Buckling Analysis of Woven Glass fiber/epoxy Laminated Composite Plate

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Abstract:-**The 'composites' concept is not a human invention. Wood is a natural composite material consisting of one species of polymer — cellulose fibres with good strength and stiffness — in a resinous matrix of another polymer, the polysaccharide lignin. Nature makes a much better job of design and manufacture than we do, although Man was able to recognize that the way of overcoming two major disadvantages of natural wood — that of size (a tree has a limited transverse dimension), and that of anisotropy (properties are markedly different in the axial and radial directions) — was to make the composite material that we call plywood. Bone, teeth and mollusc shells are other natural composites, combining hard ceramic reinforcing phases in natural organic polymer matrices. Man was aware, even from the earliest times, of the concept that combining materials could be advantageous, and the down-to-earth procedures of wattle-and-daub (mud and straw) and 'pide' (heather incorporated in hard-rammed earth) building construction, still in use today, pre-date the use of reinforced concrete by the Romans which foreshadowed the pre-tensioned and post-tensioned reinforced concretes of our own era. But it is only in the last half century that the science and technology of composite materials have developed to provide the engineer with a novel class of materials and the necessary tools to enable him to use them advantageously. In this study, the influence of cut-out shape, length/thickness ratio, and ply orientation and aspect ratio on the buckling of woven glass epoxy laminated composite plate is examined experimentally. Clamped –free -Clamped-free boundary condition is considered for all case. Experiments have been carried out on laminated composites with circular, square and rectangular cut-outs. The thickness of the plate was changed by increasing the number of layers. After the buckling experiments micro electroscopic scanning was performed for the failed specimens. Comparisons are made between the test results, by using two different approaches. The results shows effect of various cut-out shapes, orientation of fiber, aspect ratio and length to thickness ratio on the buckling load.**

INTRODUCTION

In many engineering structures such as columns, beams, or plates, their failure develops not only from excessive stresses but also from buckling. Only rectangular thin plates are considered in the present study. When a flat plate is subjected to low in-plane compressive loads, it remains flat and is in equilibrium condition. As the magnitude of the in-plane compressive load increases, however, the equilibrium configuration of the plate is eventually changed to a non-flat configuration and the plate becomes unstable. The magnitude of the compressive load at which the plate becomes unstable is called the "critical buckling load."

A composite material consists of two or more materials and offers a significant weight saving in structures in view of its high strength to weight and high stiffness to weight ratios. Further, in a fibrous composite, the mechanical properties can be varied as required by suitably orienting the fibres. In such material the fibres are the main load bearing members, and the matrix, which has low modulus and high elongation, provides the necessary flexibility and also keeps the fibres in position and protect them from the environment.

Development of new applications and new composites is accelerating due to the requirement of materials with unusual combination of properties that cannot be met by conventional monolithic materials. Actually, composite materials are capable of covering this requirement in all means because of their heterogeneous nature. Properties of composite arise as a function of its constituent materials, their distribution and the interaction among them and as a result an unusual combination of material properties can be obtained .

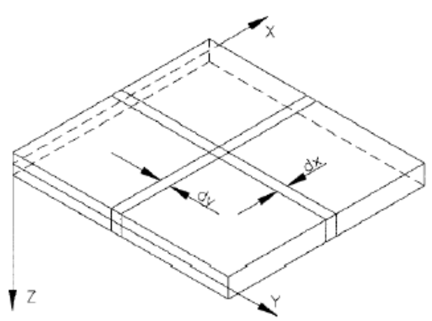
Laminated composites are gaining wider use in mechanical and aerospace applications due to their high specific stiffness and high specific strength. Fiber- reinforced composites are used extensively in the form of relatively thin plate, and consequently the load carrying capability of composite plate against buckling has been intensively considered by researchers under various loading and boundary conditions. Due to the excellent stiffness and weight characteristics, composites have been receiving more attention from engineers, scientists, and designers. During operation the composite laminate plates are commonly subjected to compression loads that may cause buckling if overloaded. Hence their buckling behaviors are important factors in safe and reliable design of these structures.

