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Computationally efficient interface modeling in fiber-reinforced composites through displacement-based component-wise approach

Ibrahim Kaleel, Marco Petrolo and Erasmo Carrera

MUL[2] Group, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Italy

*Corresponding Author: erasmo.carrera@polito.it

The paper presents a computationally efficient numerical tool for interface modeling in fiber-reinforced composite structures. The proposed numerical tool is part of computational platform built for virtual testing of composites developed within the scheme of the Carrera Unified Formulation (CUF), a unified hierarchical formulation to generate refined structural theories through a variable kinematic description [1]. 1D CUF models can provide accurate 3D-like stress fields at a reduced computational cost, e.g., approximately one to two orders of magnitude of degrees of freedom less as compared to standard 3D brick elements. In this work, Lagrange-type polynomials (LE) are used to interpolate the displacement field over the cross section leading to a purely displacement-based refined one-dimensional model. The Component-Wise modeling (CW), an approach that stems out of LE models, is utilized to model various components of composite structures across scales, e.g., fiber, matrix, laminae and laminates [2]. Based on the works of Allix et al. [3] and Camanho et al. [4], a class of higher-order cohesive elements is implemented within the CW modeling framework for simulating interfacial fracture mechanics problems. Zero thickness cohesive cross-section elements are introduced along interface of various components of composite materials and structures (such as fiber-matrix interface and inter-laminar interface). Component-Wise modeling of a Double Cantilever Beam specimen (DCB) with cohesive element introduced across the interface is illustrated in Fig. 1.

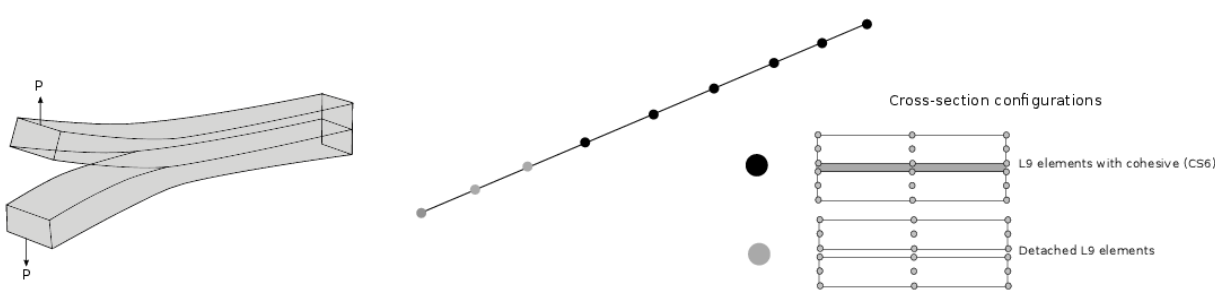

Figure 1: Double cantilever beam (DCB) specimen modeling with CUF-CW cohesive modeling technique

Cohesive elements are equipped with a mixed-mode traction-separation law, which defines the constitutive behavior of the interface element. An efficient arc-length solver based on dissipation energy constraint is implemented within the platform to trace complex equilibrium paths with multiple snapbacks [5]. Figure 2 depicts the load-displacement response of a DCB test under mode I condition. The post-peak response shows very good agreement with the analytical solution based on classical beam theory.

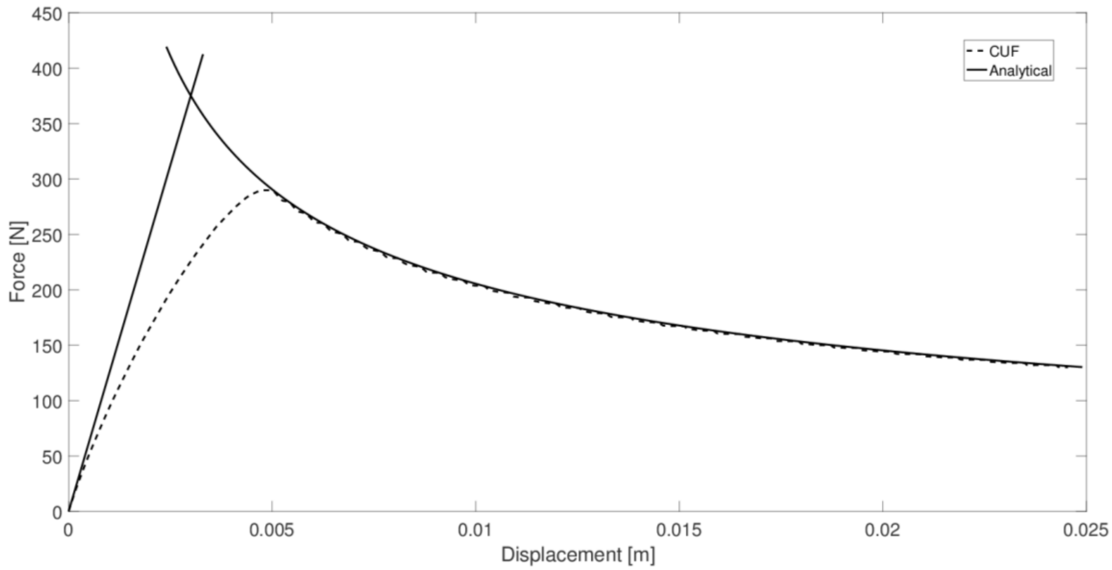

Figure 2: Load-displacement response for mode I DCB simulation

A numerical simulation campaign is undertaken to assess the accuracy and efficiency of the proposed tool. Numerical examples shall include benchmark composite delamination problems (DCB, ENF, MMB), free-edge delamination analysis and fiber-matrix debonding at the micromechanical scale.

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