading and ultrasonic survey

- Specimens were loaded incrementally
- Scanning occurred after each load step
- The hot spots grow as loading increases
- Each failure occurred in a location with hot spots, however the largest hot spot did not always precipitate failure



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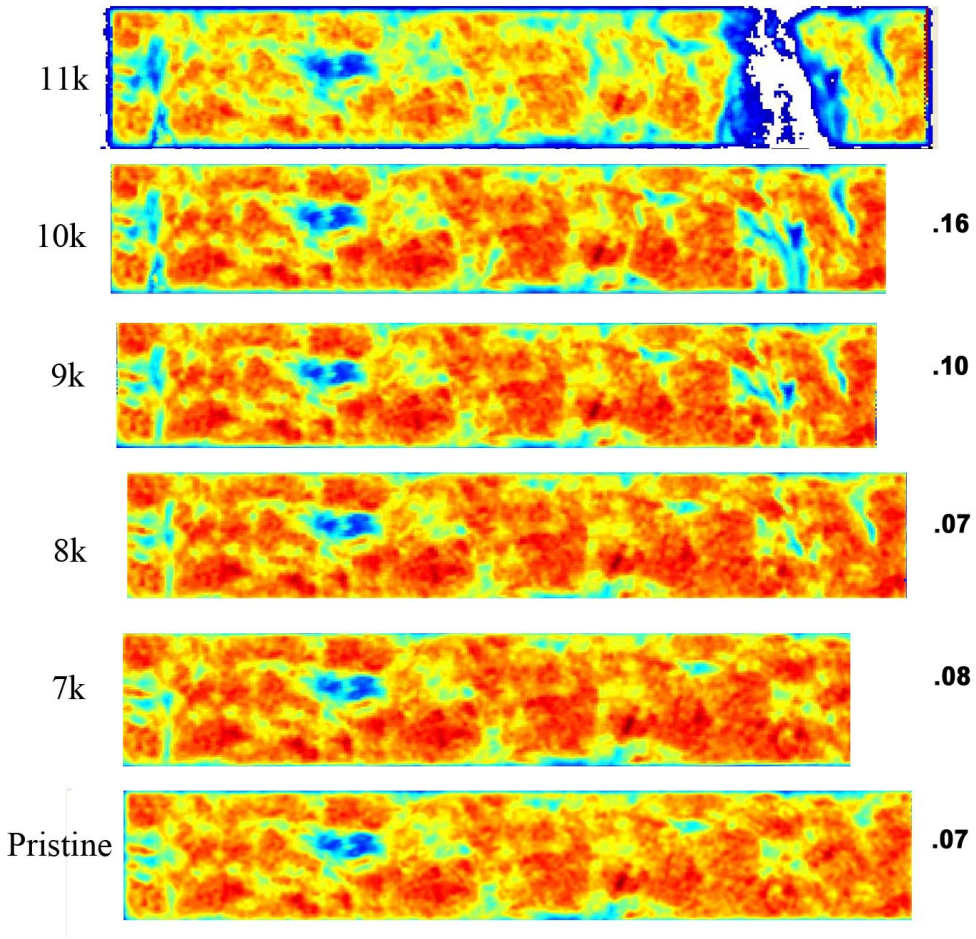
UNT Incremental loading and ultrasonic survey



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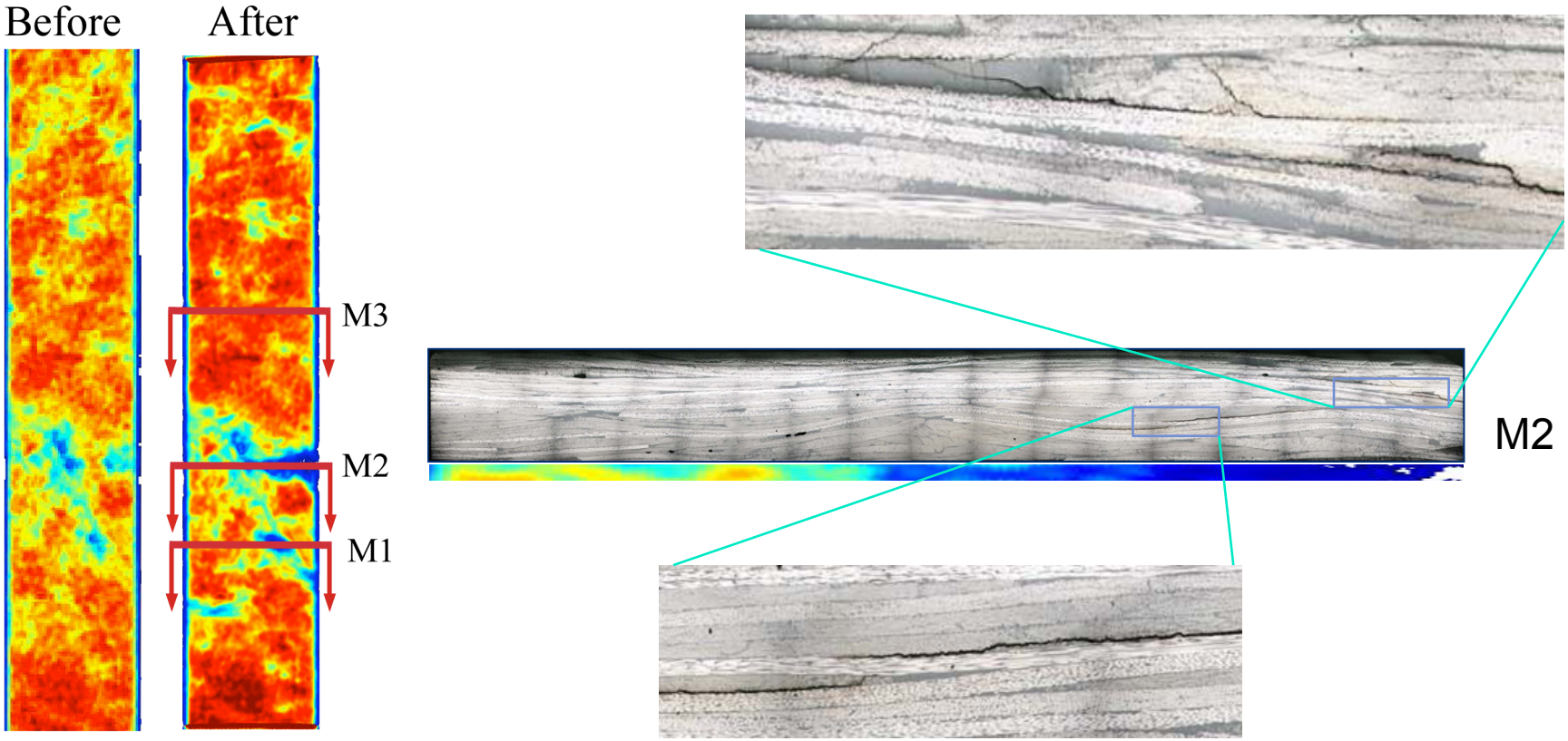
Partial Loading:

