Post-buckling of bamboo reinforced composite plates

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Abstract. Composite materials are preferred as today’s material for aerospace structural applications largely because composites provide high specific strength and stiffness. To their advantages, natural fibers such as bamboo, kenaf, jute and flax have been researched significantly for having high effective strength and stiffness and environmental friendly advantages in being renewable, biodegradable and sustainable. While many structures used in aerospace applications are thin and as such susceptible to buckling problem, this paper presents the study on the buckling and post-buckling of bamboo reinforced composite plates (BRCPs), applying the finite element method software of ANSYS APDL. A compressive load was given to the BFRC and linear buckling analysis was conducted first. The determined critical load from this analysis was then used in the non-linear post-buckling analysis to give the post-buckling path of the BRFC. In both linear and non-linear analysis, the effect of BRFC thickness was considered while both angle-ply and cross-ply orientations were used. The results of deflection of a composite plate showed an excellent agreement with past results. The study shows that as the length to thickness ratio (l/t) was increased, critical loads increased as well. Further, the critical loads for the angle-ply BFRCs were higher than the cross-ply counterparts of the same thickness. Similar pattern of behaviour can be seen for the post-buckling paths of the BFRCs.

1. Introduction

Many structures used in aerospace and other structural applications can be assumed as thin rectangular plates. Modern times have seen the switch from conventional metals to composite materials largely because composites offer high specific strength and stiffness [1, 2]. In all countries, especially Asia, bamboo is taking place as a well-known plant group. Moreover, as the extensive root base sprouts of new bamboo shoots are readily available, it does not need re-planting. Bamboo is abundantly available in Asia and South America. In Asia, it is usually used for house construction, as handicraft’s artificial and in industry of the pulp and paper production. Although bamboo is considered as natural engineering materials, it has not been fully explored by many Asia countries.

Natural fibers have appeared as a renewable and cheaper substitute to synthetic fiber. It is found within the lignocelluloses and are made up of cellulose, hemicelluloses, lignin, pectin, and water mainly. Natural fiber has high effective strength and stiffness, low cost, low production energy requirement, and has advantages to the environment. Due to these, the application of natural fibers such as bamboo, kenaf, jute, flax and wood in fibre reinforced composites has become so important [3-7]. Some of the environmental advantages of natural fiber compared to synthetic fibers such as glass and carbon is it
being renewable, biodegradable and sustainable. Furthermore, composite laminates have countless applications as advanced engineering materials, largely used as components in automotive, power plants, structural, prosthetic devices, sports equipment etc. The main benefit of composite material is capable of controlling the fiber alignment. By arranging layers and fiber direction, laminated material with necessary strength and stiffness properties to specific design conditions, can possibly be achieved.

Buckling in science is instability of mathematical that leads to the failure mode. Structurally, buckling is a failure that occurs when the applied compressive load is higher than the critical load of that structure. A precise buckling analysis of the laminated composite plates is a significant part of the structural design [8-11]. Finite element method (FEM) has been broadly used for the buckling analysis of laminated composite plates. Finite element method been used in industries today because it is cheaper and reliable. However, numerical investigations of the structural response for natural fiber laminated structures are limited.

This paper presents the study on the buckling and post-buckling of the bamboo fibre reinforced composite (BFRC) applying FEM software of ANSYS APDL. The FEM modelling of the BFRC in this study considers the effects of geometric nonlinearity.

2. Materials and Methods

In this section, the properties of the constituents and the geometry of the bamboo fibre reinforced composites are given. Furthermore, the FEM method of analysis using the ANSYS APDL is described. The analysis includes the linear eigen-value analysis for getting the critical buckling load and the geometric non-linear post-buckling analysis that gives the post-buckling path of the bamboo fibre reinforced composite. A preliminary study was conducted on similar laminated composite in order to test the modelling procedures conducted in ANSYS APDL software.

2.1. The properties

The BFRC consists of bamboo fibre and epoxy matrix. The properties of the constituents are as shown in Table 1.

| Properties          | Bamboo fibre | Epoxy matrix |
|---------------------|--------------|--------------|
| Young’s modulus, E  | 11.1 GPa     | 3.27 GPa     |
| Poisson’s ratio, ν  | 0.3          | 0.35         |
| Density, ρ          | 6356.88 kg/m³ | 1177.72 kg/m³ |
| Shear modulus, G₁₂  | 0.784 GPa    | 0.3447285 GPa |

The effective properties of the bamboo-epoxy layers are determined through the rule of mixture, assuming perfect bonding between bamboo fibres and epoxy before these data are input to the ANSYS APDL software. With the subscripts of \( c \), \( f \), and \( m \) representing composite, bamboo fibres and epoxy matrix respectively, the effective property formulas for density of composite (\( \rho_c \)), longitudinal Young’s modulus (\( E_1 \)), transverse modulus (\( E_2 \)), shear modulus (\( G_{12} \)) and Poisson’s ratio (\( ν_{12} \)) are given below:

\[
\rho_c = V_f \rho_f + V_m \rho_m
\]

\[
E_1 = E_f V_f + E_m (1 - V_f)
\]

\[
\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{1 - V_f}{E_m}
\]

\[
G_{12} = \frac{G_f G_m}{V_m G_f + V_f G_m}
\]

\[
ν_{12} = ν_f V_f + ν_m (1 - V_f)
\]
\[ \nu_{21} = \nu_{12} \left( \frac{E_2}{E_1} \right) \]  \hspace{1cm} (6)

Furthermore,

\[ E_3 = E_1 \]  \hspace{1cm} (7)

\[ \nu_{23} = \nu_{12} \]  \hspace{1cm} (8)

\[ G_{23} = G_{31} = G_{12} \]  \hspace{1cm} (9)

Using these formulas and constituent properties in Table 1, the effective properties were calculated and the values are shown in Table 2.

