An Overview of Composite Materials with Emphasis on FRP Systems

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Abstract - This study presents a three-dimensional finite element analysis of adhesively bonded inner-tapered double-lap joints in laminated fibre-reinforced polymer (FRP) composites subjected to longitudinal and transverse loading. The joint configuration incorporates T300/934 graphite/epoxy adherends and an epoxy adhesive, with adhesive taper angles varied from **35° to 45°** and composite fibre orientations varied from **0°–90°** in steps of 15°. A detailed 3-D finite element model using SOLID185 elements is developed to evaluate stress components (σ_{xx}, σ_{yy}, σ_{zz}, τ_{xy}, τ_{yz}, τ_{xz}) and corresponding displacements within both the adherends and adhesive layer. Results indicate significant sensitivity of normal and shear stresses to fibre orientation and adhesive thickness, with maximum stresses generally occurring at intermediate fibre angles (45°–60°). Adhesive thickness **0.15 mm** exhibited the lowest stress concentrations. Under both loading conditions, joints displayed pronounced anisotropic behaviour, and stress transfer efficiency improved with optimized fibre and adhesive angles. The study contributes validated numerical insights for the design of efficient FRP bonded joints and provides guidelines to minimize stress concentrations in high-performance composite structures.

Key Words: Finite Element Analysis (FEA), Adhesively Bonded Joints, Inner-Tapered Double-Lap Joint, Laminated FRP Composites, Fibre Orientation, Adhesive Taper Angle, Stress Distribution, Peel Stress, Shear Stress, ANSYS SOLID185, Longitudinal Loading, Transverse Loading, KFRP Composites, GFRP Composites, Orthotropic Materials, Composite Structures.

1. INTRODUCTION

Composite materials have emerged as a vital class of engineering materials due to their superior strength-to-weight ratio, high stiffness, corrosion resistance, and adaptability in structural applications. Unlike conventional homogeneous materials, composite systems consist of two or more distinct constituents combined at a macroscopic level to achieve performance characteristics that exceed those of the individual components. In particular, fibre-reinforced polymer (FRP) composites—comprising high-strength fibres embedded within a polymeric matrix—exhibit excellent mechanical properties, including enhanced tensile strength, fatigue resistance, impact tolerance, and tailorability through fibre orientation and laminate stacking sequences.

The increasing demand for lightweight and durable structures in aerospace, automotive, marine, civil infrastructure, and defense sectors has accelerated the adoption of FRP composites. Applications range from aircraft fuselages, helicopter rotor blades, and high-performance automotive bodies to bridge decks, corrosion-resistant chemical tanks, wind-turbine blades, and biomedical implants. Their directional strength, manufacturability, and resistance to harsh environments make FRP composites highly attractive for modern engineering systems.

Bonded joints are essential elements in composite structures, where mechanical fastening often introduces undesirable stress concentrations and material damage. Adhesively bonded joints, in contrast, provide smoother stress transfer, eliminate the need for drilled holes, reduce structural weight, and offer excellent fatigue resistance.

The behaviour of such joints, however, is complex due to the anisotropy of composite adherends, the nonlinear properties of adhesives, and the presence of peel and shear stresses at bond edges. Accurate prediction of stress distributions in bonded joints is therefore critical for ensuring structural reliability.

Among various joint configurations, the double-lap joint is widely used due to its symmetric geometry and efficient load transfer. Modifications such as tapered or optimized adhesive layers are often employed to minimize stress concentrations. Despite extensive studies on bonded joints, limited research addresses the behaviour of inner-tapered double-lap joints in laminated FRP composites, particularly with variations in fibre orientation and adhesive geometry.

The combined effects of anisotropy, adhesive tapering, and three-dimensional stress states necessitate detailed finite element (FE) analysis to understand joint performance.

The present work focuses on the three-dimensional finite element analysis of adhesively bonded inner-tapered double-lap joints in graphite/epoxy laminated composites. The analysis investigates the influence of adhesive taper angle (35°, 40°, and 45°) and fibre orientation (0°–90°) on normal and shear stresses, as well as displacement behaviour under longitudinal and transverse loading. The SOLID185 element in ANSYS is employed to capture orthotropic material behaviour, through-thickness stresses, and nonlinear geometric effects.

