The effect of transverse shear on the face sheets failure modes of sandwich beams loaded in three points bending

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Abstract

Sandwich beams loaded in three points bending may fail in several ways including tension or compression failure of facings. In this paper , The effect of the transverse shear on the face yielding and face wrinkling failure modes of sandwich beams loaded in three points bending have been studied, the beams were made of various composites materials carbon/epoxy, kevlar/epoxy, glass/epoxy at sequence $[+\theta/-\theta]_{3s,}$ $[0°/90°]_{3s.}$. The stresses in the face were calculated using maximum stress criterion and the simple beam theory. The obtained different results show that the sandwich beams with carbon/epoxy, and glass/epoxy face sheets are the best materials, in return the kevlar /epoxy facing characterised by low resistance of transverse shear in compression and tensile.

Keywords: Beam theory, Maximum stress criterion, Transverse shear, face wrinkling, face yielding.

1. Introduction

Sandwich composites consist of two thin face sheets with high stiffness and high strength and a core with low density and low stiffness.. Sandwich structures exhibit complex failure mechanisms including face sheet compressive, failure adhesive, bond failure , indentation failure , core failure and facing wrinkling. A large number of theoretical and experimental investigations on sandwich structures have been published in the literature, core failure by shear studied by Allen [1], Hall and Robson [2] and Zenkert [3].Triantafillou [4] studied failure modes of sandwich beams with aluminum face sheets and a rigid polyurethane foam core. Failure maps for various core densities and span to depth ratios were constructed for face yielding, face wrinkling ,core yield in shear , and core yield in tension and compression. Niu and Tareja [5] presented a model for the analysis of wrinkling behavior of sandwich panels in compression. They gave a single expression for the wrinkling stress for the single sided face wrinkling stress for the single sided face wrinkling , and the in phase and out phase wrinkling .They showed that the wrinkling stress in all three cases in almost the same for short wave length wrinkling. El sayed and Sridharan [6] used finite element analysis to examine the compressive behavior of sandwich columns with a variety of imperfections .Kim and Dharam [7] focused on buckling of the debonded face sheet and extended the delamination buckling model of Vizzini and Lagace [8] to debonded sandwich specimens.

2. Three points bending of sandwich beams

Consider a simply supported sandwich beam loaded in three points bending. Let $l = 180$ mm be the beam length between the supports, $b = 50$ mm the width of the beam, $h = 10$ mm the core thickness, and $t = 6$ mm the face thickness. The mechanical characteristics of the skins composites materials are listed in the table I [9].

Table 1 : Mechanical characteristics measured on various unidirectional fiber epoxy composite

Mechanical characteristics	Glass E/epoxy	Carbon HR /epoxy	Kevlar 49/epoxy
Fiber volume fraction V_f	0.6	0.6	0.6
Longitudinal young's modulus E_l **(Gpa)**	46	159	84
Transverse young's modulus E_t **(Gpa)**	10	14.3	5.6
Longitudinal shear modulus G_{lt} **(Gpa)**	4.6	4.8	2.1
Poisson ratio ν_{lt}	0.31	0.32	0.34
The tensile strength in longitudinal direction X_t **(Mpa)**	1400	1380	1400
The compressive strength in longitudinal direction X_c **(Mpa)**	910	1430	280
The tensile strength in the transverse direction Y_t **(Mpa)**	35	40	15
The compressive strength in the transverse direction Y_c **(Mpa)**	110	240	50
The in plan shear strength of the layer S **(Mpa)**	70	70	35

We consider the symmetric sandwich beams with two identical skins with orthotropy directions parallel to the direction x and y . The normal stresses are given by relation :

$$\sigma_{xx}^{k} = \pm \frac{Ph}{4b} D_{11}^{*} \left(\overline{Q}\right)_{11}^{k} x \tag{1}$$

The stresses are maximum for x= l/2 and P is the total load applied at middle of beam
The transverse stress σ_{xz}^{k} can then be deduced from equilibrium equation.

