Influence Of Boundary Conditions And Aspect Ratio On The Structural Stability Assessment Of Symmetric Cross Ply Laminate And Symmetric Angle Ply Laminate

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ABSTRACT

The study introduces a finite element formulation to examine how different localized in-plane edge stresses influence the buckling characteristics of interlayer hybrid fiber metal laminates (HFMLs). The panel has been constructed utilizing a plate element, incorporating the influences of rotating inertia and shear deformation. The present findings align with readily available literature, validating the efficacy of the current formulation. This study employs aluminum metal face sheets that are encased in four-layered, symmetric hybrid cross-ply and angle-ply laminate configurations. The integration of carbon and glass epoxy interlayer composite laminates is known as hybrid. Each scheme has analyzed six unique hybrid combinations, and the performance of each hybrid combination is evaluated across different loading scenarios. This study examines the influence of various parameters, such as panel aspect ratio, panel thickness, boundary conditions, and hybrid configurations. Analyzing mode shapes offers a comprehensive examination and clarification of the influence of each parameter.

Keywords: Boundary conditions, Aspect ratio, Structural Stability, Symmetric Cross Ply, Symmetric Angle Ply.

1. INTRODUCTION AND LITERATURE

Fiber laminates have been developed to create fiber metal laminates (FMLs), which are composite materials consisting of metal and fiber laminates, with the fiber laminates positioned between the metal facing sheets. Glass reinforced aluminum laminates, carbon reinforced aluminum laminates, and aramid reinforced aluminum laminates represent the three primary categories of fiber metal laminates. Commonly located in various components of airplanes such as the fuselage, flooring, and engine cowling, GLARE stands out as a prominent example of fiber-metal laminates. The combination of fibers and metals in FMLs results in mechanical properties that surpass those of standard fiber laminates. Moreover, the combination of the aforementioned FMLs, referred to as hybrid FMLs, enhances additional mechanical properties (Sinmazçelik et al. 2011). Choosing the right hybrid combination can lead to an optimal and cost-effective design when combining FMLs. Investigating the structural responses of different hybrid combinations under a range of challenging stress conditions is therefore essential. This observation holds especially for buckling and vibration responses, as thin-walled structures exhibit a significant tendency to buckle under relatively low stress levels. Elastic stability represents a significant challenge that has consistently drawn the attention of scholars. Extensive examination of the buckling behavior of laminated panels under uniform in-plane edge stresses has been conducted in the literature (Srivastava, Datta, and Sheikh 2004; Bulut, Yeter, and Erklig 2014). In practical engineering applications, panels typically experience partial or localized loading; it is uncommon for a panel to encounter a uniform edge load. It is crucial to examine how structures respond to localized in-plane loads. The dynamic and buckling responses of orthotropic plates subjected to localized edge loads (Kumar et al. 2003, 2005) and non-uniform loads (Jafarpour Hamedani et al. 2013; Jana and Bhaskar 2006) have been relatively underexplored in the existing literature. Employing higher order shear deformation theory, C. S. Chen et al. (2017), Chien (2009), and Wei et al. (2012) investigated the dynamic behavior of originally stressed GLARE and CLARE metal laminate. Chun Sheng Chen et al. 2017 examined the impact of hygrothermal stresses on the dynamic behavior of hybrid composite plates. The nonlinear vibration behavior of the metal laminates CLARE and GLARE on the Pasternak and Winkler elastic foundation was examined using Mindlin plate theory (Wei et al. 2012). Al-Azzowitz et al. (2017) conducted an experimental investigation into the buckling and post-buckling behavior of GLARE metal laminates featuring splices and doublers when subjected to uniformly distributed in-plane edge stresses. Bikakis et al. (2019) investigated the elastic buckling of fiber metal laminated plates subjected to homogeneous uniaxial compression through the use of ANSYS software. The investigation into the free vibration behavior of various CLARE beam designs was conducted both mathematically and empirically by Maras et al. (2018). Recent investigations into the dynamic instability and vibration behavior of bidirectional woven-based GLARE have been conducted both analytically and physically, utilizing FOSDT (Prasad and Sahu 2018, 2019). In 2016, Min Ergun and colleagues conducted an experimental study focused on the bending and vibrational properties of an impacted hybrid composite. Several studies have examined factors such as impact energy, ply orientations, and span lengths in relation to laminates. In 2015, Karim Nouri and colleagues conducted an experimental investigation into a hybrid laminate composed of carbon and jute. By conducting a series of mechanical and physical tests, different fiber combinations and jute sizes were evaluated to yield the optimal hybrid composites exhibiting enhanced tensile strengths. The buckling behavior of glass and carbon-based hybrid fiber was examined under various boundary conditions utilizing higher order shear deformation theory (Adim Belkacem et al. 2018). Theoretically, the critical buckling loads were identified through a modification of Navier's solution approach. Benhenni et al. (2018) explored the dynamic behavior of simply supported anti-symmetric cross and angle-ply thick laminates by adjusting the weight percentage in glass and carbon hybridization. The study primarily focused on numerical analysis, examining how laminar schemes, side-to-thickness ratio, and aspect ratio influence the fundamental frequency loads.

