Finite Element Analysis of Internally Ply Drop-off Composite Laminates

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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 internally ply drop-off composite laminates is presented. The effect of different lay-ups is study. The ply drop-off ratio Th/L (where Th is stagger distance and L is ply drop of length) is taken as 1/20. The finite element formulation is carried out in the analysis section of the ANSYS software.

Keywords: ply drop-off, ply ratio thickness, lay-up, stress, ANSYS

I. Introduction

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. Taper configuration is given in fig. 1. Ply drop-off in laminated has to be identified as a stress rises from the very beginning. Over past decade several experimental and analytical studies has been reported regarding various aspects of this problem. From earlier research work concerning composite laminate with ply drop-off, two major categories of work can be identified. The first is to understand failure mechanics induced by drop-off piles which include the determination of the state of interlaminar stresses in the vicinity of ply drop-offs and secondary the initiation and propagation of delamination. Daoust and Hoa [1989] developed an extensive finite-element

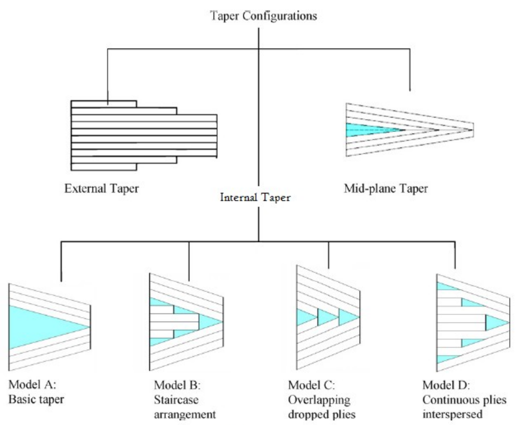

Fig.1, Schematic illutration of taper configurations

program using displacement formulation to study the effect of some parameters on the strength of the laminate. Both internal and external ply drop-off were examined and compared in their work. They concluded from their study that under tension, bending and torsion, internal ply drop-off are roughly twice as strong as external drop-off. Kant and Swaminathan (2000) have reviewed the different methods used for the estimation of transverse/interlaminar stresses in laminated composite plates and shells. Both analytical and numerical methods are considered. The World-Wide Failure Exercise (WWFE) contained a detailed assessment (Soden et al, 2004) of 19 theoretical approaches for predicting the deformation and failure response of polymer composite laminates when subjected to complex states of stress. The leading five theories (Zinoviev, Bogetti, Puck, Cuntze and Tsai) are explored in greater detail to demonstrate their strengths and weaknesses in predicting various types of structural failure. According to the investigations of WWFE, Tsai-Wu theory is the best one that can be used to predict the first-ply failure of unidirectional laminates and any of the above mentioned five failure theories can be used for multidirectional laminates. The present work, give an increased understanding of the behaviour of NCT/301 graphite epoxy composite laminated plates with 2 ply drop-off internally as shown in fig. 2 under compressive loadings. The following parameters were examined: a) the number of plies dropped, 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.

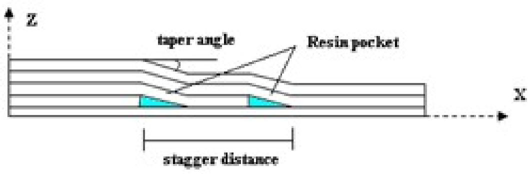

Fig 2 Section of laminate with ply drops

II. Description of Problem

For analysis, a ply drop-off composite laminated plate 135 mm long and 100 mm wide under uniform in-plane compression 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. Ply drop-off ratio Th/L (where, Th is stagger distance and L is the total length of ply drop-off) considered as 1/20. Therefore the total length of ply drop-off is 30 mm. Every 15 mm there is a section change. The material properties of NCT/301 graphite-epoxy composite ply material composite ply are given in Table 2.

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	$[(0/90)_2/0]$	$[(0/90)/0]$
LC2	$[(90/0)_2/0]$	$[(90/0)/0]$
LC3	$[(\pm45)_2/0]$	$[(\pm45)/0]$

III. Finite Element Analysis

SHELL 181 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. Results were then displayed by using post processor of ANSYS programme.

IV. Result and Discussion

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. Failue of composite laminates may occurs in different ways:

- Failure fracture

International Journal of Engineering Research (ISSN : 2319-6890)
Volume No.1, Issue No.1, pp : 12-16 01 Nov. 2012

- Matrix cracking
- Delaminations

Table 2:Material Properties of NCT/301 graphite-epoxy composite ply material	
Material Properties	Value
Ex	113.9 GPa
$E_y = E_z$	7.985 GPa
$G_{xy}=G_{xz}$	3.137 GPa
G_{yz}	2.852 GPa
$\nu_{xy} = \nu_{xz}$	0.288
ν_{yz}	0.400

Table 1: Material Properties of Composite Plate

One of the three modes delamination requires special treatment. The initiation of delamination, if any, is dictated by the transverse interlaminar stresses developed under compressive loading.

