# Buckling, Post Buckling and Progressive Damage Analysis of Woven Glass/Epoxy Composite Laminate by ANSYS

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*Abstract*— Present work mainly deals with the progressive damage, buckling and post buckling of composite laminated plate. Woven glass/epoxy unidirectional has been taken for analysis. For finite element analysis ‘Ansys 17.0’ is used which is a commercial tool for modelling. In research work Non-linear bifurcation method is used. Hashin’s criteria is used for progressive damage analysis and eigenvalue buckling is done for buckling and post-buckling analysis. Effect of change in ply orientation is reviewed followed by effect of change in length and thickness. Effect of the change in dimensions can also be seen in the validation part. Buckling under mix loading condition i.e. compression with shear loading is viewed under different proportions and for different thickness. Matrix failure occurs mainly in specimen while compression loading condition in case of buckling the critical buckling load was very low compared to that of the progressive damage failure. In case of mix loading effect found for specimens under lower length to thickness ratio is less compared to that of specimens under higher length to thickness ratio.

***Keywords:*** ANSYS, Woven Glass/Epoxy, Buckling

## I. INTRODUCTION

Scientific understanding has been increased in the last century, which witnessed a rapid revolution in science and technology. Development took place as a result of man's need to replace conventional materials with materials having better properties. As of late, scientists have started mixing materials with different properties in a new way so as to make new materials which have the good properties of the constituent materials, without having the inherent weaknesses or disadvantages of the individual materials. These new materials are called composite materials. The composite structures are highly sensitive to geometrical and loading imperfections. Various types of defects are there like different directions of fibres design, variations in thickness, initial transversal deformations etc. During application plates may be subjected to any combination of loads. Because of this, buckling is one of the most important failure criteria in these structures. That’s why it is essential to develop the appropriate methods, which are able to correctly predict the behaviour of a laminated composite plate at the collapse load as well as to understand its behaviour under repeated buckling

## II. LITERATURE REVIEW

Bipin et al. (2016) worked for buckling behavior for carbon fiber composite. Their test has been conducted under the axially compressive loading by a machine of 100-ton capacity & specimen dimensions was 100×20×2, 150×30×2. By their work they found that that thickness plays very important role in critical buckling load. As the thickness increases the critical buckling load decreases. Their experiments indicate that the variation of the buckling loads is also very sensitive to the length as buckling load generally decreases with increase in length.

## III. FINDINGS

Some of the key findings of different literature surveys are,

1) Different dimensions or variation in dimensions plays very important role in buckling and post-buckling behaviour of composite.
2) Buckling response differs for cut out sections with respect to sections without cut out.
3) Buckling occurs usually at very low loads compared to their failure loads.
4) In buckling and post-buckling responses, the composite can undergo many cycles before final failure.
5) Ply orientation and sequencing is also crucial while designing composite for buckling.
6) Responses under biaxial and tri-axial loadings are much complicated.
7) For different materials different criteria provides suitable result under progressive damage of composite.
8) No criteria can be considered as best suitable criteria as sometimes damage can occur on one lamina or on complete laminate.
9) Progressive damage takes large loads compared to the buckling.

## IV. LITERATURE GAPS

Followings are found out by literature review,

- Only theoretical models have been provided for most of the works and calculations are made on those models. Those models work satisfactory for these particular set of conditions.
- Only few have worked for mix loading (compression with shear) but not provided suitable methods applicable to group or set of materials. As previous works are mainly based on linear buckling analysis.
- Little research work about the progressive damage under specific conditions has been reported (limited boundary conditions and loading conditions).

## V. OBJECTIVE OF PRESENT WORK

Objectives of present research work is as under,

1) Analysis for effect of variation in orientation sequence.
2) Analysis for effect of variation of length.
3) Analysis for effect of variation of thickness.
4) Static response of composite under compressive loading.
5) Analysis for progressive damage for different criterion of matrix failure and fibre failure.
6) Analysis composite laminate for mix loading condition (compression with shear) for different thickness under different proportions.