$$\frac{\partial \sigma_{xx}^{k}}{\partial x} + \frac{\partial \sigma_{xz}^{k}}{\partial z} = 0 \tag{2}$$

σ_{xx}^{k} normal stress of the kth layer given by :

$$\sigma_{xz}^{k} = \pm \left(\overline{Q}\right)_{11}^{k} D_{11}^{*} \frac{Ph}{4b} \left(z + c_k\right) \tag{3}$$

The constants c_k are determined by setting σ_{xz}^{k} to zero on the upper and lower faces, and by ensuring the continuity of σ_{xz} from layer to layer.

And D_{ij} The bending stiffness , $D_{ij} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix}$ (4)

The inverse matrix of $\lfloor D_{ij} \rfloor$ given by $D_{11}^{*} = \frac{1}{\Delta}\left(D_{22} D_{66} - D_{26}^{2}\right)$ (5)

Δ is the determinant of the matrix $\lfloor D_{ij} \rfloor$, $D_{ij} = hC_{ij}^{2}$ (6)

C_{ij}^{2} the stiffness coefficients in the upper skins

$$C_{ij}^{2} = \sum_{k=1}^{n_2} \left(\overline{Q}_{ij}\right)_k e_k z_k \tag{7}$$

The reduced stiffness constant of unidirectional or orthotropic composite, off its material directions:

$$\overline{Q}_{11} = Q_{11}Cos^4\theta + Q_{22}Sin^4\theta + 2(Q_{12} + 2Q_{66})Sin^2\theta Cos^2\theta$$

$$\overline{Q}_{12} = (Q_{11} + Q_{22} - 4Q_{66})Sin^2\theta Cos^2\theta + Q_{12}\left(Sin^4\theta + Cos^4\theta\right)$$

$$\overline{Q}_{16} = (Q_{11} - Q_{12} - 2Q_{66})Sin\theta Cos^3\theta + (Q_{12} - Q_{22} + 2Q_{66})Sin^3\theta Cos\theta$$

$$\overline{Q}_{22} = Q_{11}Sin^4\theta + Q_{22}Cos^4\vartheta + 2(Q_{12} + 2Q_{66})Sin^2\theta Cos^2\theta$$

$$\overline{Q}_{26} = (Q_{11} - Q_{12} - 2Q_{66})Sin^3\theta Cos\theta + (Q_{12} - Q_{22} + 2Q_{66})Sin\theta Cos^3\theta$$

$$\overline{Q}_{66} = (Q_{11} + Q_{22} - 2(Q_{12} + Q_{66}))Sin^2\theta Cos^2\theta + Q_{66}\left(Sin^4\theta + Cos^4\theta\right) \quad (8)$$

The preceding relation allow us to express the reduced stiffness constants as functions of the engineering constants in the material directions we obtain:

$$Q_{11} = \frac{E_l}{1 - \nu_{lt}\nu_{tl}}, \quad Q_{22} = \frac{E_t}{E_l}Q_{11}, \quad Q_{12} = \nu_{lt}Q_{22}, \quad Q_{66} = G_{lt} \quad (9)$$

3. Failure modes of sandwich materials

A sandwich material must have the strength to carry the design loads without failing in one of the possible failure modes figure 1 [10].

