Material Variability Effects on Damage Development Within Composite Adhesively Bonded Joints

Abstract:

Use of composite adhesively bonded joints (ABJ) is of critical importance to the adoption of composite materials in the automotive industry, as ABJ enable lower stress concentrations as compared to conventional mechanically fastened joints. ABJ are better suited for joining composite materials as compared to fastened joints because fastened joints require drilling of holes which locally affect composite material structure. Composite materials and adhesives are subject to unavoidable stochastic local material variations which make different failure scenarios possible. An experimentally tested ABJ configuration is simulated using finite element analysis (FEA). Experimentally, under tension, the joints failed by three major failure modes, with peak loads ranging from 13.0-16.1 kips. Progressive failure analysis tools are used to simulate damage development within each material within the joint. The simulations agreed well with the average experimental peak load. Stochastically occurring adhesive porosity and matrix-fiber micro-disbonding were numerically simulated. The simulations revealed a similar trend as observed experimentally: joints which failed at higher peak loads had lower levels of damage within the face-sheets of the composite panels which were adhesively bonded; these joints which failed at higher peak loads also had greater damage in the doubler of the experimentally tested double lap joint configuration.

The models revealed *unintuitive* interactions between manufacturing defects, peak load and failure mode. Fabric material variability was not simulated, yet fabric material variability may account for discrepancies between experimentally observed strength coefficient of variance (CoV), and simulation CoVs.

Richard Larson1, Andrew Bergan2, Frank Leone1, Oleksander G. Kravchenko3

1 Old Dominion University, 5151 Hampton Blvd, Norfolk, VA, 23529, USA
2 Damage Tolerance, Durability, and Reliability Branch, NASA Langley Research Center, Mail Stop 190, Hampton, VA 23661

---

**Use of Carbon Fiber Reinforced Polymers in Car Parts**

- Conventional mechanical joining techniques such as rivets and bolts generate localized stress concentrations which can be primary sources of failure. Adhesively bonded joints (ABJ) relieve these stress concentrations
- ABJ also enable greater use of composite materials such as carbon fiber reinforced polymers, as bolted connections require drilling and fiber removal
- Sandwich panel construction also offers to reduce weight of car parts

**Motivation**

- Designing with fiber reinforced polymers (FRP) requires understanding of different failure modes and their interaction
- Designing adhesively bonded joints (ABJ) adds more complexity to this design process
- Experimentation with ABJ show several major failure modes
- It is important to understand the cost cause of these variations

**Manufacturing Defects**

- Fibrous material, as well as adhesives, can be subject to various manufacturing defects and imperfections
- Void in adhesive and adherends
- Fiber delamination in a result of residual stress
- Other possible cause for failure modes variations

**Joint Experimental Configuration**

- Use of carbon fiber reinforced polymers (CFRP) is used to model matrix crushing (Complian model material developed at NASA Langley)
- Cohesive zone modeling (CZM) is used to model delamination and adhesive damage
- Plastic behavior is used to model core crushing

**Pristine Model Results**

- Predicted strength of 33.5 MPa is within 1.0% of experimental average peak load (32.5 kips)
- Core cell wall buckling was observed in both the experiment and the analysis
- Significant core cell wall buckling occurred near the end of the specimen, immediately at the peak load
- Several layers of delaminated elements were observed in the analysis near the joint center
- Experimentally, delamination was observed near the joint center at the different ply interfaces
- Adhesive damage was similar to the experimental observation

**Damage Modeling**

- Continuum damage mechanics with deformation gradient decomposition (DGD) is used to model matrix crushing (Complian model material developed at NASA Langley)
- Cohesive zone modeling (CZM) is used to model delamination and adhesive damage
- Plastic behavior is used to model core crushing
- Continuum damage mechanics is used to model damage in fabric doubler

**Simulated Defects**

- Seven models were run with the same globally distributed matrix defects according to a gaussian distribution
- The CoV of the seven strengths was 3.0% whereas experimentally the strength CoV was 6.9%
- It was observed that 10% decrease in adhesive properties resulted in an increased joint strength
- In total 2% and 5% simulated adhesive porosity studies the peak load increased, and it was found that the stronger simulations had less facesheet damage and more doubler damage, which was consistent with experimental observations
- Five simulations were run with 0% adhesive porosity, with and without matrix defects. In the microscopic view in Fig. 3, 0% adhesive porosity is observed

---

In the combined 0% porosity and simulated facemeach micromachining simulation, the trend was observed again: simulations with more facesheet damage failed at lower peak loads.

The CoV for the combined defect simulations was 3%; for the porosity only simulations the CoV was 2.9%