Structural cohesive element for the modelling of delamination between thin shells without cohesive zone limit

X. Ai[1], B. Chen[1*], C. Kassapoglou[1]

[1] Department of Aerospace Structures and Materials, Faculty of Aerospace Engineering, Delft University of Technology,
Kluyverweg 1, 2629 HS Delft, The Netherlands, b.chen-2@tudelft.nl

Delamination is a critical mode of failure that occurs between layers in a composite laminate. The cohesive element is a widely-used interface element based on the cohesive zone model for modeling delamination. However, cohesive elements suffer from a well-known limit on the mesh density – the element size must be much smaller than the cohesive zone size.

The earlier work in 2D [1] shows that when plies are modelled with C1 structural elements (i.e., Euler-Bernoulli beams) and the cohesive element is formulated to be conformal to the ply elements, delamination modelling can be done with meshes where element sizes are larger than the cohesive zone length. This allows the new structural element models to achieve significant computational speed-up over traditional, solid-based models. Based on this earlier work, a follow-up work, which used TUBA plate elements, successfully reproduced the same result on 3D delamination in Mode I [2]. However, the TUBA elements employ curvature degrees of freedom, which makes the imposition of general boundary conditions troublesome.

In the current work, a new C1 triangular Kirchhoff-Love shell element is chosen to model the ply. No curvature degree of freedom is needed as opposed to the case in [2]. The triangular shape is chosen for its flexibility of modelling arbitrary (sub-)domain geometries. The interfaces are modelled by conforming cohesive elements. The cohesive element will share the degrees of freedom and interpolation scheme of the neighboring ply elements and account for the ply thickness projection when calculating the separation vector.

The proposed method is verified and validated on the classical benchmark problems of Mode I, Mode II and mixed-mode delamination [3]. All the results show that the size of elements can be at least 2 times larger than the cohesive zone length without suffering from the huge strength overprediction as in the case of solid-element models. This would then allow the accurate modelling of delamination without worrying about the cohesive zone limit on mesh density. Therefore, a lot of computing time can be saved by the proposed method.

References

[1] R. Russo, B. Chen, Overcoming the cohesive zone limit in composites delamination: modelling with slender structural elements and higher-order adaptive integration. Int. J. Numer. Methods Eng. 121 (2020) 5511-45.

[2] G. Tosti Balducci, C1 cohesive element models for 3D delamination: towards overcoming the mesh density constraint in FE delamination analysis. TU Delft Repository (2019).

[3] R. Krueger, A summary of benchmark examples to assess the performance of quasi-static delamination propagation prediction capabilities in finite element codes, J. Compos. Mater. 49 (2015) 3297-3316.