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# STUDY THE EFFECT OF EXTERNALLY AND INTERNALLY PLY DROP-OFF IN COMPOSITE LAMINATE ANALYSIS

Priyanka Dhurvey and N. D. Mittal
Department of Applied Mechanics, Maulana Azad National Institute of Technology, Bhopal, India
Email: priya_dhu@yahoo.com

## ABSTRACT

Tapered laminated structures, which are formed by dropping off some of the plies at discrete positions over the laminate, have received much attention from researchers because of their structural tailoring capabilities, damage tolerance, and their potential for creating significant weight savings in engineering applications. The inherent weakness of this construction is the presence of material and geometric discontinuities at ply drop region that induce premature interlaminar failure at interfaces between dropped and continuous plies. In the present work the finite element analysis of composite laminates with externally and internally ply drop-off is presented. The effect of different lay-ups and different ply drop-off ratio Th/L (where Th is total thickness of ply drops and L is ply drop of length) under tensile load is study. The finite element analysis is carried out using ANSYS software.

**Keywords:** ply drop-off, ply ratio thickness, lay-up, displacement, ANSYS.

## INTRODUCTION

Composite structures are increasingly being used in aerospace, mechanical and automotive industries due to their high strength-to-weight and stiffness-to-weight ratios. The laminated tapered beams are increasingly being used in engineering applications, such as turbine blades, helicopter blades and yokes, robot arms and satellite antennas wherein the stiffness of the structure needs to be varied along the length of the beam. Such tapered structure can be made by terminating selected plies at discrete locations along the length of the beam so as to change the stiffness of the beam. Different types of ply drop-off configurations can be achieved in practice. Some of the most common types of tapered configurations are shown in Figure-1.

In general, finite element model based on lower-order polynomial displacement function incorporates only crude curvature distributions and usually yields discontinuous bending moments across element interfaces. Accurate results can be obtained more efficiently by increasing the number of degrees of freedom in the element rather than increasing the number of elements that have the same or lesser degrees of freedom. Thomas and Dokumaci [1] developed an internal node element with eight degrees of freedom considering the total deflection and bending slope as the coordinates at the two terminal nodes and two internal nodes. Thomas and Abbas [2] presented a finite element model for Timoshenko beam element by considering the total deflection, total slope, bending slope and the first derivative of bending slope as degrees of freedom.

They raise the order of element matrices to the eighth-order. Mukharjee and Varghese [3] designed a drop-off element to reduce the stress concentration by studying the effect of important parameters that determine the strength of laminates. Varghese and Mukharjee [4] developed a novel ply drop-off element for the analysis of tapered composites.

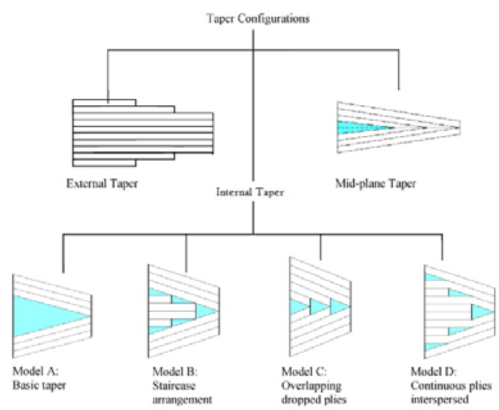


**Figure-1.** Schematic illustration of taper configurations.

Thomas and Webber [5] applied a fracture mechanics based analysis to predict the tensile delamination load of tapered composite plates. Mukharjee and Varghese [6] presented a global-local approach for the analysis of tapered composites. The present work, give an increased understanding of the behaviour externally and internally as shown in Figure-2 under tensile loadings. The material properties of AS4D/9310 are given in Table-2. The following parameters were examined: a) the ply drop ratio (Th/L), and b) the lay-up configurations is reported here. As the analytical treatment for such problem is very difficult, the investigation is carried out using ANSYS software.

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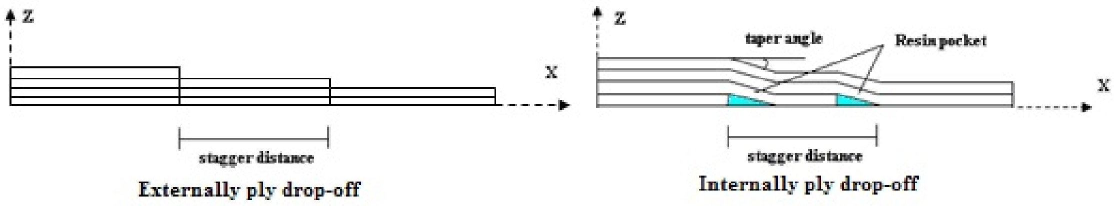


**Figure-2.** Composite Laminates with ply drop-off.

## Description of problem

For analysis, a ply drop-off composite laminated plate 120mm long and 100mm wide under uniform in-plane tensile loading for all cases analyzed by finite element method. The analysis is carried out for three different layup configurations are given in Table-1. The lamina thickness is taken as 0.75mm for all layup configurations.