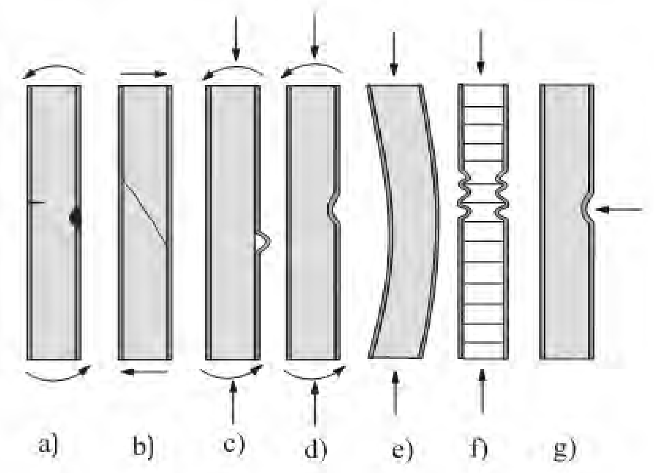


Fig.1. Some failure modes a) Face yielding /fracture , b) Core shear failure , c) and d) face wrinkling , e) general buckling , f) face dimpling , g) local indentation.

If the beam fails by face yielding, the normal stress in the face at the critical section σ_f equal the yield stress of that face σ_{yf} .

$$\sigma_y^f = \sigma_f = \sigma_{xx}^k \quad (10)$$

The compression face of a sandwich beam subject to bending is likely to fail by a particular kind of local instability described as wrinkling. The local buckling of wrinkling or face wrinkling occurs when the normal stress in the face reaches the local instability stress**.**

$$\sigma_w^f = \sigma_f = \sigma_{xx}^k \quad (11)$$

4. Results and discussion

In order to study the effect of transverse shear stress in the face sheets failure modes of sandwich beams loaded in three points bending , we considered the faces made of various composite laminates (glass/ epoxy, carbon/epoxy or kevlar /epoxy) of stacking sequence $[+\theta/-\theta]_{3s}$ and $[0°/90°]_{3s}$ with unidirectional fiber reinforced at 60 %.

4..1.The effect of transverse shear on face yielding and face wrinkling failure modes in sandwich beams with various face sheets materials oriented at $[0° /90°]_{3s}$

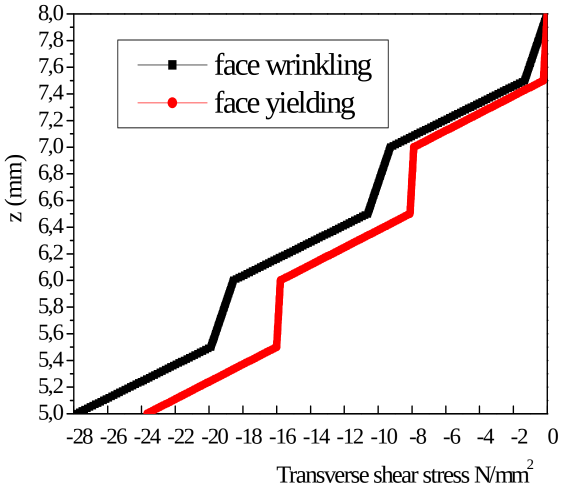


Fig.2. Variation of transverse shear stress through the thickness in sandwich beams with carbon/epoxy face sheets oriented at $[0°/90°]_{3s}$

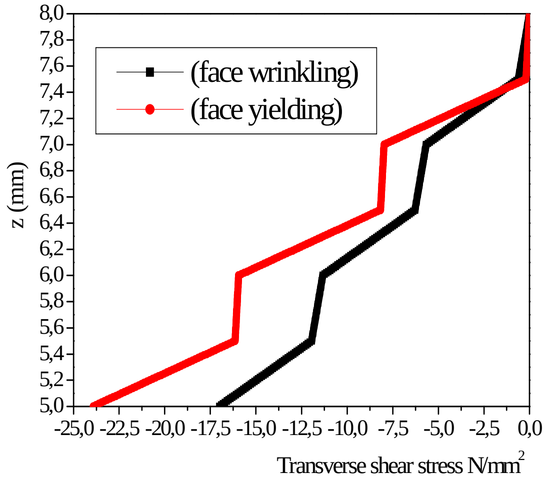


Fig .3. Variation of transverse shear stress through the thickness in sandwich beams with glass/epoxy face sheets oriented at $[0°/90°]_{3s}$

