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First Ply Failure Analysis of Laminated Composite Plates on ANSYS Mechanical APDL

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***Abstract*— The first ply failure analysis is widely accepted method to predict strength of laminated composite structures and also considered as its design criterion. Previously the first ply failure load is calculated through experiments which consume time and labor. In this work the first ply failure load is predicted using finite element analysis on ANSYS mechanical APDL. Failure criteria adopted is maximum stress theory. It is found that results obtained in present works are in good agreement with previously obtained experimental results.**

***Index Term*- First ply failure, Finite element analysis, ANSYS**

I. INTRODUCTION

Assemblies of layers of fibrous material which are joined to obtain various engineering properties such as bending stiffness and in plane stiffness etc are called as laminated composite material. Laminated composite material is formed by the layers of different material or some time same material in different fiber orientation angle. Bimetals, clad metals and laminated glass are some best examples of laminated composite materials. Now-a-days, Laminated composite plates has become an important engineering material, due to their high strength to weight ratio, high stiffness and many other superior properties which make it suitable for the application demanding high degree of reliability such as Ship building aerospace industries etc. The most interesting feature of laminated composite materials is independency in orientation of ply fibers to obtain desired properties. Thus laminated composite material became a vast area of research.

Lamina & Laminates

Lamina- A lamina is a building block of a laminate. It is a sheet comprised of fibers. The fibers can be bidirectional, unidirectional, woven, continuous or discontinuous. The fibers are distributed in a matrix which can be metallic, organic or ceramic. The principal function of matrix is to protect and support fibers. It also provides means for distributing load between the fibers.

Laminates- A bonded stack of lamina with various orientations are called as laminate. Different layers of a laminate are generally bonded together by the same matrix material which is used in individual lamina. A laminate may consist of layers of different material or same material with different orientations. The main purpose of lamination is to eradicate the directional dependence of stiffness and strength of the composite material to withstand the load condition.

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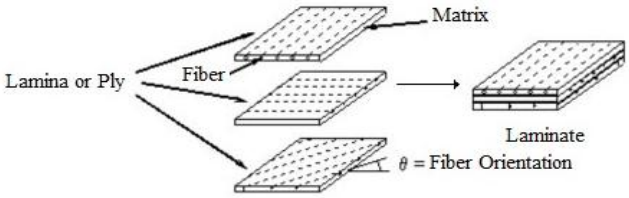

Fig 1: Lamina and Laminate

Laminates are categorized into following two types Cross Ply: When plies are oriented at right angles to each other and angle of orientation is limited to 0˚ and 90˚ then the laminate is called as Cross ply laminate.

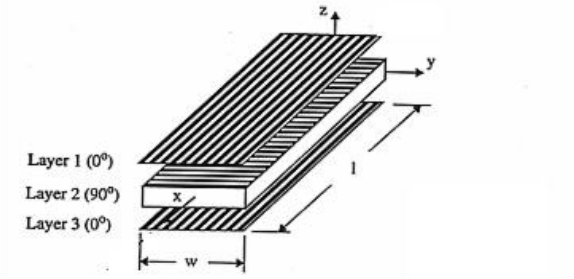

Fig 2: Pictorial depiction of cross ply laminate

Angle Ply Laminate: Angle Ply laminates are those laminates which has ply orientation angle between 0˚ and 90˚.

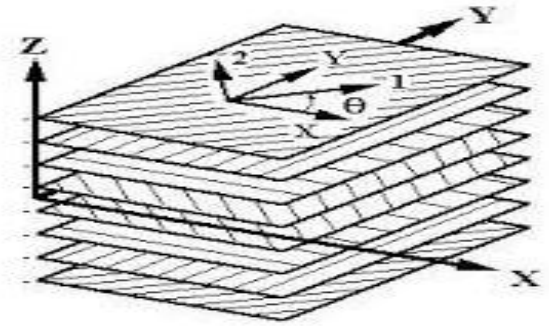

Fig 3: Pictorial depiction of angle ply laminate

Laminated composite plate consist of various plies, failure of which doesn't take all at a time, instead a ply fails prior to all plies, under the application of load. This is termed as first ply failure. Thereafter progressive failure of structure takes place. First ply failure results in drastic reduction in the stiffness of the structure. Thus for the reliable design it is necessary to compute first ply failure strength accurately.

