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Parametric Numerical Framework for Functionally Graded Adhesive Joints under Adherend Stiffness Mismatch

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Introduction

Adhesively bonded single-lap joints are widely used in lightweight and multi-material structures, where adherends often exhibit different stiffness levels. Such stiffness mismatch can strongly affect load transfer, stress concentration, and damage initiation near the overlap ends.

Functionally graded adhesives provide a promising strategy to tailor the local mechanical response of the bondline. Instead of using a uniform adhesive layer, the adhesive properties can be spatially varied to control stress redistribution and damage development.

In this ongoing study, adherend mismatch is treated as a design variable, and the adhesive distribution is described within a unified parametric framework. The objective is to develop a numerical methodology for evaluating how graded adhesive distributions interact with adherend stiffness mismatch in single-lap joints.

Methods

- A two-dimensional finite element model of a single-lap joint is developed, with the adhesive layer represented by cohesive elements. The geometry and modelling procedure are kept consistent across all cases to enable controlled comparison of adhesive distribution effects.
- The adhesive distribution is described by a normalized spatial variable, ψ(x), defined along the overlap length. Through a field-variable-based implementation in Abaqus, ψ(x) is assigned to the cohesive elements as FV, allowing local cohesive parameters, including traction stiffness, damage initiation strength, and fracture energy, to be interpolated from material property tables.
- Both stepwise and smooth adhesive distributions are considered. Step profiles serve as sharp-transition references, while sigmoid-type profiles are used to represent smoother property transitions along the bondline.

