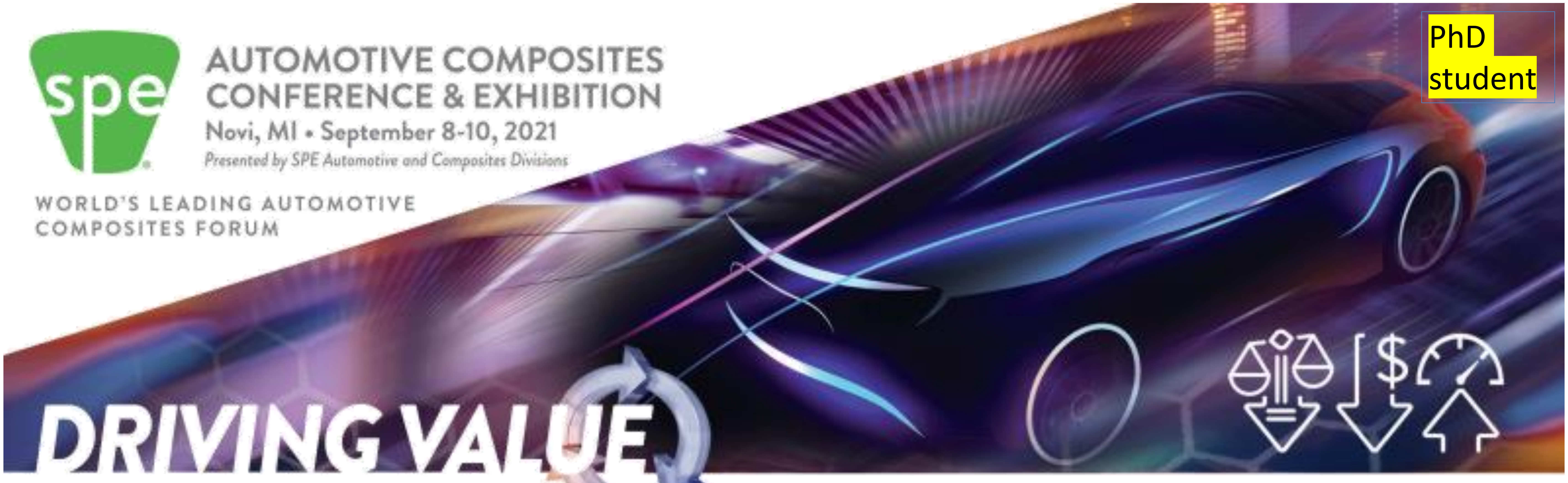

PhD student

Material Variability Effects on Damage Development Within Composite Adhesively Bonded Joints

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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 simulation 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.