Critical review is carried out on the first ply failure analysis of laminated composite plates and it is found that much of the research work done so far in evaluating first ply failure load is limited to mathematical finite element model formulation and experimental work. Not much study has been done in simulation of first ply failure analysis. The present work is

focused on the simulation of first ply failure analysis problem under transverse point load and in plane axial compressive load on ANSYS.

II. First Ply Failure Analysis

It is a method used to predict strength of a laminate. Under applied load, stress of different value will be induced in different layer depending upon its orientation and material. A finite element model, based on various available theories is formulated to determine stresses in different layer. Once stresses are determined, a failure theory is adopted and load is calculated at which one of the ply will fail prior to all other. This load is termed as first ply failure load. After the failure of the first ply, stiffness of the laminate will decrease drastically. For reliability assurance, maximum load a structure can withstand must be known. First ply failure analysis is used generally as criterion for the design of laminated composite structures. Thus the prediction of first ply failure load of laminated composite plates has become an intense topic of research.

The present work is done on ANSYS Mechanical APDL, which adopts First order shear deformation theory to perform Finite Element Analysis. Failure theory adopted is Maximum Stress theory. In Experiments done in previous works 1st ply failure load value is identified by Energy vs Load charts directly obtained from ASM3 acoustic emission system [1]-[3]. First peak in above mentioned chart indicates 1st ply failure load value. In this work 1st ply failure value is calculated by failure analysis done in ANSYS Mechanical APDL

III. Finite Element Analysis

The mathematical analysis of first ply failure problem is done through the ANSYS Mechanical APDL software. This software package is based on the finite element analysis and basic steps involved in this are as follows

- Preprocessing
- Solution Phase
- Postprocessing

Preprocessing- In this step, finite element model is developed for various testing. This involves element type selection, model creation and then division of model in to nodes and elements i.e meshing. The element type used in this study is SHELL 181. SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. SHELL181 may be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory. SHELL181 element is chosen in this work because with the help of the function tool, sectioning can be done easily i.e various lay-ups with different fiber angle orientation can be easily prepared. Besides for this type of analysis this element type gives faster results. In this research work only orthotropic elastic material are under consideration. Two orthotropic material used in this work are Gr/ep(Q1115) [1],and Gr/ep(T300/2500) [2]. After element type selection Real Constant is provided if any. In this work real constant is not given as SHELL 181 doesn't require any. And problem in this analysis is modeled in 2D only. After this section is provided, this is yet another important step. Under this fiber angle orientation and lay-up is provided

Solution Phase- The finite element model created in preprocessing phase is solved in this phase. The analysis type used for 1st ply failure analysis of laminated composite plate is Static. The boundary conditions used in this analysis are clamped, free and simply supported. The element type used in this study is SHELL 181 which has rotation and translation in all the axes, so it is very necessary to restrict end condition in order to get accurate results. The loading condition used in this analysis is transverse and axial compressive load.

Postprocessing- In this phase of the analysis, results are viewed and plotted. It includes plotting of contours, vector display, deformed shape and tabulating of results obtained at nodes. In 1st ply failure analysis, model is checked for failure criteria in this step only. For this, failure criteria are to be provided.

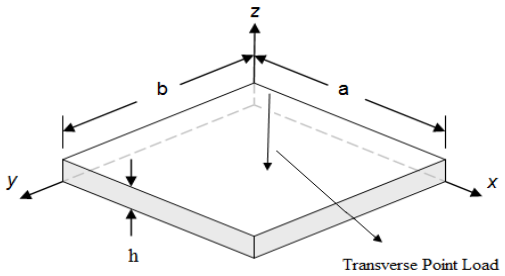

Fig: 4(a) Transverse Point Load

Fig: 4(b) Axial Compressive Load

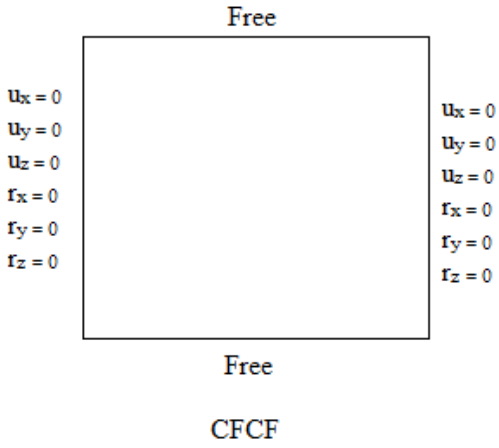

Fig: 5 Boundary Condition

Fig 4 illustrates the loading condition while Fig 5 illustrates the boundary condition used.