- A specimen was loaded to 8000lbs and C-Scanned before and after
- Hot spots were observed to grow on the scans
- Microscopy revealed cracking in hot spot regions



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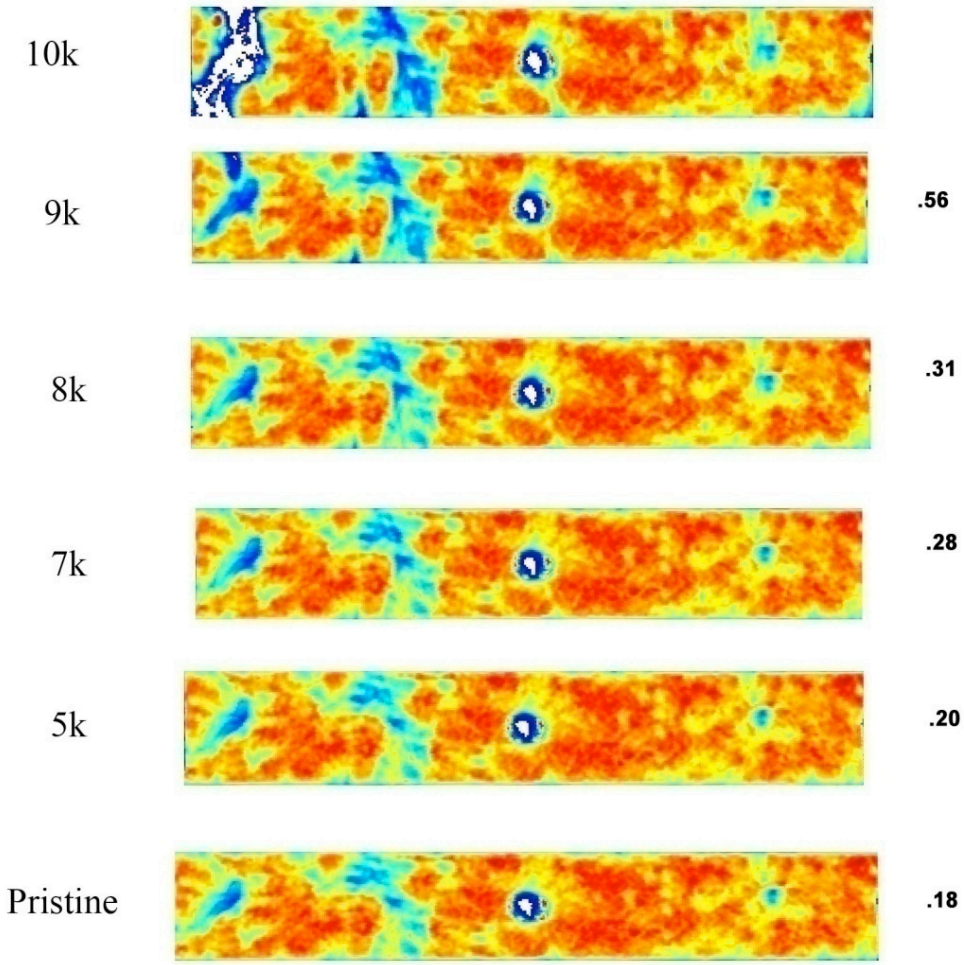
OHT Incremental loading and ultrasonic survey

- Once again hot spot growth is noted
- Damage around hole not visible on C-scan
- Open hole specimens failed away from the hole
- Damage leading to failure was visible in C-scan