Use of Carbon Fiber Reinforced Polymers in Car Parts

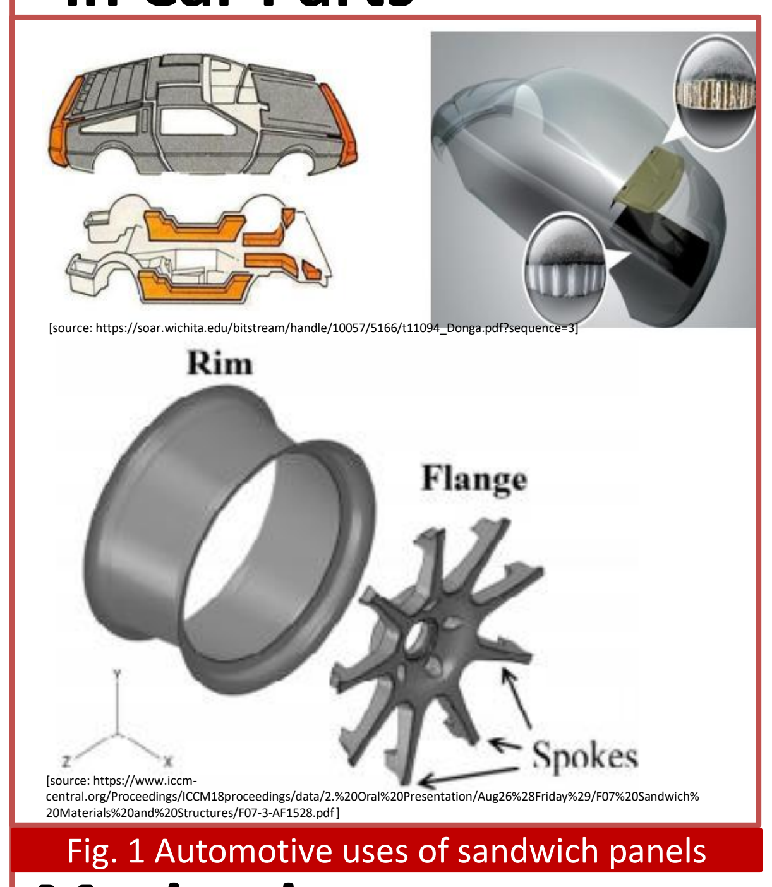

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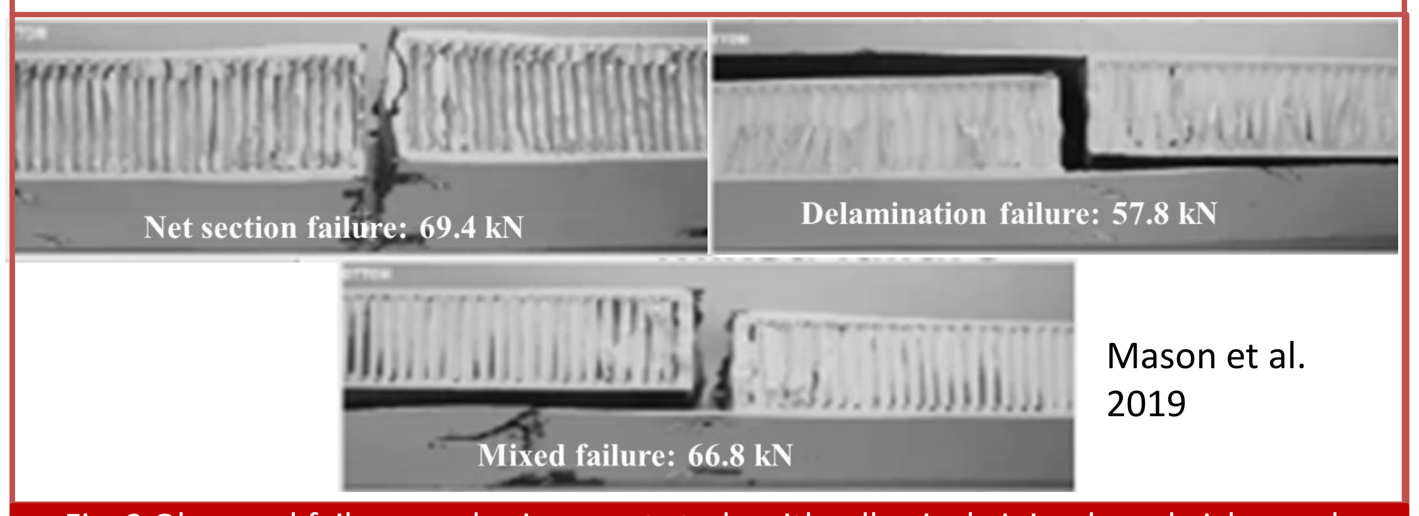
Fig. 1 Automotive uses of sandwich panels

