Finite Element Analysis of Fibre Composite Sandwich Panel

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ABSTRACT

This research work aims to understand the behaviour of fibre composite sandwich panel by using non-linear Finite Element (FE) method. The original FRP sandwich panel is associated with waste of materials usage related to its ability to resist the external load and stay in the working load serviceability. The experimental analysis was done by CEEFC in the University of Southern Queensland and it showed that the failure load is (5-10) times the working load recommended by EUROCOMP. The analysis of composite FRP panel using 3D solid Finite Element and shell element shows a relatively accurate simulation for the behaviour of the FRP panel compare to the experimental results. The Objective of this research is to verify the behaviour of FRP sandwich panel by using finite element methods. The numerical finite element model using traditional available ABAQUS software was developed to simulate the structural behaviour of FRP panel.

Keywords: design, FRP, composite, panel, finite element, sandwich.

1. INTRODUCTION

The fibre composite structure was used during the Second World War in radar equipments and aircraft industry (Kelly & Zweben 1999). The fibre composite material has been attracted by many industrial sectors due to its robust characteristics such as high strength and high stiffness to weight ratio. The sandwich panel consists of three main components: i) the upper part which called top skin, ii) the middle part which called core and iii) lower part which called bottom skin. The sandwich structures are used by engineers due to its ability to carry the high flexural load, less weight and good thermal insulation. In contrast, it has low fire resistance and it suffer from the buckling failure (Gay, Hoa & Tsai 2003). The main function of the top and bottom skin is to carry the normal stresses, while the core is used to connect the two faces and carries the shear force (Johannes et al. 2009). Sandwich panel is popular in the constructions of the bridges deck engineering. Roy et al (2005) started to develop a new sandwich bridge deck made from GFRP to replace the old timber deck. The replacement is due to the degradation of the timber by the time under the service and environmental effects. This deck was made of top and bottom layer of glass fibre with and corrugated web. The voids of the deck was filled with a structural foam (E=14.7 MPa). The experimental investigation of this type of sandwich structures was investigated by Manalo et al (2009) to find the bending behaviour of simply supported FRP sandwich panel. The behaviour of the sandwich panel with solid core is approximately linear up to failure. Reis and Rizkalla (2008) studied 3-D analysis of fibre composite sandwich panel under the effect of skin delamination. It was noticed that the shear stiffness decreased by the cracking of the core material.

However, standards specification and codes for FRP constructions in civil engineering is not available yet except for British standard code for the design of composite BS4994 (Bank 2006)and the EUROCOMP (Clarke 1996) design code. Civil engineers have started using sandwich panel in structural applications. Highway bridge deck represents one of the most well-known sandwich panel applications because it solves several problems related to the decking system (Davalos et al. 2009; O'Connor 2008). LOC Composites Pty Ltd has fabricated a new structural sandwich panel for the applications such as pedestrian bridges and railways sleepers (Erp & Rogers 2008). In addition, there are many applications for sandwich panels in the constructions of partitions, doors and furniture(Gay, Hoa & Tsai 2003).

This paper discusses the Finite element analysis (FEA) and the design of composite sandwich panel. The sandwich panel is made from ECR-Glass Fibre for the skin material and modified phenolic solid core as shown in Figure 1. This panel is produced by LOC Composites Pty Ltd. The mechanical properties of these materials are reliable enough to be used as a structural element. This paper tries to find the behaviour of composite panel to give a better numerical simulation under external load. It depends on the commercial FE software ABAQUS to analyse the structure.

2. ANALYSIS OF SANDWICH PANEL

The finite element simulation is made for the analysis of FRP composite sandwich panel by using ABAQUS commercial software. The behaviour of the FRP sandwich panel is complex in the numerical simulation. The behaviour of core material is non-linear in compression and approximately linear in tension as shown in Figure 2, where as the behaviour of GFRP skin is almost linear in compression and tension. The first part of both tension and compression behaviour curve was found by the experimental work, while the softening part is assumed for the analysis to get a solution convergence. The behaviour of the elastic skin is assumed linear up to failure at a stress of 336 MPa. The materials specification is shown in Table 1.

