Numerical analysis of hat stiffened composite panels for pre and post buckling conditions

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Abstract
This research aims in studying the pre-buckling and post-buckling behaviour of composite panels stiffened by hat stiffeners under compressive loading. Stiffened panels are used in aerospace, marine and also in bridge structures. They are used to make the plate girders stiff. By using composite materials, the strength can be increased, and the weight can be reduced. In Composite panels which are stiffened, local buckling and failure of panel happens because of the applied compressive loads and due to combination of compressive and shear loads. The Collapse of the stiffened composite structure starts from the intersection between the plate and the stiffeners due to stress effect caused by deformation of lamina skin and stiffeners then leads to the structural buckling of skin of the panel. This research uses nonlinear Finite element approach to investigate the collapsing behavior using ABAQUS software.

Keywords: Stiffeners, Finite Element Method, Composites, Laminated Panels, Buckling.

1. Introduction:
The need for strong, efficient and light weighted structures led all experts to use composite materials in a lot of areas. The purpose of designing the laminated composite materials is to achieve better performance, which are not possible with the traditional materials. This is because of their high stiffness and strength to weight ratio. Some of the applications are Aircrafts, Automobiles and Space vehicles. However, there are many difficulties, when it comes in choosing the suitable material for the structural applications. Composite panels are nowadays used in bridges for retrofitting of the structures as they possess high strength. In stiffened composite panels, the in-plane material possesses strong material properties when compared to the direction which is normal to the fibre orientation. They have very low resistance against Shear and compression because of very weak inter laminar interfaces. Because of the weak inter-laminar interfaces, cracks are formed which leads to failure. This is known as delamination and it will reduce the load carrying capability of the structure. Delamination in compressive loaded structures causes buckling. Loss of stiffness is the main cause of this failure. Manufacturing defects and dropping of tools are some of the causes of buckling. The Ply orientation also have impact on the strength and stiffness of the composite laminates. Many researches have been done on stiffened composite panels with different type of stiffeners.

Stiffeners are used to control local buckling. They stiffen the panels against out of plane deformations. Most of the researchers have worked on different type of stiffeners like T-shaped and J-shaped stiffeners. (Faruk Eladi,[1]) studied the post buckling durability of J-stiffened and hat stiffened boards by comparing the experimental results with the analytical results. He concluded that Hat stiffened panel is 25% more efficient than the J-stiffened panels. (L.Boni et al, [2]) concentrated on developing a proven method for modeling, by means of Finite Element method, the post-buckling behaviour of stiffened composite flat panels exposed to compression loads. The experimental values for model validation were taken during a test on two sets of CFRP flat stiffened panels.
The similarity between the numerical and experimental outcome shows the efficiency of the FEM method in anticipating the buckling behavior. (Shashi Kumar et al, [3]) used artificial neural networks for estimating the buckling load of laminated hat stiffened panels under compressive loading. It is found that artificial neural networks can be used in an efficient manner to identify the buckling load for different type of loading conditions. (Vishwanath Vashisht, [4]) investigated the stiffened panel structure which is made up of different materials under pressure loads. He found that the combination of HYBOR/Boron composite and Aluminium and steel is the suitable material for stiffening in re-entry vehicles in aerospace industry. (Nitin Kumar et al, [5]) studied the structural weight optimization of hat stiffened aircraft wing by varying the distance between the stiffeners and the number of stiffeners. He found that 150 mm stringer gap is optimum. (Weibgraever et al, [6]) presented about linear investigation of buckling behavior of an orthotropic plate under compressive load. He determined the absolute minimum bending stiffness which enables the reinforcement to act as near rigid support for arbitrary long plates. (Riming Tan et al,[7]) studied the effect of impact location on the composite panels with Single-L shaped stiffener due to compression. He concluded that the bending stiffness in the impact location affects the damage formation. In order to reduce the damage, the stiffness discontinuity in structural design should be avoided. (Yao Yao ye et al, [8]) investigated and analyzed about how sub-stiffeners can enhance the anti-buckling performance of the composite panel stiffened using T stiffeners. The optimal stacking ply sequence of the sub-stiffeners also increased the critical load value of T-stiffened panel by 112.6%. (WeibSun,[7]) investigated the effect of failure of a composite panel with three T-shaped stiffeners due to low velocity impact when it is subjected to compressive buckling. When the impact energy is increased there is serious debonding of stiffener and panel. The increase of compressive load decreases the compressive stiffness of the panel as result of the damage propagation of the stiffener and buckling of panel. The buckling phenomenon of composite panels depends on the properties of the material used and also the type of fibre orientation of the composite panel. In this paper, CFC and Kevlar have been considered to analyze the clasp behaviour of the composite panel using non-linear FEM with ABAQUS software.