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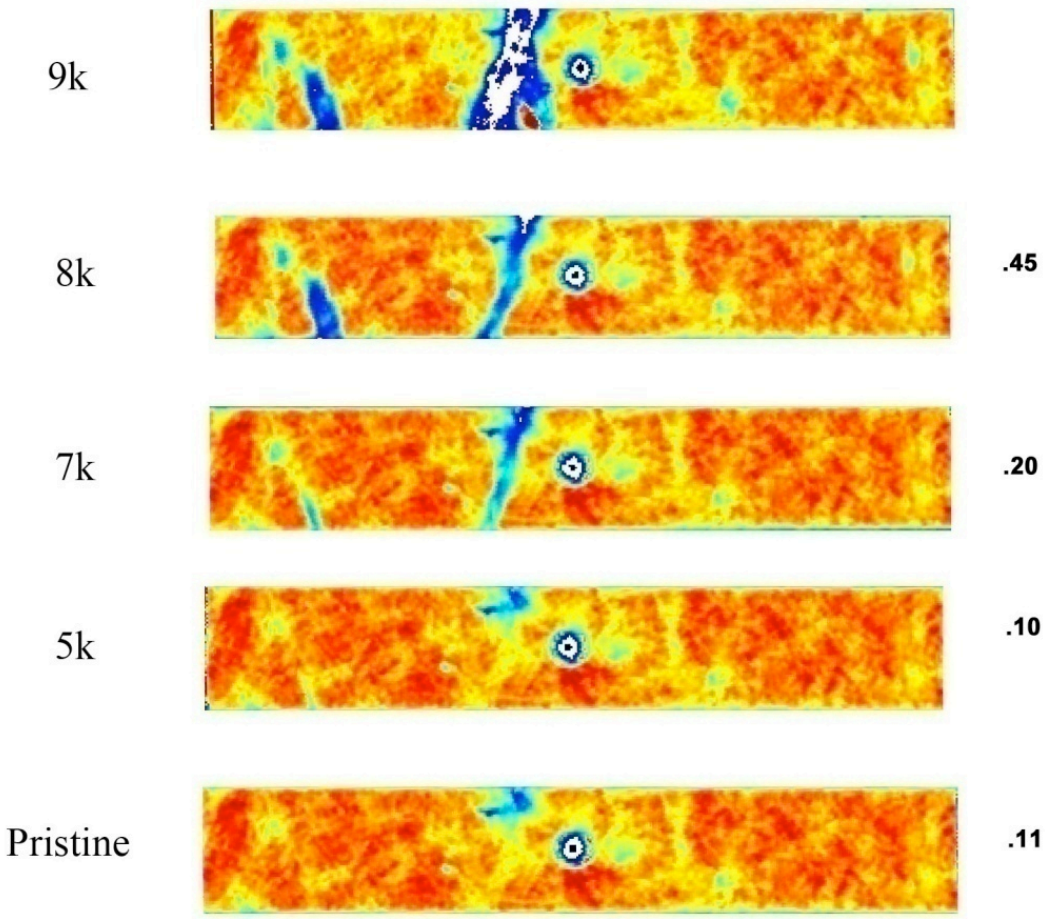
OHT Incremental loading and ultrasonic survey



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SUMMARY

- Hot spots are composed of resin rich areas and voids
- Hot spots indicate some weak areas (8/14 tensile specimens failed at hot spots)
- Incremental loading shows that hot spots can act as weak areas which can initiate damage growth
- However, hot spots do not account for all large stress concentrations

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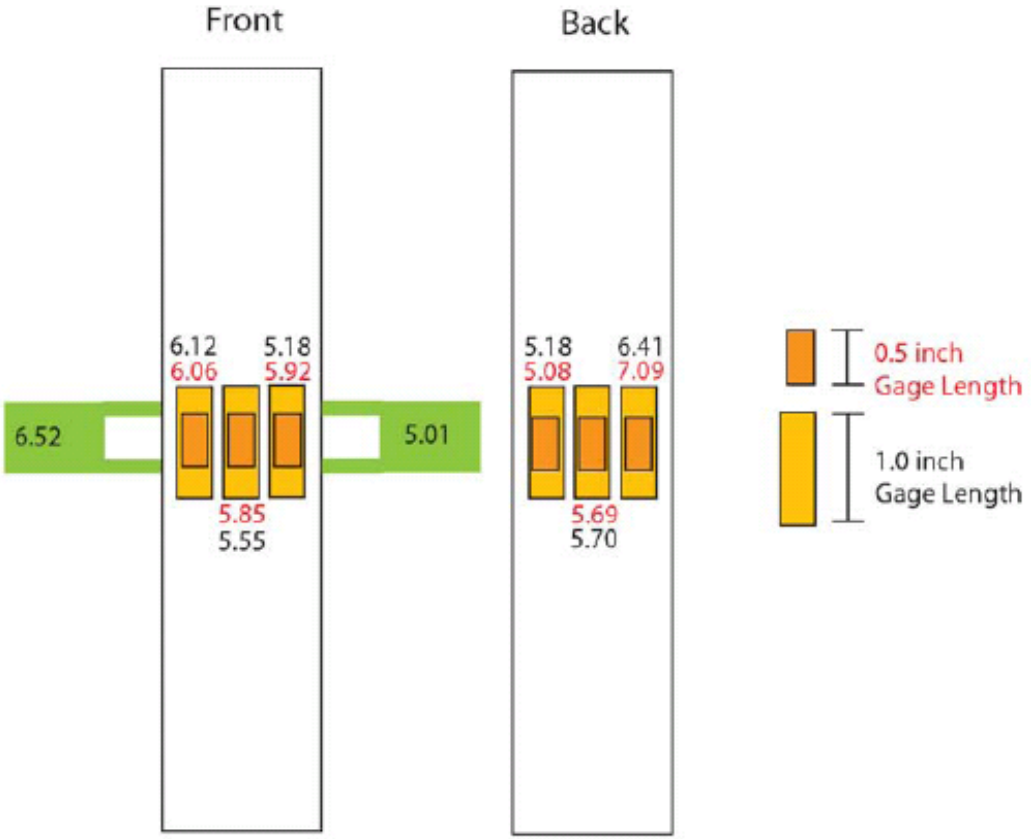
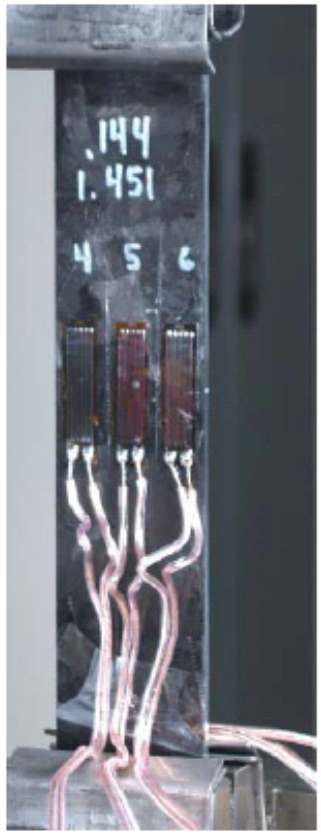
Modulus measurement





