Static Analysis of Laminated Composite Structures by Finite Element and Semi-Analytical Methods

Synopsis submitted by

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SYNOPSIS

While designing a structure made of laminated composite material, there are many aspects to investigate because the behaviour of composite material under loading depends upon many factors. The properties of fiber and matrix, orientation of fiber in the matrix, stacking sequence of lamina or ply within the laminate, and different combinations of composite materials are some of the important factors which affect the response of the composite laminate under loads. The flexibility in producing different composite materials mainly depends upon the combination of these factors in an optimum way. The behaviour of composite structures can be studied in two ways: Semi analytical methods and Finite element method.

A comparative study of semi analytical method and finite element method is conducted for different laminated composite structure from simpler to complex problems. Finite element analysis is done using a two dimensional finite element model. Percentage error between the results from semi analytical and finite element model is determined for different problems of laminated composite structure under different boundary conditions and loadings. Two types of laminated composite structure are studied: Laminated composite Plate and beam. Two types of stacking sequence of laminate are studied: symmetric angle ply and symmetric cross ply. Problems discussed in this thesis as:

1. Laminated composite plate under in-plane loads (simplest problem)
2. Simply supported laminated composite plate under transverse uniform pressure.
3. Buckling of simply supported laminated composite plate under compressive load.
4. Laminated composite beam under different boundary conditions (Hinged-hinged, Clamped-clamped, fixed-fixed) subjected to uniformly distributed loads.
5. Hybrid composite laminated structure under different loads and boundary conditions.
6. First ply failure load and strength ratio are determined for laminated composite plate and beam using interactive and non interactive failure theories.

The stresses and displacement of laminated composite plate under in-plane load (in x direction or in y direction or combination) is determined by solving laminate equations. The results obtained from semi analytical methods are compared with results obtained by solving two dimensional finite element models using finite element software ANSYS 15.0. Both the models show good agreement with each other with less than 1% error, because the laminate equations are free from higher order terms and therefore can be solved easily by matrix operations. Also both the models are verified with published literatures. The effect of orientation angles, number of lamina and length to thickness ratio on stress and deflection are studied for different loadings and stacking sequence (symmetric angle ply and cross ply laminate). Both deflection and stress increases with the increase in length to thickness ratio (a/h). As the a/h ratio increases, the thickness of the laminate decreases, and therefore stress and deflection increase. Also the stress and deflection decrease with the increase in the number of lamina within the laminate because with the increase in the number of the lamina, the thickness of laminate increases, so deflection and stress decreases.

Deflection of laminated composite plate under transverse load is found out by the semi analytical method and the result is compared with results obtained by solving two dimensional finite element models using finite element software. Classical lamination theory (CLT) is used to find the deflection by the semi analytical method. The equations of CLT are solved by the Navier method and Rayleigh-Ritz method for symmetric angle ply and cross ply arrangement. And the results obtained from both the methods are compared with the results obtained from finite element method (FEM). Percentage error of the results from FEM with Navier and Rayleigh-Ritz methods are noted separately and compared. From the comparative study, it is found that Navier method is suitable for solving the problems of symmetric cross ply arrangement whereas Rayleigh-Ritz method is suitable for symmetric angle ply arrangement. Also the percentage error depends on the value of bending coefficient for both the stacking sequence. The model is extended to study the effect of orientation angle, number of lamina and length to thickness ratio on the deflection of simply supported composite plates for symmetric angle ply plates of stacking sequence (orientation angle) of $[+\theta/-\theta]_s$. The deflection decreases as the orientation angle increases and becomes minimum at 45° angle, then increases and becomes maximum at 90° angle. The deflection decreases as the number of plies increases for both symmetric angle ply and cross ply composite and deflection of the plate increases as length to thickness ratio increases. Therefore the percentage error for laminated composite plate under transverse load depends on the variables: number of lamina, thickness of each lamina, orientation angle and mesh size. Mesh size is an insignificant variable because mesh size can be converged by convergence analysis. The significance of these variables in reducing the percentage error is studied by statistical tool: ANOVA and the relationship between these variables are established by regression equation. Statistical analysis is conducted by testing their significance at the 5% significance level. Therefore the percentage error may be reduced by proper optimization of these variables. The significance of number of lamina on percentage error is more than the orientation angle.

