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Modelling of Honeycomb Core Sandwich Panels with Fibre Reinforced Plastic Facesheets and Analysing the Mechanical Properties

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Abstract. Using experimentally obtained specific material properties, numerical finite element models were created, one was honeycomb core sandwich structure other neat FRP composite structure was designed and experimentally verified. The honeycomb core sandwich composite comprised facesheets from wound glass fibre and polyvinylester resin and a core from recycled paper hexagonal honeycomb impregnated with polyvinylester resin and neat FRP composite structure consisted only two thin layers of facesheets. The model was used to obtain the optimal thickness of facesheet in honeycomb core sandwich structure at which the effective strength and stiffness properties can be obtained. It was determined that thickness of the facesheets had a significant effect on stiffness properties when the length between the supports are high.

1. Introduction

Sandwich fibre reinforced polymer (FRP) composites have emerged as important material because of their high specific strength and high specific stiffness, light weight, high fatigue resistance compared to common metallic alloys. Composite materials are used in almost all aspects of industrial and commercial fields such as ships, aircrafts, and general vehicles [1-2]. Honeycomb structures are especially becoming more prevalent in the field of civil engineering where the need of high structural strength and low weight is necessary [3].

Sandwich panels consist of two thin facesheets covering the light weight core. For numerical analysis of honeycomb sandwich structure various modelling approaches are developed. The finite element analyse is one of the means used to find the approximation of global behaviour of the sandwich panels [4-5]. The high mechanical performance with minimum unit weight can be provided by fibre reinforced polymer honeycomb sandwich structure [6].

In order to increase the performance and use of honeycomb sandwich material in different applications, knowledge of the mechanical behaviour is required. This motivates to develop complex numerical models and experimental methods, which characterise the design, material models and optimizing the honeycomb sandwich panels in certain specific conditions.

The object of the investigation is the sandwich composite with facesheets made of wounded glass fibre and polyvinylester resin and core made of recycled paper hexagonal honeycomb impregnated in polyvinylester resin.

The aims of this study are to find the appropriate numerical material models and compare these models with experimental data; using obtained numerical models to determine the optimal thickness of facesheet in honeycomb sandwich structure at which the effective optimal strength and stiffness properties are obtained and increase the mechanical behaviour of sandwich structure.

2. Material and Modelling

The sandwich structure presented in Figure 1 was used for the investigation. In order to find the mechanical properties of the sandwich materials various tests were carried out according to the standards. For facesheets ISO 527, ISO 604, ISO14129 and honeycomb core ISO 844, ISO 1922 were used. The obtained mechanical properties are presented in Table 1 and Table 2. According to the obtained material properties of the honeycomb it is found that material is highly anisotropic. The average thickness of the ply was 0.7 mm and fibre volume was 43%.

Figure 1. Model of sandwich with honeycomb core. 1 – woven glass fibre and polyvinylester resin composite facesheet; 2 - recycled paper hexagonal honeycomb impregnated in polyvinylester resin.

Table 1. Mechanical properties of FRP facesheet.

Mechanical properties	**Value**	**Units**
Tension strength	645	MPa
Compression strength	248	MPa
Longitudinal young's modules E_1	37.5	GPa
Transverse young's modules E_2	7.32	GPa
Poisson's ratio v_{12}	0.28	-
Poisson's ratio v_{21}	0.05	-
Shear modules G_{12}	3.79	GPa
In plain shear strength, S_{12}	23.0	MPa

Table 2. Mechanical properties of paper honeycomb core.

Mechanical properties	**Value**	**Units**
Young's modules	10	MPa
Compression strength	0.48	MPa
Shear modules	235	MPa
Shear strength	0.64	MPa

The recycled paper hexagonal honeycomb impregnated with polyvinylester resin was used for sandwich core thickness of wall was 0.22 mm, height was 10 mm, and edges was 10mm. the model was modelled using shell element for facesheet and solid element for honeycomb core.
According to experimentally obtained data the models of honeycomb core sandwich structure (with a honeycomb) and neat FRP facesheet material (without the honeycomb) were created using finite element modelling in ANSYS 14.5 as shown in Figure 2. The bonding between the honeycomb core and the facesheet was modelled with a "glue" layer with the thickness of 0.05 mm. The properties of the glue for the numerical model were defined as the mechanical properties of synolite 8388-P-1 resin (Young's modulus and tensile strength were 3.7 GPa and 14 MPa, respectively).
Verification of facesheet material model was performed using linear analysis by simulating tension test. Previously, an experimental test was carried out. The laminate code was [±65/90], the thickness of the plies were 0.9 mm and 0.75 mm for ±65 and 90 plies, respectively. The total thickness was 2.4 mm. Stress versus strain was measured in this test and the linear dependence curve shows a good agreement with experimentally obtained curve as shown in Figure 3.

