Effect of Material Anisotropy on Buckling Load Analysis of Symmetric Cross – Ply Laminated Composite Plate

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Abstract: **The finite element method is employed to assess the biaxial effects of in-plane compressive stresses on thin rectangular laminated composite plates. The classic laminated plate theory (CLPT) employed in this investigation fails to accommodate shear deformations. This hypothesis posits that each lamina demonstrates linear elasticity, with a comprehensive interconnection between layers, resulting in the laminate being subjected to plane strain. The classical laminated plate theory (CLPT) builds upon the classical plate theory (CPT) by positing that the mid-surface normal retains its straightness both prior to and following deformation. This theory is thus exclusively relevant to the examination of buckling phenomena in thin laminates. The Fortran programming language was created with this objective in mind. An analysis of the finite element solutions pertaining to the biaxial buckling of thin laminated rectangular plates, juxtaposed with diverse theoretical and experimental findings, serves as a means to evaluate the convergence and accuracy of the results obtained. Recent numerical findings have been generated concerning in-plane compressive biaxial buckling, aimed at examining the influences of the laminar arrangement, aspect ratio, material anisotropy, fiber orientation of layers, reversed laminar arrangement, and boundary conditions. The variation in buckling load is contingent upon the type of end support employed, exhibiting different rates of change across mode numbers. Moreover, it was demonstrated that an increase in the mode number necessitated additional support for the plate.**

Keywords: **Aspect ratio, Buckling load, Modulus ratio, Boundary Conditions.**

1. INTRODUCTION

The first focus of composite research was on their use as possible building materials around 75 years ago. Ever then, their impact has been felt across the board in the fields of theoretical analysis, manufacturing technology, and materials science. Almost anything may be meant by taking the word "composite" at face value. Under close inspection, every substance is composed of unique components that differ from one another. Allow me to explain. A more specific meaning is provided by the term's frequent usage in modern materials engineering to describe a matrix material reinforced with fibers. A matrix that uses thermosetting polyester and glass fibers is called "FRP," which stands for "Fibre Reinforced Plastic." At the moment, this specific composite is dominating the commercial sector.

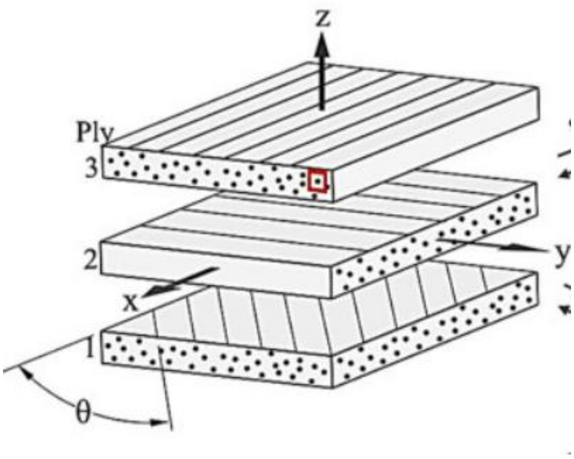

Fig. 1. Structure of a fibrous composite

Composites nowadays are often state-of-the-art products of cutting-edge materials research. These materials are ideal for spaceflight and other demanding applications due to their performance-to-cost ratio. However, for millions of years, nature has been making use of heterogeneous materials, which combine the best qualities of different components.