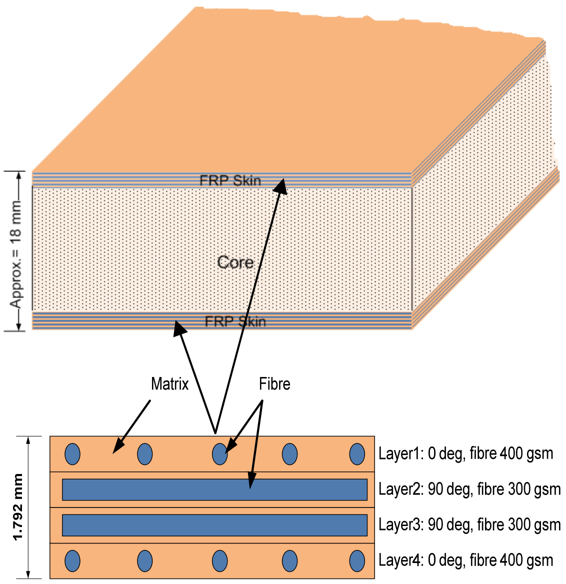


Figure 1 FRP sandwich Panel

The top and bottom skin is formulated by using shell element type S8R (8- node doubly curved shell element). On the other hand, the core is meshed by using 3D solid element type C3D20R. The total number of the elements for half of the panel is 2400 elements. The interaction is assumed to be full between skin and core. The reason behind using plan stress element is to get benefit from the Hashin elastic failure model, which it is available in the ABAQUS software.

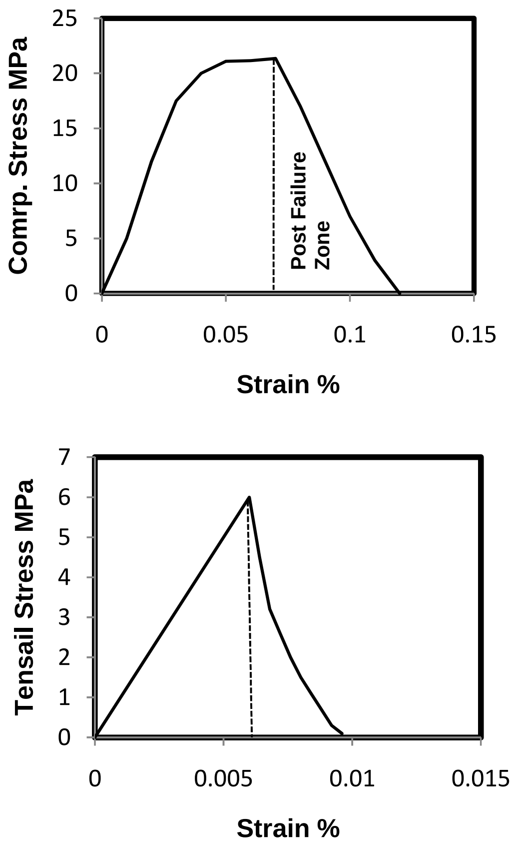


Figure 2 Uni-Axial Stress-Strain for Core Materile

	Density Kg/m^3	Elastic MPa	Poisson Ratio	Ultimate Tensile strain%	Tensile strength MPa
FRP Skin	1800	24,000	0.25	0.018	336
Core	850	1,000	0.20	0.006	6.2

Table 1 Materials Properties

The damage of FRP materials is considered and it depends on Hashin failure theory. Hashin theory considers four failure types: fibre tension, fibre compression, matrix tension and matrix compression. The damage initiation criteria (*F*) in the four cases are:

Fibre in tension:

$$F_f^t = \left(\frac{\sigma_{11}}{X^L}\right)^2 + \alpha\left(\frac{\tau_{12}}{S^L}\right)^2 \quad (1)$$

Fibre in compression:

$$F_f^t = \left(\frac{\sigma_{11}}{X^L}\right)^2 \quad (2)$$

Matrix in tension:

$$F_f^t = \left(\frac{\sigma_{22}}{Y^L}\right)^2 + \left(\frac{\tau_{12}}{S^L}\right)^2 \quad (3)$$

Matrix in compression:

$$F_f^t = \left(\frac{\sigma_{22}}{Y^L}\right)^2 + \left[\left(\frac{Y^C}{2S^T}\right)^2 - 1\right]\frac{\sigma_{22}}{Y^L} + \left(\frac{\tau_{12}}{S^L}\right)^2 \quad (4)$$

Where X^T and X^C are tension and compression strength in longitudinal direction. Y^T and Y^C are tension and compression strength in transverse direction. S^L and S^T shear in longitudinal and transverse directions. $\boldsymbol{\alpha}$ is a factor represents shear contribution in the tensile fibre initiation (0 or 1.0). σ_{11}, σ_{22} and τ_{12} stress components (Abaqus 2008; Hashin & Rotem 1973). Core material is considered relatively same as concrete behaviour. So, the plasticity concrete model was used to simulate the non linear behaviour of the core. The plasticity model is more qualified to model concrete and any quasi-brittle materials (Abaqus 2008). Two types of sandwich panel were tested numerically.

2.1 Flat Wise Panel Main Direction

This simulation is made in a form of the main fibre direction along the longitudinal X-axis of the panel as shown in figure 3. Only half of the panel is simulated due to the symmetry. The load deflection curve is shown in figure 4 and it can be noticed that the behaviour of the panel is approximately linear up to the failure. It is realized from the analysis that the first failure in the top layer of the top skin under compression. Hashin failure model for the composite laminate structure is used to predict the failure of FRP skin. The failure happens in the top skin first. The stress analysis of four layered top skin shows that the most of stresses carry by the 0^o plies compared to the 90^o plies which were shown in Figure 5. The failure of the 0^o plies was noticed under the load. The failure of matrix in 90^o plies was noticed also in top and bottom skins. On the other hand, bottom skin stress with 0^o ply carries 80% of the ultimate tensile strength. Some cracks were developed through the bottom face of the core. The service load value for the deflection limit of (span/400) is 380N and the allowable load for the deflection limit of (span/150) is 1000N. These correspond to 0.75 mm and 2.0 mm respectively.

