Theory and Numeric of Solid-Shell Elements to Analyse the Delamination of Fibre-Reinforced Laminates

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This work discusses the investigation of shell structures and the analysis of the post-critical behaviour of fibre-reinforced structures. A main focus lies in the description of the deformation of thin-walled shell structures consisting of isotropic and transverse isotropic materials. In particular, the significance of transverse stresses on the deformation behaviour has been considered for the investigated structures. A solid shell element is presented with trilinear shape functions without rotational degrees of freedom. Locking effects of shell elements are prevented with established numeric procedures. The Assumed Strain method is used against shear and thickness locking. With the Enhanced Assumed Strain method, which is based on a mixed finite element formulation, the thickness strain is expanded to prevent the transverse strain defect of the 6-parameter shell theory. Different possibilities for the extension of the thickness strain are presented and their efficiency is demonstrated by numeric examples. The extension of the thickness strain with three parameters proves optimal because this extension of the solid-shell passes the patchtest for plates.

The multi-layer formulation for shells is used in order to improve the kinematic description of the shell in thickness direction. This formulation is a suitable instrument for the advanced analysis of transverse stresses for laminated structures and thick cross sections. A second focus of this work lies in the consideration of the failure process within fibre-reinforced laminates by progressive delamination. The layer, which connects the lamina, is understood as an interface. Brittle interface models are examined referring to crack models of Barenblatt and Dugdale. The energy release rate represents the crucial parameter for the determination of the crack opening displacement. Especially developed interface elements are used for the description of the crack propagation. The displacement in lengthwise direction to the interface is carried out bilinear, thus these elements can be used together with the solid-shell. Well-known models in literature, which describe the softening behaviour of the interface, are presented and examined. These models include a bilinear, a trilinear or a cubic distribution of the interface traction belong over the displacement jump. The comparison of the softening models is tested using interlaminar fracture tests. In mode I the DCB sample is considered and the ENF test in mode II. The discussed interaction possibilities for the mixed-mode are examined with the FRMM sample, whereby the square interaction of the energy release rates proves meaningful. Altogether it could be stated that the variation of the form of the softening model is not suitable for the adjustment of the numeric results to experimental load displacement curves. The maximum interface traction affects the largest breaking load, while the critical energy release rate considerably controls the softening behaviour of the load displacement curve.