THEORETICAL FORMULATION

The buckling of a plate involves two planes, namely, xz, yz and two boundary conditions on each edge of the plate. The basic difference between plate and column lies in the buckling characteristics. The column, once it buckles, cannot resist any additional axial load. Thus, the critical load of the column is also its failure load. On the other hand, a plate, since it is invariably supported at the edges, continues to resist the additional axial load even after the primary buckling load is reached and does not fail even when the load reaches a value 10-15 times the buckling load.

THEORY OF BENDING OF THIN PLATES

The theory for thin plates is similar to the theory for beams. In pure bending of beams, "the stress distribution is obtained by assuming that cross-sections of the bar remain plane during bending and rotate only with respect to their neutral axes so as to be always normal to the deflection curve." For a thin plate, bending in two perpendicular directions occur. A rectangular plate element is shown below:



(fig.1.a) Thin plate notation

THE BASIC ASSUMPTIONS OF ELASTIC PLATE BENDING ARE:

1. Perfectly flat plate and of uniform thickness.
2. The thickness of the plate is small compared with other dimensions. For plate bending, the thickness, t, is less than or equal to ¼ of the smallest width of the plate. For plate buckling equations, the thickness, t, should be 1/10 of the smallest width of the plate.
3. Deflections are small, i.e., smaller or equal to 1/2 of the thickness.
4. The middle plane of the plate does not elongate during bending and remains a neutral surface.
5. The lateral sides of the differential element, in the above figure, remain plane during bending and rotate only to be normal to the deflection surface. Therefore, the stresses and strains are proportional to their distance from the neutral surface.

BUCKLING OF COMPOSITE PLATE

Composite materials consist of two or more materials which together produce desirable properties that cannot be achieved with any of the constituents alone. Fiber-reinforced composite materials, for example, contain high strength and high modulus fibers are the principal load carrying members, and the matrix material keeps the fibers together, act as a load-transfer medium between fibers from being exposed to the environment. The layup sequence of unidirectional reinforced “plies" as indicated in Fig.1. Each ply is typically a thin (approximately 0.2 mm) sheet of collimated fibers impregnated with an uncured epoxy or other thermosetting polymer matrix material. The orientation of each ply is arbitrary, and the layup sequence is tailored to achieve the properties desired of the laminate

EXPERIMENTAL STUDY

In view of difficulty of theoretical and numerical analysis for laminated structure behaviors, experimental methods have become important in solving the buckling problem of laminated composite plates. The experimental and numerical analysis done on aluminum plate showed an appreciable match in the results. Taking the above proof for the correctness of the experimental procedure. Here the same experimental procedure was followed for a composite plate. To understand the effect of cut out shape, length/thickness ratio, ply orientation, and length/breadth ratio on the compressive behavior of woven glass epoxy laminated composite plates compression test was performed. The specimen was clamped at two sides and kept free at other two sides the specimens were loaded in axial compression by using a tensile testing machine of 100 tons load capacity.

TEST PROCEDURE

The specimen was loaded in axial compression using a Intron tensile testing machine of 100 KN capacity. The specimen was clamped at two ends and kept free at the other two ends. A dial gauge was mounted at the Centre of the specimen to observe the lateral deflection. All specimens were loaded slowly until buckling. The experimental set up is shown below. Clamped boundary conditions were simulated along the top and bottom edges, restraining 40mm length .For axial loading, the test specimens were placed between the two extremely stiff machine heads, of which the lower one was fixed during the test, whereas the upper head was moved downwards by servo hydraulic cylinder.

All plates were loaded at constant cross-head speed of 1mm/min. The test set up is shown below.

Fig.2

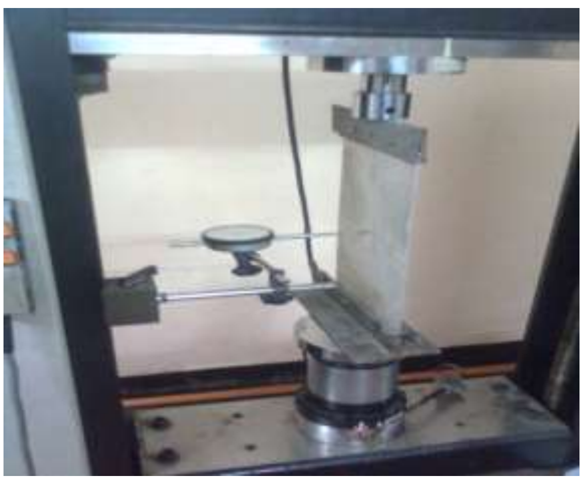


Fig.3

As the load was increased the dial gauge needle started moving, and at the onset of buckling there was a sudden large movement of the needle. The load corresponding to this point will be the buckling load of the specimen. The load v/s displacement curve and load v/s end shortening curve was plotted. The displacement is plotted on the x -axis and load was plotted on the y- axis. The load, which is the initial part of the curve deviated linearity, is taken as the critical buckling load. That point is determined from the intersection of two tangents drawn from the pre-buckling and post-buckling regions.