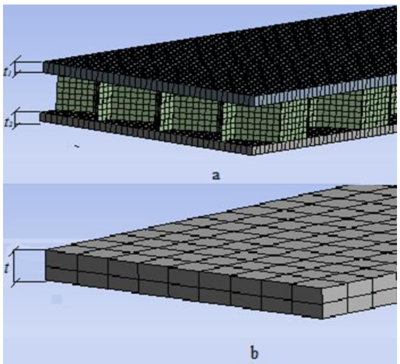

Figure 2. Models: (a) - model of honeycomb core sandwich composite; (b) – model of neat FRP sandwich composite. t_1 & t_2 - thickness of top facesheet and bottom facesheet; t ($t = t_1+t_2$) – thickness of neat FRP sandwich

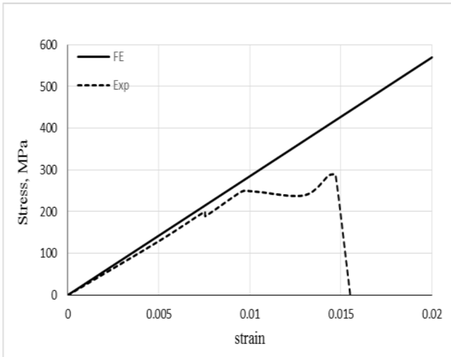

Figure 3. Tension stress – strain curve of FRP composite

Verification of the sandwich structure model was performed using linear analysis by simulating three point bending test. Previously, an experimental test was carried out. The dimensions of the specimens were as follows: width 60 mm, distance between the supports 200 mm, thickness of the top facesheet 2.68 mm, the thickness of bottom facesheet 2.81 mm, the core thickness 10 mm and thickness of sandwich 15.5 mm. The force versus deflection was measured during this test and the linear dependence curve of FE model shows a good agreement with experimental obtained curve as shown in Figure 4.

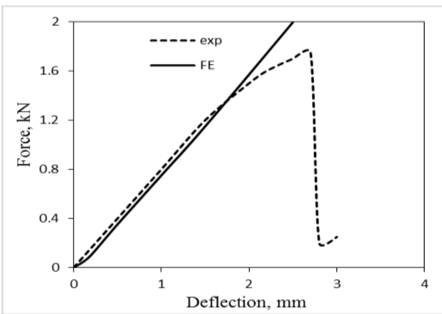

Figure 4. Force versus deflection curve obtained experimentally and by FE simulation

Using verified model the quasi-static in three point bending tests were simulated. A constant load of 800 N was applied in all simulation. This investigation was carried out in three different ways by varying the facesheet thickness. Such as $t_1 > t_2$, $t_1 < t_2$, $t_1 = t_2$ (t_1- thickness of top facesheet and t_2- thickness of bottom facesheet). In first condition $t_1 > t_2$ where, thickness of the top face sheet t_1 is varied by increasing the plys for each simulation and the bottom facesheet thickness t_2 was kept constant. In second condition $t_1 < t_2$ where thickness of the bottom facesheet t_2 was varied by increasing the plys for each simulation and top facesheet thickness t_1 was kept constant. In third condition were $t_1 = t_2$ thickness of the both facesheets t_1 and t_2 were changed equally by adding the equal number of layers for each simulation. Laminate code for the top facesheet and the bottom facesheet were changed as $[\pm 65]_n$ and $[\pm 65/90]_n$ respectively.

The thickness of facesheet was increased step by step in every investigation and three point bending simulation was simulated as shown in Figure 5. For each thickness change of facesheet, deflection and maximum equivalent stress the maximum equivalent stress was measured on middle of sandwich panel (Point where the load was applied in sandwich structure).

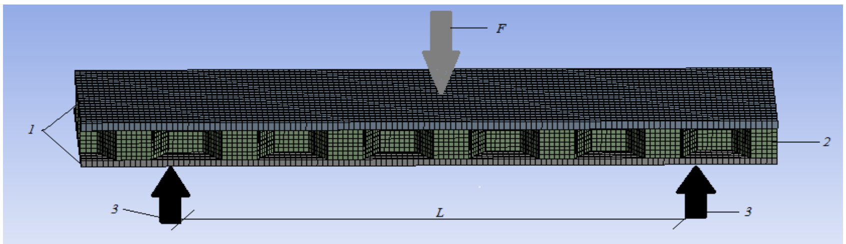

Figure 5. The numerical model of three point bending specimen. F - force applied, 1 - facesheets, 2 - hexagonal honeycomb core, 3 - supports, *L* – length between the supports.

