Phase field model for transverse cracks in composites: Effect of residual stresses

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Residual stresses in fiber reinforced composites are inherent due to various factors such as: laminate layup, difference in the coefficients of thermal expansions in fiber and matrix directions, curing cycles etc. This work considers the contribution of all these factors to evaluate the influence of residual stresses on the material behavior in flat and curved composite laminates with 0º/90º cross-ply layup configurations. This behavior is further introduced into the phase field formulation to model transverse cracks in composite laminates, considering both material and fracture behavior.

At first, isotropic phase field formulation in terms of HETVAL subroutine available from the literature [1] is fully exploited by recreating benchmark problems with flat and curved geometries in Abaqus. After establishing a clear understanding of the isotropic model for all the three different formulations AT1, AT2 and PF-CZM, orthotropic material behavior is introduced. Regarding the fracture behavior, various strain energy decomposition methods from the literature are analyzed and the energy split scheme with stiffness degradation method employed in [2] is implemented with only one phase field variable addressing transverse damage. The phase field implementation is further validated by testing the standard models from the literature.

Additionally, the effect of residual stresses, in respect of thermal strains is constituted into the phase field formulation in the straightforward way. The formulation is further validated by performing tests on a flat laminate with 0º/90º layup and corelating the results with the experimental data from [3].

Furthermore, four point bending tests(4PBT) on the $[0,90_2,0_n]_S$ cross-ply curved laminates is conducted to study the induced unfolding failure, a phenomenon where damage is initially initiated by intralaminar matrix crack and propagates further as interlaminar delamination under the presence of high stresses[4]. The detailed finite element study on 4PBT is conducted to assess the following:

1. Induced unfolding failure phenomenon (Stacking sequence is particularly chosen to illustrate the existence of induced unfolding)
2. Comparison with the experimental data [4]
3. Results with and without the effect of residual stresses for AT1, AT2 and PF-CZM formulations to show the significant influence of residual stresses.

To this end, efforts are made to extend this study to curved laminates with quasi-isotropic layups.

References

[1] Y. Navidtehrani, C. Betegón, E. Martínez-Pañeda. A Unified Abaqus Implementation of the Phase Field Fracture Method Using Only a User Material Subroutine. Materials, 14(8): 1913, 2021.

[2] P. Zhang, X. Hu, T.Q. Bui & W. Yao, Phase field modeling of fracture in fiber reinforced composite laminate. International Journal of Mechanical Sciences, 161, 105008, 2019.

[3] I.G. García, J. Justo, A. Simon, & V. Mantič, Experimental study of the size effect on transverse cracking in cross-ply laminates and comparison with the main theoretical models. Mechanics of Materials, 128, 24-37, 2019.

[4] P. L. Zumaquero, E. Graciani, J. Justo, Unfolding failure in curved composite laminates: Test campaign and stress analysis, Analysis of fracture mechanics, 2019.