20th European Mechanics of Materials Conference - EMMC20
Florence, Italy | May 27th-29th, 2026
www.emmc20.unifi.it

Load Transfer in Stepped-lap Joints: Optimal Geometry and Effective Bond Length

Alessio Rubino[1], Bernardino M. Chiaia[2], Alberto Sapora[3], Pietro Cornetti[4]

[1] Politecnico di Torino, Italy. alessio.rubino@polito.it
[2] Politecnico di Torino, Italy. bernardino.chiaia@polito.it
[3] Politecnico di Torino, Italy. alberto.sapora@polito.it
[4] Politecnico di Torino, Italy. pietro.cornetti@polito.it

Paper ID: 546
Symposium S8: Fracture, and damage of materials

Abstract

Adhesively bonded joints have been increasingly adopted across several engineering fields as an attractive alternative to traditional joining techniques such as welding and mechanical fastening. Their advantages include improved load transfer, reduced stress concentrations, enhanced fatigue resistance, and increased durability, especially in lightweight and composite structures. Among the various joint configurations, stepped-lap joints have attracted considerable attention due to their intrinsic capability to mitigate stress concentrations at joint extremities, as well as their practical suitability for composite repair applications. The analysis and design of stepped-lap joints benefit significantly from the use of dedicated fracture-mechanics tools. Analytical approaches play an essential role in providing fundamental insights into the mechanics governing load transfer and interfacial debonding, allowing the influence of material, geometric, and interfacial parameters to be explicitly identified. At the same time, numerical approaches, such as cohesive-zone models embedded within Finite Element (FE) frameworks, are widely employed for the detailed analysis and final design of adhesively bonded joints in real engineering applications. Within this context, fracture mechanics offers a unified and rigorous framework in which analytical and numerical tools can be consistently combined to describe the onset and propagation of damage at the adhesive–adherend interface. In this work, the fracture (debonding) behavior of one-step and multi-step lap joints is investigated by combining global (energy-based) and local (stress-based) fracture-mechanics analytical approaches. The global analysis is used to evaluate the joint capacity in terms of energy release rates, while the local analysis provides the stress field developing along the adhesive layer. In the latter case, a cohesive shear-lag model under pure Mode II (no peeling stresses) loading is assumed at the interface, leading to closed-form solutions for the interfacial stress distribution. In particular, the stress-based solution enables the identification of the transition in the governing failure mechanism as a function of the bond length, which evolves from a strength-governed failure for short joints to an energy-governed failure for long joints, as the bond length approaches the effective bond length. Within both frameworks, the focus is on the role played by the joint geometry, specifically the relative height of the steps. This parameter, which is typically not treated as an independent design variable and is usually kept constant for all steps in practical applications, is shown to significantly affect both the load-carrying capacity of the joint and the associated effective bond length. As a key result of the investigation, an optimal geometric configuration is identified for each number of steps, whereby the joint capacity and effective bond length are maximized. Based on the derived closed-form solutions, design diagrams are proposed for different step configurations. The resulting analytical framework and design tools are intended to support the fracture-mechanics-based design of adhesively bonded stepped-lap joints, with particular relevance to repair applications in aeronautical, mechanical, and related engineering fields.

Keywords:

Stepped-lap adhesive joints Interface failure Fracture mechanics Cohesive zone model Optimal geometry