**Table 2: Effective properties of BFRC**

| Properties                      | Value                  |
|---------------------------------|------------------------|
| Density, \( \rho_c \)           | 3.24942\( \times 10^3 \) kg/m\(^3\) |
| Longitudinal Young’s modulus, \( E_1 \) | 6.402 GPa              |
| Transverse modulus, \( E_2 \)   | 4.56 GPa               |
| Shear modulus, \( G_{12} \)     | 2.407 GPa              |
| Poisson’s ratio, \( \nu_{12} \) | 0.33                   |
| Poisson’s ratio, \( \nu_{21} \) | 0.235                  |

2.2. The geometry

The BFRC is a three-layer composite such as shown in Figure 1. The cross-ply BFRC has [0/90/0] orientation while the angle-ply has [45/-45/45] orientation. The aspect ratio of 1 has been used throughout the analysis.

![Figure 1: The geometry of the BFRC](image)

2.3. The methods

The finite element method was used via the ANSYS APDL software to conduct 2 analyses: the eigenvalue analysis to determine the critical load and the geometric non-linear analysis to determine the post-buckling path of the BFRC plates. The critical load is necessary to estimate the starting point of bifurcation, a value needed in the geometric non-linear analysis.

2.3.1. The critical load.

The critical load was determined in FEM by solving the following eigen-value problem:
\[(\{K\} + \lambda\{K_G\})\{\alpha\} = 0\]

(10)

where \([K]\) is the linear stiffness of the BFRC, \([K_G]\) is the geometric stiffness matrix, \{\alpha\} is the generalized displacement and \(\lambda\) is a scalar representing critical load. In the ANSYS APDL, this is conducted through 2 steps: linear static analysis with pre-stress effect and eigen-buckling analysis. In the eigen-buckling analysis, the block Lanczos method was chosen.

2.3.2. The post-buckling. The post-buckling path is extracted from the static analysis considering large deflection such as in the following equation:

\[(\{K\} + \{K_{NL}\})\{\alpha\} = \{F\}\]

(11)

where \([K_{NL}]\) is the non-linear stiffness of the BFRC and \{\(F\)\} is the force vector? In the ANSYS APDL, this analysis is conducted thru linear static analysis applying large deformation effect.

2.4. The preliminary study

A study was conducted in determining the central deflection of a simply supported laminated composite plate loaded with uniform pressure, \(P=1.0\ N/m^2\) using ANSYS APDL software. The 4-layer square plate has a symmetric cross-ply orientation of [0/90/90/0]. Each layer is set to have equal thickness of \(t=0.025\ m\). The composite has the following properties:

\[E_x = 25\ MPa,\ E_y = 1\ MPa,\ v_{xy} = 0.25,\ G_{xy} = 0.5\ MPa,\ G_{yz} = 0.2\ MPa\]

Using the software, the linear static type analysis was conducted.

3. Results and Discussions

In this section, the validation study is given first, followed by the results of the Eigen-value analysis and the non-linear post-buckling analysis.

3.1. Validation

The preliminary study conducted has given the converged values of central deflection of the composite plate such as shown in Table 3 and Figure 2. Even for the 3x3 meshing has resulted in a deflection value that differ from [12] by only 1.53%.

Table 3: Value of deflection in y-axis with difference number of meshing elements

| No of Meshing Element | Deflection in Y-direction, mm | Percentage difference (%) |
|-----------------------|-------------------------------|---------------------------|
| 3                     | 0.06755                       | 1.53                      |
| 6                     | 0.068273                      | 0.48                      |
| 9                     | 0.068413                      | 0.27                      |
| 12                    | 0.068469                      | 0.19                      |
| 15                    | 0.068501                      | 0.14                      |
| 18                    | 0.068522                      | 0.11                      |
| 21                    | 0.068537                      | 0.09                      |
| 24                    | 0.06855                       | 0.07                      |
| 27                    | 0.068559                      | 0.06                      |
| 30                    | 0.068568                      | 0.05                      |
3.2. The critical load
The results of the Eigen-buckling analysis that gave the critical loads of the angle ply and cross ply BFRC plates are shown in Table 4. The effect of the length to thickness ratio ($l/t$) is taken into consideration here.