For both honeycomb core sandwich structure and neat FRP composite the stiffness were calculated according to the equation:

$$K = \frac{F}{y_{\max}} \quad (1)$$

Where K – stiffness, F – force applied, y_{max} – maximum deflection.

The maximum deflection coefficient $k_{y_{\max}}$ which can be represented as ratio of maximum deflection of neat FRP composite to the maximum deflection of honeycomb core composite structure was used:

$$k_{y_{\max}} = \frac{y_{\max_1}}{y_{\max_2}} \quad (2)$$

Where $y_{\max_1}$ - maximum deflection of neat FRP composite; $y_{\max 2}$ - maximum deflection of honeycomb core composite structure.

The coefficient $k_{\sigma_{max}}$ represented the ratio of maximum stress σ_{max} of neat FRP composite to the maximum stress of honeycomb core FRP sandwich. This can be expressed as:

$$k_{\sigma_{max}} = \frac{\sigma_{max_1}}{\sigma_{max_2}} \tag{3}$$

Where σ_{max_1} – maximum equivalent stress of neat FRP composite; $\sigma_{max\,2}$ – maximum equivalent stress of honeycomb core composite structure.

3. Result and discussion

The stiffness variation influenced by thickness of FRP was calculated for both honeycomb core sandwich structure and neat FRP. The stiffness increases as the thickness of the FRP increases in all the cases. For lower thickness value, stiffness for honeycomb sandwich structure is higher than neat FRP composite. At a particular thickness value, stiffness of both honeycomb sandwich structure and neat FRP are same, but that particular point differs depending on the thickness orientation and distance between the supports. For $t_1 > t_2$ when L = 100 mm the value is t = 9 – 10 mm, when L = 150 mm the value is t = 10 – 11 mm, when L = 200 mm twice higher the other thickness. For $t_1 < t_2$ when L = 100 mm the value is t = 7 – 8 mm, when L = 150 mm the value is t = 8 – 9 mm, when L = 200 mm the value is twice higher the other thickness. For $t_1 = t_2$ when L=100 mm the value is t = 8 – 9 mm, when L = 150 mm the value is t = 9 – 10 mm, when L = 200 mm the value is also double. Below this thickness value, stiffness of the honeycomb core sandwich structure is higher than the neat FRP. In the same case above this thickness value, stiffness of the neat FRP is higher than the honeycomb core sandwich structure. The graph clearly represents that stiffness value of L = 100 mm higher than L = 150 mm that is more or less double the value also in L = 200mm.

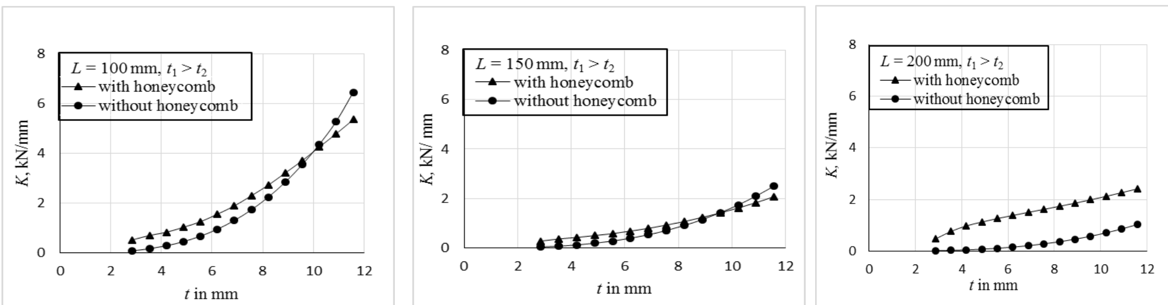

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Figure 6. Influence of FRP thickness t on stiffness K: a, b, and c – where the top facesheet thickness t_1 is greater than bottom face sheet t_2 lengths between supports respectively 100, 150, 200 mm.