- 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 rims

Motivation

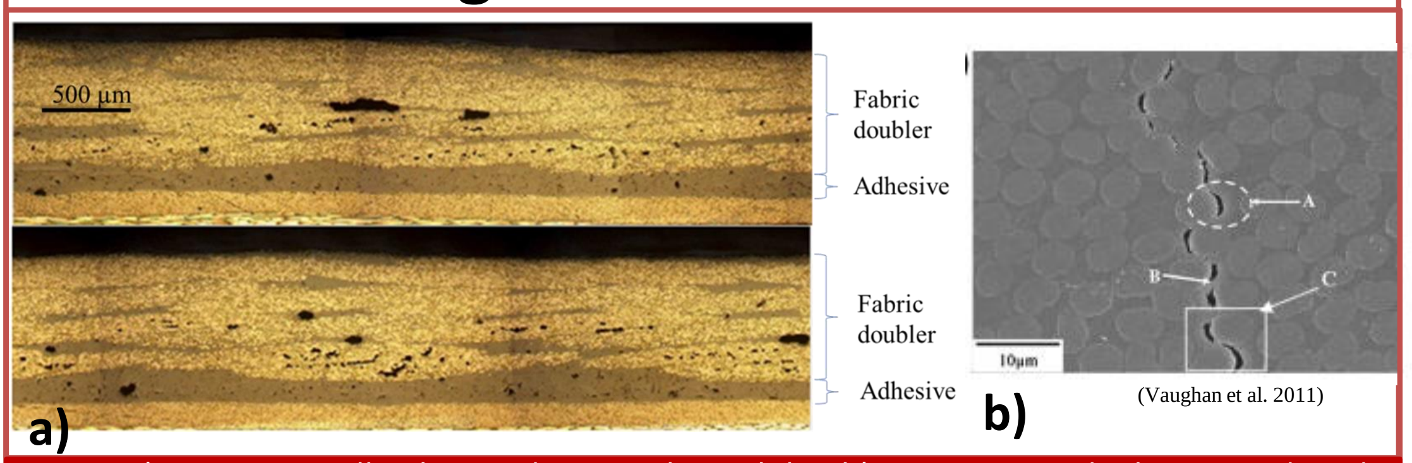


Mason et al. 2019

Fig. 2 Observed failure modes in recent study with adhesively joined sandwich panels

- 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 root cause of these variations

Manufacturing Defects



(Vaughan et al. 2011)

Fig. 3 a) experimentally observed material variability b) common residual stress induced matrix fiber microcracking

- FRP materials, as well as adhesives, can be subject to various manufacturing defects and imperfections
- Voids in adhesive and adherends
- Fiber disbonding as a result of residual stress
- Offer a potential cause for failure mode variation

Joint Experimental Configuration

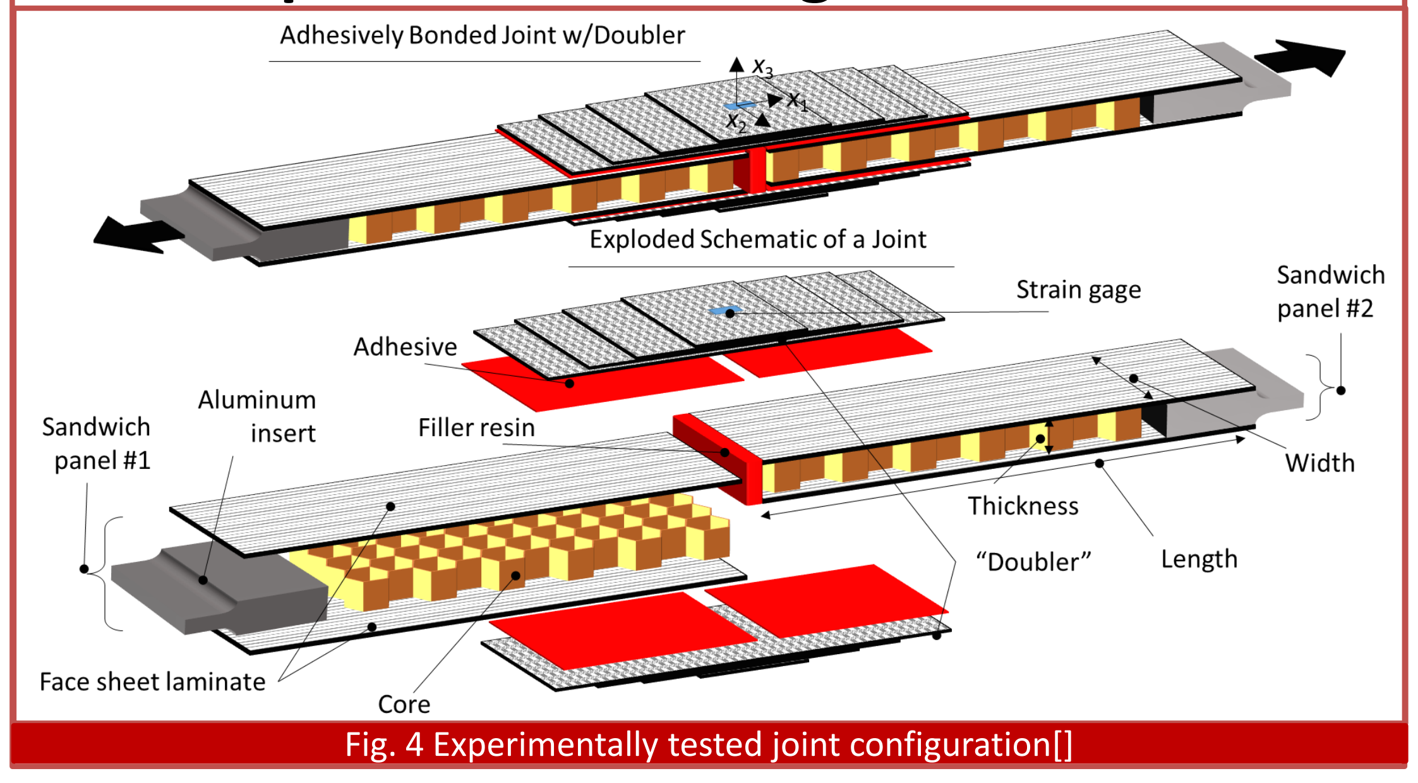


Fig. 4 Experimentally tested joint configuration[]