**Table 4:** The critical loads (N) for different laminate configurations and aspect ratios.

| $l/t$ ratio | [0/90/0]  | [45/-45/45] |
|------------|-----------|-------------|
| 20         | 127410.0  | 107370.0    |
| 50         | 8731.7    | 7330.1      |
| 100        | 1161.9    | 974.9       |
| 150        | 345.4     | 289.8       |
| 200        | 145.9     | 122.4       |

It can be seen from Table 4 that as the $l/t$ ratio increases, the critical load increases as well for both types of lamination scheme. At any $l/t$ ratios, the $P_{cr}$ is higher for the cross-ply BFRC.

3.3. The post-buckling path
The results of the post-buckling paths of the angle ply and cross ply BFRC plates are given in this section. The post-buckling paths are shown in the forms of load vs lateral deflection plots for both BFRC plates. Again, the effect of the length to thickness ratio is considered here.

3.3.1. The cross-ply BFRC.
The plots of the post-buckling path of the cross-ply BFRC plates correspond to several $l/t$ ratio are given in Figure 3 and Figure 4 correspond to thick and thin composites, respectively. In all cases,
there are no clear bifurcation points can be seen in the graphs. The higher the thickness of the plates, the higher the forces needed to give lateral deflections of the plates.

![Figure 3: The post-buckling path of the thick cross-ply BFRC](image)

![Figure 4: The post-buckling path of the thin cross-ply BFRC](image)

3.3.2. The angle-ply BFRC.

The plots of the post-buckling path of the angle-ply BFRC plates correspond to several \( \frac{l}{t} \) ratio are given in Figure 5 and Figure 6, again correspond to thick and thin composites, respectively. Again, it can be seen that in all \( \frac{l}{t} \) cases, there are no clear bifurcation points in the graphs. Furthermore, similar to the cross-ply plates, the higher the thickness of the plates, the higher the forces needed to give lateral deflections of the plates.
4. Conclusion
In this study, the buckling and post-buckling of laminated bamboo fibre reinforced composite were determined using FEM software of ANSYS APDL. The critical loads for the BFRC plates were determined using the linear Eigen-buckling function in ANSYS while the post-buckling paths were determined through the non-linear static analysis with large deformation. It was found that as the ratio of the length to thickness increases, the critical loads were increased and the force-deflections were shifted higher. Furthermore, the determined plots showed no clear bifurcation points in the post-buckling paths.

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References

[1] Yusof, Z., et al., *The parametric instability improvement of fully anisotropic composite plates with embedded shape memory alloy*. Advanced Composites Letters, 2020. 29.

[2] Roslan, S.A.H., et al., *Dynamic instability response of smart composite material*. Materialwissenschaft und Werkstofftechnik, 2019. 50(3): p. 302-310.

[3] Roslan, S.A.H., Z.A. Rasid, and M.Z. Hassan, *The natural fiber composites based on bamboo fibers: a review*. ARPN journal of engineering and applied sciences, 2015. 10: p. 6279-6288.

[4] O. Nurihan, M.R.M.H., Z.A. Rasid, M. Z. Hassan and A.F.M. Nor, *The Elastic Properties of Unidirectional Bamboo Fibre Reinforced Epoxy Composites*. International Journal of Recent Technology and Engineering (IJRTE) 2019. 8(3): p. 7187-7193.

[5] Hassan, M.Z., et al., *Mercerization Optimization of Bamboo (Bambusa vulgaris) Fiber-Reinforced Epoxy Composite Structures Using a Box-Behnken Design*. Polymers (Basel), 2020. 12(6).

[6] Hassan, M.Z., et al., *Impact Damage Resistance and Post-Impact Tolerance of Optimum Banana-Pseudo-Stem-Fiber-Reinforced Epoxy Sandwich Structures*. Applied Sciences, 2020. 10(2).

[7] S. A. H. Roslan, M.Z.H., Z. A. Rasid, H. I. Ibrahim, *Tensile Behaviour of Chemical Treatment for Bamboo Epoxy Composites*. Chemical Engineering Transactions 2018. 63: p. 745-750.

[8] Rasid, Z.A., R. Zahari, and A. Ayob, *The Instability Improvement of the Symmetric Angle-Ply and Cross-Ply Composite Plates with Shape Memory Alloy Using Finite Element Method*. Advances in Mechanical Engineering, 2015. 6.

[9] Rasid, Z.A., R. Zahari, and A.B. Ayob, *The Instability Improvement of the Shape Memory Alloy Composite Plates Subjected to In-Plane Parabolic Temperature Distribution*. Applied Mechanics and Materials, 2014. 554: p. 32-36.

[10] Rasid, Z.A., et al., *The Strain Energy Tuning of the Shape Memory Alloy on the Post-Buckling of Composite Plates Using Finite Element Method*. Advanced Materials Research, 2012. 445: p. 577-582.

[11] Rasid, Z.A., et al., *Thermal Buckling and Post-Buckling Improvements of Laminated Composite Plates Using Finite Element Method*. Key Engineering Materials, 2011. 471-472: p. 536-541.

[12] Reddy, J.N., *Exact Solutions of Moderately Thick Laminated Shells*. Journal of Engineering Mechanics, 1984. 110(5): p. 794-809.