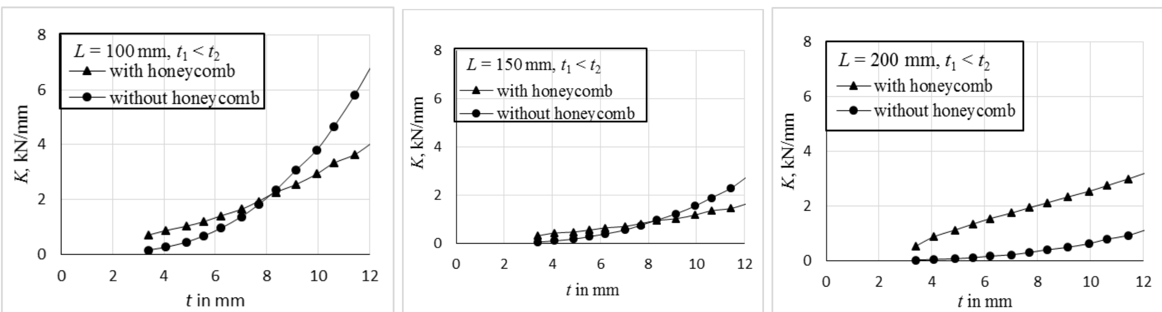

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Figure 7. Influence of FRP Thickness t on stiffness K: a, b, and c – where the top facesheet thickness t_1 is lesser than bottom face sheet t_2 lengths between supports respectively 100, 150, 200 mm.

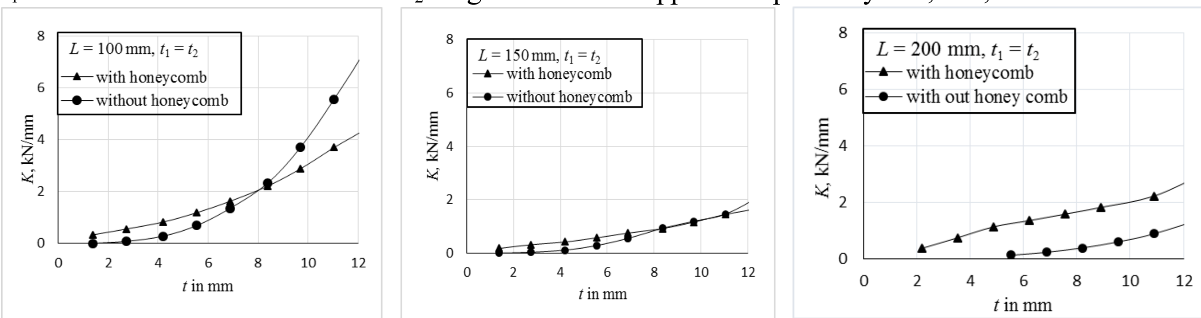

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Figure 8. Influence of FRP Thickness t on stiffness K: a, b, and c – where the top facesheet thickness t_1 is equal to bottom face sheet t_2 lengths between supports respectively 100, 150, 200 mm.

By only comparing the optimal thickness, stiffness of the composite is not so clear because of the same value of stiffness can be obtained from constant F and different y_{max} values. So influence of thickness separately on y_{max} and σ_{max} were investigated.

The coefficient $k_{y_{max}}$ and $k_{\sigma_{max}}$ are defined by y_{max} and σ_{max} values, which is obtained from different thickness and length between the supports. It is clear that the deflection decreases when the thickness of the FRP increases and the distance between the support decreases. The effects of the maximum deflection value of honeycomb core composite was found only when the thickness of FRP is lower and distance between the supports is increased.

In case of neat FRP composite, it has the minutiae stiffness in the lower thickness values so coefficient $k_{y_{max}}$ cannot be calculated

In contrast for thickness t equal to 5 mm (at this value honeycomb height is 80% of the total composite thickness [7, 8]). The deflection of the honeycomb core FRP composite is close to 2.1, 2.6, and 14 times lower than the neat FRP composite in all three conditions as the distance between composite are 100, 150 and 200.

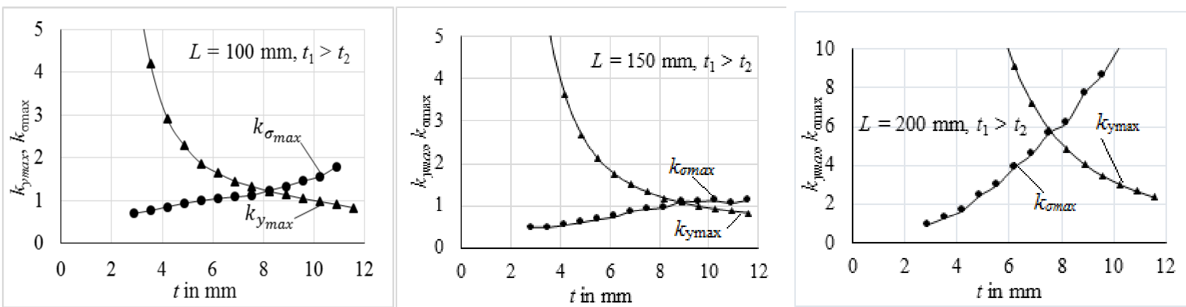

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Figure 9. Influence of FRP Thickness t on coefficient $k_{y_{max}}$ and $k_{\sigma_{max}}$ - where the top facesheet thickness t_1 is greater than bottom face sheet t_2 lengths between supports respectively 100, 150, 200 mm.

