A HOMOGENIZED APPROACH FOR DELAMINATION FRACTURE IN LAMINATED STRUCTURES

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Summary Progressive damage in multi-layered structures is dominated by delamination fracture at the layer interfaces. Current modeling relies on cumbersome and computationally expensive discrete-layer models which represent the structures as an assembly of layers joined by cohesive interfaces and where the number of variables depend on the number of layers and may be very large. In this paper, fracture of laminated plates will be studied using a novel multi-scale homogenized model which has been recently formulated by the author. The model depends on a limited number of global variables, equal to those of classical single layer theories, and account for the small-scale fields, e.g. zig-zag displacements, jumps at the layer interfaces, through a homogenization technique. The model accurately predicts stresses and displacements in multi-layered plates with continuous imperfect interfaces and delaminations subjected to thermo-mechanical loading. Here the accuracy of the approach in deriving fracture parameters will be verified using some simple reference problems.

MULTISCALE HOMOGENIZED APPROACH

In this paper the potential of a novel homogenized structural theory to study fracture of multi-layered plates will be investigated.The theory was recently formulated in [1,2] and based on the original works in [3,4].
The theory uses a multiscale approach and a homogenization technique and couples an equivalent single layer theory and a detailed discrete-layer cohesive-interface model, in order to obtain efficient homogenized field equations while accounting for the inhomogeneous material structure and for the presence of imperfect interfaces and cohesive or traction-free delaminations. The equations depend on a reduced number of variables, which is independent of the numbers of layers or imperfections and coincides with that of the coarse grained model (four in wide plates and beams; six in general plates), Fig.1. The homogenized theory allows closed form solution of problems that would otherwise require numerical solutions if treated using classical discrete-layer approaches. Global displacements and force and moment resultants are obtained through the solution of the homogenized equations using solution techniques previously developed for homogeneous structures, while the local fields, in the layers and at the layer interfaces, can be easily evaluated a-posteriori. The accuracy and efficacy of the theory for the analysis of laminated wide plates and beams with imperfect sliding interfaces and delaminations subjected to thermo-mechanical loads has been demonstrated in [5]. Figure 2 shows stress and displacement fields in a thick highly anisotropic wide plate with imperfectly bonded layers and fully delaminated layers; the results are compared with exact elasticity solutions.

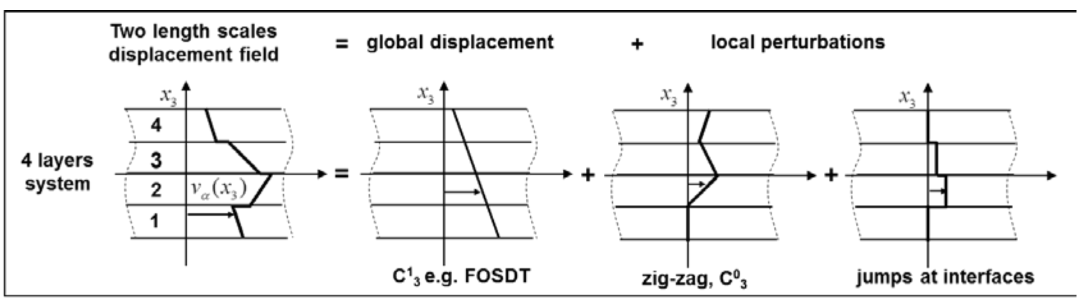

Figure 1: Global displacements (single layer theory) and local perturbations in the two length-scales displacement field assumed in the model in [1]. The local perturbations are derived, as functions of the global variables, through a homogenization technique.

FRACTURE ANALYSIS

The model in [2] will be used to define the fracture parameters in simple reference problems, e.g. beams with finite length delaminations under mixed-mode conditions, in order to verify its accuracy in predicting crack tip force resultants and local stress fields both for cohesive and traction free cracks. This verification is preliminary to the application of the approach for delamination damage progression analyses.

