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# Effect of shear load direction in the critical buckling of anisotropic composite laminates under combined in plane loading

**Muthana Sh. Al-Saymaree [1, 2], David Kennedy [1] and Carol Featherston [1]**

[1]Cardiff School of Engineering, Queen's Buildings, The Parade, Cardiff CF24 3AA, United Kingdom
[2]Basrah University, Basrah, Iraq
Al-SaymareeMS@cardiff.ac.uk

**ABSTRACT**

This paper studies the buckling behaviour of anisotropic composite laminates under combined in-plane compression and shear loading using the exact strip analysis software VICONOPT to calculate the critical buckling load of a range of plates. Changes in critical buckling load are studied for both flat and stiffened composite plates and the results presented in the form of interaction curves. Different lay-ups are studied to illustrate the effect of different combinations of anisotropy and shear load direction on the critical load factor. Results are validated using the finite element software ABAQUS/Standard.

***Key words:*** *Buckling, Anisotropic, Laminates, Combined loading, VICONOPT*

## 1. INTRODUCTION

Composite plates and panels are used in aerospace, marine structures, bridges and other structural applications, where they offer mass reductions over conventional materials, fulfilling a key commercial objective. When used for example in aircraft fuselage and wings, these structures are subject to in-plane compression, shear or a combination of both making them sensitive to buckling failure. The buckling of composite plates under combined loading can be described by buckling interaction curves. Many theoretical and experimental studies have investigated this buckling failure. Stowell and Schwartz [1] studied the behaviour of an infinitely flat plate under combined shear and direct stress, whilst Selyugin [2] studied flexural anisotropic plates under combined loading using a special Galerkin-type solution and compared it with a high accuracy numerical solution, for cases of combined in plane compression, shear and in plane bending.

In the case of an anisotropic composite laminate under pure compression the nodal lines (i.e. lines of zero out of plane displacement) are skewed. In the presence of shear loading the skewing of these nodal lines can be increased or decreased according to the shear load direction, with consequent decreases or increases in the critical buckling load. This study explores this effect using the exact strip analysis software VICONOPT [3] which has the capacity to carry out buckling, post buckling and vibration analysis and optimum design for prismatic composite plate assemblies to determine critical buckling loads for composite plates under different combinations of loads. Examples for flat plates and stiffened panels with different aspect ratios and stiffener sizes are studied, with results validated using the finite element software ABAQUS/Standard [4]. Composites are designed to minimize panel mass subject to critical buckling constraints involving specified loading combinations.

## 2. CASE STUDY

Results are first presented for two rectangular composite flat plates under combined in plane compression ($N_x$) and shear ($N_{xy}$). The plates are made of T300-carbon/5208 epoxy tape material, of thickness 0.125 mm with Young's moduli $E_1$=181 GPa, $E_2$= 10.3 GPa, shear modulus $G_{12}$=7.17 GPa and Poisson's ratio $\nu_{12}$= 0.28. Plates 1 and 2 have the symmetric layups $[45,-45, 45, 90, 45,-45, 45, 0]_s$ and $[45, 45, -45, -45, 45, 45, -45, -45]_s$, respectively. Both plates have length a, width b=500 mm and total thickness 2 mm. Results are then presented for two stiffened panels made from the same material, each of length a and width b=400mm, and having four blade stiffeners of height 25mm, 100mm from each other and 50mm from the panel edges. In both panels the skin has the symmetric layup $[45, -45, 0, 90]_s$. The stiffeners also have this layup in panel 1, while in panel 2 they have the thicker layup $[45, -45, 0, 90, 45, -45]_s$. Each of the plates and panels has simply supported edges.

The results for flat plates and stiffened panels are denoted by FL i-j and ST i-j, respectively, where i (=1,2) indicates the different layups defined in this paragraph, and j (=1,2,3) indicates one of three aspect ratios considered: (1) a/b=1, (2) a/b=1.5, (3) a/b=2.