The literature referenced above clearly demonstrates that laminated panels subjected to uniformly distributed edge loads have been thoroughly examined regarding their vibration and buckling characteristics. There has been minimal investigation into the impacts of partial and concentrated edge loads, particularly concerning laminated panels. The literature reveals a significant gap in understanding the buckling and vibration behavior of FMLs when subjected to homogeneous edge loads. To the authors' knowledge, there is a lack of literature addressing the impact of localized edge loads on the vibration and buckling behavior of fiber metal laminates and hybrid fiber metal laminates. In this study, we aim to explore the influence of localized edge loads on the vibrational and buckling properties of fiber metal laminates and hybrid fiber metal laminates. This investigation involves varying several parameters, such as panel aspect ratio, thickness, boundary conditions, hybrid configurations, and the width and position of the localized edge loads. Visualizing mode shapes allows for a comprehensive examination of the impact of each parameter.

2. GOVERNING EQUATIONS

The internal stress distribution within an element shows considerable variation under defined loading and boundary conditions. The buckling loads were ascertained through the application of the dynamic technique. The generalized differential equation of motion for tackling buckling challenges via dynamic methods can be expressed through the extended Hamilton principle in the following manner:

$$[M]\{\ddot{q}\}+[K_e]\{q\}-P[K_g]\{q\}=0 \tag{1}$$

The governing equation for solving vibration problems can be obtained by substituting, P = 0 in Eq. (1) as,

$$-\omega^2[M]\{q\}+[K_e]\{q\}=0 \tag{2}$$

The governing equation for solving buckling problems in static approach can be obtained by substituting, $\{\ddot{q}\}$ = 0 in Eq. (1) as,

$$[K_e]\{q\}-P_{cr}[K_g]\{q\}=0 \tag{3}$$

where P and P_{cr} are applied edge load and critical buckling load respectively.

3. RESULTS AND DISCUSSIONS

This study focuses on thin plate hybrid FMLs characterized by a b/h ratio of 100. Within the context of various support conditions, the symbols S, C, and F represent simply supported, clamped, and free conditions, respectively. The notations serve to specify the conditions. This study considers the following displacement-based boundary conditions:

The vibration frequency and the critical loads are presented in non-dimensional form as follows

Non-dimensional frequency, $$\bar{\omega} = \omega_{abs} B^2 \sqrt{\left(\frac{\rho_{Al}}{E_{Al} h^2}\right)} \qquad (4)$$

Non-dimensional load, $$\gamma_{cr} = \frac{P_{cr} B^2}{DD} \; ; \; DD = \frac{E_{Al} B^3}{12\left(1-\mu_{Al}^2\right)} \qquad (5)$$

Where ω_{abs} and P_{cr} are the absolute frequencies and buckling loads respectively