Where,

CFCF is two opposite end clamped while other two opposite end fixed type boundary conditions.

u_x, v_y, w_z is displacement in x, y, z direction respectively

r_x, r_y, r_z rotation in x, y, z direction respectively

IV. RESULTS AND DISCUSSION

After providing all the failure criteria Maximum Result Value on Failure Analysis plot (SMX) is obtained for all the plies in the laminated composite. Ply which has maximum value of SMX, indicates failure of the same prior to all the ply.

$$FC = \frac{P}{(SMX)max} \quad (1)$$

Where, FC is First ply failure load value
P is maximum load applied
(SMX) max is Maximum of SMX value among all the plies

First ply failure analysis is done and SMX values for different ply are summed up in tables as follows, for three different analyses and FC is calculated using (1)

Table 1: Gr/ep(Q1115) with layup $[0^\circ/90^\circ/0^\circ/90^\circ]_s$ and maximum load 1400 N, Ply thickness 0.155 mm

Ply No.	SMX Value
1	4.46
2	2.7
3	1.48
4	0.63
5	0.65
6	0.59
7	1.95
8	1.19

$$FC = \frac{1400}{4.46} = 313.90\ N$$

Table 2: Gr/ep(T300/2500) with layup $[45^\circ_3/90^\circ_3/45^\circ_3 90^\circ_3]_s$ and maximum load 3500 N, ply thickness 0.121 mm

Ply No.	SMX Value
1	2.67
2	2.42
3	2.18
4	1.82
5	1.59
6	1.36
7	0.81
8	0.64

$$FC = \frac{3500}{2.67} = 1310.86\ N$$

Table 3: Gr/ep(Q1115) with layup $[0^\circ_8/90^\circ_8]_s$ $_s$ and maximum load 3500 N, ply thickness 0.155 mm

Ply No.	SMX Value
1	2.55
2	2.38
3	2.21
4	2.04
5	1.87
6	1.70
7	1.53
8	1.36

$$FC = \frac{6000}{2.55} = 2352.94\ N$$

Comparison of results obtained in this work with results obtained in previous literatures

In previous works first ply failure load value is determined by experiments. In this work the same is obtained by simulation performed on ANSYS. Table as follows gives the comparison between the two.

Table 4: Comparison of results

Parameter	Analysis 1	Analysis 2	Analysis 3
Material	Gr/ep (Q1115)	Gr/ep(T300/2500)	Gr/ep (Q1115)
Boundary Condition	Two edges Clamped Two edges Free	Two edges Clamped Two edges Free	Two edges Clamped Two edges Free
Lay-up	$[0^\circ/90^\circ/0^\circ/90^\circ]_s$	$[45^\circ_3/90^\circ_3/45^\circ_3 90^\circ_3]_s$	$[0^\circ_8/90^\circ_8]_s$
Thickness of ply (mm)	0.155	0.121	0.155
Loading Condition	Transverse Point Load	Transverse Point Load	Transverse Point Load
Maximum Load Applied (N)	1400	500	000
1st ply failure load-Experimental (N)	325 [1]	1300 [2]	2250 [3]
First ply failure load calculated in present work (N)	313.9	1310.86	2352.94
Error %	3.41	0.83	4.57

It is found that percentage error is within permissible limit

V. Conclusion

Finite element method is very powerful tool for engineers to analyze complicated problems. The software package ANSYS uses finite element method to analyze various problems. In present work, first ply failure analysis is done by ANSYS Mechanical APDL with varying various affecting parameters. With the use of ANSYS, both time and efforts are saved considerably. Results obtained by ANSYS are in good agreement with that obtained from higher order theories.

Acknowledgment

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