## 3. SOFTWARE USED

VICONOPT [3] incorporates the earlier programs VIPASA [5] and VICON [6]. VIPASA analysis uses exact flat plate theory and an algorithm that guarantees convergence on critical buckling loads or natural frequencies [7]. The buckling and vibration modes are assumed to vary sinusoidally in the longitudinal direction. However, when shear or anisotropy is present the nodal lines are skewed and the solution becomes excessively conservative because it cannot satisfy simply supported end conditions [5]. VICON analysis overcomes this limitation by coupling VIPASA responses using Lagrangian multipliers to satisfy point constraints representing the required end conditions. VICON and VIPASA results are compared with finite element results from ABAQUS/Standard 6.12 software. The flat plates and panels with aspect ratio a/b=1 were modelled, respectively, using 400 and 1280 shell elements of type S4R5 [2].

## 5. DISCUSSION OF NUMERICAL RESULTS

Fig. 1 shows interaction curves for plate FL 2-3. The VICON results show that under pure compression the buckling load $N_x$ is 9.64 kN/m, which increases to 9.99 (10.00) kN/m when accompanied by a positive shear load $N_{xy}$ of 2.00 (4.00) kN/m. These increases occur because of the anti-clockwise skewing of the mode due to anisotropy is negated by the clockwise skewing due to the shear load, so that eventually the nodal lines become normal to the longitudinal edges of the plate and then skew in the opposite direction. It can be seen that there is good agreement between the critical buckling loads obtained by VICONOPT and ABAQUS, and it was noted that there is also good agreement between the mode shapes with the ABAQUS results showing the same pattern. Both programs show that the composite laminate can carry greater loads when the shear load acts to reduce the skewing which then reduce as the skewing occurs in the other direction. Shear loading in the same direction of the skewing also cause a reduction in buckling load

The results for stiffened panel ST 1-1 are shown in Fig. 2. Although the buckling mode is different from that of the flat plates, the same effect is observed. The VICON compressive buckling load $N_x$ increases from 33.5 kN/m to 34.3 (34.4) kN/m when accompanied by a positive shear load $N_{xy}$ of 4.29 (8.60) kN/m, and similar results were obtained using ABAQUS.

Figs. 3 and 4 summarise the interactions for all the plates and panels. In all cases the addition of a small positive shear load (which in this case acts to reduce the skewing) increases the compressive buckling load. Buckling load factors under combined compression and positive shear exceed those under combined compression and negative shear by 2%-8% for flat plates and by 3%-12% for stiffened panels. Fig. 5 illustrates that the maximum compression can be carried when there is no skewing in the buckling mode.

## 6. CONCLUSIONS

- The critical compressive buckling load increases slightly and then decreases for both flat composite plates and stiffened composite panels when the skewing of the buckling mode due to an applied shear load acts in the opposite direction to the skewing due to anisotropy.
- Conversely the compressive buckling load decreases significantly when the shear and anisotropy effects act in the same direction to increase the skew in the buckling mode.
- Critical buckling loads under combined compression and positive shear are significantly higher than those under combined compression and negative shear.
- The increment in critical buckling load depends on the layup of the composite laminate, whose anisotropy can be optimised to carry a particular combination of compression and shear.