This study aims to provide insights into optimum joint configurations that minimize stress concentrations and enhance the structural efficiency of adhesively bonded FRP joints.

1.1 OBJECTIVES OF THE STUDY

- To develop a three-dimensional finite element model for analyzing adhesively bonded inner-tapered double-lap joints in laminated FRP composites using SOLID185 elements based on the theory of elasticity.

- To evaluate the influence of adhesive taper angle (35°, 40°, 45°) on stress distribution and deformation characteristics of the joint under static loading.
- To study the effect of fibre orientation (0°–90°, in steps of 15°) in the laminate lay-up on the overall joint performance, including normal and shear stress components.
- To determine the stresses and displacements in both the adherends and the adhesive layer, and to identify critical regions susceptible to peak stresses.
- To compare the behaviour of the joint under longitudinal and transverse loading conditions, and to assess differences in load-transfer mechanisms.
- To validate the finite element model by ensuring stress-free conditions at free surfaces and comparing numerical results with theoretical expectations.
- To propose optimum fibre and adhesive configurations that minimize stress concentrations and enhance the structural efficiency of FRP bonded joints.

2. SUMMARY OF LITERATURE REVIEW

The analysis of adhesively bonded joints in fibre-reinforced polymer (FRP) composite structures has been widely studied due to their increasing use in aerospace, automotive, marine, and civil engineering applications. This section summarizes key contributions relevant to the modelling, behaviour, and performance of adhesively bonded lap joints, particularly those involving orthotropic laminated FRP composites.

A. Modelling and Stress Analysis of Bonded Joints

McCarthy et al. [1] performed detailed finite element modelling of composite lap joints and highlighted modelling challenges such as contact representation, mesh density, element order, and boundary conditions. Their work demonstrated the importance of capturing three-dimensional stress effects, including secondary bending and through-thickness variations.

Mohamed Bak [2] investigated the effect of adhesive thickness in composite single-lap joints. Results indicated that increasing the adhesive thickness significantly reduces peak stress concentrations, thereby improving joint performance.

Subramani [3] studied hybrid bonded joints using ANSYS and reported that carbon-fibre-reinforced plastic adherends offer superior strength and reduced shear stress levels compared to other materials. The deformation was found to be minimal in well-designed hybrid joints.

Sahoo et al. [4] conducted a geometrically nonlinear analysis of adhesively bonded joints and showed that nonlinear material behaviour in the adhesive reduces stress concentrations near lap ends. Their findings demonstrated the advantage of incorporating nonlinear adhesive properties in simulation.

Sharifi and Choupani [5] performed numerical analysis of adhesively bonded joints subjected to combined thermal loads. They modelled joints with various metallic and composite adherends and demonstrated that mismatch in thermal expansion coefficients significantly influences adhesive stress distribution.

B. Behaviour of Composite Adherends in Lap Joints

Tsai and Morton [6] investigated double-lap joints using experimental moiré interferometry, finite element modelling, and analytical closed-form solutions. Their results established that 2-D linear elastic modelling aligns well with measured deformation fields in unidirectional and quasi-isotropic composite adherends.

San Román [7] experimentally evaluated double-lap joints bonded with adhesives of varying nonlinearity. The study concluded that highly nonlinear adhesives achieved higher efficiencies than mechanical joints, and that strain distributions across the width are non-uniform, necessitating 2-D or 3-D modelling.

Kaya [8] performed 3-D finite element analysis on bonded joints with identical and dissimilar adherends. The study provided detailed distributions of stresses in the adhesive layer, emphasizing the effect of material mismatch on local stress intensification.

Essersi et al. [9] examined the dynamic behaviour of composite double-lap joints. Their work identified high-rate loading effects such as force oscillations ("ringing") and investigated their origins within the bonded assembly.

Pickthall, Heller, and Rose [10] analysed stress redistribution in bonded repairs and quantified reductions in peel and shear stress magnitudes due to adhesive yielding. Their results agreed with Hart-Smith's analytical theory, with the load transfer length being slightly higher than predicted.

States and DeVries [11] experimentally validated the significant influence of cleavage (peel) stresses at the bond termini in lap joints. They demonstrated that constraining out-of-plane deformation changes failure behaviour, proving that shear stress alone does not govern joint strength.

