PERFORMANCE OF TAILORED JOINTS IN DISCONTINUOUS CERAMIC-CORED SANDWICH STRUCTURES

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INTRODUCTION

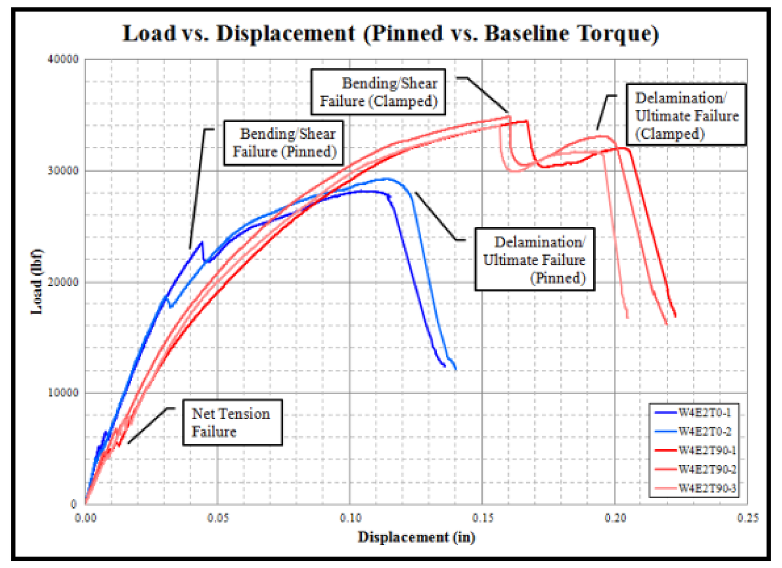
- Bolted joints continue to be the primary fastening mechanism used in advanced composite materials
- The use of bolted joints create significant areas of stress concentration, often resulting in trademark failure modes, such as net tension, shear out and bearing.
- Bolted joints require a particular magnitude of torque, optimized through knowledge of the bolt strength, various methods of joint loosening and material relaxation properties.

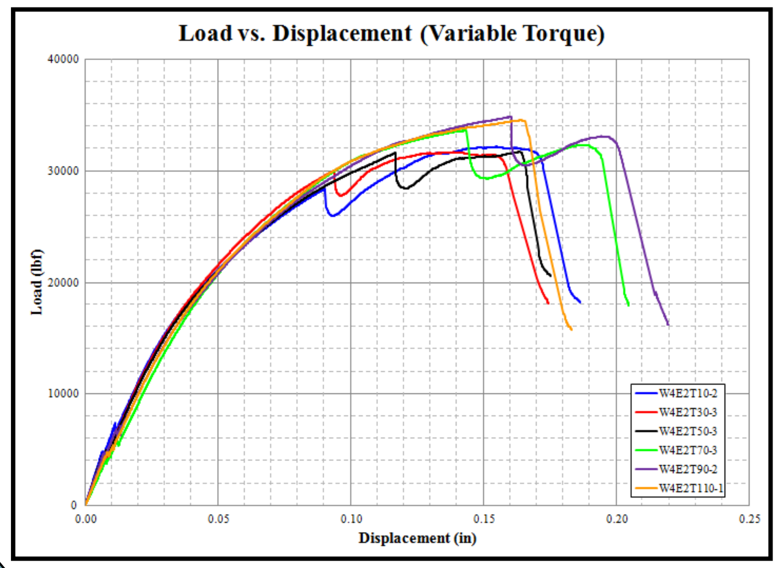
OBJECTIVES

- Understanding the performance of torqued joints in discontinuous ceramic cored sandwich structures.
  - Determine the optimal torque needed to prevent excessive stress loss without damaging the specimen
  - Perform static bearing tests of clamped joint; compare results to pinned joint case
  - Derive high-level and low-level stresses for fatigue testing; high-level to determine the maximum fatigue stress at which infinite life can be achieved, and low-level to determine the stress that exhibits no residual strength or stiffness loss of the joint
  - Continue improving joint efficiency by modifying joint through different constituent materials and addition of inserts