3.1 IMPACT OF BOUNDARY CONDITIONS ON HYBRID FML'S BUCKLING BEHAVIOR

The outcomes of a study that studied the impact that changing the aspect ratio, boundary condition, and fiber orientations had on the critical buckling load are shown in Figure 1. The study was conducted to explore the relationships between these factors. The load length, which is equal to one hundred percent, and the aspect ratio of the mesh, which is one, remained the same regardless of the aspect ratio. Both of these values are represented by the number one. Following an investigation, it was found that there were seven distinct border problems that needed to be handled. With regard to cross and angle ply hybrids, Figures 1(a) and (b) respectively provide an example of the impact that changing the aspect ratio has on the γcr value. When the aspect is changed from 0.5 to 4 levels, the kinks that are present in the cross-ply and angle-ply orientation graphs under the CCCC, SSCC, and SSSS boundary conditions indicate the way in which the mode forms of the plate experience variations resulting from the change. The plate has a propensity to stay in first mode regardless of any changes in aspect ratio, particularly when the ratio of a to b is between 1 and 3. This is especially true for situations such as CCFF, CFFF, SSSF, and CCCF. Figure 2 depicts the contours of the mode shape for cross-ply hybrids under a range of boundary conditions when they are measured. These contours are shown in the figure. It is abundantly evident from the example in Figure 1 that the cross ply orientation provides a greater amount of buckling resistance than the angle ply configuration does.

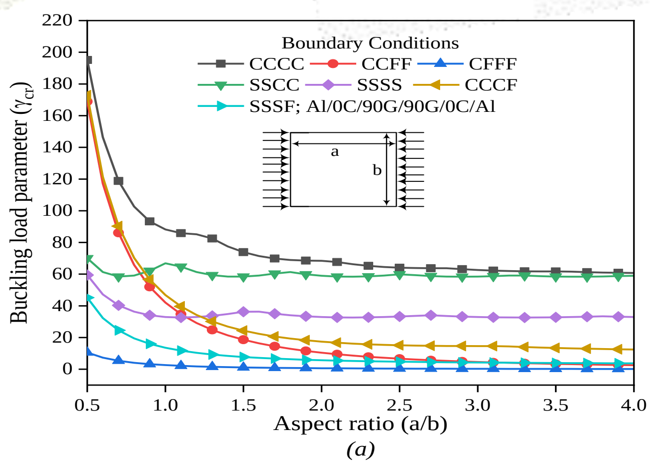
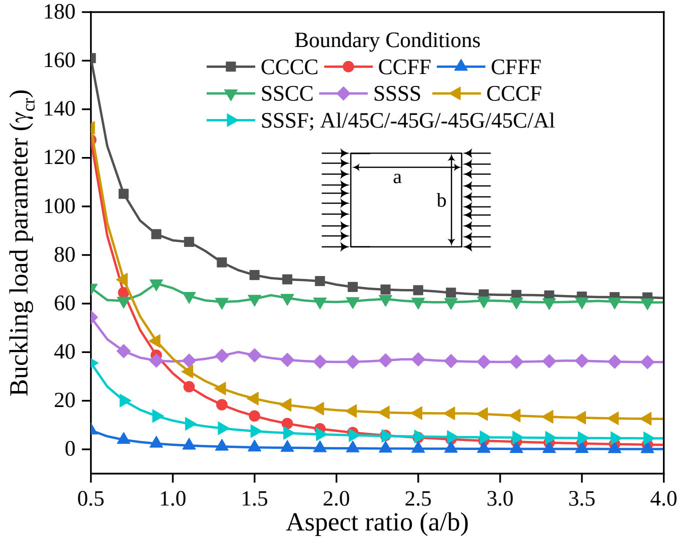