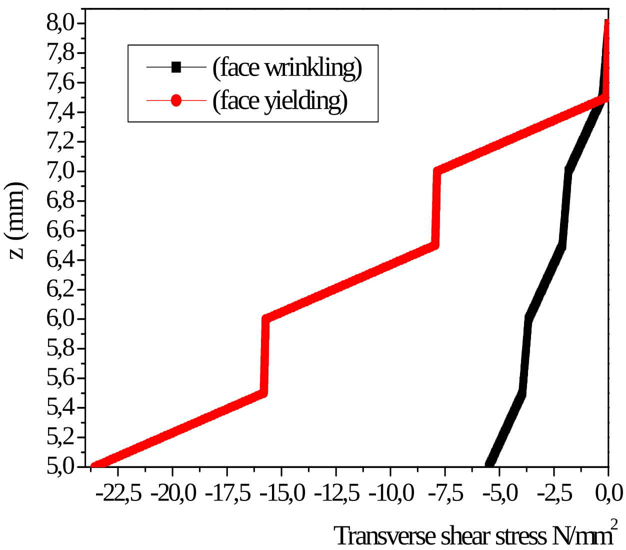
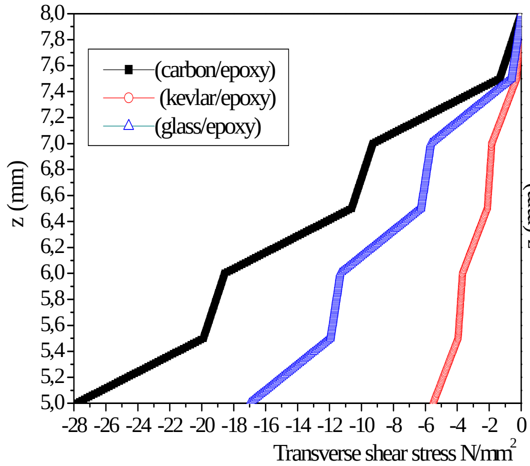


Fig.4.Variation of transverse shear stress through the thickness in sandwich beams with kevlar/epoxy face sheets oriented at $[0°/90°]_{3s}$

Figure 2 shows the variation of the transverse shear stress through the thickness of the higher skin of a sandwich beam with carbon/epoxy face sheets oriented at $[0°/90°]_{3s}$. We notices that the curves represent the six layers have a linear form and that the value of shear stresses is higher in the face wrinkling failure mode than

the face yielding, we can say that the sandwich beams with carbon/epoxy face sheets resist better the transverse shear stress in compression than in tensile.
Figures 3 and 4 show that the value of transverse shear stress is more significant in face yielding failure mode than the face wrinkling failure mode for the sandwich beams with glass/epoxy and kevlar/epoxy coatings when we approaches to the core, the value of the transverse shear stress become similar for the two failure modes .



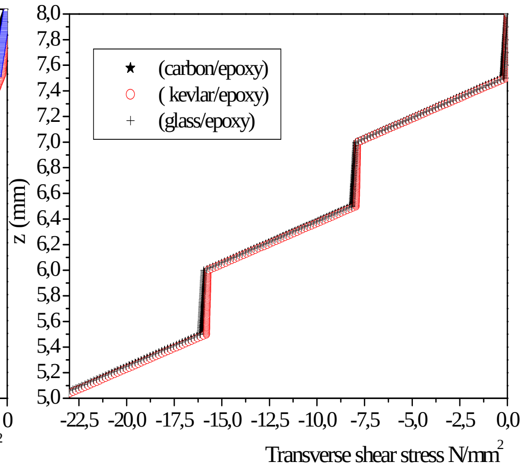


Fig. 5. Variation of transverse shear stress through the thickness with various face sheets materials oriented at $[0°/90°]_{3s}$ in face wrinkling failure mode

Fig. 6. Variation of transverse shear stress through the thickness with various face sheets materials oriented at $[0°/90°]_{3s}$ in face yielding failure mode

Figures 5 and 6 show the variation of the transverse shear stress through the thickness of sandwich beams with various face sheets materials. In the case of the face wrinkling failure mode ; figure 5 shows that the sandwich beams with coatings carbon/epoxy resist better the effect of transverse shear stress than glass / epoxy and the kevlar/epoxy is the least resistant material. Figure 6 shows that the value of transverse shear stress is almost similar for the three materials in face yielding failure mode.