## VI. MATERIAL SELECTION

### A. *Material's Selection and Properties*

The material that has been taken for analysis is Epoxy E-glass unidirectional fibre, having density of 2000 kilogram per cubic meters. The reason behind selection of Epoxy E-glass is that, it can provide considerable strength and other parameters comparable to carbon epoxy fibres at reasonable cost efficiency. The E-glass Epoxy is easily available in market also easy in manufacturing and processing as compared to carbon fibre composite. Different mechanical properties of E-glass Epoxy are shown below (refer tables 4.1, 4.2 and 4.3).

| Young modulus X direction (MPa) | Young modulus Y direction (MPa) | Young modulus Z direction (MPa) | Poisson's ratio XY | Poisson's ratio YZ | Poisson's ratio ZX | Shear modulus XY (MPa) | Shear modulus YZ (MPa) | Shear modulus ZX (MPa) |
|---|---|---|---|---|---|---|---|---|
| 45000 | 10000 | 10000 | 0.3 | 0.4 | 0.3 | 5000 | 3836.1 | 5000 |

Table 4.1: Orthotropic elasticity properties.

| Tensile X direction | Tensile Y direction | Tensile Z direction | Compression X direction | Compression Y direction | Compression Z direction | Shear XY | Shear YZ | Shear ZX |
|---|---|---|---|---|---|---|---|---|
| 0.0244 | 0.0035 | 0.0035 | -0.015 | -0.012 | -0.012 | 0.016 | 0.012 | 0.016 |

Table 4.2: Orthotropic strain limits.

| Tensile X direction (MPa) | Tensile Y direction (MPa) | Tensile Z direction (MPa) | Compression X direction (MPa) | Compression Y direction (MPa) | Compression Z direction (MPa) | Shear XY (MPa) | Shear YZ (MPa) | Shear ZX (MPa) |
|---|---|---|---|---|---|---|---|---|
| 1100 | 35 | 35 | -675 | -120 | -120 | 80 | 46.15 | 80 |

Table 4.3: Orthotropic stress limits

### B. *Modelling Procedure*

Modelling is done on "Ansys 17.0" a commercial tool for finite element modelling, which is very user friendly. Some basic steps followed are described here,

- Composite laminate material selection on ACP (pre),
- Defining different material properties for material selected,
- Creating geometry for analysis,
- Defining mesh size followed by ply group sequencing,
- Defining load and boundary conditions.

This process can be adopted in workbench of ANSYS,

For analysis on mechanical APDL of ANSYS, the following procedure can be employed,

- Selection of shell element,
- Adding material properties,
- Defining layers sequence and thickness,
- Defining geometry for specimen,
- Creating mesh for geometry,
- Apply loading and boundary conditions,
- Selection of analysis type, in this case it is static followed by eigenvalue buckling,
- Solve and post-processing of solution.

### C. *Validation*

For validation purpose same modeling procedure is used with work of Bipin et al. (2013). They worked on carbon fiber with different specimen sizes. Comparative results are shown below (table 4.4 and 4.5) –

| S. No. | Length (mm) | Width (mm) | Thickness (mm) | Experiment result (B) Buckling load (kN) | Present work Buckling load (kN) |
|---|---|---|---|---|---|
| 1 | 100 | 20 | 2 | 0.810 | 0.8319 |
| 2 | 150 | 20 | 2 | 0.265 | 0.2448 |
| 3 | 150 | 30 | 2 | 0.250 | 0.2471 |

Table 4.4: Validation from experimental work of Bipin et al.

| S. No. | Length (mm) | Width (mm) | Thickness (mm) | Analytical result (B) Buckling load (kN) | Present work Buckling load (kN) |
|---|---|---|---|---|---|
| 1 | 100 | 20 | 2 | 0.8272 | 0.8319 |
| 2 | 150 | 20 | 2 | 0.245 | 0.2448 |
| 3 | 150 | 30 | 2 | 0.2432 | 0.2471 |

Table 4.5: Validation from analytical results of Bipin et al.

From tables 4.4 and 4.5, we can assert the followings –

In first case (100×20×2) deviation of present work is 2.7% from experimental result and 0.5% from analytical work.

In second case (150×20×2) deviation of present work is 7.6% from experimental result and 0.8% from analytical work.

In third case (150×30×2) deviation of result is 1.16% from experimental and 1.6% form analytical work.

Validation results obtained are shown below, how specimen looks after buckling is shown for different specimens in figures 4.1, 4.2 and 4.3. From above results we can say that present work is in good relation with previous researches within the maximum of less than 8 % of deviation from experimental and analytical works. Therefore, it is inferred that, the present method can be employed for further analysis as it provided good agreement between present work and work of other (refer figure 4.4).