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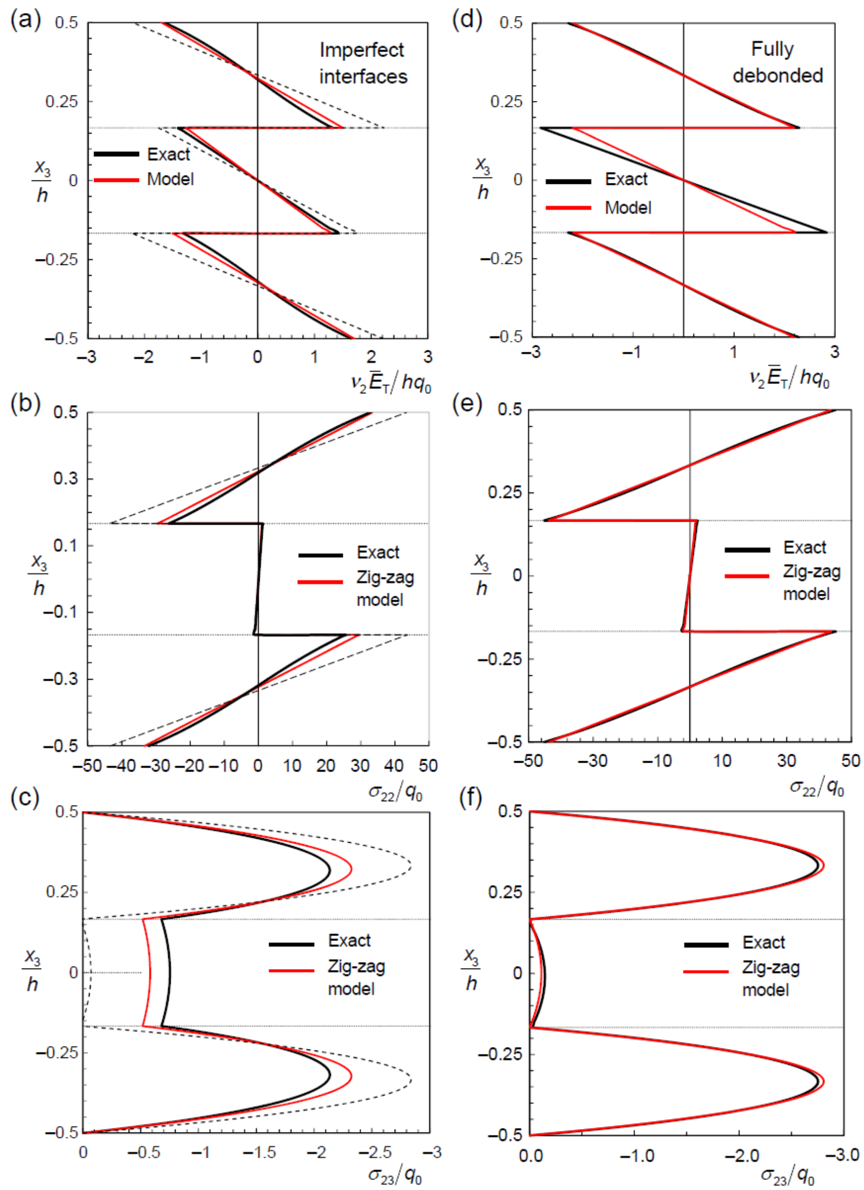

Figure 2: Longitudinal displacements, transverse shear (at plate end) and bending stresses (at mid-span) shown through thickness for a highly anisotropic simply supported thick, L = 4h, plate with three layers [0,90,0] subjected to a sinusoidal transverse load,and deforming in cylindrical bending. The first column refers to a plate with partially bonded layers joined by linearly elastic sliding-only interfaces with stiffness $K_S h / \bar{E}_T = 0.25$. The second column to a fully delaminated plate. Elastic constants: $E_T = E_L / 25$, $G_{LT} = E_L / 50$, $G_{TT} = E_L / 125$, $\nu_{LT} = \nu_{TT} = 0.25$, $\bar{E}_T = E_T / (1 - \nu_{LT}\nu_{TL})$. (dashed curves refer to early solutions based on the homogenized approach which were not energetically consistent)

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