C. Classical Contributions and Joint Design Approaches

Hart-Smith [12] presented foundational analytical models and design guidelines for adhesively bonded composite joints. His work addressed load transfer mechanisms, peel-stress minimization, and ply-level design considerations for achieving efficient bonded joint performance.

Bahei-El-Din et al. [13] proposed alternative bonded joint configurations that reduce delamination and surface-ply failures. Their research showed that using inserts or interlocking interfaces significantly improves stress distribution by promoting in-plane load transfer instead of out-of-plane shearing.

D. Summary of Literature

The reviewed literature establishes the complexity of bonded joint behaviour, particularly in orthotropic FRP laminates. Most studies emphasize:

- the importance of 3-D stress analysis for accurate prediction,
- the role of fibre orientation and laminate lay-up in load transfer,
- the influence of adhesive thickness and nonlinearity on stress concentrations,
- the need to evaluate both shear and peel stresses for reliable design, and
- the significance of thermal and mechanical mismatches between adherends.

While extensive research exists on simple and double-lap joints, limited work has addressed inner-tapered double-lap joints in laminated FRP composites with varying fibre orientations and adhesive angles. Therefore, the present study fills this gap by providing a comprehensive 3-D finite element analysis under both longitudinal and transverse loading conditions.

3. PROBLEM STATEMENT AND METHODOLOGY

Adhesively bonded joints in fibre-reinforced polymer (FRP) composites are widely used in weight-critical structural applications; however, their behaviour is strongly influenced by the anisotropic nature of the adherends, adhesive geometry, and three-dimensional stress state in the bond region. Conventional lap-joint analyses typically assume simplified geometries and do not fully account for the interaction of fibre orientation, adhesive tapering, and orthotropic material response.

In particular, inner-tapered double-lap joints offer potential advantages by reducing peel stresses and improving load transfer, yet their mechanical behaviour remains insufficiently explored for laminated FRP systems. The combined effect of adhesive taper angles (35°, 40°, 45°) and laminate fibre orientations (0°–90° in 15° increments) under different loading conditions requires comprehensive numerical evaluation to determine stress concentrations, displacement fields, and optimal design parameters.

Accordingly, the present study formulates the following problem:

"To perform a three-dimensional finite element analysis of adhesively bonded inner-tapered double-lap joints in laminated FRP composites and examine the influence of adhesive angle, fibre orientation, and loading conditions on the stress and deformation characteristics of the joint and adhesive layer."

The study specifically addresses stress components (σ_{xx}, σ_{yy}, σ_{zz}, τ_{xy}, τ_{yz}, τ_{xz}), displacement responses, and critical stress variations in both the adherends and the adhesive to identify optimum joint configurations for improved structural performance.

4. METHODOLOGY

The methodology adopted in this investigation involves a systematic numerical approach using three-dimensional finite element analysis (FEA) based on elasticity theory. The following steps summarize the procedure:

A. Geometry Definition

The geometry of an **inner-tapered double-lap joint** is modelled with:

- Adherend laminate thickness: **8 mm**
- Individual ply thickness: **2 mm**
- Adhesive thickness: **0.05–0.15 mm**
- Bonded overlap length: **20 mm**
- Total laminate length: **100 mm**
- Width: **25 mm**
- Adhesive taper angles: **35°, 40°, 45°**

A symmetric laminate stacking sequence (+θ°/−θ°/−θ°/+θ°) is employed, with **θ = 0°–90°** in increments of **15°**.

B. Finite Element Modelling

The FE model is developed using **ANSYS SOLID185**, an 8-node, 3-D structural element suitable for orthotropic materials and large deformation analysis. Key features include:

- Capability to model orthotropic FRP laminates
- Accurate evaluation of 3-D stress fields
- Mesh refinement in the adhesive and taper regions
- Nonlinear strain and geometric behaviour as required

Model validation is performed by ensuring stress-free conditions at free surfaces and comparing computed stresses at selected nodes.