The laminated composite with ply drop-off is analyzed under gradually varying compressive load. The material properties are given in Table 2 respectively. The analysis is carried out for three different layup configurations are given in Table 1.

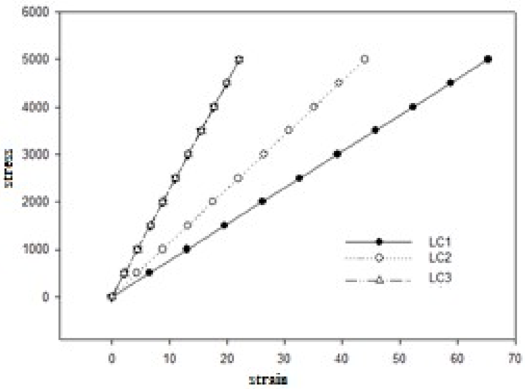

Figure 3 stress vs strain for different layup configurations

Figure 3 show the stress-strain curve for different layup configurations. Figure4, show the contour plot of displacement and stress field of layup configuration LC1. It is being observed that as the stress increases their strain also increases linearly. 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. 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. It is also being observed from results, that the ultimate load layup configuration LC1 has the highest value followed by LC2, and LC3.

V. 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.

- 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
- 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.

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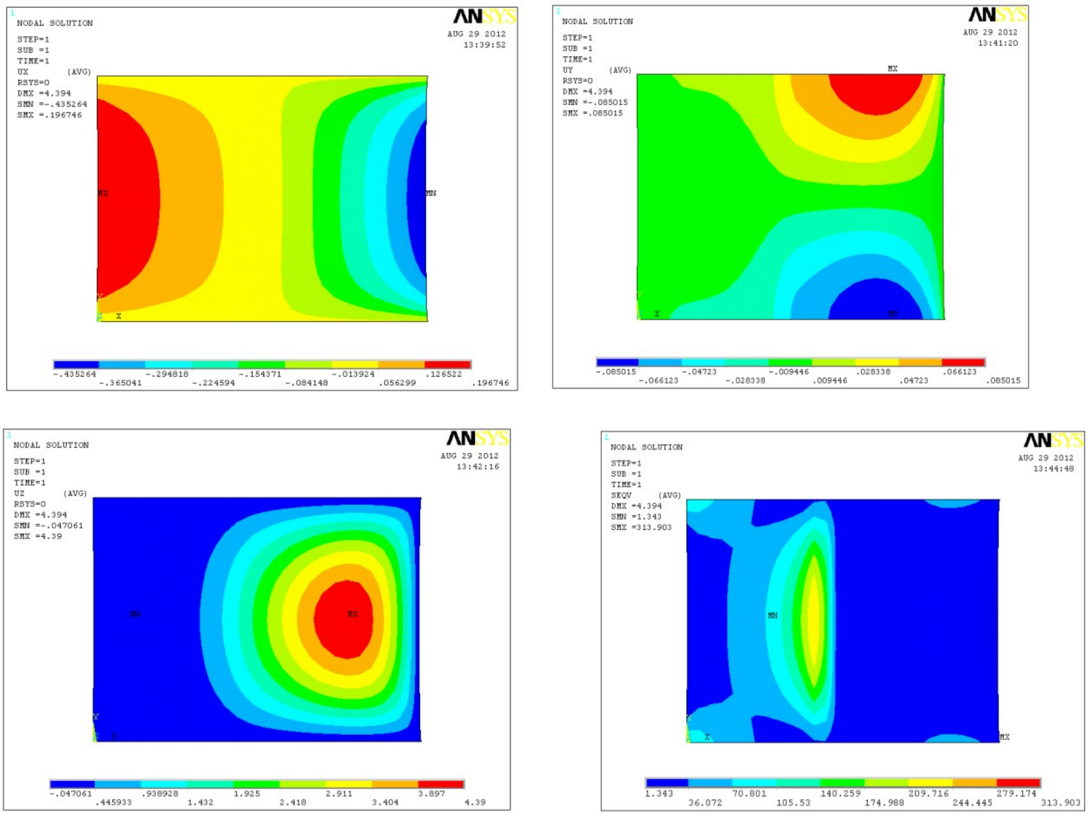

Figure 4. Counter plots of displacements and stress fields of Layup configuration LC1.