Graphics / Images

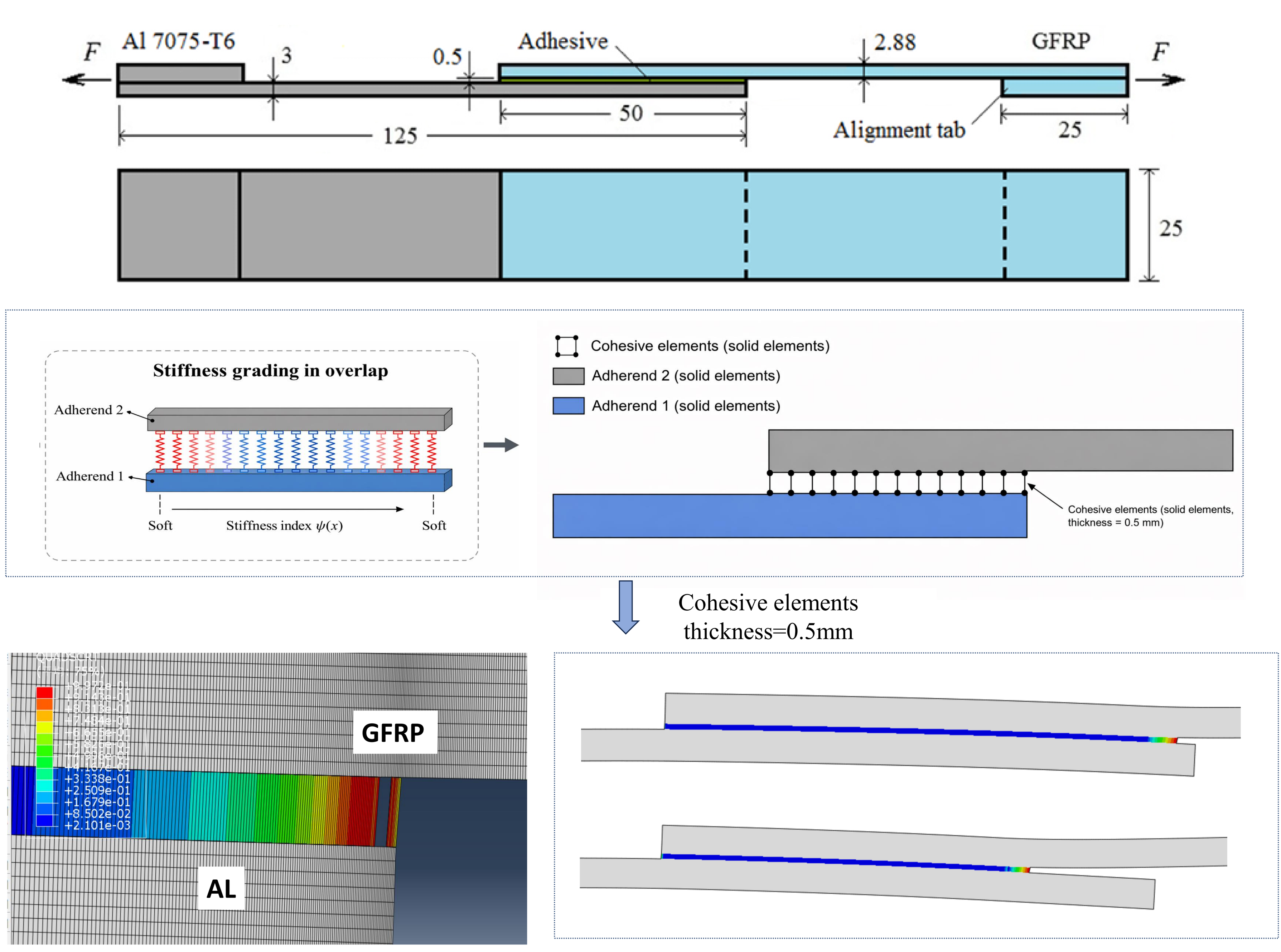

Figure.1 Geometry, cohesive-layer implementation, and representative FE response of functionally graded single-lap joints