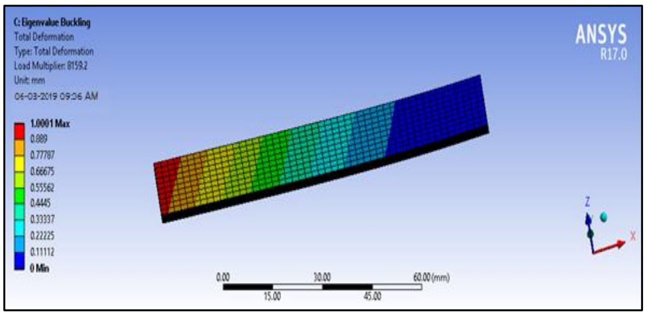

Fig. 4.1: Validation for specimen 1

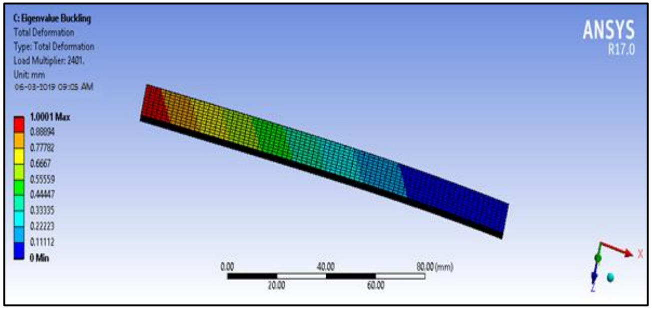

Fig. 4.2: Validation for specimen 2

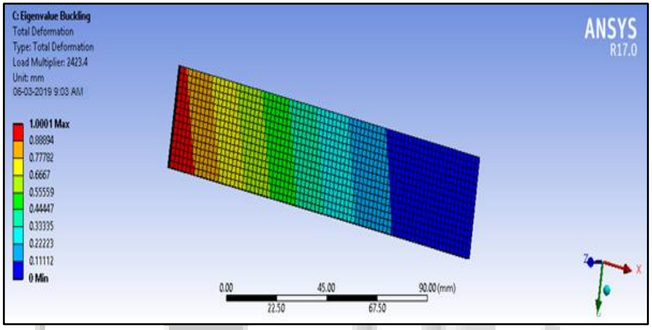

Fig. 4.3: Validation for specimen 3

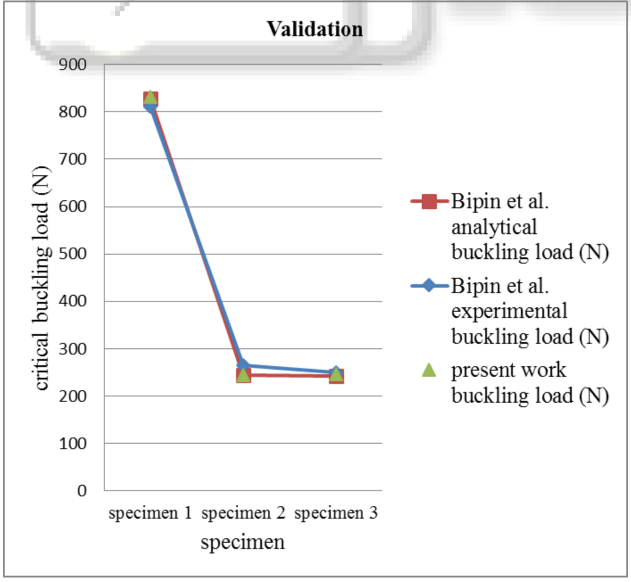

Fig. 4.4: Validation of modelling procedure

## VII. RESULTS AND DISCUSSION

Two different types of results are explained in this chapter. Figure 5.1 describes how the load and boundary condition (one end is fixed support and other end is free) is applied on the specimen for the analysis processes.