2. Methods:
The Linear buckling analysis is also known as eigen value buckling analysis, it predicts the buckling strength of a structure. However, eigen value buckling does not consider non linearities and imperfections. So, more precise post- buckling analysis needed to determine the load value at which the structure will become unstable.

2.1 Mathematical Model:
Considering Eigen value pre-buckling analysis, appropriate stiffness matrix is given by,

\[
[K_0] = \int_{\Omega} [B_0]^T [C][B_0] d\Omega 
\]  
(1)

Where \([B_0]\) corresponds to strain-displacement matrix. The solution can be found from,

\[
[K_0][q_0] = [f_0] 
\]  
(2)

Where \([q_0]\) are pre-buckling response
\([f_0]\) = load vectors respectively.

The Geometric stiffness matrix \([K_P]\) is given to be,

\[
[K_P] = \frac{1}{\Omega} \int_{\Omega} [G][\sigma][G] d\Omega
\]  
(3)

Where \([\sigma]\) = stress vector, Hence, the linear buckling problem is given by,

\[
([K_0] - [K_P])[\chi] = 0
\]  
(4)
3. **Geometry:**
The Geometry of hat stiffened laminated composite panel can be seen from the figure 1. The dimensional parameters of the Composite panel have a thickness of 356mm and height 356 mm. There are three hat stiffeners and the spacing between the stiffeners is 100mm. The Ply configuration of the panel is \([45/-45/0/90/]\)s and it has thickness of 2 mm. The thickness of each ply is 0.125mm and the panel is made up of 16 layers.

![Composite panel with hat stiffeners](image)

Figure 1 Composite panel with hat stiffeners

4. **Materials Properties:**
Two materials, CFC/epoxy and Kevlar/epoxy were used for this buckling analysis of composite panel. The material properties are given below in Table 1.

| Table 1 Material properties. |
|-----------------------------|
| Symbol | Units | CFC | Kevlar |
| ------ | ----- |-----|--------|
| E11   | Gpa   | 164.00 | 195.00 |
| E22~E23 | Gpa    | 12.60 | 14.60 |
| G12~G13 | Gpa   | 4.50 | 7.50 |
| G23   | Gpa   | 2.50 | 5.00 |
| 912~913 | None | 0.32 | 0.30 |
| 312   | None | 0.45 | 0.45 |
| X11   | Mpa   | 2724.00 | 3100.00 |
| X1c   | Mpa   | 111.00 | 500.00 |
| X2t   | Mpa   | 50.00 | 150.00 |
| X2c   | Mpa   | 1690.00 | 1800.00 |
| X2t   | Mpa   | 290.00 | 600.00 |
| X2c   | Mpa   | 290.00 | 600.00 |
| S12   | Mpa   | 120.00 | 250.00 |
| S13   | Mpa   | 137.00 | 320.00 |
| S23   | Mpa   | 90.00 | 200.00 |
| \(\rho\) | Kgm\(^{-3}\) | 1800 | 1400 |
5. **Meshing:**
The composite panel is discretized with S4R element for the analysis. The S4R element has the bending capability and can be used when the loading of the structure is asymmetric. The S4R element possesses a DOF of 3 per node. The size of the mesh is 5mm and have generated 12400 elements as shown in Figure 2.