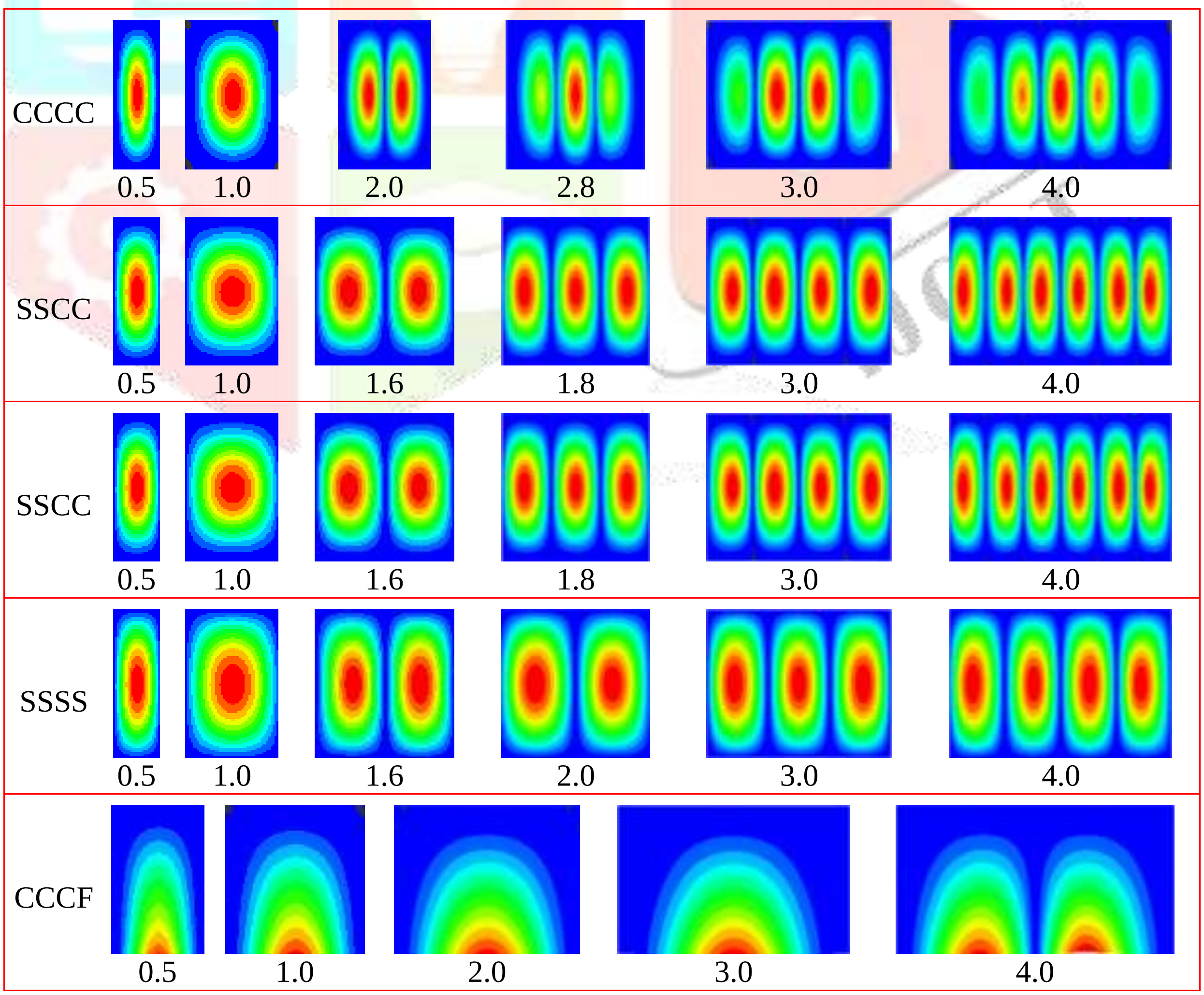
Fig. 1 (a) Effect of boundary conditions and aspect ratio on buckling load - Symmetric cross ply laminate



(b)

Fig. 1 (b) Effect of boundary conditions and aspect ratio on buckling load - Symmetric angle ply laminate