Damage Modeling

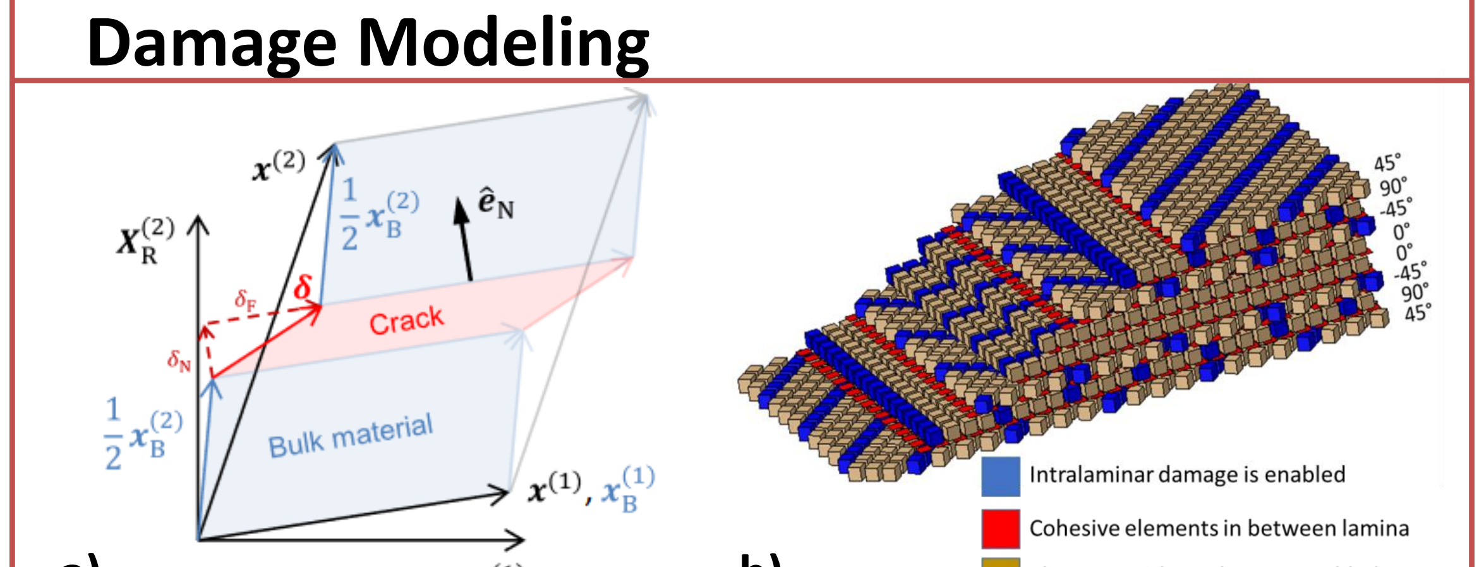


Fig. 5 a) DGD graphical representation b) meshing requirement for DGD and CZM

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

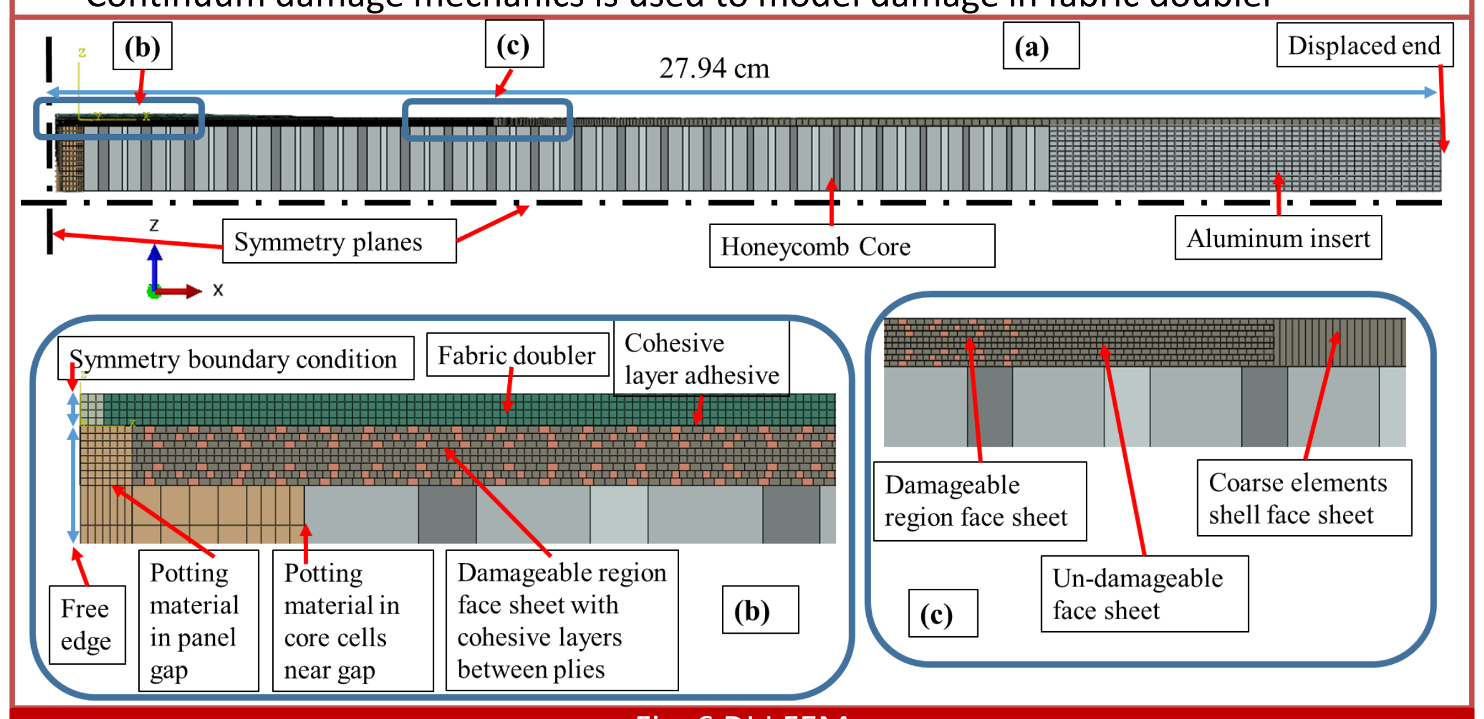


Fig. 6 DLJ FEM

Pristine Model Results

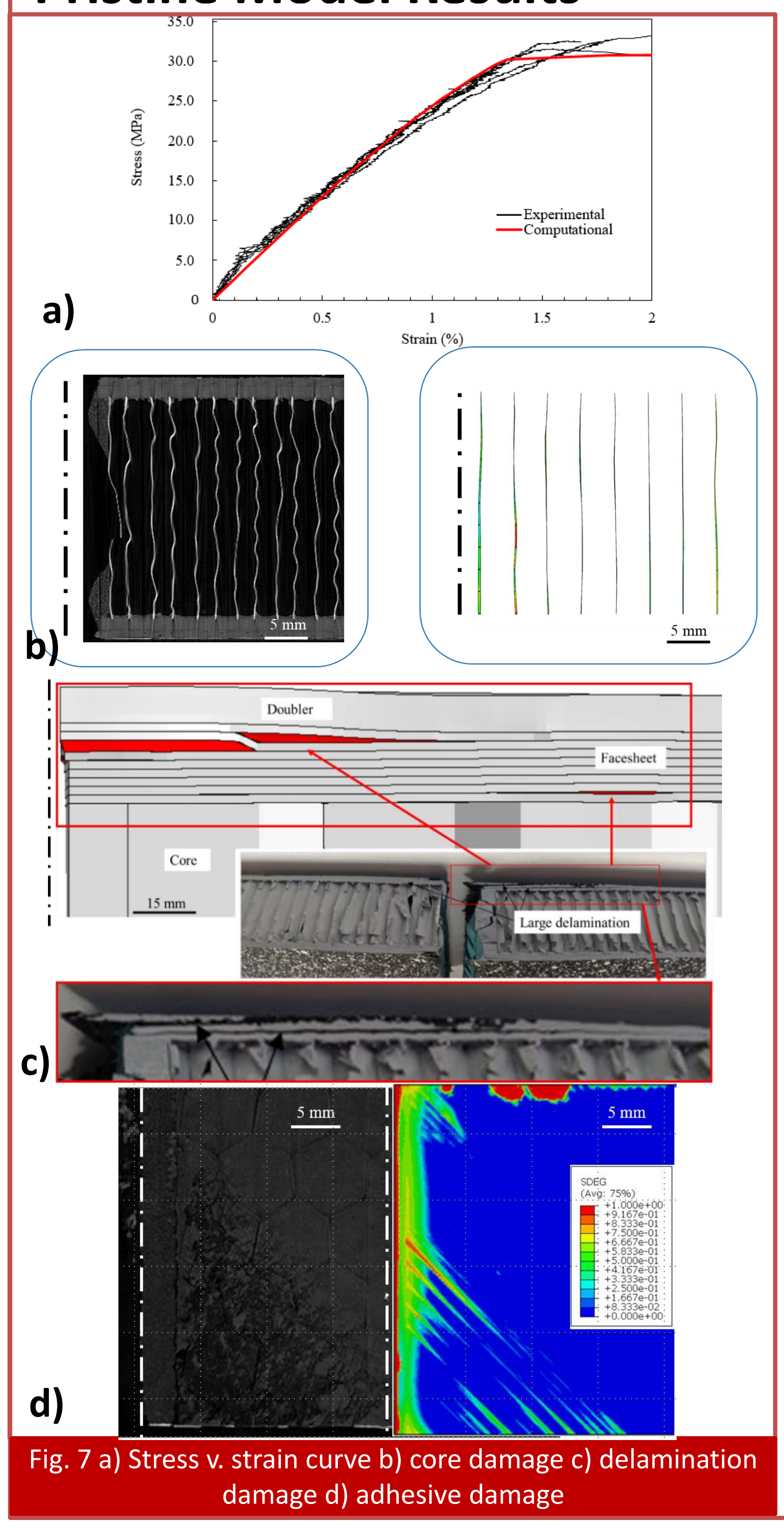


Fig. 7 a) Stress v. strain curve b) core damage c) delamination damage d) adhesive damage

- Predicted strength of 31.5 MPa is within 1.02% of experimental average peak load (31.0 MPa)
- Core cell wall buckling was observed in both the experiment and the analysis
- Significant core cell wall buckling occurred near the end of the analysis, 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 different ply interfaces
- Adhesive damage was similar to the experimental observation