The book of Exodus demonstrates that bricks would be quite weak without the addition of straw, demonstrating how ancient societies mimicked nature in this way. Without straw, the structural integrity of bricks would not be as strong as it is in modern applications. The Meroe people of ancient Sudan used zibala, a mixture of mud and animal waste, as a powerful building material. This practice has not faded from modern times. Combining these materials with a matrix material enhances load transmission to the fibers while simultaneously providing wear resistance and environmental degradation avoidance. This is necessary since the individual fibers sometimes lack the necessary qualities to operate on their own. Although the matrix may reduce the intrinsic attributes of these materials to some extent, their weighted particular features are still quite high. Unsaturated styree-hardened polyesters are used in most low to medium performance settings, whereas more advanced thermosetting polymers or epoxy resins are used in the highest echelons of the market. Polymers have a wide range of applications. Thermoplastic matrix composites are intriguing materials, but their production complexity is their main drawback. These materials are often coupled with a matrix material since they do not possess the necessary characteristics to operate alone as fibers. The matrix protects the fibers from environmental degradation and wear while also distributing stress. These materials nevertheless have decent particular features when weight is taken into account, despite the fact that the matrix may somewhat reduce their natural attributes. A wide variety of sectors make extensive use of polymers. At the low to medium performance levels, unsaturated styrene-hardened polyesters are the norm, while the high-end market is defined by epoxy and other advanced thermosetting polymers. One major drawback of the intriguing thermoplastic matrix composites is how complicated they are to produce.

2. LITERATURE REVIEW

Flexible deformation from cross-section rotation and shear deformation from section or layer sliding create plate deformation under transverse and/or plane pressure in solid mechanics. The thickness-to-length ratio and elastic-shear moduli dictate ultimate deformation. Shear deformation dominates a plate with a high thickness-to-length ratio, whereas flexure or bending deformation dominates a thin plate. Under equal stress circumstances, composite laminates have a larger in-plane modulus to transverse shear modulus ratio than isotropic plates, making shear deformation effects more noticeable. Reddy says three-dimensional laminate theories, which regard each layer as homogenous anisotropic media, are impracticable. Laminated composite systems' extension, bending, and shear deformation modes are typically compounded by anisotropy, resulting in a broad variety of reactions under different loading circumstances. With certain exceptions, complexity, processing needs, and unnecessary data, especially for composite structures, make three-dimensional problem solving challenging. Mindlin's analysis shows that several theories help explain normal stresses and transverse shear processes. Due to their quantity, a full discussion is impossible. We shall examine a few fundamental works to illustrate the issue. Individual layer laminate theories see each layer as a separate plate. Because displacement fields and equilibrium equations are created for each layer, neighboring layers must align at each contact point using proper displacement and stress interfacial conditions. According to ESL laminate theories, the thickness coordinate defines the stress or displacement field and a linear combination of unknown functions. In nth-order shear deformation theory, in-plane displacements are increased to the nth power with regard to the thickness coordinate. Classical laminated plate theory allows exploration of ESL laminated structures. This idea implies that homogeneous thin plates' length-to-thickness ratio ($a/h > 20$) is important. The first theoretical framework for studying laminated plates was classical laminated plate theory (CLPT), an extension of CPT designed for laminated structures. Kirchhoff and Love's key idea—lines normal to the mid-surface before deformation stay straight and normal after deformation—was advanced by Reissner and Stavsky in 1961. It fails flexural testing of thick laminates. As Srinivas and Rao and Reissner and Stavsky have demonstrated, it produces exact results for a broad range of engineering problems when used with thin composite plates. This theory treats a laminate as a single equivalent layer, ignoring transverse shear stress. Transverse shear strain is ignored in the typical laminated plate theory (CLPT), which Turvey, Osman, and Reddy showed understates deflections. Deflection errors become more obvious when plates made of advanced filamentary composite materials like graphite-epoxy and boron-epoxy have elastic modulus to shear modulus ratios much higher than 2.6 for typical isotropic plates.

3. CONVERGENCE STUDY

Determining the optimal quantity of plate components in all directions—specifically, mesh size or discretization—necessary for precisely calculating buckling loads to an acceptable degree of accuracy can be achieved through a convergence evaluation. The determination of the appropriate number of finite elements is influenced by several considerations, including the properties of the material, the dimensions of the plate, the arrangement of the laminations, the boundary conditions, and the available random access memory (RAM) of the computing system. As the mode order ascends to a higher echelon, it becomes increasingly clear that a greater number of finite components is necessitated. Consequently, one might deduce that the elevated modes would necessitate a larger quantity of components. ANSYS offers an extensive array of engineering simulation solutions that address a wide range of technical challenges. These solutions are meticulously crafted to enhance the design process. This software is employed by a considerable array of enterprises functioning across diverse sectors. ANSYS endeavors to replicate and enhance a diverse array of design challenges through the application of the Finite Element Method (FEM), complemented by various programming methodologies.