STATIC TESTING

- Pinned vs. Clamped Joints
  - Clamping force compresses DCCS Structure, causing the compliance of the interlayer to increase, reducing stress transfer between face sheet and ceramic tile, resulting in a lower initial stiffness
  - Less load carrying responsibility by the ceramic tile allows the second failure mode (bending/shear crack) to occur much later
  - Addition of clamping force results in higher joint strength and increased displacement of joint at failure

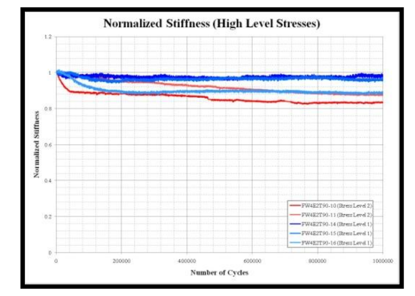


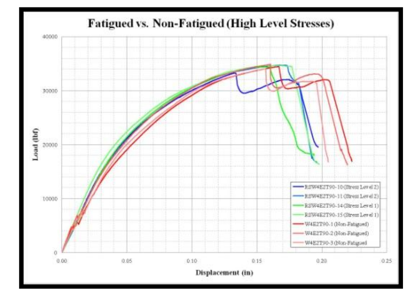


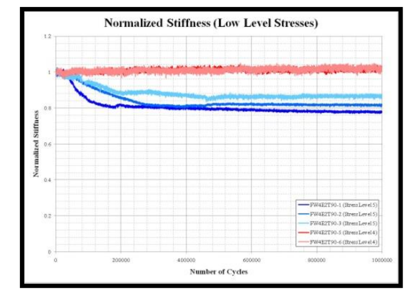
- Variable Torque Testing
  - Initial stiffness and strength at first failure mode consistent at all torque levels
  - Joint strength at second failure mode (bending/shear crack) increases with increasing torque
  - Simultaneous bending/shear failure and delamination of DCCS Structure at torque levels above baseline torque of 90 ft-lbs, resulting in catastrophic failure

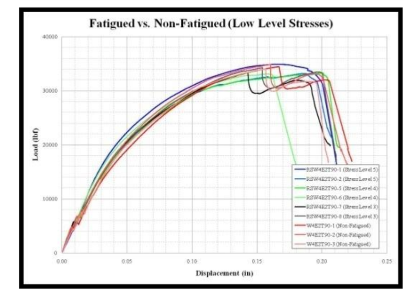
FATIGUE TESTING

- High Level Fatigue Testing
  - Stress Level 5 – Failure of DCCS Structure after an average of 1242 cycles due to debonding of the face sheet, interlayer and ceramic tile
  - Stress Level 4 – Failure of DCCS Structure after an average of 7328 cycles due to debonding of the face sheet, interlayer and ceramic tile
  - Stress Level 3 – Failure of bolt fastener after an average of 35526 cycles due to bolt bending
  - Stress Level 2 – Successful completion of 1 million cycles, with average stiffness loss of 12-16%; residual strength demonstrated no strength loss, but change in failure progression – bending/shear crack occurs after delamination has initiated
  - Stress Level 1 – Average stiffness loss of 3-12%; same change in failure progression as Stress Level 2
- Low Level Fatigue Testing
  - Stress Level 5 – Average stiffness loss of 12-24% with no visible damage; residual strength demonstrated no strength loss, but change in failure progression – bending/shear crack occurs after delamination has initiated
  - Stress Level 4 – No loss in stiffness; same change in failure progression as Stress Level 5
  - Stress Level 3 – No loss in stiffness; failure progression consistent with non-fatigued specimens
  - Stress Level 2 – Testing not required
  - Stress Level 1 – Testing not required