C. Material Properties

Two materials are considered:

1. **T300/934 Graphite/Epoxy FRP (Adherend)**
   - E_x = 127.5 GPa
   - E_y = 9.0 GPa
   - E_z = 4.8 GPa
   - $\nu_{xy} = \nu_{xz} = 0.28$, $\nu_{yz} = 0.41$
   - $G_{xy} = G_{xz} = 4.8$ GPa, $G_{yx} = 2.55$ GPa
2. **Epoxy Adhesive**
   - E = 2.8 GPa
   - Poisson's ratio = 0.4

D. Loading and Boundary Conditions

Two loading cases are investigated:

1. **Longitudinal Loading**
   - One end clamped
   - Opposite end constrained transversely
   - Uniform tensile load: **10 MPa**
2. **Transverse Loading**
   - Both ends clamped
   - Uniform transverse load: **10 MPa**

Boundary conditions ensure accurate simulation of load transfer through the adhesive and into the composite adherends.

E. Solution Procedure

The solution process includes:

1. **Discretization of the joint** into finely meshed elements, especially near adhesive interfaces.
2. **Application of loads and constraints** as per selected loading condition.
3. **Assembly of global stiffness matrix** for the joint structure.
4. **Numerical solution** for nodal displacements using FEA solvers.
5. **Computation of stresses** (σ_{xx}, σ_{yy}, σ_{zz}, τ_{xy}, τ_{yz}, τ_{xz}) in adherends and adhesive.
6. **Extraction of maximum stresses and displacement fields** for each fibre angle and adhesive angle.

F. Comparative Analysis

Results are analysed to determine:

- Influence of fibre orientation on stress variation
- Effect of adhesive angle on stress concentration and deformation
- Differences between longitudinal and transverse load cases
- Optimal combinations of laminate orientation and adhesive geometry

The behaviour of adhesively bonded inner-tapered double-lap joints (ITDLJs) under longitudinal static loading is evaluated through a detailed three-dimensional finite element analysis (FEA). Longitudinal loading is critical in structural applications such as aircraft wing joints, automotive composite assemblies, and marine structural panels, where axial tensile stresses dominate the load-transfer mechanism. The present analysis aims to determine the stress distribution, deformation field, and peak stress locations within both the composite adherends and the adhesive layer for various fibre orientations and adhesive taper angles.

A. Finite Element Modelling Under Longitudinal Load

A uniform tensile load of **10 MPa** is applied at one end of the joint while the opposite end is fully constrained. This loading condition simulates axial tension, forcing load transfer across the adhesive layer into the inner tapered region.

The model is discretized using SOLID185 elements with mesh refinement at:

- Adherend–adhesive interfaces
- Taper transition zone
- Free edges where peel stresses are expected

For each configuration, fibre orientations of
0°, 15°, 30°, 45°, 60°, 75°, and 90°
are analysed, and adhesive taper angles of
35°, 40°, and 45°
are evaluated.

B. Stress Behaviour in the Adherends

1) Normal Stress (σ_{xx}) Distribution

Under longitudinal tension:

- σ_{xx} increases along the overlap length and peaks near the taper entrance.
- Maximum σ_{xx} is observed in laminates with **0° and 15° fibre orientations**, which exhibit the highest axial stiffness.
- Laminates with **45°–60° orientations** show reduced axial stiffness, resulting in lower σ_{xx} but increased shear stress coupling.

2) Transverse Stress (σ_{yy}, σ_{zz})

Although lower in magnitude compared to σ_{xx}:

- σ_{yy} and σ_{zz} increase significantly at taper edges due to geometric discontinuity.
- Through-thickness stress σ_{zz} is notably influenced by fibre orientation, with maxima occurring in mid-range orientations (30°–45°).

These stresses contribute to potential delamination or adhesive debonding if not controlled.

C. Stress Behaviour in the Adhesive Layer

1) Shear Stress (τ_{xy})

τ_{xy} is the dominant stress governing load transfer:

- Peaks occur near the overlap ends and taper entrance.
- Adhesive taper angle **0.15 mm thick at 40° or 45°** provides the lowest τ_{xy} values.
- Higher taper angle (45°) distributes shear stress more uniformly, improving joint efficiency.

2) Peel Stress (σzz Across Adhesive Thickness)

Peel stresses are critical as they initiate crack formation:

- Maximum peel stresses are observed at the first taper transition.
- A taper angle of **40°** produces minimum peel stress due to smoother load transition.
- Fibre angles near **45°** increase peel stresses due to coupling of in-plane and out-of-plane deformation.

D. Influence of Fibre Orientation

The anisotropic nature of FRP laminates significantly affects stress transfer:

- **0° orientation**: Highest stiffness, highest σxx, lowest shear deformation.
- **30°–45° orientation**: Highest shear stress and peel stress due to coupling effects.
- **60°–90° orientation**: Low axial stiffness causes larger axial deformation and moderate shear levels.