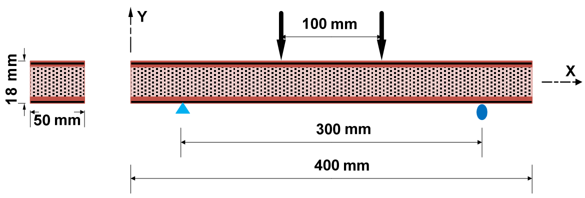


Figure 3 The FRP panel dimensions

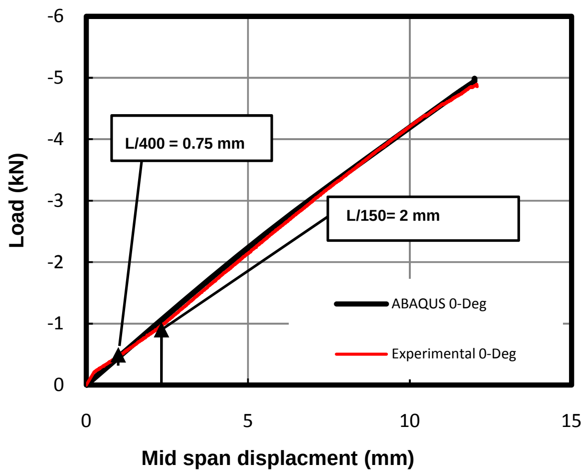


Figure 4 Load deflection curve of FRP panel

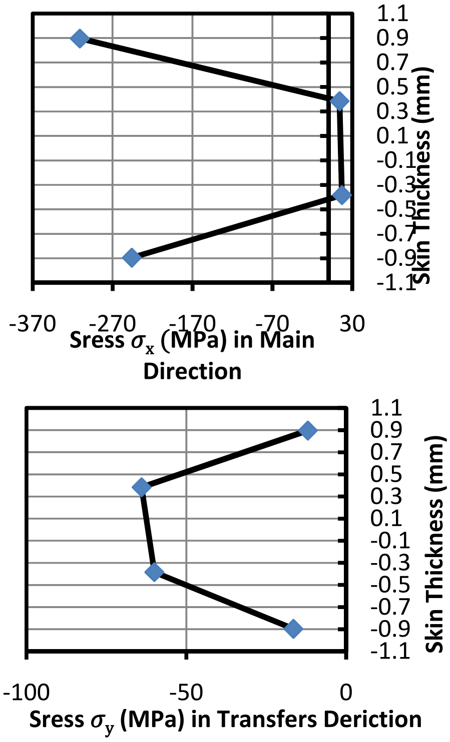


Figure 5 Thickness Stresses of Top Skin.

The hand calculation of sandwich panel is also applicable. So, engineers could use hand calculation to check the deflection under service external load. The estimated deflection is classified into (Huang & Gibson 1990):

Flexural deflection = $\delta_f = \frac{PL^3}{48(EI)_{eq}}$ 5

Where, P=load; L=span and $(EI)_{eq}$= equivalent for skin and core.

The other part of the deflection is the shear deflection and it is assumed to happen by the core:

Shear deflection = $\delta_s = \frac{PL}{4AG}$ 6

Where, A= area of core cross section and G= core shear modulus (Gay, Hoa & Tsai 2003).

Calculation:

$$EI_{eq} = 2\left(\frac{b.h^3}{12} + A.d^2\right)_{Skin} . E_{Skin} + \left(\frac{b.h_c^3}{12}\right)_{Core} . E_{Core}$$ 7

Where, b,h and h_c are the width of sandwich panel, thickness of skin and thickness of the core respectively. The values are: b=50mm, h=1.792 mm and h_c=14.42. The load value is 1000N and span=300 mm.

The estimated deflection=$\delta_f + \delta_s$= 1.89 + 0.111=2.001 mm

This value is approximately the same values of FE analysis and experimental test.

2.2 Flat-Wise 90-Degree

The 90-degree flat wise panel test is made to know the effect of different configuration of fibre on the behaviour of the FRP panel. The same boundary conditions were used and the same load conditions as shown in Figure 3. It shows that the elastic modulus of total panel becomes less due to decreasing the amount of the fibre in the 90^o direction. The load deflection curve is shown in Figure 6. The analysis results show that the main layers in the top skin (mid skin layers 2 and 3) have un-failed fibre as shown in Figure 7/a, while the top layer is failed by matrix failure in compression as shown in Figure 7/b. On the other hand, the bottom skin has a fibre failure as shown in Figure 8, which is different to the 0^0 test. The core material has yield points with cracks in the bottom face, while the uncracked section is about 1/2 of the core thickness as shown from the stress contour in Figure 9.