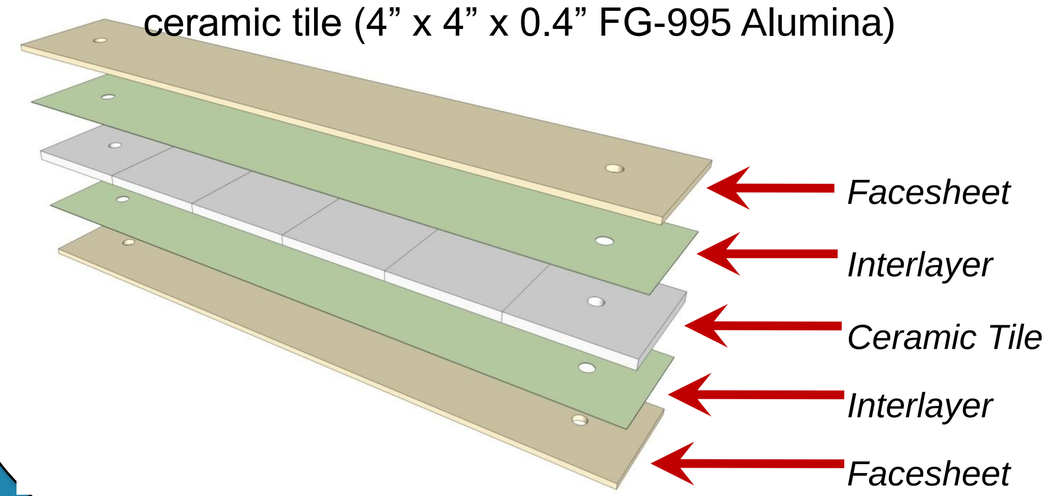




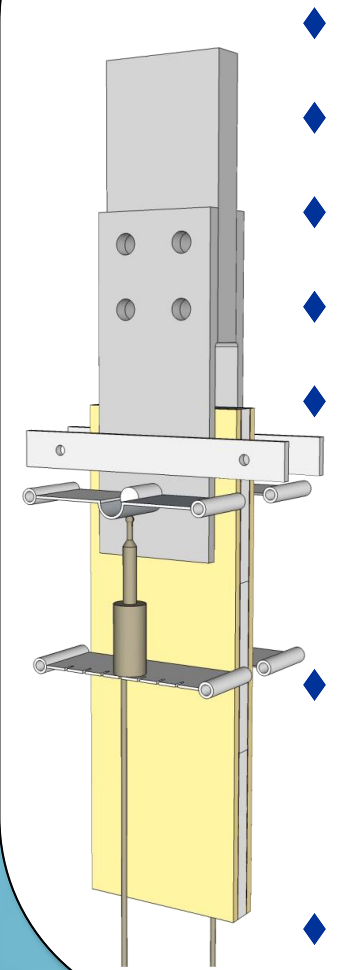


DCCS STRUCTURE

- Discontinuous Ceramic Cored Sandwich (DCCS) Structure
  - Structure design allows for high energy absorption properties
  - Discontinuous core prevents propagation of damage
  - Adhesive interlayer controls stress-transfer between face sheet and ceramic core
  - Three main constituents: facesheet (3Weave 100 oz. ZZ S2 Glass Fabric), interlayer (Grade 8150 Surlyn), and ceramic tile (4” x 4” x 0.4” FG-995 Alumina)