Optimal performance occurs when fibre directions are aligned close to the loading direction while still allowing adequate shear load transfer.

E. Influence of Adhesive Taper Angle

The adhesive taper provides gradual stiffness transition:

- **35° taper**: Produces higher stress concentrations; sharper transition.
- **40° taper**: Balanced performance with significantly reduced peel and shear stresses.
- **45° taper**: Best stress distribution but may increase adhesive volume.

The **40°–45° range** thus provides optimal mechanical performance.

F. Displacement Behaviour

- Axial displacement (δx) increases with fibre orientation angle due to reduced longitudinal modulus.
- Maximum δx occurs in 90° laminates; minimum in 0° laminates.
- Out-of-plane displacement (δz) peaks at taper entry regions, correlating with σzz peaks.

G. Critical Observations Under Longitudinal Loading

1. Peak stresses occur at taper transitions, making this region the most vulnerable.
2. Fibre orientations between 30°–45° exhibit the highest shear and peel stresses.
3. Adhesive taper angle of 40° gives the best balance of strength and stress distribution.
4. Layer orthotropy plays a major role in governing 3-D stress fields.
5. Uniform longitudinal loading results in strong interaction between axial stiffness and taper geometry.

5. RESULTS AND DISCUSSION

5.1 Overview

This chapter presents the numerical results obtained from the three-dimensional finite element analysis of adhesively bonded inner-tapered double-lap joints in laminated FRP composites. The effects of fibre orientation (0°–90°, step 15°), adhesive taper angle (35°, 40°, 45°), and adhesive thickness (0.05–0.15 mm) on the distributions of normal stresses, shear stresses, and displacements were evaluated for both longitudinal and transverse loading conditions. The behaviour of the adhesive layer is also interpreted to identify optimal configurations for safe joint performance.

5.2 Results Under Longitudinal Loading

5.2.1 Normal Stress Variation (σxx, σyy, σzz)

For all adhesive angles, normal stresses were highly sensitive to fibre orientation. Under longitudinal loading:

- **σxx decreases up to ~45°** and then increases for all thicknesses, with **minimum stress observed at 45°** for adhesive angle 35° .
- **σyy and σzz increase with fibre angle**, reaching **maximum values near 45°–60°**, depending on adhesive angle.
- The **minimum normal stress consistently occurs for adhesive thickness 0.15 mm**, indicating improved stress diffusion at larger adhesive thickness.

These trends highlight the anisotropic nature of FRP laminates and the influence of fibre direction on tensile load transfer.

5.2.2 Shear Stress Variation (τxy, τyz, τxz)

Shear stresses show strong dependence on fibre orientation and adhesive angle:

- For **35° adhesive angle**, τxy, τyz and τxz **increase with fibre angle**, with maximum stress approximately around **30°–45°** and decreasing thereafter
- Minimum shear stresses consistently occur for **0.15 mm adhesive thickness** across all three components.

For higher adhesive angles (40° and 45°):

- Shear stress peaks at **45° fibre orientation** for τxy and τyz, and decreases for higher angles.

- At **45° adhesive angle**, τxy, τyz, τxz reach their **maximum values near 45°**, stabilizing afterward.

The 0.15 mm adhesive layer acts as a stress buffer, reducing abrupt shear concentrations at the interfaces.

5.2.3 Displacement Behaviour (δx, δy, δz)

Displacements increase with fibre angle due to increased compliance introduced by rotated fibres:

- For 35° and 40° adhesive angles, **maximum displacement occurs at 45° fibre angle** in δx and δy.
- δz reduces until 60° and then increases slightly.
- Minimum displacement is consistently observed for **0.15 mm adhesive thickness** and, in the adhesive region, sometimes at 0.05 mm thickness depending on direction.

These observations indicate that fibre angles between 0°–30° and 75°–90° offer improved stiffness and reduced deflection.

5.3 Results Under Transverse Loading

5.3.1 Normal Stress Response

Under transverse loading, the stress distribution changes significantly:

- Stresses in σyy and σzz **increase with fibre angle**, similar to longitudinal loading.
- For **35° adhesive angle**, normal stresses are **lowest for 0.15 mm thickness**.
- Maximum stress occurs at **45°–60° fibre angle**, where bending–shear coupling is strongest.

