PUCK'S CRITERION - NONLINEAR 6 PARAMETER SHELL THEORY APPROACH

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1. Introduction

We discuss the use of Puck criterion (PC) in the analysis of shell structures made of fiber reinforced plastics (FRP) within the framework of nonlinear 6 parameter shell theory (6p theory), in which the in-plane shear stress components are not symmetric. The PC is formulated on the basis of strong theoretical foundations (Mohr's theory [1],[2]), in contrast to other popular criteria derived from assumptions allowing to fit the initial failure envelope into experimental data [3]. The application of PC in the 6p theory is possible though as Puck defined precisely which in-plane shear component enters the formulation of the failure mode. The PC is focused mainly on the analysis of inter fiber failure (IFF), which will be investigated here. The fiber failure (FF) is predicted with the the maximum stress criterion .

Numerical FEM example is solved to present the differences between initial failure moment predicted with aid of the classical and adjusted criterion.

2. Theory

The equivalent single layer technique together with the 6p theory are used. The 6th parameter denotes the drilling rotation. The theory is supplemented with particular plane-stress material law that incorporates asymmetric stress measures [4].

In defining IFF, Puck consciously distinguishes the failure plane and therefore introduces the σ_{ba} component into the failure surface definition [1], [2]. Although in Puck theory $\sigma_{ba} = \sigma_{ab}$, it is the component σ_{ba} not σ_{ab} that leads to the crack development on the IFF plane, since the plane remains parallel to fiber direction (see e.g. [5]). In view of this, direct application of the Puck criterion in the analysis carried out by means of the 6p theory is possible. The use of Puck criterion in the 6p theory may lead to different damage predictions because the value of σ_{ba} ($\sigma_{ba} \neq \sigma_{ab}$) may differ as compared with the symmetric one.

3. Numerical example

A rib-stiffened cantilever is analyzed using FEM, see also [6], in order to show the difference between the damage onset predictions resulting from the classical and modified criterion. The standard criterion is implemented into Abaqus 6.14 code, as own UVARM procedure, while the modified one is implemented into the CAM code (see e.g. [4]). The panel properties are shown in Figure 1. Geometrically nonlinear calculations are performed until the failure initiation is achieved. It is monitored in each layer at points that match the in-plane integration rule.

The calculations are performed using 4-node S4 element in Abaqus for a mesh created by the following edge divisions: 15 elements across narrower part of the plate, 12 elements across the stiffener, 30 elements across wider part of the plate, 45 elements along the panel - [(15+12+30)×45 elements]. Whereas (5+4+10)×15 16-node elements CAMe16FI (see e.g. [4] for details) are utilised in CAM. The chosen finite elements are not affected by the locking phenomenon (see e.g. [6]).

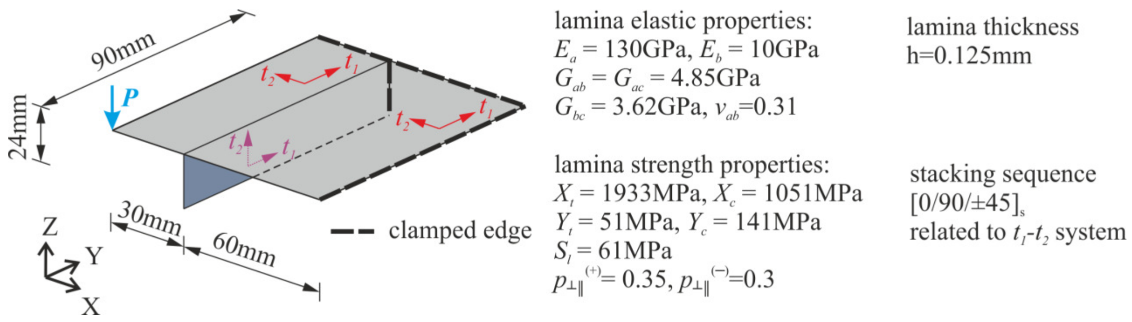

Figure 1. The properties of the analyzed panel.

The failure initiation is observed for P = 29.8N in the classical variant and for P = 28.5N in the modified one. This is a consequence of a different stress state, which is predicted by the used theories - Abaqus: σ_{bb}= 50.13MPa σ_{ba}=σ_{ab}= -9.4MPa; CAM: σ_{bb}= 50.34MPa σ_{ba}= -7.68MPa (σ_{ab}=-7.98MPa). The initial damage in both cases is the IFF mode A and is observed in narrower part of the plate at the stiffener-plate intersection, near the free edge of the panel.

4. Final remarks

The non-linear 6p shell theory is found to be applied especially in the analysis of shell structures with intersections, folds and branches. As opposed to some 5 parameter theories with drilling rotation, the 6th degree here of freedom is not introduced artificially. Therefore behavior of shell structures can be estimated more precisely. This in conjunction with the modified Puck criterion may result in different damage onset predictions as compared with the standard 5 parameter approach. The modification of Puck criterion extend the library of failure criteria that are available in the analysis of shells with 6p theory, available in e.g. [6].

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5. References

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