This model is further extended for buckling analysis of simply supported laminated composite plate under axial compressive load for different orientation angles of symmetric angle ply arrangement. A finite element model of buckling is built up using ANSYS software and the results from the ANSYS software is compared with existing literature and a semi-analytical model. The equations of buckling formulated by classical lamination theory are solved by Navier method and percentage errors are found out. The errors are within the acceptable limit for 0^{o} and 90^{o} fiber orientation angle but it shows a significant error for the other angles. Also the percentage error depends on the value of bending coefficient for both the symmetric angle ply and cross ply stacking sequence. In the similar way as that of plate percentage error depends on number of lamina, thickness of lamina and orientation angle. The effects of orientation angle on critical buckling load for different loadings are discussed.

The problems of laminated composite beam under different boundary condition subjected to different loadings are solved by Classical lamination theory (CLT) and first order shear deformation theory (FSDT). The results obtained from semi-analytical methods: CLT and FSDT are compared with those of FEM using software packages like ANSYS and percentage errors are noted. The deflection obtained from FSDT is greater than that of CLT because of the presence of shear deformation in Timoshenko beam theory (FSDT), which increases the total deflection of the beam. The percentage error of results from CLT with ANSYS is less than that of FSDT because it contains a higher order term in addition to CLT deflection. This higher order term introduces an error. The model is further extended to study the effect of fiber orientation angle, number of lamina and length to thickness ratio on the deflection of beam for symmetric angle ply stacking sequence (orientation angle) of $[+\theta/-\theta]_s$. The non dimensional maximum transverse deflection ($\overline{w}$) increases as the fiber orientation angle increases from $0^0\ to\ 90^0$ of a symmetrical angle ply composite beam. Maximum deflection is obtained at a 90° angle and a minimum of 0°. The beam with one end clamped and the other end free experiences maximum deflection as compared to Clamped-Clamped and Hinged-Hinged boundary conditions. The effect of shear deformation is more significant for beams with a length to thickness ratio ($\frac{a}{h}$) ratio smaller than 10. As the $\frac{a}{h}$ ratio increases, maximum transverse deflection decreases and almost becomes constant. Length to thickness ratio has no effect on transverse deflection when the problem is solved by CLT due to the absence of shear deformation term in total deflection. As the number of lamina increases, the maximum transverse deflection decreases and almost becomes constant. The effect of non dimensional deflection is more significant for beams with a number of lamina smaller than 8. Percentage error of the semi analytical method with FEM results depends on mesh size, L/W ratio, laminate thickness, and orientation angle. Statistical analysis using the ANOVA tool was conducted to test the significance of these variables at a 5% level of significance. From statistical analysis, it is concluded that laminate thickness and orientation angle has more significant effect on percentage error as compared to other variables. The effect of mesh size can be eliminated by convergence analysis.

The analysis is further extended to study the effect of these factors on deflection and strength ratio based on first ply failure load. A comparative study of different failure criteria is also conducted based on first ply failure load. Mode of failure is determined by using maximum stress or maximum strain theory. The effect of hygro thermal load on strength ratio for composite laminate and beam is studied. The strength ratio based on first ply failure load obtained from CLT is compared with that obtained from FEM and good agreement found between them for composite laminate under in plane load. Also the result obtained from the finite element software ANSYS is compared with the semi-analytical method for the problem defined in the thesis for hinged-hinged laminated composite beams of symmetric angle ply arrangement and the percentage errors are noted. It is found that the errors for orientation angles of 15, 30 and 45 degrees are above 5 percent and the rest are below 5 percent. This percentage error therefore depends on the angle, thickness of the laminate and aspect ratio (length to width ratio).

This study is further extended for analysis of hybrid composite laminated structures. Different combinations of graphite epoxy (G) and glass epoxy (C) composites are studied and compared to get the best combination. The G-C-C-G combinations is found suitable with respect to cost and mass as compared to graphite epoxy (G) and glass epoxy composite (C). Percentage errors of semi analytical results with ANSYS results are noted for laminated composite plate and beam. Strength ratio based on first ply failure load is determined for different hybrid combinations of symmetric angle ply and cross ply laminated beam and plate and compared.

The comparative study and analysis of the percentage errors of the semi-analytical methods with finite element methods in solving the problem of laminated composite plates or beams is essential to study the degree of approximation in the results. And after getting the percentage error, it is very essential to study the method of reducing the percentage error and select the factors to be optimized for percentage error reduction.