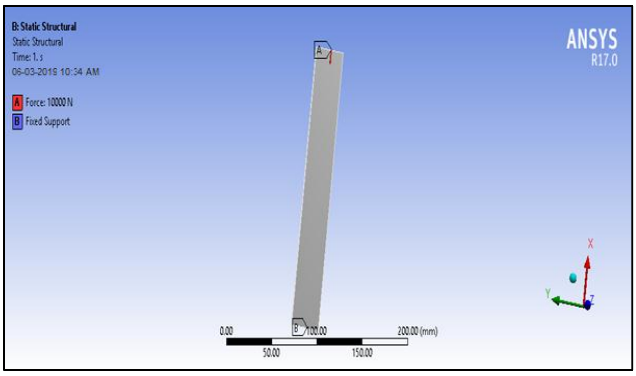

Fig. 5.1: Load and support application

### A. *Buckling and Post-Buckling*

This part deals with the buckling and post-buckling analysis of composite specimen.

### B. **Length Variation Effect**

After selection of sequencing the next problem arises is dimension variation's effect. Width and thickness, taken for that analysis are held constant but length is varied and following result is observed (table 5.2),

| Specimen | Dimension | Buckling load (N) | Remark |
|---|---|---|---|
| 1 | 180×30×3 | 1169.1 | Figure 5.7 |
| 2 | 200×30×3 | 864.9 | Figure 5.8 |
| 3 | 220×30×3 | 728.28 | Figure 5.9 |

Table 5.2: Length variation and buckling load

Different obtained eigen-value buckling deformations for length variation are shown below (figure 5.7, 5.8 and 5.9)

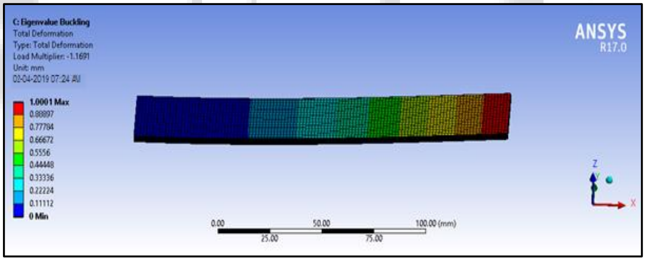

Fig. 5.7: buckling for dimension 180×30×3 specimen

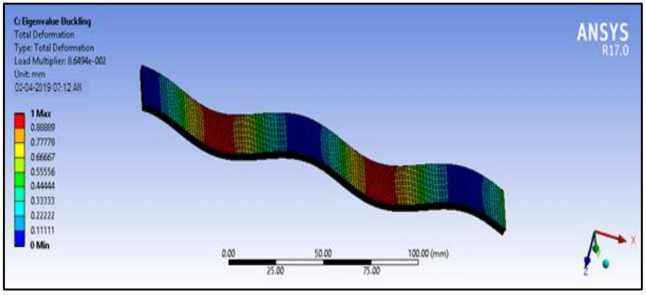

Fig. 5.8: Buckling for dimension 200×30×3 specimen

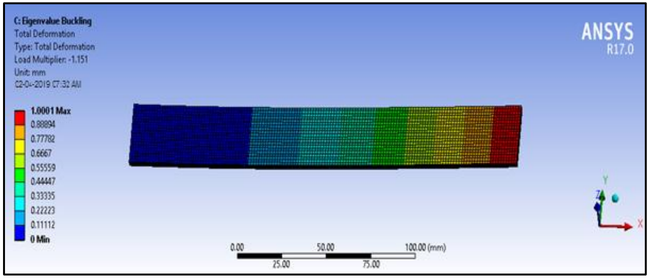

Fig. 5.9: Buckling for dimension 220×30×3 specimen

### C. *Thickness Variation Effect*

Following length variation, effect of change in thickness is checked. This is given in below table 5.3.

| Specimen | Dimension | Buckling load (N) | Remark |
|---|---|---|---|
| 1 | 200×30×2 | 740.39 | Figure 5.11 |
| 2 | 200×30×2.5 | 829.2 | Figure 5.12 |
| 3 | 200×30×3 | 864 | Figure 5.13 |
| 4 | 200×30×3.5 | 1017.68 | Figure 5.14 |
| 5 | 200×30×4 | 1324.9 | Figure 5.15 |

Table 5.3: Buckling load for thickness variation

Thickness plays very important role in buckling analysis, from figure 5.10 and table 5.3, we can assert that for lower values of

Different observed Eigen-value buckling deformations for thickness variation are shown (figure 5.11, 5.12, 5.13, 5.14 and 5.15).