Field-variable assignment through FV = $\psi(x)$

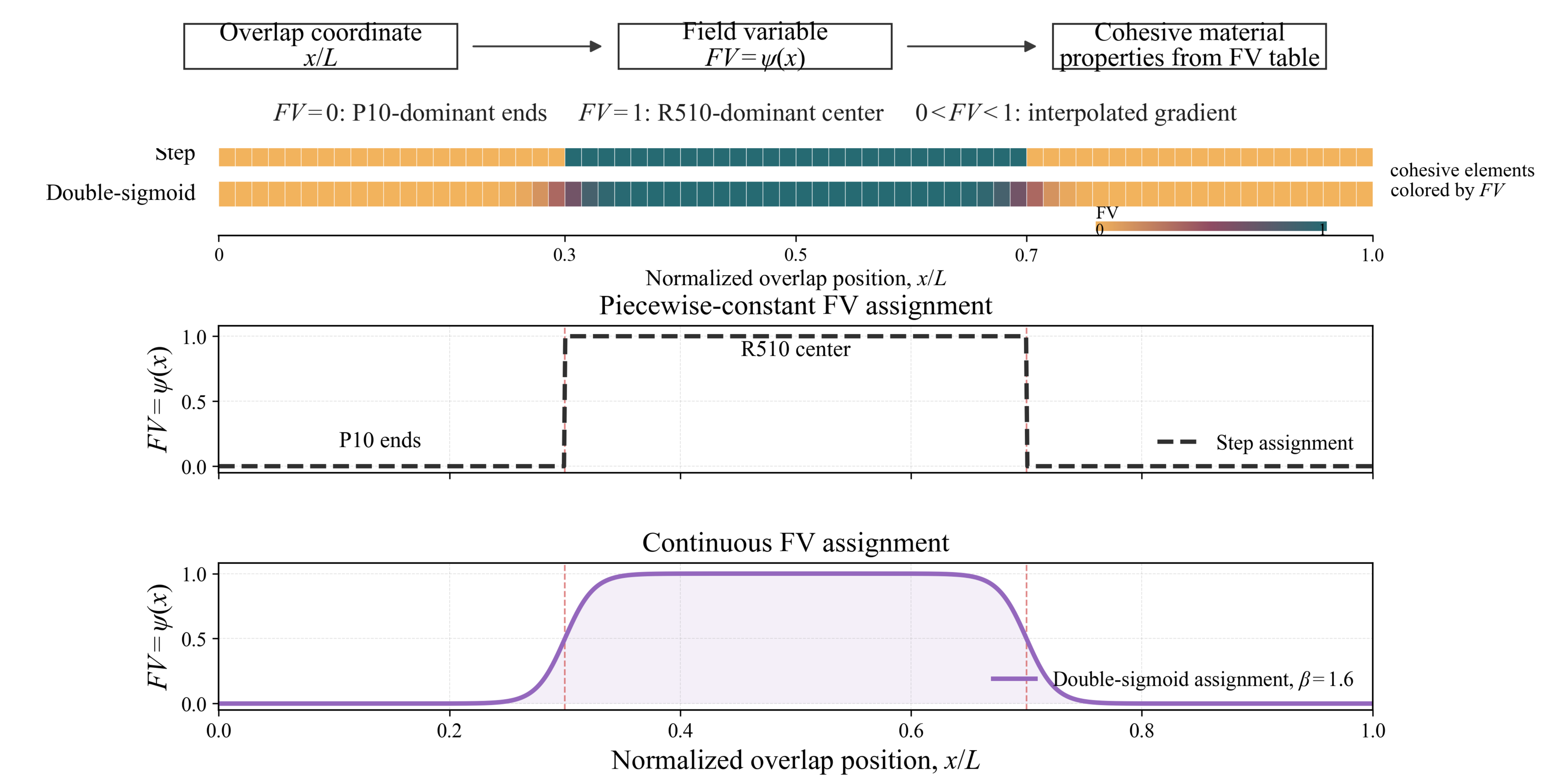

Figure.2 Field-variable assignment and cohesive property interpolation for continuously graded adhesive joints

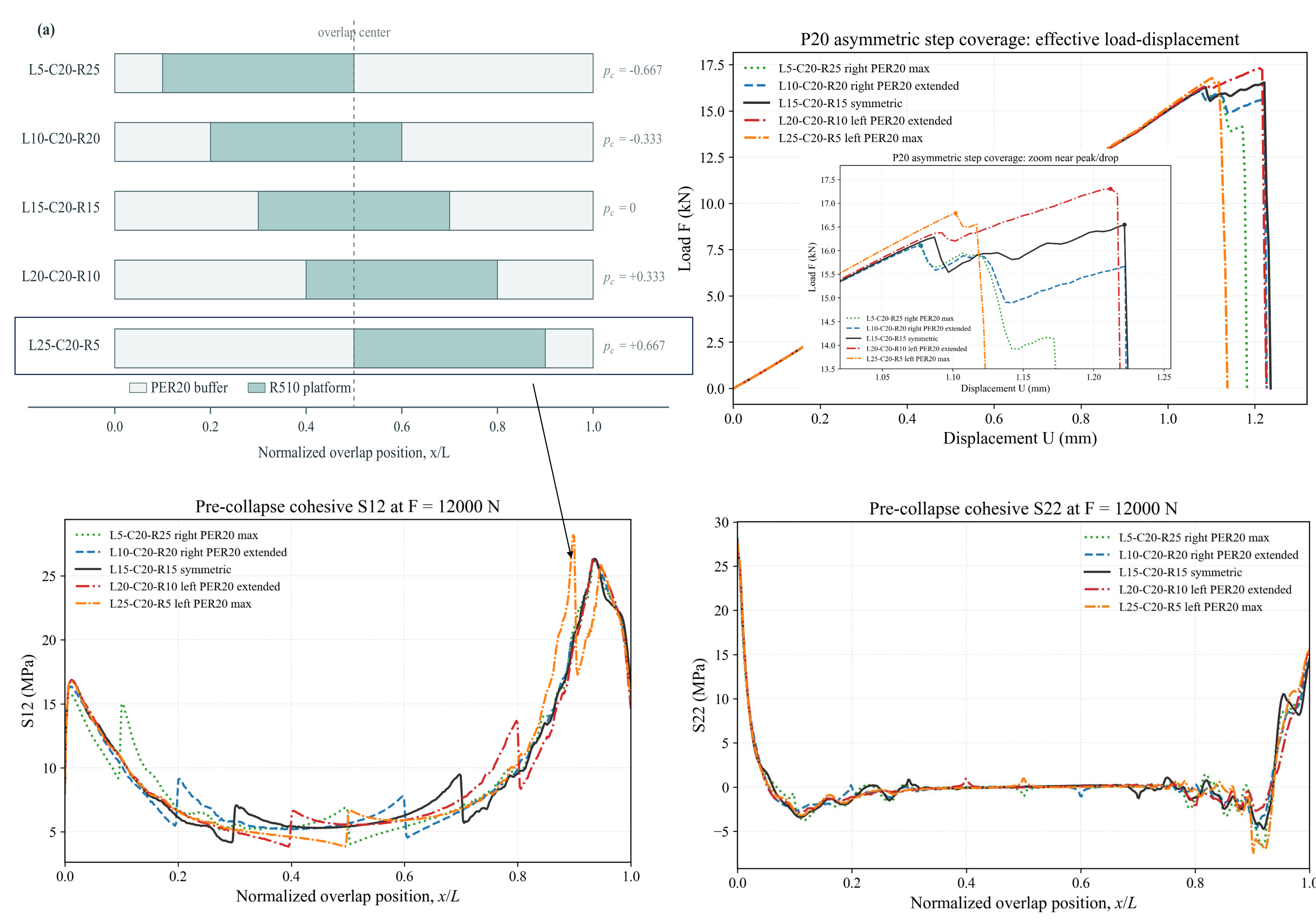

Figure.3 Representative analysis of asymmetric stepwise adhesive layouts, showing platform allocation, load–displacement response, and pre-collapse S12/S22 stress distributions.

