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Failure Analysis in Postbuckled Laminated Composite Shell Structures

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ABSTRACT

In industrial applications of shell-like structures made of composite laminates a numerical estimation of failure loads is necessary to avoid extensive testing or over-dimensioning. Especially in the aircraft industry this is an important issue since reduction of weight leads to decreasing service and production costs. Besides, the current discussion on reducing carbon dioxide emissions forces companies to further reduce weight and to improve the exploitation of material reserves.

Several damage scenarios may occur in composite laminates such as delamination or intralaminar damage like fiber breaking, transverse matrix cracking or shear failure, or any combination of these. Since the first occurrence of a defect not necessarily leads to final failure of a structure, the evolution of damage should be taken into consideration. In addition to the above cases, one damage scenario may trigger another one and if in-plane compression occurs buckling can also trigger damage or drive existing damages to propagate. Obviously, the processes inside of a laminated composite until final failure are very complicated, especially in the postbuckling region.

In this contribution a meso-level approach is presented which accounts for almost all damage scenarios mentioned above. The laminae are modelled with bilinear shell elements of Reissner-Mindlin type in combination with a transversely isotropic material law. Shear locking effects are reduced via the well-known Bathe-Dvorkin approach. In order to account for buckling a geometrically nonlinear formulation is employed. Ply failure is simulated using a ply discount model. The extended Hashin failure criteria are given by

$$f_F = \frac{\langle \sigma_x \rangle}{X_t} + \frac{\langle -\sigma_x \rangle}{X_c} \; , \tag{1}$$

$$\left.\begin{aligned} f_{Mt} &= \left(\frac{\sigma_y}{Y_t}\right)^2 + \frac{\tau_{xy}^2 + \tau_{xz}^2}{S_{xy}^2} + \left(\frac{\tau_{yz}}{S_{yz}}\right)^2 \; , \\ f_{Mc} &= \frac{\sigma_y}{Y_c}\left[\left(\frac{Y_c}{2S_{yz}}\right)^2 - 1\right] + \left(\frac{\sigma_y}{2S_{yz}}\right)^2 + \frac{\tau_{xy}^2 + \tau_{xz}^2}{S_{xy}^2} + \left(\frac{\tau_{yz}}{S_{yz}}\right)^2 \; , \end{aligned}\right\} \tag{2}$$

$$f_{FM} = \frac{\langle -\sigma_x \rangle}{X_c} + \frac{\tau_{xy}^2 + \tau_{xz}^2}{S_{xy}^2}\,, \tag{3}$$

cf. GOYAL ET AL. [1], where $\langle \bullet \rangle = \frac{1}{2}(\bullet + |\bullet|)$ are the Macauley brackets. Eqs. (1-3) hold for fiber breaking, matrix cracking or fiber-matrix shear failure, respectively, and σ and τ denote normal or shear stresses. The subscripts x, y, z denote the fiber direction, the in-plane transverse direction and the out-of-plane direction. X_t, X_c are the tensile and compressive normal strengths in x-direction, Y_t, Y_c are the tensile and compressive normal strengths in y-direction and S is the shear strength in the direction of the respective subscripts. If one of the above equations exceeds a value of 1 then the respective material properties are reduced by a constant knock-down factor $\lambda = 0.1$. Delamination is modelled through so-called interface elements which include the cohesive zone approach. The interface element has an initial zero thickness and relates interfacial tractions to relative displacements which occur between the two surfaces of the interface. The particular cohesive law is kink-free and history dependent leading to non-recurring stiffness degradation. A penalty term in the cohesive free energy function avoids the interpenetration of the crack faces. A detailed description of the cohesive law can be found in BALZANI & WAGNER [2] and WAGNER & BALZANI [3].

The model is applied to several validation examples with experimental evidence. One of these is the simulation of an axially compressed small specimen which compounds of a small composite strip connected to a T-shaped stiffener. The specimen is made of multi-directional IM7/8552 laminate which is a typical material for aircraft applications. Two kinds of specimens have been tested: Intact ones and some with a predamage introduced by insertion a Teflon layer between skin and stiffener. A layer of interface elements accounts for delamination between skin and stiffener in the predamaged version. Fig. 1 shows the response in terms of load-deflection curves. Excellent agreement with the experiments can be observed. Some other examples will highlight the applicability of the proposed concept.

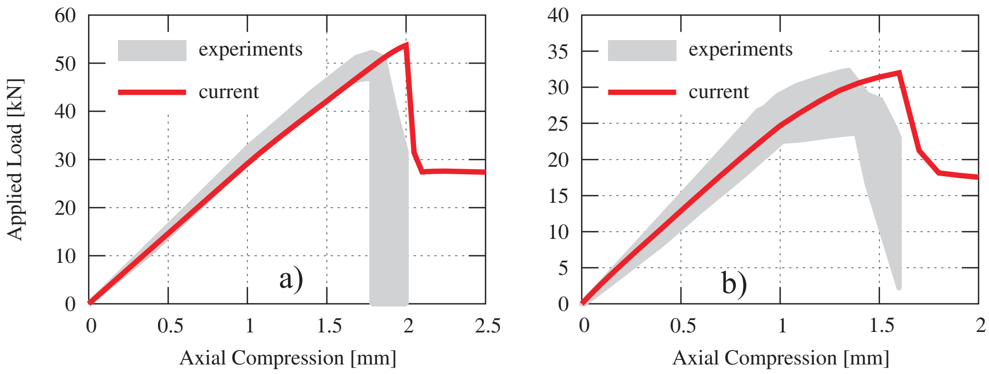

Figure 1: Load-deflection curves of the small stiffened specimen: a) undamaged; b) predamaged

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