Simulated Defects

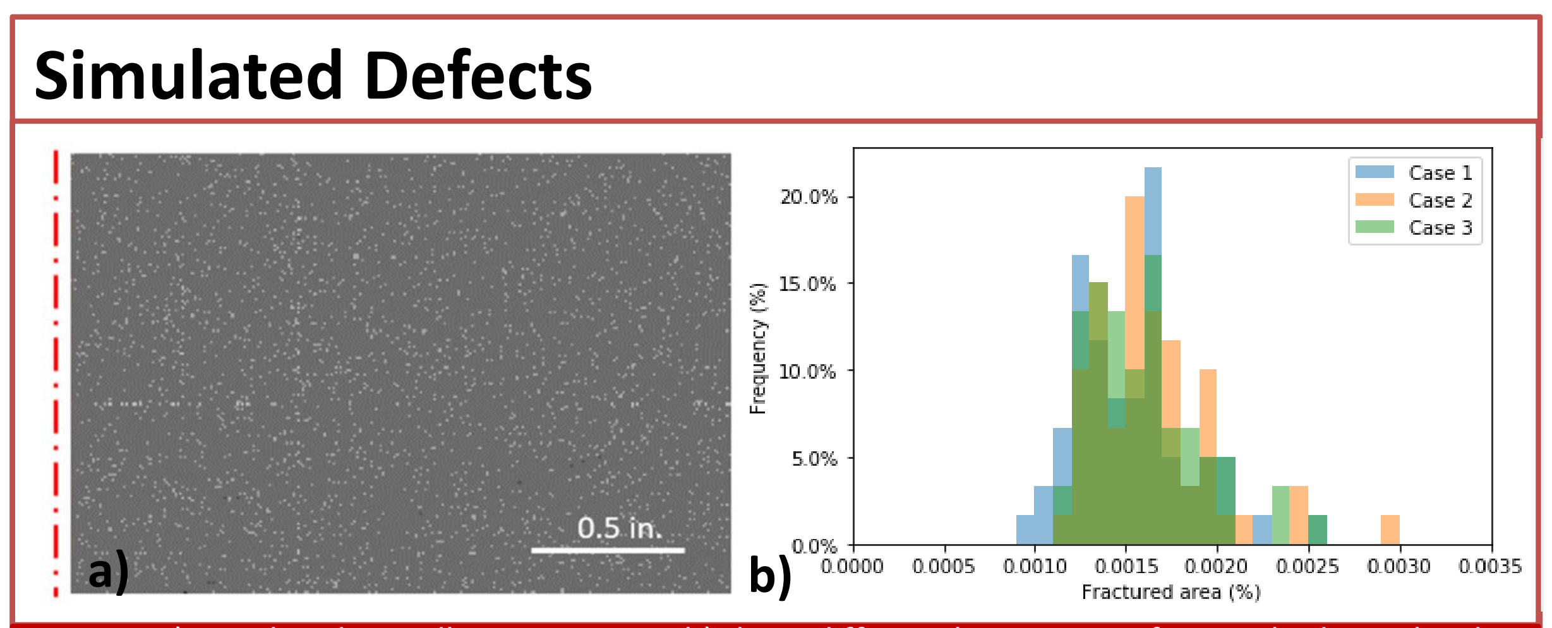


Fig. 8 a) Simulated 5% adhesive porosity b) three different histograms of prescribed initialized intralaminar damage levels

- Matrix damage variables were initialized in each strip in which matrix damage is enabled in order to represent residual stress induced microcracking
- Adhesive porosity was simulated by randomly selecting adhesive elements and setting the strength and toughness values to near zero
- Adhesive variability was also investigated by uniformly modifying the adhesive properties

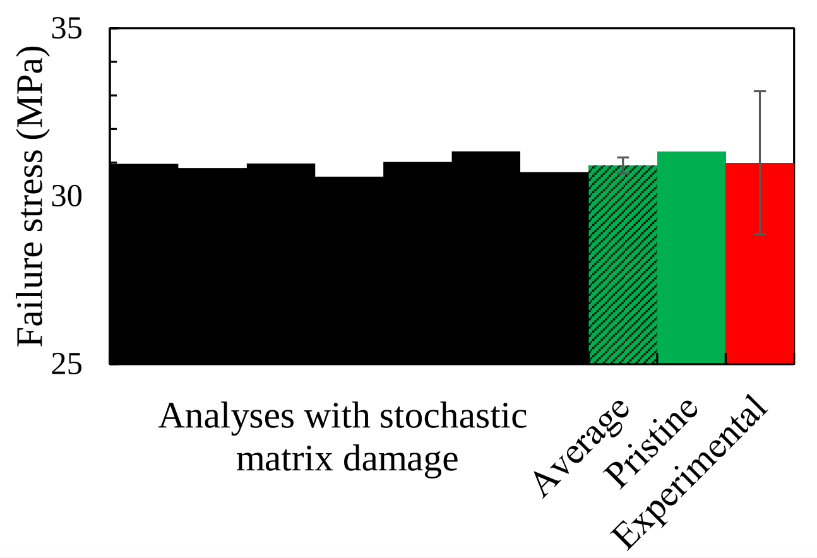


Fig. 9 Failure stress in initialized matrix damage simulations

