ANSYS Cohesive Zone Modeling

Fatigue and Fracture Seminar
Composite Part Failure Assessment

- Introduction to composite part and/or adhesive structural assessment.
- **Why** you may need Cohesive Zone Material (CZM) failure modeling.
- **What** you need for CZM finite element analysis.
- **How** to implement Cohesive Zone in Ansys tools.
- Interpret and gauge success in using your results.
Composite Part Failure Assessment

- **Composite Parts** can offer more durable, weight efficient, and lower life cycle costs.
- Companies must have **durability & damage tolerance** methodology for design, qualification, and life management of parts.
- Durability is an **analysis challenge** in modern composite part design:
  - Part shapes and material composition are increasingly complex.
  - Large primary structures such as beams and frames.
  - Complex layups & joints.
  - From thin to very thick structural parts.
  - Susceptible to interlaminar failure and barely visible impact damage.

The Boeing Company, AHS 66 Forum
Composite Structural Evaluation

- Finite Element Analysis is required for detailed composite part structural evaluation.
- For complex composite part FE analysis, how can failure be evaluated?

  - **Static Design**
    - Fiber breakage, max strain criteria
    - Fiber crushing, buckling
    - Core damage, face sheet wrinkling
    - Hole & fastener damage

  - **Delamination**
    - Onset of delamination
    - Critical unstable growth
    - Repeated/cyclic load growth

  ![ANSYS Composite PrepPost (ACP)](image)
  ![Cohesive Zone Modeling (CZM)](image)
Composite Structural Evaluation

- Integration of delamination into composite part/adhesive joint life cycle:

  - Material Data
  - Geometry
  - Layup Info
  - Loads

  ▶ 2D & 3D FE Analysis
  - Ansys & ACP Analysis

  ▶ Repeated Loads
  - Damage Initiation
  - Delamination Growth

  ▶ 2D & 3D FE Analysis With Cohesive Zone Modeling

  ◀ Structural Usage
  - Monitoring and Life Management

  ◀ 2D & 3D FE Analysis With Cohesive Zone Modeling
Cohesive Zone Modeling

- **Cohesive Zone** technology models interface delamination and progressive failure where two materials are joined together.
- This approach introduces a failure mechanisms by gradually **degrading the material** elasticity between the surfaces.
- The material behavior at the interface is characterized by the **stresses** (normal and tangential) and **separation** distances (normal gap and tangential sliding).
- Cohesive Zone debonding allows **three modes** of separation:
  - Mode I debonding for normal separation
  - Mode II debonding for tangential separation
  - Mixed mode debonding for normal and tangential

![Cohesive Zone Debonding Modes](image)
Cohesive Zone Modeling

- Material test data is required for desired failure modes.
- Test data can include either:
  - Traction – Separation
  - Traction – Critical Fracture Energy

![Graph showing delamination behavior](image)

Area under curve represents **critical fracture energy** to separate surfaces.

**Onset of delamination**

Hybrid composite w/ carbon nanotube testing
Penn State
AHS 66 Annual Forum
Cohesive Zone Modeling

- This nonlinear analysis technique is integrated in the finite element method and the **separation mechanism** of two surfaces can be simulated.

Typically **two methods** of implementation are used:

1. **Interface elements** designed specifically to represent the cohesive zone between the components and to account for the separation across the interface.
2. The cohesive zone between components can also be modeled with **bonded contact**.
Cohesive Zone Modeling

- **Interface Elements**
  - Elements are meshed in between layers with initial zero thickness.
  - Elements use exponential material law for elasticity and disbond.
  - Exponential law curve shape helps with nonlinear convergence.

- **Bonded Contact**
  - General surface to surface contact technology is used.
  - Linear traction-separation material law
  - After debonding occurs, standard contact behavior ensues.
  - Damage is actively tracked so, unloading and reloading can occur.
Cohesive Zone Modeling

- Cohesive Zone Material Capability – **Cyclic Loading**
- ANSYS automatically adjusts the **critical interlaminar tension** magnitude based on **remaining energy** available.
- This enables cyclic tracking of energy released in delamination!
Cohesive Zone Modeling

- How do we set up a Cohesive Zone Model?
- First, determine delamination methodology:
  - Interface Elements
  - Bonded Contact
- Build or utilize existing FE model of structure.
- Keep in mind:
  - Mesh density – focus refinement in area of delamination.
  - Anticipated size of growth of delamination
- Set up appropriate material model.
- Run nonlinear analysis with appropriate time step controls.
- For each separate methodology, see following slides for additional setup.
Cohesive Zone Model – Interface Elements

- Interface elements can be automatically created in an uncracked mesh.
  - By named components on both sides of delamination area or
  - Local coordinate system defining plane to split mesh.
Cohesive Zone Model – Bonded Contact

- Set up Contact in Mechanical or Mechanical APDL
- For Bonded Contact:
  - Use Contact Manager to define areas of bonded contact for delamination.
  - Assign Material ID to contact pair to reference CZM material Model
Cohesive Zone Model – Bonded Contact

- Define contact properties to represent stiffness of interface material.
Cohesive Zone Model

- CZM Analysis can support new design analysis or part inspection and field support.
- Utilize assumed or measured delamination information.
Cohesive Zone Model – Results

- Postprocessing Cohesive Zone delamination.
- Often interested in onset of failure and progressive failure behavior.
Cohesive Zone Model – Results

- Postprocessing Cohesive Zone Delamination.
- For bonded contact:

Monitor Damage Parameter.
1.0 = Fully Separated

Mode 1 or Mode 2 Delamination Energy
Cohesive Zone Modeling - Examples

- 2D DCB Specimen Modeling – Interlaminar Tension Stress
- Traveling contact pressure profile at delamination tip as specimen opens. (Negative pressure = tension stress)
Cohesive Zone Modeling - Examples

- 3D DCB Modeling – Interlaminar Tension Stress
Cohesive Zone Modeling

- CAE has used CZM successfully to:
  - Estimate critical load to grow unstable delamination.
  - Nonlinear prediction of deformation and opening of delamination.
  - Predict growth shape of delamination and demonstrate residual load capability.
  - Predict growth shape with correlation to ultrasonic scans.
  - Investigate emerging methodology for cyclic damage of composites.

![Diagram showing delamination growth over 1,000 cycles and 2,000 cycles](image_url)
Cohesive Zone Analysis Capability

- In Summary, Cohesive Zone Material analysis can support composite part and/or adhesive structural assessment.
- CZM will provide you with information for your complex part analysis:
  - Onset of delamination.
  - Load and direction of critical unstable growth.
  - Progressive failure.
  - Repeated/cyclic load growth.