EFFECTS OF 3D OUT-OF-PLANE STRESSES ON DAMAGE INITIATION AND PROGRESSION OF OHT AND OHC IN LAMINATED COMPOSITES

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Abstract: Composite laminate classical plate theory (LCPT) assumes 2D stress state (plane stress) for the stacked plies. However, for problems which include strong stress concentrations, 3D stresses may play an important role in the strength. Particularly for open-hole tensile (OHT) and compressive (OHC) behavior, 3D out-of-plane stresses may cause important damage, which is not taken into account in LCPT. Thus, notched OHT and OHC specimens' strength test results can not be predicted accurately from finite element 2D simulations. The present study aims to understand the effects of out-of-plane stresses in the behavior of notched OHT and OHC specimens. For this purpose, using the finite element commercial platform Abaqus, the Hashin failure criterion, which was originally used for 2D continuum shell elements, is extended into a 3D Hashin-based failure criterion to take into account pertinent out-of-plane 3D stresses. Cohesive layers were also modeled and considered in the analysis to better simulate mesomechanical delamination during progressive damage. Three groups of laminates were considered for the current OHT and OHC study: quasi-isotropic (QI) 45/0/-45/90]2s, Soft [45/-45/0/45/-45/90/(45/-45)2]s, and Hard [0/45/0/90/0/-45/0/45/0/-45]s, made of IM7/8552 carbon fiber reinforced polymers (CFRP). The 2D vs. 3D analyses were compared with experimental results. It was clearly shown that the out-of-plane stresses and delamination play an important role in the failure initiation of open hole composite material laminates. The cohesive layer in a 2D model did not considerably increase the accuracy. It is also shown that the OHC strength is similar to the OHT in the Soft case, but 40% lower in the Hard case. This indicates cohesive delamination is more prominent in Hard laminate. In the case of 3D elements, the adoption of a cohesive layer in the model would increase strength predictions because it would allow the representation of the delamination stress relief effect in the model. This effect can cause a reduction in strength in some cases, and as much as 14.4% increase (in the OHT QI laminate) in laminate predicted strength. Overall, the 3D analyses using 3D Hashin-based criteria and cohesive layers show much better prediction than 2D. It is also shown that models built with 3D elements with cohesive surfaces between plies are recommended for the analysis of critical structural composite parts.

Keywords: composite material, open hole compression, open hole tension, 3D stresses, CFRP, FEA, delamination, damage mechanics, progressive damage.