4.2. The effect of transverse shear on failure modes in sandwich beams with various face sheets materials oriented at $[+\theta° /-\theta°]_{3s}$

The figure 7 shows that for small values of fiber orientation from 0° to 3° the transverse shear stress of sandwich beams with carbon/epoxy face sheet is very important in face wrinkling failure mode than in face yielding failure mode ,and when the fiber orientation are between 4° to 33° the transverse shear stress is similar for the two failure modes and from 34° to 90°, the carbon/epoxy is the best material in face wrinkling than in face yielding failure mode .

Figure 8 shows that for small values of the fiber orientation from 0° to 7° the value of transverse shear stress is very significant in face yielding than in face wrinkling failure mode , we notice that the sandwich beams resists the effect transverse shear in tensile than in compression. from 8° to 90° the transverse shear stress value is almost similar for the two failure modes.

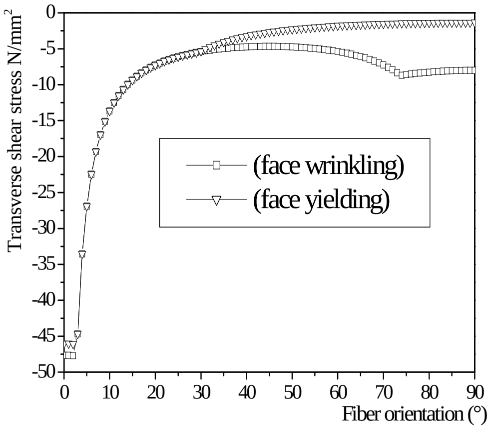


Fig .7. Transverse shear stress in sandwich beams at z=h/2 with carbon /epoxy face sheets in face wrinkling and face yielding failure modes

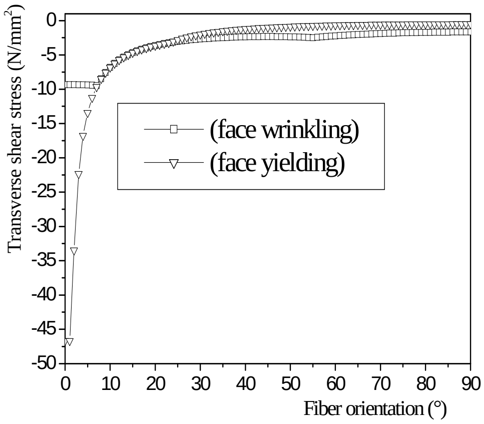


Fig .8. Transverse shear stress in sandwich beams at z=h/2 with kevlar /epoxy face sheets in face wrinkling and face yielding failure modes

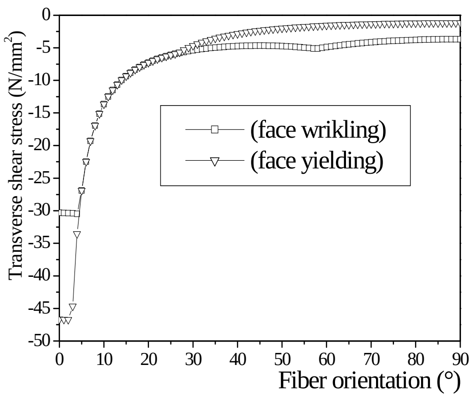


Fig .9. Transverse shear stress in sandwich beams at z=h/2 with glass /epoxy face sheets in face wrinkling and face yielding failure modes

Figure 9 shows that for small values of the fiber orientation sandwich beams with glass/epoxy face sheets resist better the effect of transverse shear in face yielding than in face wrinkling failure mode ,from 5° to 26 ° the value of the transverse shear stress is similar for the two failure modes . from 27° to 90° the sandwich beams resist better the effect of transverse shear in compression than in tensile.