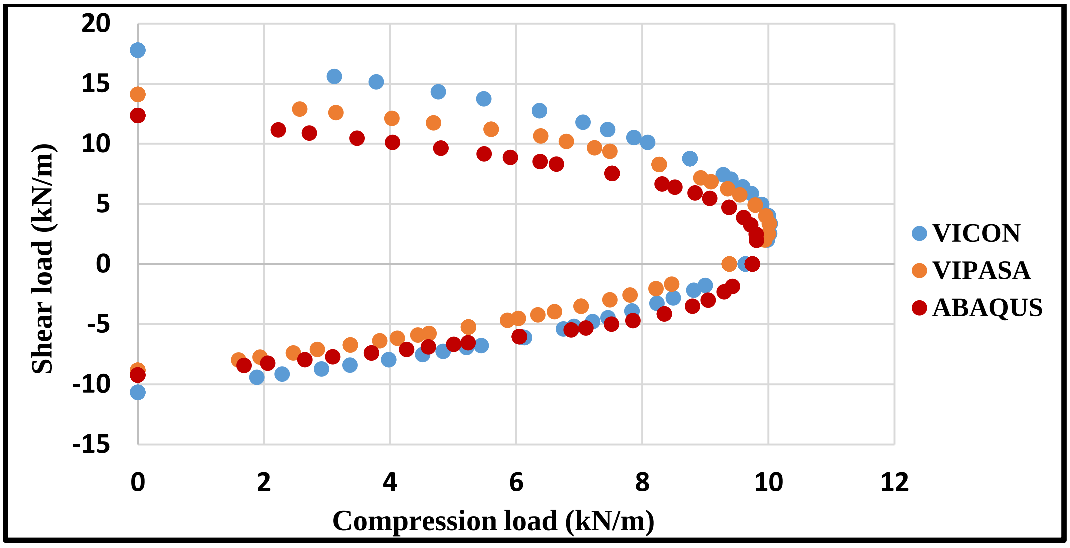



Fig. 1. Interaction curve for flat plate FL 2-3.

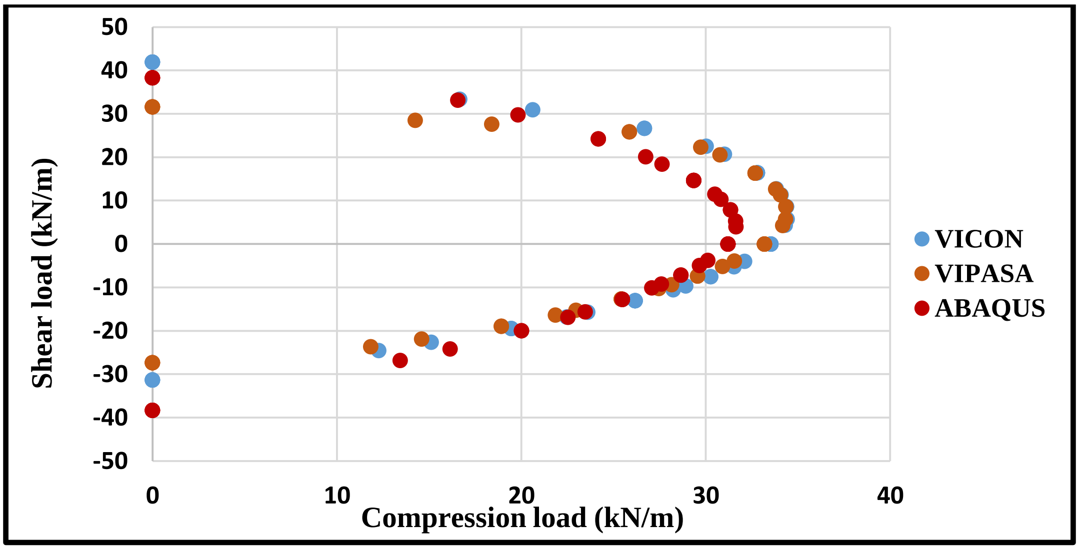



Fig. 2. Interaction curve for stiffened panel ST 1-1.