**Table-1.** List of Layup configurations considered for analysis.

| Lay-up configuration | Lengths of the laminated composite with ply drop-off (mm) | |
|---|---|---|
| | Thick Section | Thin Section |
| LC1 | [(0/90)$_S$] | [0/90] |
| LC2 | [(90/0)$_S$] | [90/0] |
| LC3 | [(±45)$_S$] | [±45] |

Different ply drop-off ratio Th/L (where, Th is total thickness of ply drops and L is the total length of ply drop-off) considered (1/16, 1/18, 1/20). The material properties of AS4D/9310 are given in Table-2.

**Table-2.** Material properties of AS4D/9310.

| Material properties | Value |
|---|---|
| Ex | 133.86 GPa |
| $E_y = E_z$ | 7.706 GPa |
| $G_{xy} = G_{xz}$ | 4.306 GPa |
| $G_{yz}$ | 2.76 GPa |
| $\nu_{xy} = \nu_{xz}$ | 0.301 |
| $\nu_{yz}$ | 0.396 |

## Finite element analysis

SHELL181 is used for the analysis using ANSYS. SHELL181 is a 4-node element with six degree of freedom (three translations and three rotations) at each node. This element is used for analyzing thin to moderately thick shell structures with a side-to-thickness ratio of roughly 10 or greater. It is used for layered applications for modeling laminated composite shells. The element is well suited for linear and nonlinear applications. Due to the symmetric nature of different models investigated, it was necessary to discretize the quadrant plate for finite element analysis. Main task in finite element analysis is selection of suitable elements. Numbers of checks and convergence test are made for selection of suitable elements from different available elements and to decide the element length.

**Table-3.** The displacements of composite plate with externally and internally ply drop-off.

| Ply drop ratio (Th/L) | Layup configurations | Lengths of the Laminated composite with ply drop-off (mm) | | Displacement(mm) | |
|---|---|---|---|---|---|
| | | Thick section | Thin Section | Externally ply drop-off | Internally ply drop-off |
| 1/16 | LC1 | [(0/90)$_S$] | [0/90] | 3.475 | 1.479 |
| | LC2 | [(90/0)$_S$] | [90/0] | 2.816 | 4.429 |
| | LC3 | [(±45)$_S$] | [±45] | 4.788 | 5.185 |
| 1/18 | LC1 | [(0/90)$_S$] | [0/90] | 3.576 | 1.511 |
| | LC2 | [(90/0)$_S$] | [90/0] | 2.861 | 4.491 |
| | LC3 | [(±45)$_S$] | [±45] | 4.889 | 5.296 |
| 1/20 | LC1 | [(0/90)$_S$] | [0/90] | 3.688 | 1.544 |
| | LC2 | [(90/0)$_S$] | [90/0] | 2.906 | 4.552 |
| | LC3 | [(±45)$_S$] | [±45] | 4.993 | 5.354 |

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Results were then displayed by using post processor of ANSYS programme.

## RESULTS AND DISCUSSIONS

Ply drop-off causes a discontinuity within the laminate and therefore, it introduces structural difficulties like stress concentration at the drop station. This leads to failure of the components through delamination and/or failure of resin. Failure of composite laminates may occur in different ways:

- Fibre failure
- Matrix cracking
- Delaminations

The composite laminate with externally and internally ply drop-off is analyzed under tensile loading. The layup configurations and material properties are given in Tables 1 and 2, respectively. Table-3 shows the displacements for different layup configurations and ply drop ratio. It is also being observed from results, that when the ply drop-off externally the ultimate load layup configuration LC2 has the highest value followed by LC1, and LC3. The strength of layup configuration LC1 is high followed by LC2, and LC3 when the ply drop-off internally.

It is also being observed with increase of ply drop ratio the deflection also increase for same loading and boundary conditions and with decrease of taper angle the stress decreases for same loading and boundary conditions. The maximum deflection occurs near the junction of tapered and thin section. Stress concentration is prominent at ply drop-off and insignificant at other locations. It is also being observed that cross ply laminate of LC1 configuration underwent the largest inelastic deformation before failure when ply drop-off internally. These finding suggest that this type of ply configuration is capable of absorbing large amount of energy before failure, where energy absorbed is given by the area under load-displacement curve.

## CONCLUSIONS

The finite element analysis of composite laminates with internally ply drops has been presented. Effects of lay-up configuration on the behavior of tapered laminates have been investigated. Based on the findings, the following conclusions can be made.

- Internally ply drop-off composite laminates have more strength compare to externally ply drop-off composite laminates.
- With increase of ply drop ratio the deflection also increase for same loading and boundary conditions.
- With decrease of taper angle the stress decreases for same loading and boundary conditions.
- $90^0$ and ±45 plies should be dropped as $0^0$ plies lead to the largest stresses followed by $90^0$ and ±45 plies have considerably less severe effects.
- For smooth load transfer and reduced stress concentration, the plies should be dropped in decreasing order of their stiffness means stiffest plies (0) should be dropped at the thick section and softest plies (90) should be dropped at the thin section/end.
- High stress concentration zones are identified along taper section (drop-off) and away drop-off at other locations the stresses are insignificant.
- With increase in number of ply dropped the strength of drop-off decreases.
- Layup configurations also play an important role in behaviour of composite laminates with ply drop-off

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