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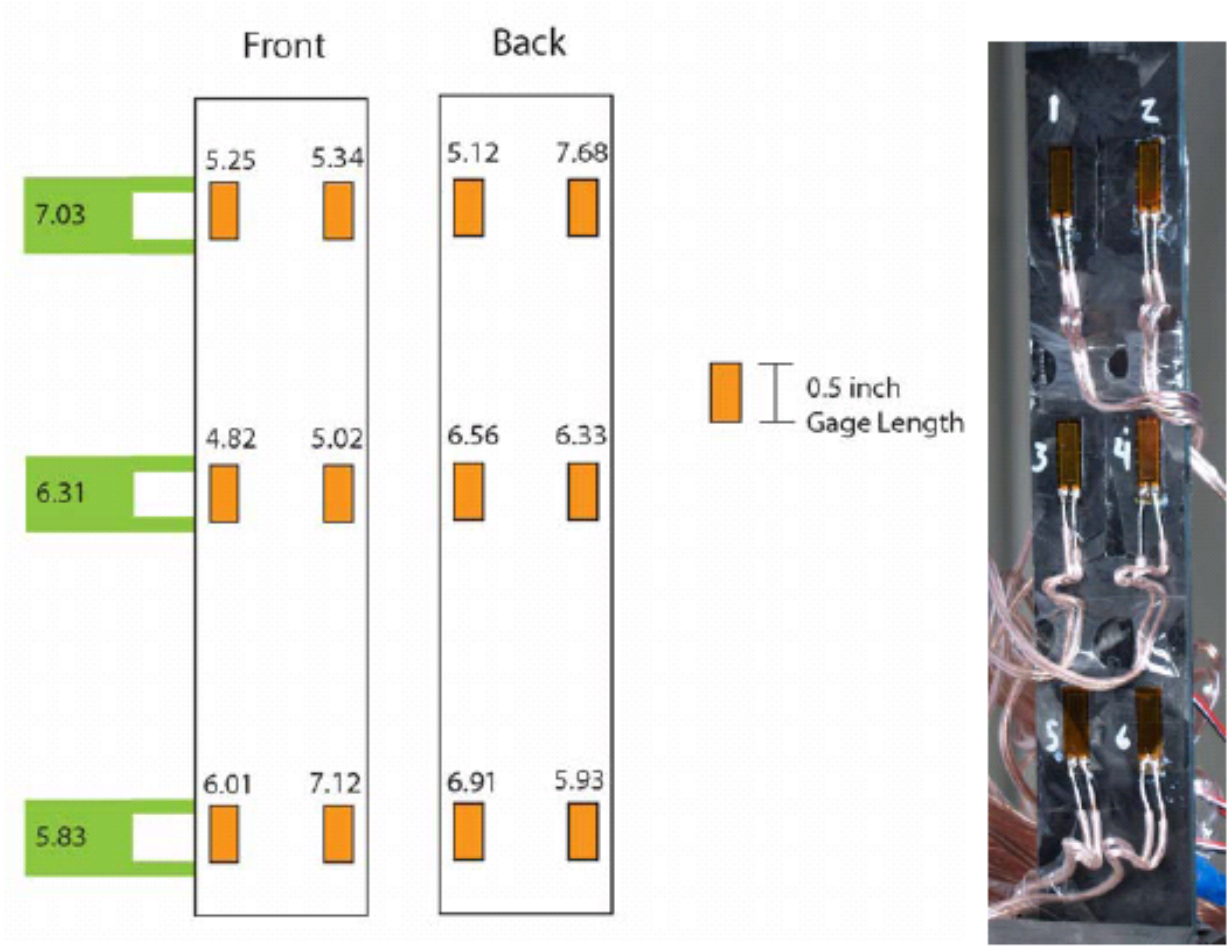
Modulus measurement