4. MODES SHAPES FOR DIFFERENT BOUNDARY



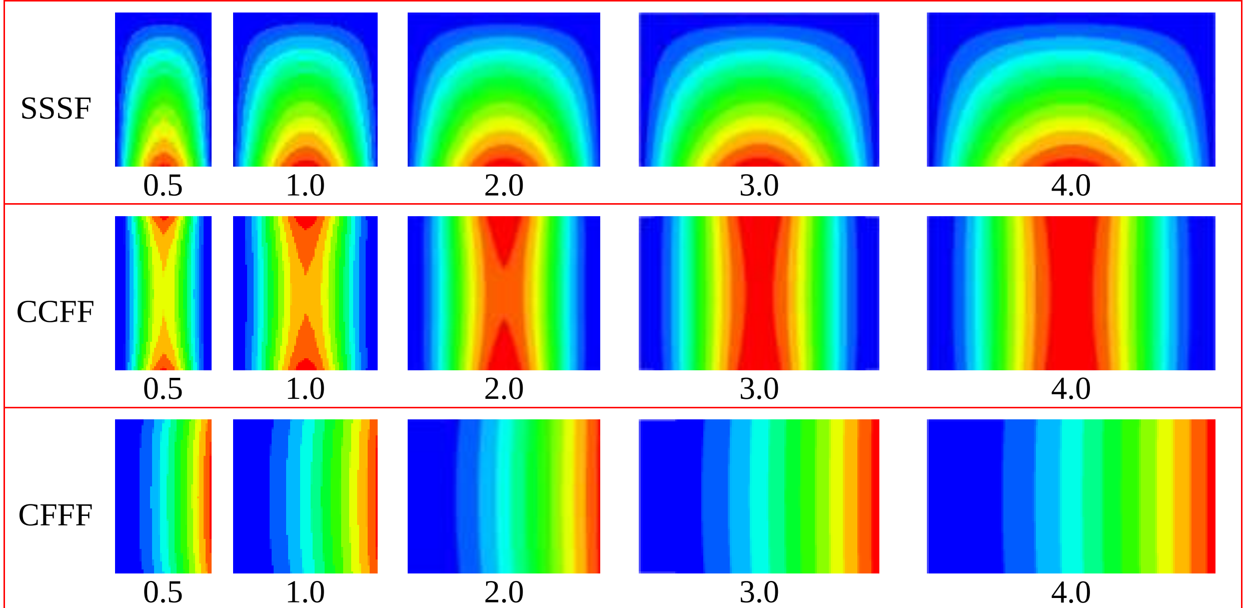


Fig. 2 Modes shapes for different boundary and aspect ratio for cross ply Orientations

5. CONCLUSIONS

When it comes to the critical buckling load, the impacts of aspect ratio, boundary condition, and fiber orientation are investigated, and the results of this analysis are reported. Regardless of alterations in the aspect ratio, the plate consistently stays in the first mode under situations such as CCFF, CFFF, SSSF, and CCCF. This is the case even when the aspect ratio is between 1 and 3, where 1 is less than 1. The images depict the mode shape contours for cross-ply hybrids that have been exposed to a variety of boundary conditions. The findings make it abundantly evident that the cross ply orientation provides a higher level of buckling resistance in comparison to the angle ply orientation. It is possible that this is due to edge restrictions, which result in a much higher degree of stiffness at the plate's edges in comparison to its middle region. Both the cross and angle ply hybrid orientations provide a visual pattern that is constant throughout in appearance. During the course of the research that was conducted to determine the impact of aspect ratio and boundary conditions on buckling load, it was discovered that the mode forms of CCCC, SSCC, and SSSS boundary conditions changed as the aspect ratio increased. All of the remaining boundary conditions that were taken into consideration for this research have mode forms that are similar. In order to study the impact that in-plane load has on the vibrational response of the hybrid FML, a dynamic technique was used. It is found that the natural frequency decreases noticeably as the compressive load increases, and it eventually becomes zero as the in-plane load gets closer and closer to the critical buckling threshold.

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