Table 1. Convergence study of non – dimensional modes of buckling of simply supported (SS) isotropic square plate with a/h=20.

Mesh Size	Mode Sequence Number						
	1	2	3	4	5	6	7
2×2	30.69	76.89	83.18	83.49	94.71	94.95	101.78
3×3	32.64	79.12	79.18	117.58	179.04	189.78	191.05
4×4	33.60	82.38	82.44	123.22	165.70	166.35	192.53
5×5	34.10	84.08	84.14	127.71	168.69	168.92	202.10
6×6	34.39	85.10	85.15	130.85	170.41	170.52	208.35
7×7	34.58	85.75	85.79	133.03	171.55	171.61	212.50
8×8	34.70	86.19	86.23	134.57	172.34	172.39	215.79
9×9	34.78	86.50	86.53	135.68	172.92	172.97	218.07
10×10	34.84	86.72	86.75	136.52	173.35	173.40	219.78

4. RESULTS AND DISCUSSION

In light of the confidence garnered through various verification activities associated with the finite element (FE) software, a determination was reached to undertake targeted research scenarios aimed at yielding novel insights into biaxially loaded laminated composite rectangular plates. The plates were presumed to demonstrate clamped (CC), simply supported (SS), or a hybrid of clamped and simply supported characteristics (CS) along each of the four edges. The investigation and resolution of critical buckling stresses in laminated composite plates are conducted through an energy approach and a finite element model. We analyze a rectangular segment of a plate featuring four nodes in connection with this concept. Each individual component at every node possesses three distinct degrees of freedom.

Researchers are currently examining the influence of various factors on the non-dimensional critical buckling stresses of laminated composite plates. The components include laminar scheme, aspect ratio, material anisotropy, layer fiber orientation, reversed laminar scheme, and boundary conditions.

Table 2. The first three non – dimensional buckling loads

E_1/E_2	Mode Number	Boundary Conditions		
		SS	CC	CS
5	1	0.6972	2.1994	1.8225
	2	1.2552	2.5842	2.0097
	3	2.4284	4.1609	2.7116
10	1	0.5505	1.8548	1.3928
	2	0.8557	1.8951	1.8292
	3	1.6532	2.9814	1.9089
15	1	0.5019	1.6663	1.2505
	2	0.7232	1.7248	1.6428
	3	1.3966	2.6049	1.7694
20	1	0.4775	1.5515	1.1791
	2	0.6569	1.6524	1.5096
	3	1.2683	2.4228	1.7394
25	1	0.4629	1.4828	1.1365
	2	0.6172	1.6055	1.4299
	3	1.1916	2.3171	1.7214
30	1	0.4531	1.4366	1.1078
	2	0.5907	1.5723	1.3766
	3	1.1402	2.2481	1.7094
35	1	0.4462	1.4044	1.0877
	2	0.5723	1.5479	1.3391
	3	1.1043	2.2006	1.7009
40	1	0.4409	1.3795	1.0723
	2	0.5580	1.5286	1.3105
	3	1.0763	2.1648	1.6946

