COMPARATIVE STUDY OF LINEAR AND NON-LINEAR PROGRESSIVE FAILURE ANALYSIS OF COMPOSITE AEROSPACE STRUCTURES

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Summary. The article presents a finite element based comparative study of linear and geometrically non-linear progressive failure analysis of thin walled composite aerospace structures subjected to different in-plane and out-of-plane loadings which are typically encountered in thin walled aerospace structures. Different ply and constituent based failure criteria and material property degradation schemes have been coded into a PCL code in Nastran, and progressive failure analyses of sample composite laminates with and without cut-outs are executed. Case studies are performed to study the effect of geometric nonlinearity on the first ply failure and progression of failure. Different ply and constituent based failure criteria and different material property degradation schemes are also compared in terms of predicting the first ply failure and failure progression.

ABSTRACT

The use of composite materials in primary aerospace structures is rapidly increasing. Understanding the failure response of composite laminates which are the building blocks of composite aerospace sub-structures is essential in order to exploit the full strength of composite materials in aerospace structures. Progressive failure analysis of fiber reinforced thin walled composites is a powerful method, which is widely studied in the literature [1], to determine the capability of composite structures to sustain loads.

In this article finite element based progressive failure analysis method is used to study the first ply failure and progression of failure of composite aerospace structures under in-plane and out-of-plane loading and geometrically non-linear deformations. In progressive failure analysis, for structures exposed to especially out-of-plane loads geometric nonlinear effects become prominent in different aspects such as stress stiffening and follower forces. Therefore, one of the aims of the article is to study the effect of geometric nonlinearity on the first ply failure and progression of failure through case studies. For this purpose different ply and
constituent based failure criteria and material property degradation schemes have been coded into a PCL code in Nastran. Depending on the failure criteria used, failure indices are calculated based on the strains or stresses at the center of shell elements, at the mid plane of plies. In order to effectively allow material property degradation at the ply level, before the failure analysis is initiated, for each element in the finite element mesh distinct composite laminate properties with distinct two dimensional orthotropic materials for each ply are generated via the PCL code that is developed. Thus, stiffness reduction scheme can be implemented easily for each failed ply by referencing the element property identification and material identification numbers of the failed ply. Currently, linear static and large displacement-small strain non-linear static solution sequences of Nastran are implemented in the PCL code. During the progressive failure analysis of the sample cases the limitation of the large displacement-small strain non-linear static solution is also investigated. In the abstract a sample case study is demonstrated for the progressive failure analysis of a 400x200 mm all edges simply supported laminate, with a circular cut-out of 100 mm in diameter at the center, subjected to pressure loading. One millimeter thick laminate is composed of 4 T300/1034-C plies with a stacking sequence of [0°/90°/90°/0°]. For this example Hashin’s failure criteria [2] is used during the progressive failure analysis. The elements with simultaneous first ply failures are shown in Fig.1 and it is observed that first ply failures occur at the edge of the cut-out along the longer side of the panel. First ply failure pressures given in Table 1 show that the first ply failure load determined from non-linear analysis is approximately 32 times the first ply failure load determined from linear analysis. Such differences are typical in geometrically non-linear progressive failure analysis and the article presents a comprehensive comparative study and discussion of linear and nonlinear progressive failure analysis through case studies. The same case studies are used for the comparison of different ply and constituent based failure criteria and different material property degradation schemes in terms of predicting the first ply failure and failure progression.

In the article it is also shown how the Patran command language (PCL) can be used effectively to exploit the capabilities of Nastran solver in performing progressive failure analysis and to visualize failure progression at the ply level.

Table 2: Ply properties and first ply failure pressures

<table>
<thead>
<tr>
<th>Analysis</th>
<th>FPF (N/mm²)</th>
<th>Failed Ply</th>
<th>Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonlinear</td>
<td>0.126</td>
<td>4 (top)</td>
<td>Matrix Compression</td>
</tr>
<tr>
<td>Linear</td>
<td>0.004</td>
<td>1 (bottom)</td>
<td>Matrix Tension</td>
</tr>
</tbody>
</table>

REFERENCES