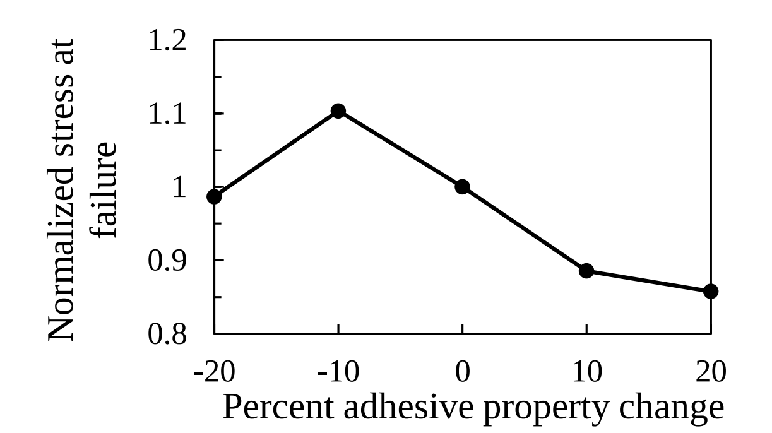


Fig. 10 Stress at failure in specimens with uniformly modified adhesive properties

- Seven models were run with the same globally distributed matrix defects according to a gaussian distribution
- The CoV of the seven strengths was 0.72% whereas experimentally the strength CoV was 6.9%
- It was observed that a 10% decrease in adhesive properties resulted in an increased joint strength
- In initial 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 6% adhesive porosity, with and without matrix defects. In the micrograph in Fig. 3, 6% adhesive porosity is observed