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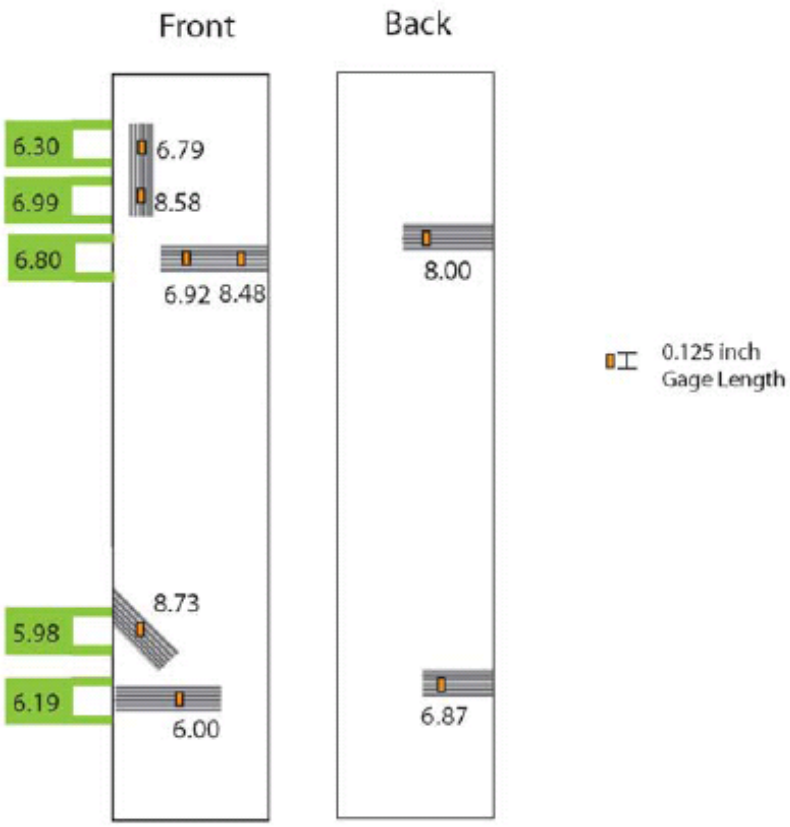
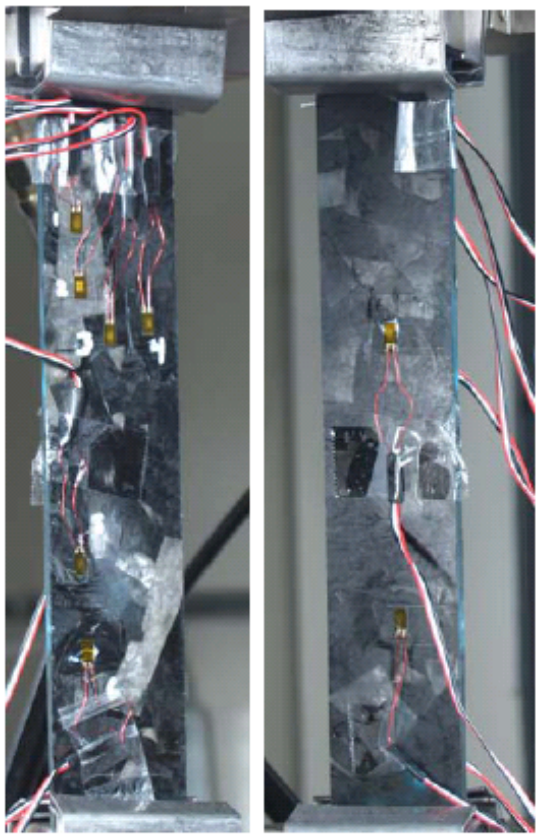
Modulus measurement





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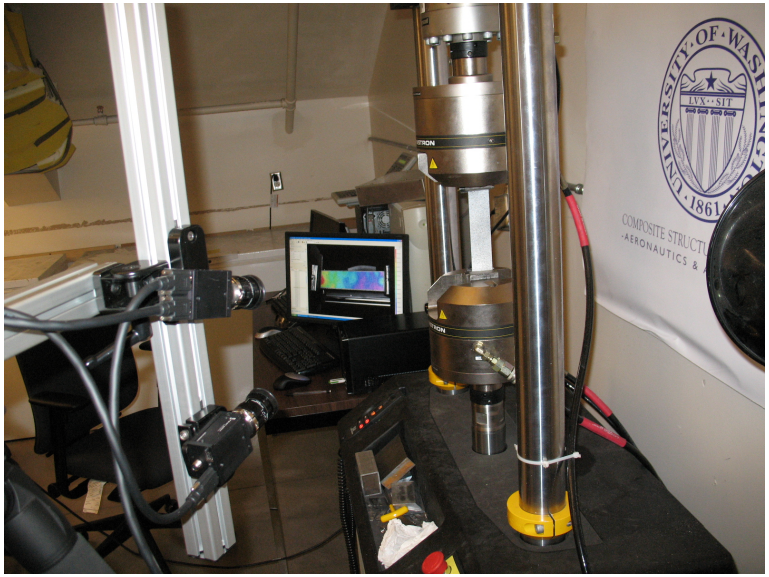
Digital image correlation (DIC)

- Black speckles are applied to a white background on one side of a specimen
- Images are taken during testing by a pair of digital cameras
- Post processing allows to measure full field strain