COMPOSITE SPECIMEN PREPARATION AND MANUFACTURING

To meet the wide range of needs which may be required in fabricating composites, the industry has evolved oven a dozen separate manufacturing processes as well as a number of hybrid processes. Each of these processes offers advantages and specific benefits which may apply to the fabricating of composites. Hand lay-up and spray-up are two basic moulding processes. The hand lay-up process is the oldest, simplest, and most labour intense fabrication method. The process is most common in FRP marine construction. In hand lay-up method liquid resin is placed along with reinforcement (woven glass fiber) against finished surface of an open mould. Chemical reactions in the resin harden the material to a strong, light weight product. The resin serves as the matrix for the reinforcing glass fibers, much as concrete acts as the matrix for steel reinforcing rods. The percentage of fiber and matrix was 50:50 in weight.

Fig.4

Fig.5

Contact moulding in an open mould by hand lay-up was used to combine plies of Wring the prescribed sequence. A flat plywood rigid platform was selected. A plastic sheet was kept on the plywood platform and a thin film of polyvinyl alcohol was applied as a releasing agent by use of spray gun. Laminating starts with the application of a gel coat (epoxy and hardener) deposited on the mould by brush, whose main purpose was to provide a smooth external surface and to protect the fibers from direct exposure to the environment. Ply was cut from roll of woven roving. Layers of reinforcement were placed on the mould at top of the gel coat and gel coat was applied again by brush. Any air which may be entrapped was removed using serrated steel rollers. The process of hand lay-up was the continuation of the above process before the gel coat had fully hardened. Again, a plastic sheet was covered the top of plate by applying polyvinyl alcohol inside the sheet as releasing agent. Then, a heavy flat metal rigid platform was kept top of the plate for compressing purpose. The plates were left for a minimum of 48 hours before being transported and cut to exact shape for testing. The following constituent materials were used for fabricating the plate:

1. E-glass woven roving as reinforcement
2. Epoxy as resin
3. Hardener as catalyst
4. Polyvinyl alcohol as a releasing agent

After 48 hours curing the specimen were cut in to desired sizes, with and without cutout shown in fig. Circular, square, and rectangular cutout of same area (9.62cm2) was made for the experiments. The specifications of plate tested in the present study shown in the table-1 and the plate with various cut out shape was shown in fig.6,7,8. The mechanical properties of the composite plates were determined by Instron tensile testing machine of 100KN load capacity. A specimen whose fiber direction coincides with the loading direction was used to obtain the modulus of elasticity along the fiber direction. The specimen was loaded step-bystepup to rupture by the test machine. Strains in the fiber (1 e) and transverse directions were measured, by using these strains E values are determined

Fig.6

Fig.7

Fig.8

BUCKLING EXPERIMENTS FOR COMPOSITE PLATES

The specimen was loaded in axial compression using a uniaxial tensile testing machine of 100 tonne capacity. It is shown in fig.9 the specimen was clamped at two ends and kept free at the other two ends. A dial gauge was mounted at the centre of the specimen to observe the lateral deflection. All specimens were loaded slowly up to failure. Clamped boundary conditions were simulated along the top and bottom edges, restraining 40mm length .For axial loading, the test specimens were placed between the two extremely stiff machine heads, of which the lower one was fixed during the test, whereas the upper head was moved downwards by servo hydraulic cylinder. The shape of the plate after buckling was shown in fig.10 All laminated plates were loaded at constant cross-head speed of 200Kn/min. The image of failed specimen obtained after scanning was shown in fig.11. As the load was increased the dial gauge needle started moving, and at the onset of buckling there was a sudden large movement of the needle. The load corresponding to this point will be the buckling load of the specimen. The load v/s displacement curve and load v/s end shortening curve was plotted. The displacement is plotted on the x -axis and load was plotted on the y-axis. The load, which is the initial part of the curve deviated linearity, is taken as the critical buckling load. That point is determined from the intersection of two tangents drawn from the pre-buckling and post-buckling regions.