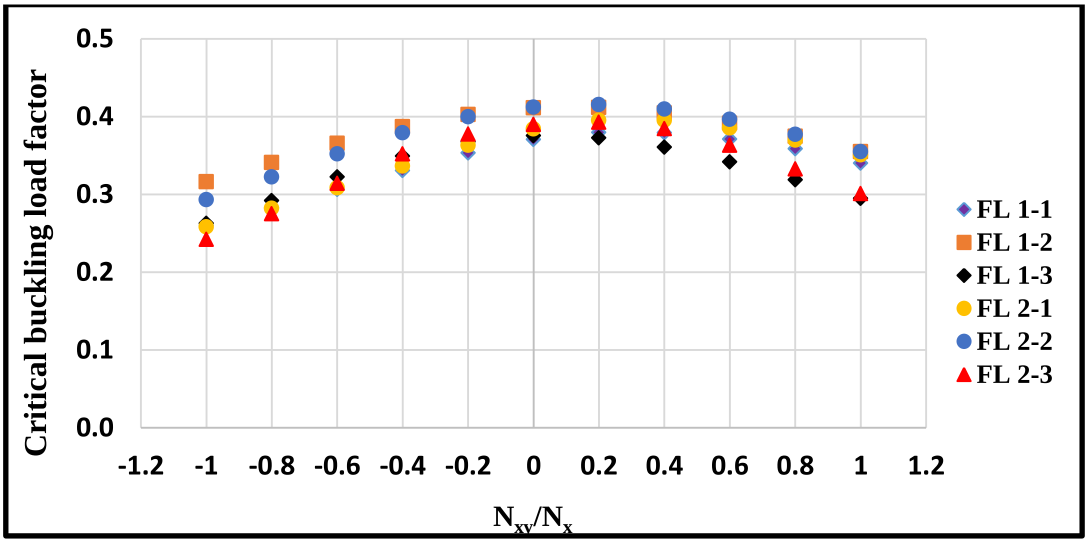



Fig. 3. Variation of ABAQUS buckling load factor with interaction ratio for all flat plates.

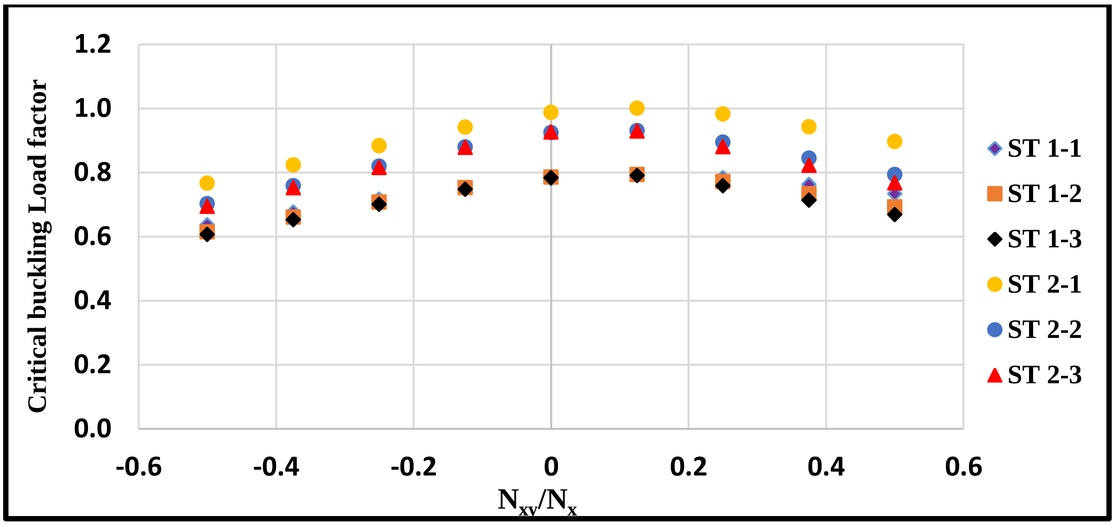
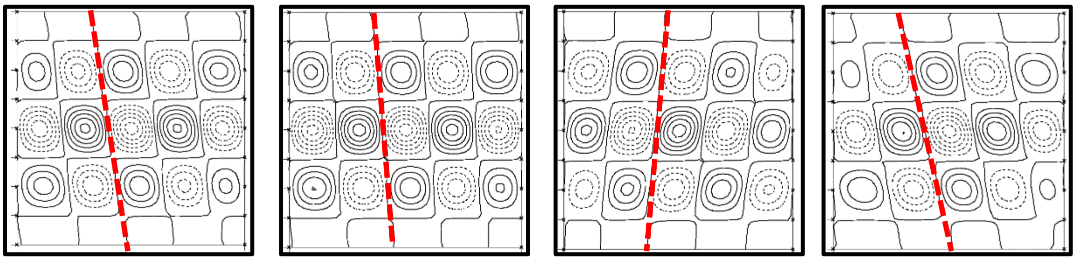



Fig. 4. Variation of ABAQUS buckling load factor with interaction ratio for all stiffened panels.



(a) $N_{xy}/N_x = 0$ (b) $N_{xy}/N_x = 0.125$ (c) $N_{xy}/N_x = 0.375$ (d) $N_{xy}/N_x = -0.125$

Fig. 5. VICON mode shapes of stiffened panel ST 2-1 for four different interaction ratios.

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