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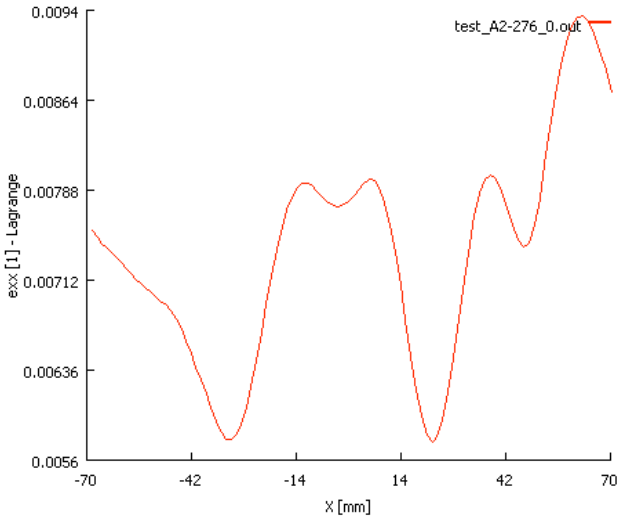
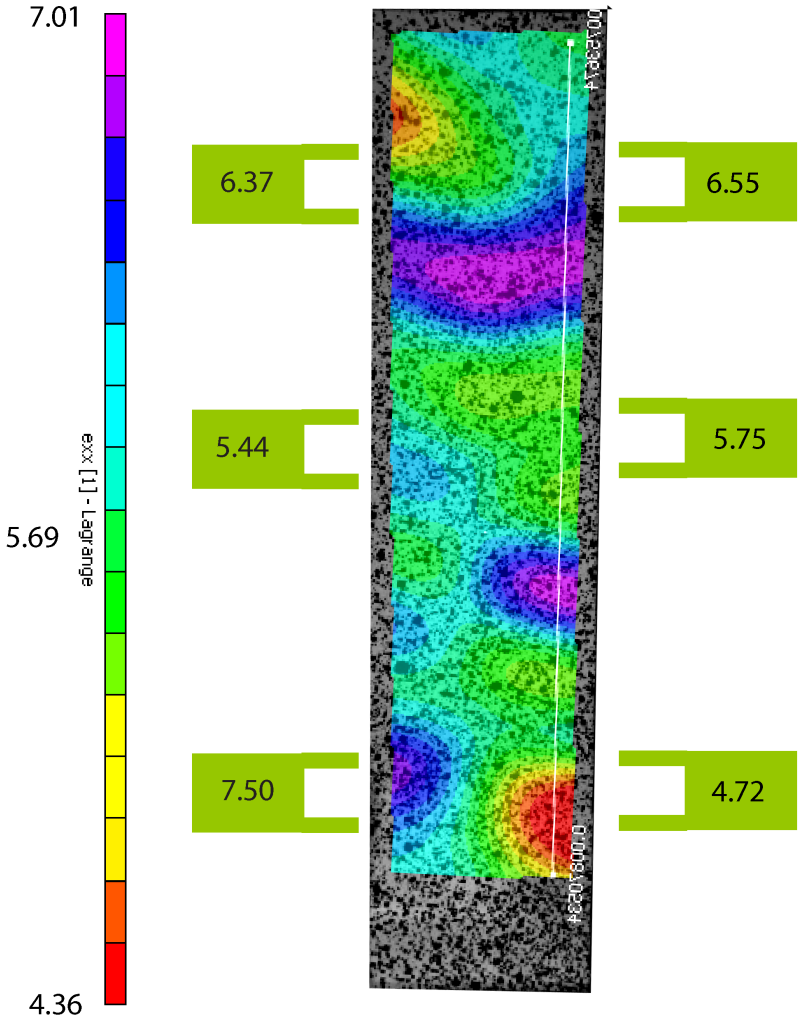
Modulus measurement

- 3D digital image correlation system utilized to monitor surface displacements
- Full-field strain measurement yields great insight in variation as well as average





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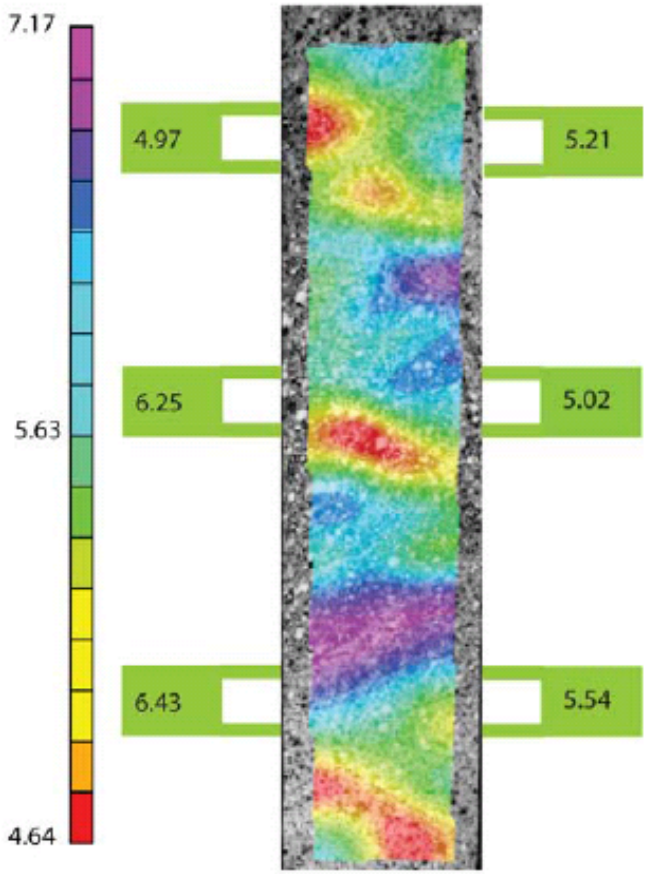
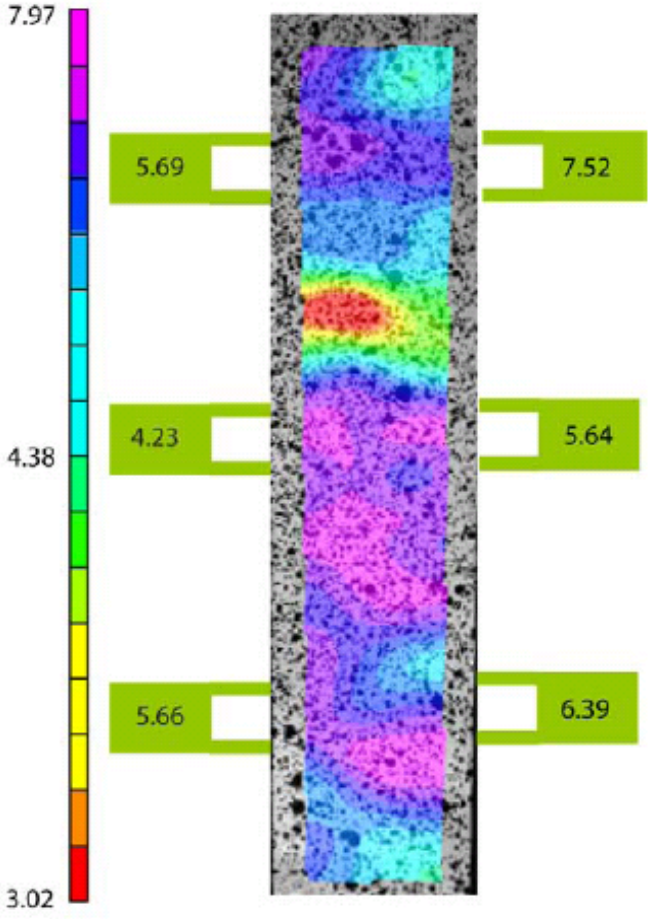
Modulus measurement