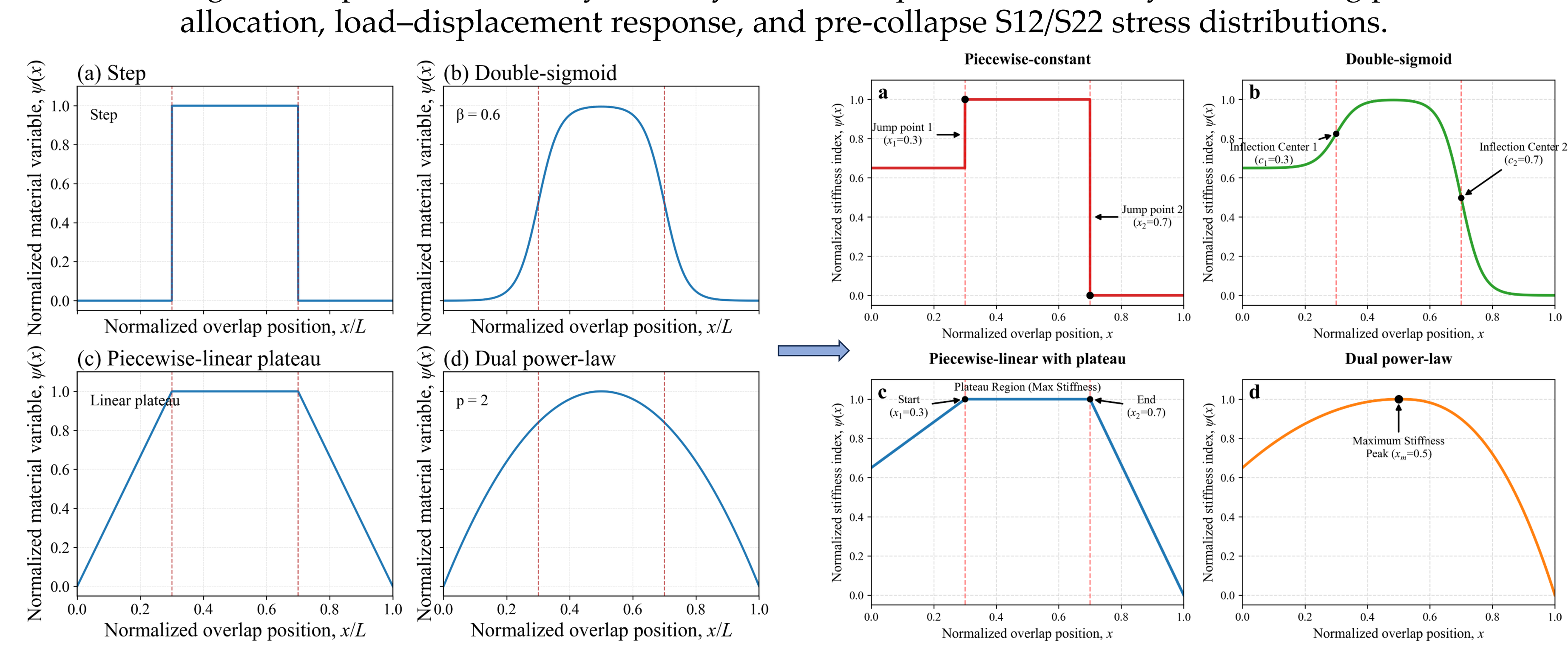

Figure.4 Representative adhesive distribution families used to describe spatial adhesive property allocation, including step, double-sigmoid, piecewise-linear plateau, and dual power-law profiles.

Conclusions

1. Stepwise profiles provide a useful reference for identifying how spatial allocation affects load transfer.
2. Smooth sigmoid profiles provide a continuous counterpart for examining whether similar mechanical trends can be retained without abrupt property transitions.
3. A cohesive finite element framework and field-variable implementation enable spatially varying adhesive properties to be assigned in a controlled and reproducible way. The analysis combines global load response, interfacial stress distribution, and damage evolution to evaluate the mechanical role of adhesive grading.
4. This work develops a parametric finite element framework to study how graded adhesive distributions interact with adherend stiffness mismatch in bonded joints.