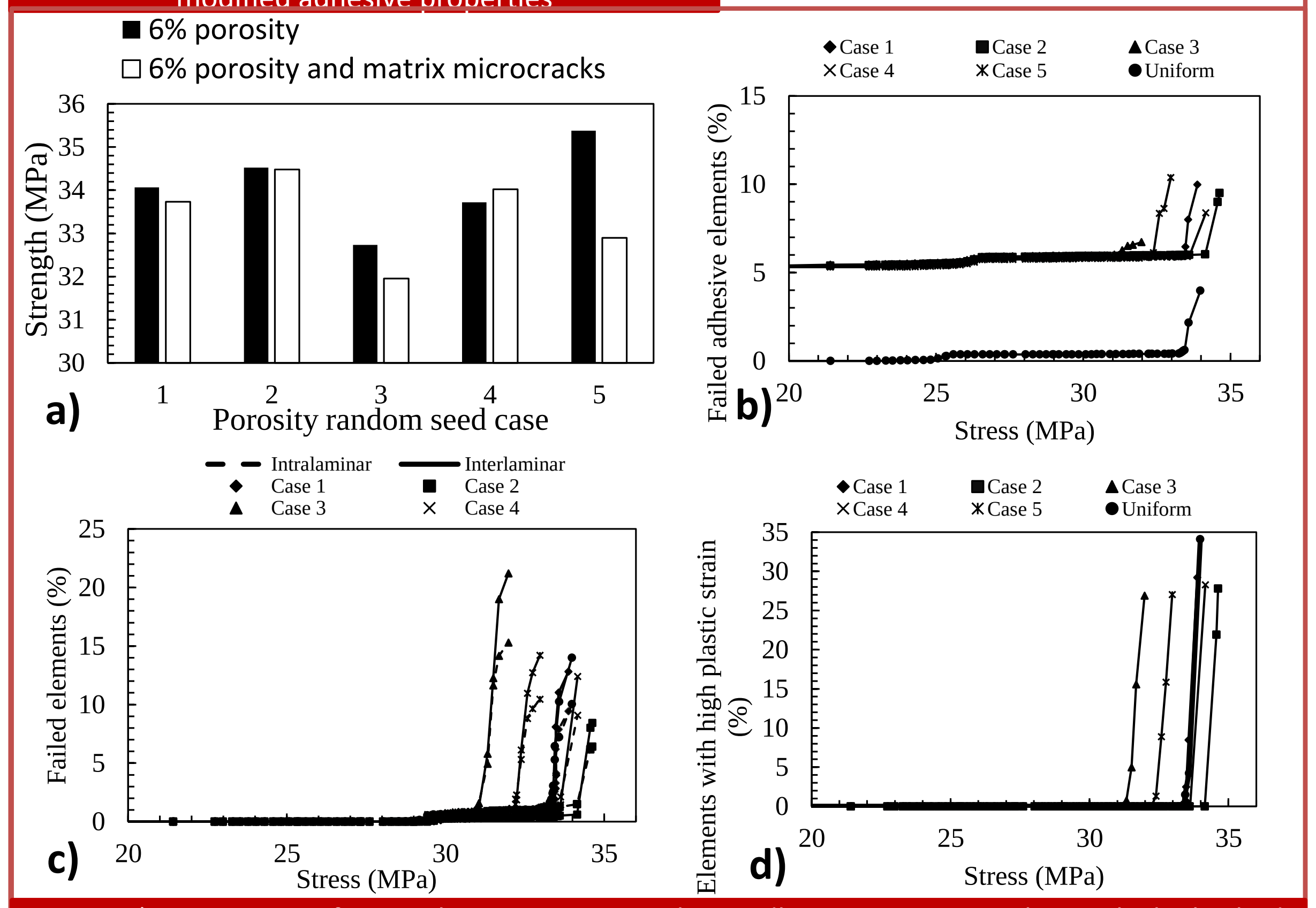


Fig. 11 a) comparison of strength in specimens with 6% adhesive porosity to those which also had initialized matrix damage and b) adhesive damage development c) facesheet damage development and d) fabric damage development in mixed defect simulations

- In the combined 6% porosity and simulated facesheet microcracking simulation, the trend was observed again: simulations with more facesheet damage failed at lower loads.
- The CoV for the combined defect simulations was 3%; for the porosity only simulations the CoV was 2.9%

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.