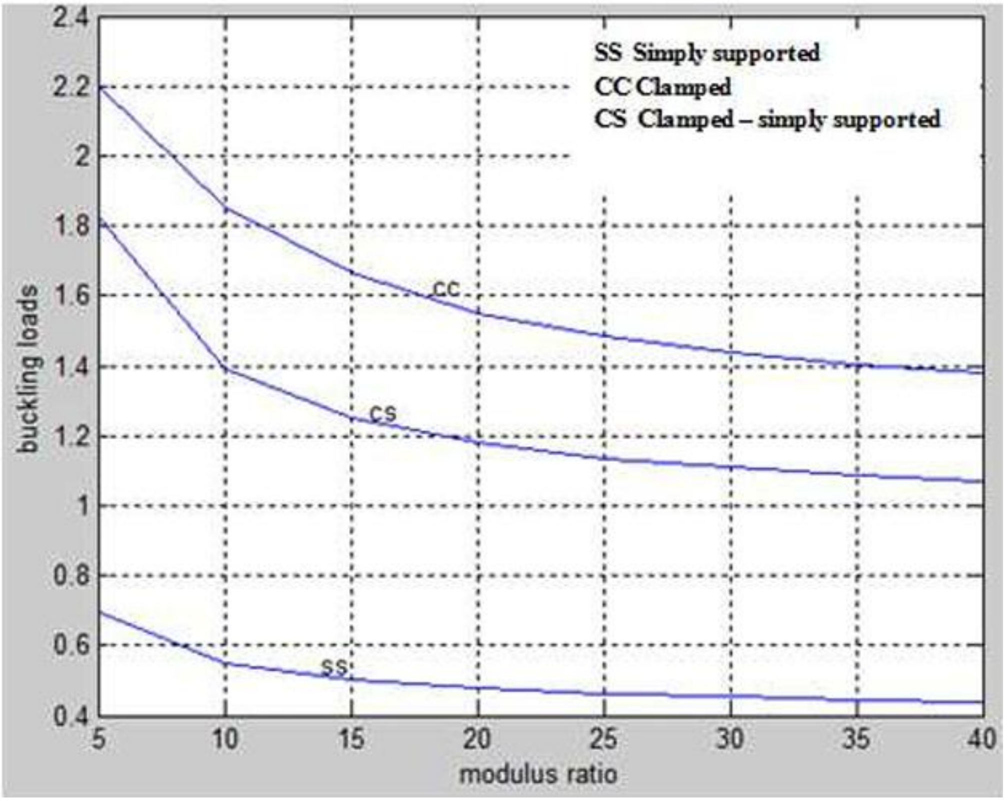

Fig. 2 Effect of material anisotropy

The buckling loads as a function of modulus ratio of symmetric cross – ply plates (0/ 90/ 90/ 0) are illustrated in table 2 and Fig. 2. As confirmed by other investigators, the buckling load decreases with increase in modulus ratio. Therefore, the coupling effect on buckling loads is more pronounced with the increasing degree of anisotropy. It is observed that the variation of buckling load becomes almost constant for higher values of elastic modulus ratio.

5. CONCLUSION

A software named Fortran, using finite element techniques, was created to investigate buckling in thin rectangular laminated plates according to classical laminated plate theory (CLPT). Experts have explored the buckling stresses that may occur in layered composite plates. A finite element model and an energy strategy are used to examine and resolve the problem. This four-node configuration utilizes quadrilateral elements. Each component at each node may have three potential orientations. The stress resulting from buckling was assessed using the finite element model. This study examined the non-dimensional critical buckling stresses of rectangular laminated composite plates and the influence of several parameters such as aspect ratios, material anisotropy, fiber orientation of layers, boundary conditions, and the reversal of lamination schemes on these stresses. The audience was apprised of recent findings. The buckling stress is increased by the aspect ratio, however this increase is not uniform. The critical load may increase due to the rigidity in bending and torsion. The buckling resistance of a plate depends on its boundary conditions. These phenomena may be explained by the notion that limitations diminish structural rigidity. The buckling load rises with the mode number, but the rate of increase differs depending on whether the plate is clamped (CC), simply supported (SS), or both. The rates of load increase are not uniform across all mode numbers. The buckling load is minimized while the plate is supported and maximized when it is clamped. Under clamped boundary circumstances, the buckling load exceeds that of simply supported boundary conditions. This is attributable to the more rigorous clamped border condition. The support needs of the plate increase in direct correlation with the mode number.

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