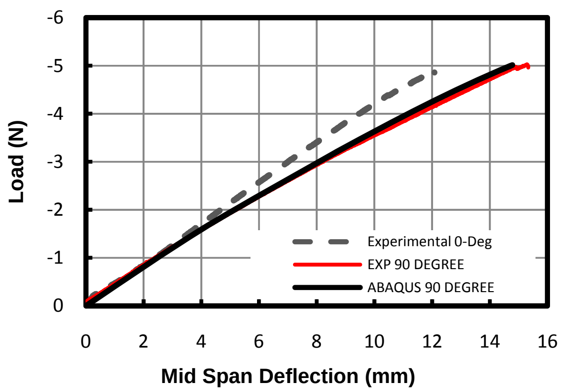
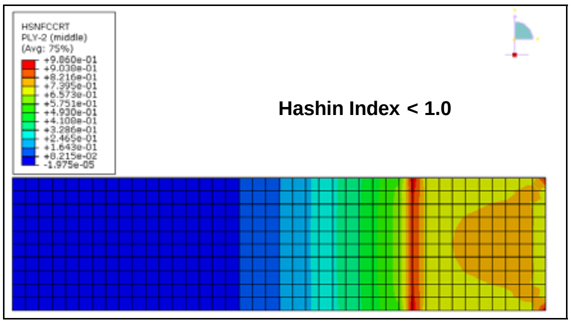
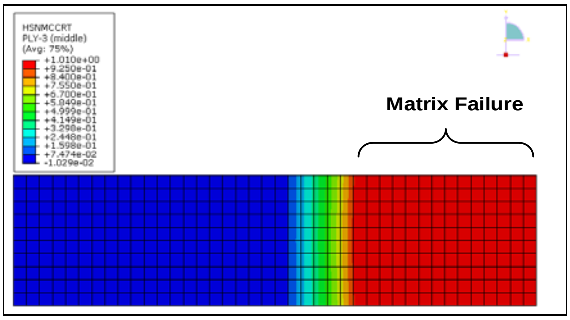


Figure 6 Load Deflection Curve for 90^0 Sandwich Panel



(a) Mid Layer Hashin Failure Index in Fibre



(b) Top layer Hashin failure Index in matrix

Figure 7 Hashin Failure Index of Top Skin

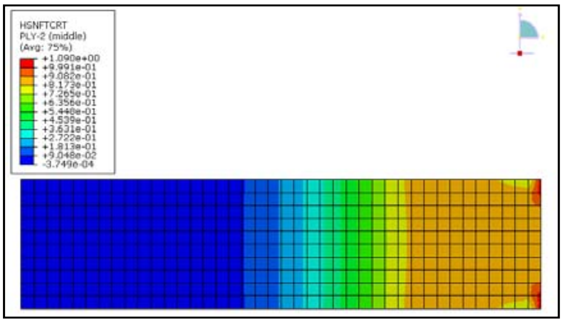


Figure 8 Hashin Failure Index in Fibre (Bottom Skin mid Layer)

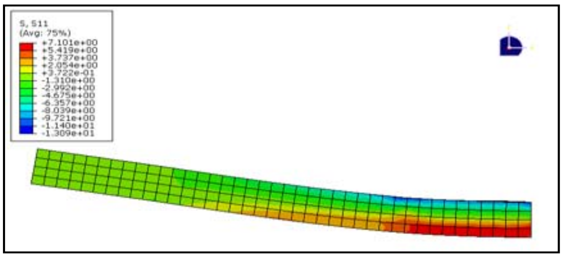


Figure 9 Core Stress Distributions in Longitudinal Direction.

3. CONCLUSIONS

This paper demonstrates that the FE method is capable to develop a reliable and acceptable behaviour simulation. It was found in bottom skin that the intermediate plies or 90^o plies are failed in matrix tension before the failure of the 0^o fibre. This means that the separation between two plies in 0^o happens before the rupture of the fibre. The failure of the top skin happens in the fibre wrinkling under the compression force under the load position. The 90^0 analysis shows low stiffness but high failure load with low effective fibre amount. The failure happens in the top skin by the delamination in the skin without failure of the fibre under compression. This is because the effective fibre is not in touch with the applied load. So, this allows the fibre to transfer the load through the fibre length. The authors recommend extending this study to a panel with woven fabric, to see whether delamination at ply level could be prevented. In addition, an optimization work should be done to save material usage in the civil engineering applications.

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