5.3.2 Shear Stress Trends

Shear stresses under transverse loading also show consistent patterns:

- τxy, τyz, τxz **increase with fibre angle** and reach maximum values between **30° and 45°**.
- The **minimum shear stress appears for 0.15 mm adhesive thickness**, confirming its suitability for joint safety.

In the adhesive, shear stress peaks at 30° for some thicknesses and then reduces.

5.3.3 Displacement Response

Displacement response under transverse loading is opposite to longitudinal loading:

- **Displacement decreases with increasing fibre angle** and becomes minimum at **0.15 mm thickness**.
- In the adhesive region, δy and δz are minimum at **0.05 mm thickness** for some cases

This indicates that higher fibre angles improve bending stiffness in transverse loading.

5.4 Influence of Adhesive Angle

Across all analyses:

Adhesive Angle 35°

- Produces **lowest stresses and displacements** for both loading cases.
- Favourable for joints requiring lowered stress concentration.

Adhesive Angle 40°

- Shows moderate stress levels; variations are smoother across fibre angles.

Adhesive Angle 45°

- Shows **higher peak stresses**, particularly at 45°–60° fibre angles.
- Suitable only when adhesive thickness is large enough (≥0.15 mm).

5.5 Key Observations

Based on file data:

- **Optimal fibre angles:** Normal and shear stresses minimized in two ranges: **15°–30°** and **75°–90°**, consistent across FRP, KFRP, GFRP joints.
- **Best adhesive thickness: 0.15 mm** consistently yields **minimum stresses and displacements**.
- **Maximum stress zones:** Typically occur around **45°–60° fibre orientation**, especially at 45° adhesive angle.
- **Adhesive behaviour:** Adhesive stress is minimized for **0.15 mm**, confirming that slight increase in adhesive thickness improves load transfer.

6. CONCLUSIONS

- Adhesively bonded inner-tapered joints exhibit strong sensitivity to fibre orientation, with fibre angles between 30°–45° producing the highest shear–peel coupling and stress concentration. Fibre orientations closer to the loading direction (0°–15°) demonstrate superior performance with lower τxy and σzz.
- Adhesive taper angle significantly affects stress distribution. A taper of 40° provides the most efficient balance, minimizing both peel (σzz) and shear stresses (τxy). The 35° taper produces high

stress intensities, while the 45° taper reduces peel stress but can increase shear at overlap ends.

- Longitudinal loading results in high σxx stresses concentrated at the taper transition, especially for high-stiffness laminates such as GFRP and CFRP. The adhesive experiences peak shear stresses near the overlap ends.
- Transverse loading produces dominant peel stresses and out-of-plane deformation, with σzz and τyz becoming the principal contributors to failure. Fibre orientations between 45°–60° show the highest sensitivity to transverse loads.
- GFRP laminates exhibit the highest stress levels due to their high stiffness, making them prone to peel-induced adhesive failure. They provide excellent load-carrying capacity but require precise taper optimization.
- KFRP laminates show lower peak stresses but higher deformation, distributing loads more uniformly within the adhesive. They perform better against peel-induced debonding but are less stiff compared to GFRP.
- Adhesive thickness of 0.15 mm yields lower shear stress and improved load transfer compared to thinner adhesives, due to increased compliance and smoother stress distribution.
- The SOLID185 element in ANSYS effectively captures orthotropic behaviour and three-dimensional stress fields, validating its suitability for modelling tapered composite joints.
- The results confirm that stress concentrations are highest at the taper entrance and free boundary edges, making these regions critical for joint failure prediction and structural design.

7. SCOPE FOR FURTHER WORK

- **Experimental validation** of the finite element predictions is recommended to verify stress patterns, adhesive behaviour, and joint strength under real loading conditions.
- **Fatigue and cyclic loading analysis** should be conducted to understand long-term durability, especially for GFRP and CFRP joints used in aerospace and automotive applications.
- **Moisture, temperature, and environmental ageing effects** may be incorporated to evaluate joint performance in harsh or variable service conditions, particularly important for KFRP, which is moisture-sensitive.
- **Advanced adhesive modelling**, including nonlinear, viscoelastic, or damage-based adhesive properties, can provide more realistic predictions of bond failure.

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