![Figure 2 Mesh](image)

6. **Boundary conditions:**
The composite panel is completely fixed at the bottom edge and it is allowed to move in axial direction along the top edge. The Vertical edges are simply supported. The uniform axial load of 1 KN/m is applied axially in the Z-Direction of the panel.

![Figure 3 Boundary conditions](image)

6.1 **Pre-Buckling analysis:**
The composite panel is made up of 16 layers and the material properties are assigned for each layer. The thickness of each layer of the composite panel and the stiffener is 0.125 mm. The total thickness of the composite panel and the stiffeners is 2 mm. Considering the linear analysis the Eigen value step is used in place of general static step. Axial load of 1KN/m is applied along the edge of the composite panel. After the necessary conditions being assigned, the finite element model is tested for pre-buckling analysis. The buckling modes can be viewed in the visualization module. The buckling load can be acquired through the product of the Eigen value and load magnitude.

\[
\text{Buckling load} = \text{Eigen value} \times \text{Axial load magnitude}
\]
6.2 Post Buckling analysis:
Under post buckling study, the non-linear F-S curve data for the corresponding FE model can be obtained by utilizing the modified Riks algorithm [9]. It is thereby intended to study the post buckling behavior, hence the governing conditions pertaining to pre buckling behavior, as discussed previously, is updated to obtain the load displacement criteria corresponding to post-buckling behavior. In the post-buckling analysis, the non-linear load vs displacement curve is found using the modified Riks algorithm. The study for pre-buckling is updated to conduct a nonlinear analysis of load deflection to predict Post-buckling behavior. For post buckling analysis, Eigen value step is replaced by Riks method. The Load is replaced by critical load and a new job is created which can be submitted for post buckling analysis.

Figure.4 Buckling modes of (CFC/epoxy)
Figure 5 Von Mises (CFC/epoxy):
7. Results and discussion:
The buckling analysis of hat stiffened composite panel is done which is made up of CFC/epoxy and Kevlar/epoxy. The linear buckling analysis is done in order to identify the modes of the stiffened composite panel. The composite panel is loaded axially with load of 1KN/m and submitted for analysis. Five buckling modes are taken. Then the Eigen value buckling step is replaced by static Riks method to proceed to the post buckling analysis in ABAQUS. Now the model is submitted for post-buckling analysis which uses static riks method to solve the problem. The Critical load is applied axially in post buckling analysis.
Hashin’s damage criteria is applied to identify the anisotropic damage in elastic-brittle materials. It is used to find the failure modes in fibre reinforced composite materials. The elastic properties of CFC/epoxy and Kevlar/epoxy are given in Table 1 for Hashin’s damage criteria. In case of composite panel made of CFC/epoxy, the first buckling load value is 229 KN/m. The buckling load value is a product of Eigen value and applied load. The von mises contours are also taken. In case of composite panel made of Kevlar/epoxy the buckling load is 245 KN/m. Kevlar/epoxy possess more stress than CFC/epoxy. The buckling load is also higher in Kevlar/epoxy when compared to CFC/epoxy.

![Load vs Displacement](image1)

**Figure 8 Load vs Displacement**

![Mode Vs Load](image2)

**Figure 9 Load vs mode**
Figure 8 shows the Load vs mode graph comparison between CFC/epoxy and Kevlar/epoxy. In post buckling analysis, the load at which the panel becomes unstable is identified. The curve of load vs displacement curve increases linearly and after the increase of load it gets reduced. Composite panel with stiffeners made up of Kevlar/epoxy with stands maximum load when compared to composite panel with stiffeners made of CFC/epoxy. Figure 9 shows the Load vs Displacement curve comparison between CFC/epoxy and Kevlar/epoxy.

8. Conclusion:
The pre-buckling and post-buckling analysis of composite panels stiffened with hat stiffeners made up of CFC/epoxy and Kevlar/epoxy is done using the finite element method. The hat stiffened composite panel made up of Kevlar/epoxy has the maximum load capacity when compared with CFC/epoxy at the ply configuration of ([45/-45/0/90]s)s. The Kevlar/epoxy panel is stiffer when compared to CFC/epoxy hat stiffened panels.

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