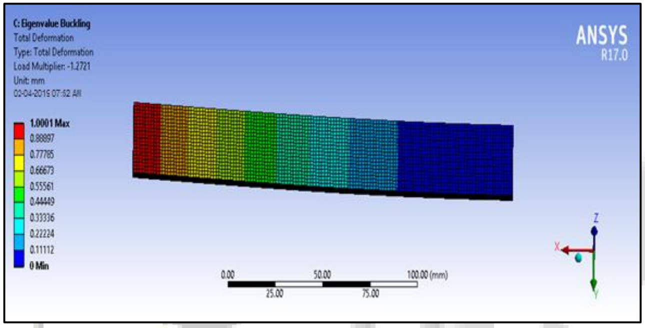

Fig. 5.11: Buckling for dimension 200×30×2 specimen

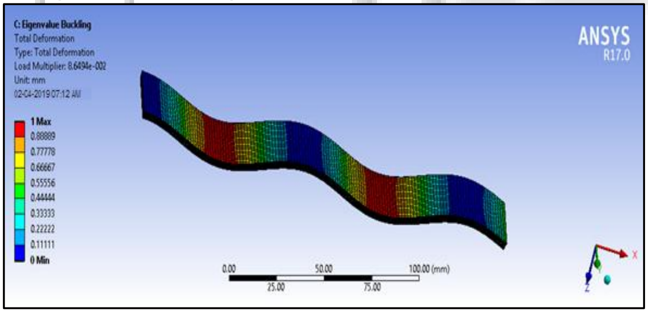

Fig. 5.12: Buckling for dimension 200×30×2.5 specimen

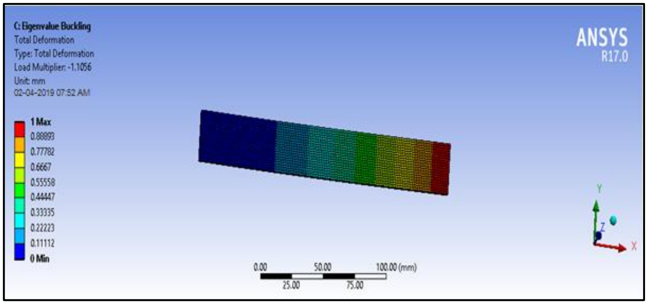

Fig. 5.13: Buckling for dimension 200×30×3 specimen

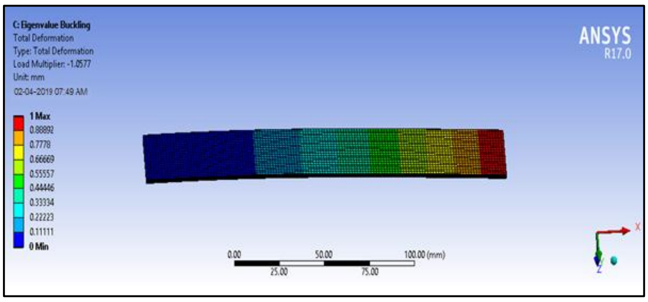

Fig. 5.14: Buckling for dimension 200×30×3.5 specimen

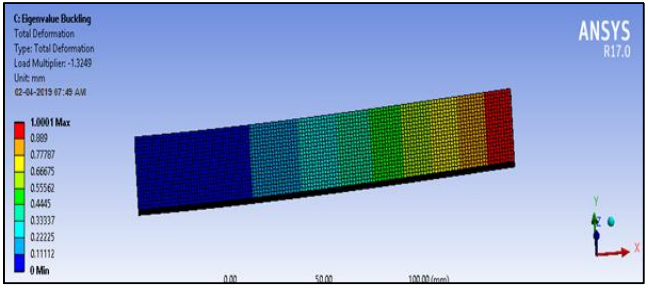

Fig. 5.15: Buckling for dimension 200×30×4 specimen

## VIII. CONCLUSIONS

### A. *Buckling and Post-buckling*

- Length and thickness play an important role in buckling; as the length increases, the buckling load decreases up to 500 N for change in aspect ratio 6 to 8. While other dimensions are constant, increase in thickness causes 600 N increase in the critical buckling load, for length to thickness ratio of 100 to 50.

### B. *Future work*

- Further work can be performed using different criteria and evaluate which criteria give better result for uniaxial, biaxial or triaxial type of loading.

Present work is focused on the plate without cutout section, in further work, cutout sections can be induced.

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