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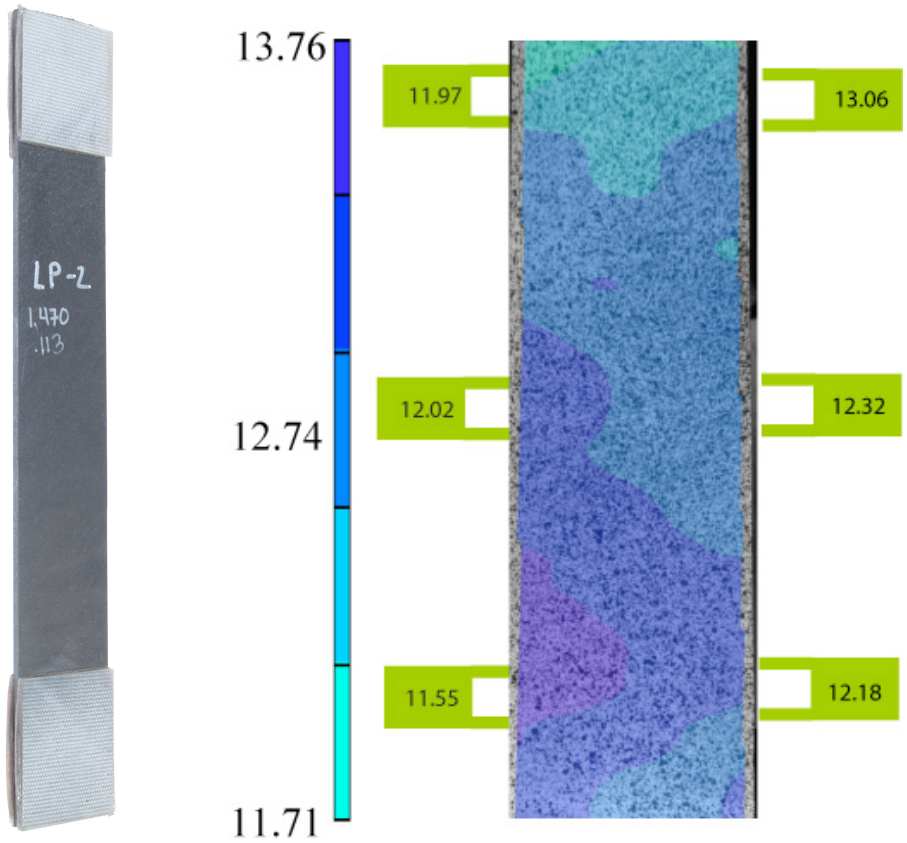
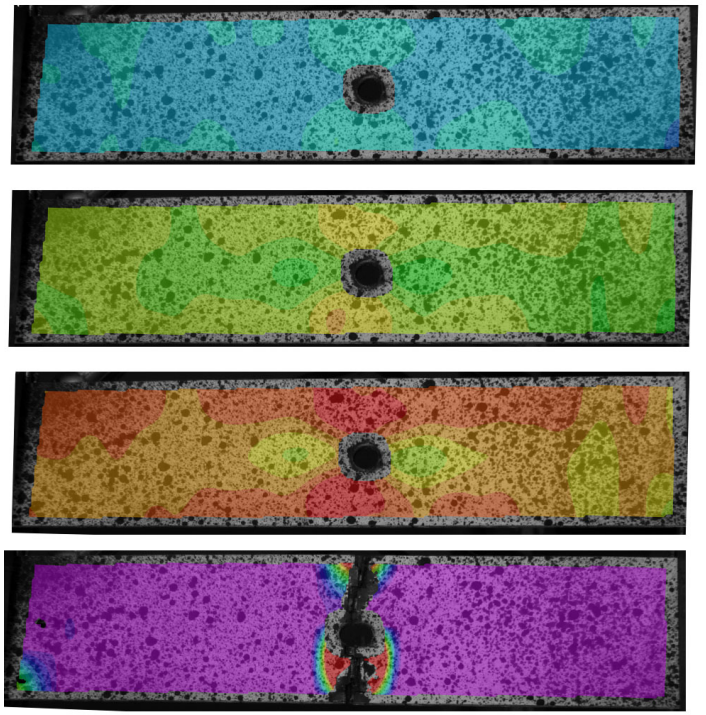
Benchmark DIC Part A