TEST FIXTURE AND PROCEDURE

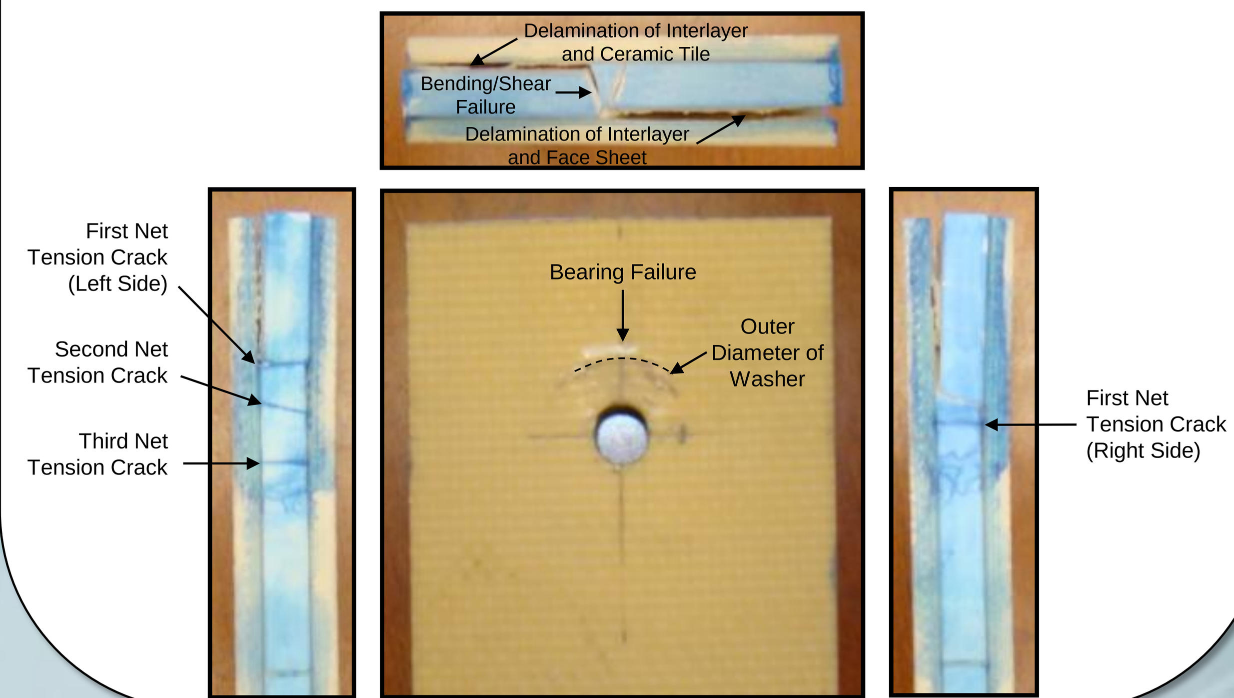


- Double overlap fixture in accordance with ASTM Standard D5961
- Specimen geometry of w/D = 8.0 and e/D = 4.0, using 0.5 inch joint diameter
- Record visible damage and location with respect to joint, acoustic emissions, and corresponding loads
- Static Testing of Pinned Joints and Various Torque Levels
- High-Level Fatigue Stresses
  - Stress Level 5 – 25600 lbs (90% of minimum ultimate failure)
  - Stress Level 4 – 20480 lbs (80% of Level 5)
  - Stress Level 3 – 15360 lbs (60% of Level 5)
  - Stress Level 2 – 10240 lbs (40% of Level 5)
  - Stress Level 1 – 5120 lbs (20% of Level 5)
- Low-Level Fatigue Stresses
  - Stress Level 5 – 3400 lbs (90% of minimum first crack)
  - Stress Level 4 – 2720 lbs (80% of Level 5)
  - Stress Level 3 – 2040 lbs (60% of Level 5)
  - Stress Level 2 – 1360 lbs (40% of Level 5)
  - Stress Level 1 – 680 lbs (20% of Level 5)
- Residual Strength Testing after fatigue

FAILURE MODES

(Static Baseline Torque)

- Average Load of First Net Tension Crack – 4267 lbs
- Average Load of Second Net Tension Crack (when present) – 9745 lbs
- Average Load of Third Net Tension Crack (when present) – 15606 lbs
- Average Load of Fourth Net Tension Crack (when present) – 20017 lbs
- Average Load of Bending/Shear Failure in Tile – 34462 lbs
- Average Load of Delamination/Ultimate Failure – 32283 lbs



FUTURE WORK

- Develop Finite Element Model to compare the distribution of bearing stresses in the face sheet and ceramic tile when utilizing pinned and clamped joints
- Replace 3Weave face sheet with 2D quasi-isotropic face sheet
  - Will the addition of ±45º plies increase the shear/bending capacity of the DCCS Structure?
- Use metallic inserts in the joints
  - Can the inserts re-distribute the load through the full thickness of DCCS Structure and reduce tile-cracking?