From figure 10 we distinguishes three zones, the first relates to the angles between 0° and 4° the value of transverse shear stress is higher for the sandwich beam with carbon/epoxy than with glass/epoxy and the kevlar/epoxy coatings. From 5° to 58° the transverse shear stresses value is similar for the sandwich beams with carbon/epoxy and glass/epoxy face sheets . From 59 ° to 90° it is always the carbon/epoxy the best material and kevlar/epoxy the least resistant material in face wrinkling failure mode taking the effect the transverse shear.

From 0° to 57° figure 11 shows that the value of transverse shear stress is similar for the sandwich beams with glass/epoxy and carbon/epoxy face sheets , when the fiber orientation is between 58° and 90° the three materials have a similar resistance in face yielding failure mode taking the effect of transverse shear.

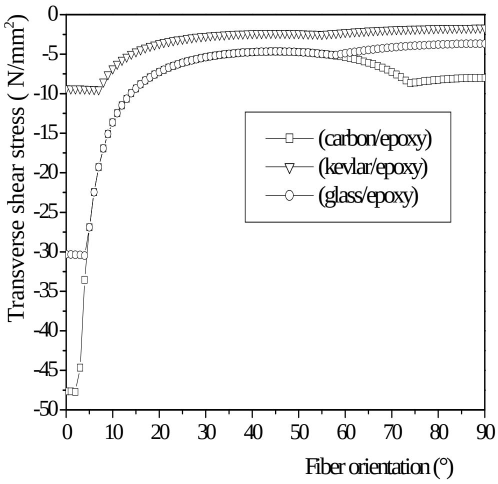


Fig. 10.Transverse shear stress in sandwich beams at z= h/2 with various face sheets materials in face wrinkling failure mode

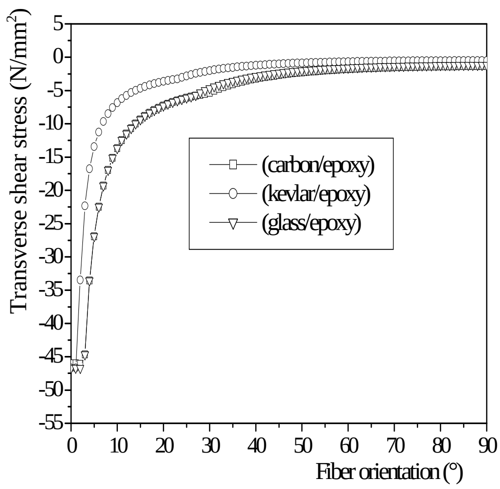


Fig. 11.Transverse shear stress in sandwich beams at z= h/2 with various face sheets materials in face yielding failure mode

5. Conclusion

Sandwich structures, constructed by bonding two stiff, thin-walled face sheets to a light weight , relatively flexible thick core, are widely used in various industrial applications demanding a high bending stiffness per unit weight. Sandwich beams are know to exhibit a number of possible failure modes, including failure of the core in shear, in compression and failure of faces. In this study , the face yielding and face wrinkling failure modes of sandwich beams loaded in three points bending have been studied. The beams were made of various composite materials carbon/epoxy , kevlar /epoxy, glass/epoxy at sequence $[+\theta/ -\theta]_{3s}$, $[0°/90°]_{3s.}$The effect of transverse shear on the facings failure modes has also been studied in this paper. Results shows that the face yielding and face wrinkling failure modes depend on the transverse shear, on the type of loading, constituent materials properties, and the fiber orientation of face sheet materials.

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