- Typical open hole strain field distributions are for a carbon fiber/ epoxy multidirectional tape (unnotched and notched)





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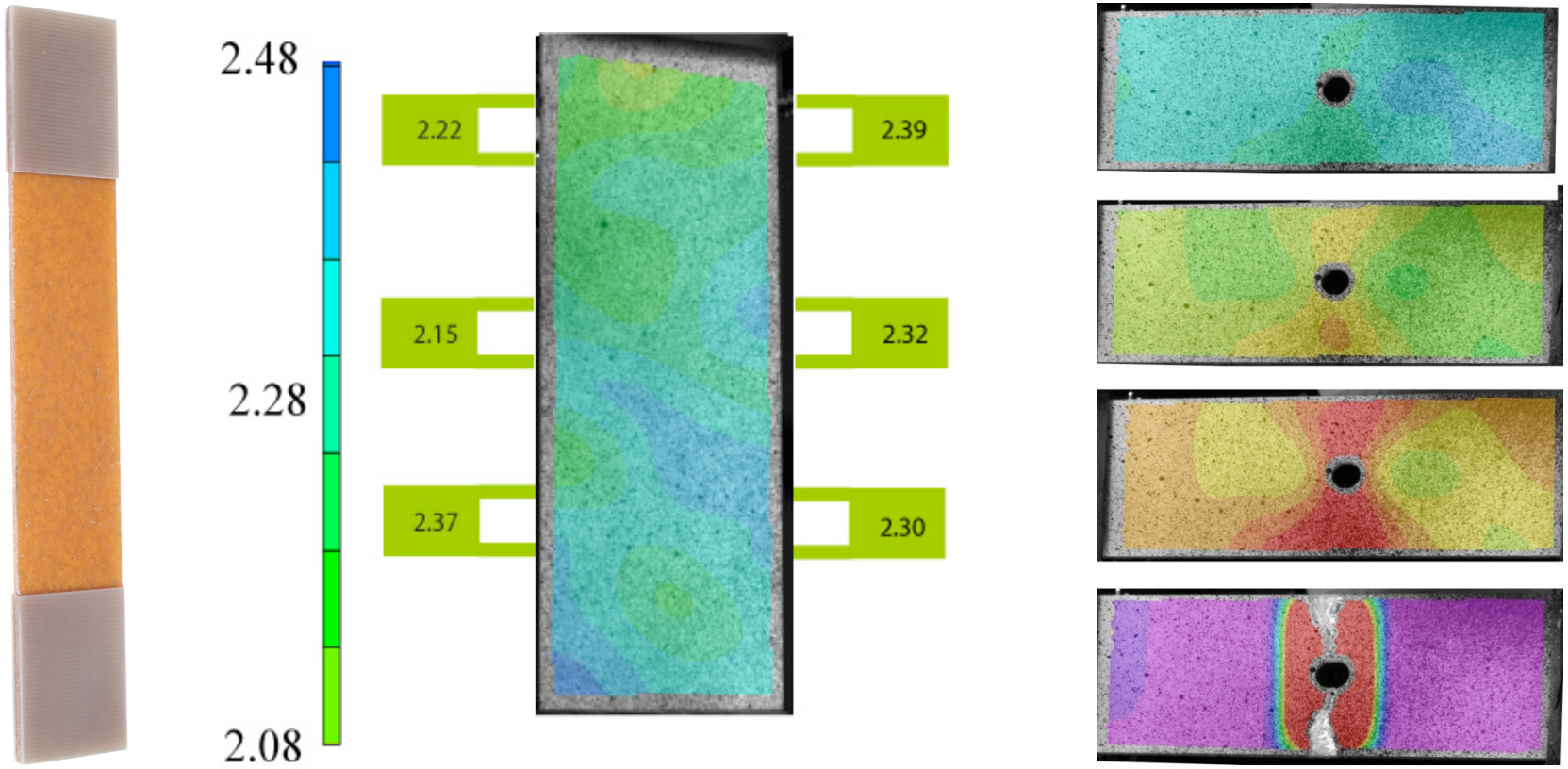
Benchmark DIC Part B

- Typical open hole strain field distributions are for a glass fiber/ epoxy discontinuous RTM mat (unnotched and notched)



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SUMMARY

- Modulus varies within the specimen (CoV 14%)
- Through-thickness non-homogeneity of material root of this behavior, not surface effect alone
- Strain gages or extensometers cannot be used to measure modulus
- Full-field modulus measurements are within 4%
- DIC shows that compliant (low-modulus) areas tend to correspond to hot-spots
- Stress distribution around hole is unlike traditional stress concentration

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Year I Project deliverables

- Study feasibility of a TSO with FAA/Industry. Verify how SCD can be turned into TSO.
- Identify key M&P characteristics for part quality control
- Evaluate most suitable NDI methods and acceptance criteria
- Identify part for evaluation and demonstration
- Identify key structural properties for substantiation, and associated analysis methods for the specific part
- Identify the analysis approach and supporting test data needed to meet structural requirements (incl. reliability)
- Define test methods that can be standardized
- Investigate the possibility for using HexMC as stock for machining parts

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