Fig.10

Fig.9

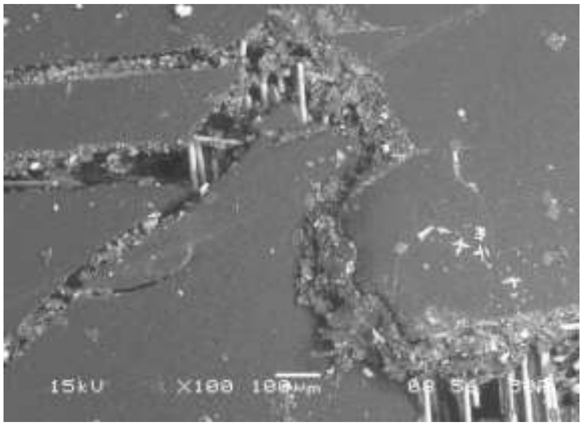


Fig.11

NUMERICAL ANALYSIS

ANSYS was used to carry out the finite element analysis in the work. ANSYS is used to analyse the critical buckling load aluminum plates of different sizes. The dimension of the specimen was 300*200* 1.7mm and 200*200*1.7mm in length, width and thickness.

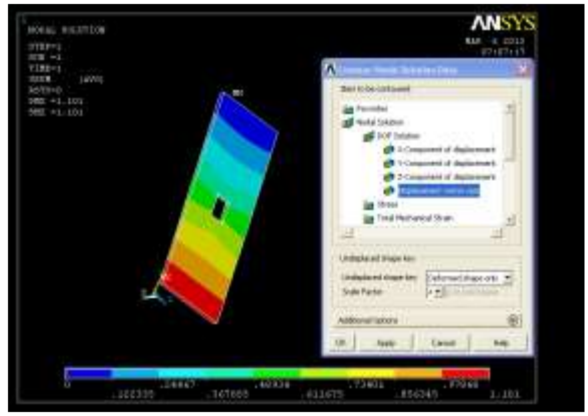
Eigen value buckling analysis in ANSYS has four steps:

1. Build the model: It includes defining element type, real constants, material properties and modeling. In this study shell, Elastic 8node 93 selected as the element type.

2. Solution (Static Analysis): It includes applying boundary conditions, applying loads and solving the static analysis. The applied boundary condition and load is shown below.

3. Eigen buckling analysis: Eigenvalue buckling analysis predicts the theoretical buckling strength of an ideal linear elastic structure.

4. Postprocessor: This steps includes listing buckling loads and viewing buckled shapes. We can plot the deformed and unreformed shape of the plate.



RESULTS

The buckling load for clamped- free aluminum plate determined. The results were both experimental analysis and finite element analysis. The agreement between the two methods was generally good. The critical buckling load obtained experimentally and by ANSYS is shown in the table1.

plate No.	Length mm	Width mm	Thickness mm	Experimental Buckling load(N/mm)	ANSYS Buckling load(N/mm)
Plate-1	300	200	1.7	11.75	13.44
Plate-2	200	200	1.7	24.25	30.55

Table-1

It was observed that the buckling load of plate-1 obtained from experimental and numerical analysis are identical and less than that of plate-2.The experimental buckling loads for both specimens are less than the ANSYS results.

CONCLUSION

This study considers the buckling response of laminated rectangular plates with clamped-free boundary conditions. The laminated composite plates have varying L/T ratio, aspect ratio, cut out shape and ply orientation. From the present analytical and experimental study, the following conclusions can be made.

1. It was noted that different length to thickness ratio affected the critical buckling load. The buckling load

decreases as the L/t ratio increases. The rate of decrease of buckling load is not uniform with the rate of increase of L/t ratio.

2. As the aspect ratio increases, the critical buckling load of the plate decreases. When the aspect ratio changed from 0.5 to 1, the variation in buckling load is almost 24%. The rate of change of buckling load with the aspect ratio is almost uniform.

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