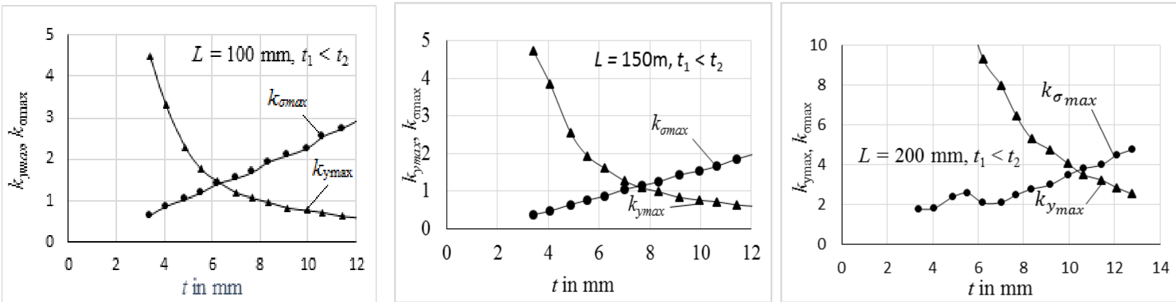

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Figure 10. Influence of FRP Thickness t on coefficient $k_{y_{max}}$ and $k_{\sigma_{max}}$ – where the top facesheet thickness t_1 is lesser than bottom face sheet t_2 lengths between supports respectively 100, 150, 200 mm.

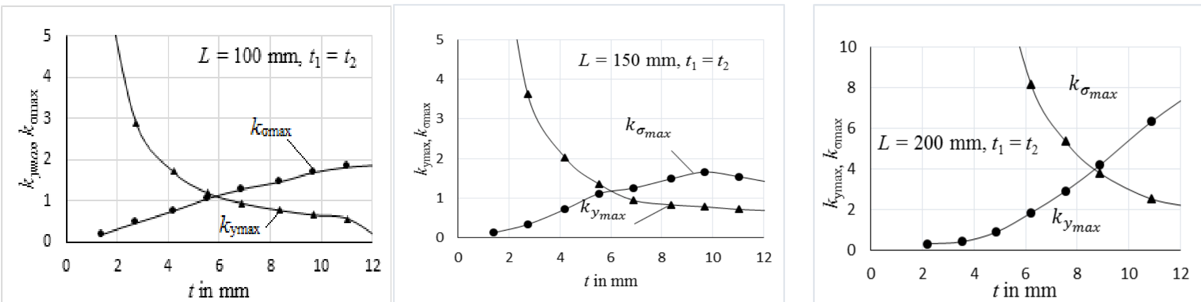

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Figure 11. Influence of FRP Thickness t on coefficient $k_{y_{max}}$ and $k_{\sigma_{max}}$ - where the top facesheet thickness t_1 is equal to bottom face sheet t_2 lengths between supports respectively 100, 150, 200 mm.

The significant effects of equivalent stress in honeycomb core were found only when the FRP thickness is low. It is clear that, when the thickness of FRP is increased and distance between the supports decreased, the equivalent stress in the FRP have decreased. In case of lower thickness stress on the honeycomb core FRP composite is lower than neat FRP composite in different conditions and distance between the supports. But in higher thickness value the situation is inversed and the stress on honeycomb core composite is high when compared to the neat FRP composite.
The effective performance of the honey combe core sandwich structure can be found when the coefficients $k_{y_{max}}$ and $k_{\sigma_{max}}$ are higher than one.
In the above Figure 9, Figure 10, and Figure 11 the average range of FRP thickness for all three conditions are: when L=100 mm the thickness range is 5 -9 mm, L = 150 mm thickness range is 6 – 10 mm and L = 200 mm thickness range is 5 – 14 mm, where the condition is sustain and the range of the thickness depends on the distance between the supports. When the length between the supports increased the range of thickness is also increased.

4. Conclusions
An analysis of strength and stiffness of sandwich structure comprises of honeycomb core sandwich and neat FRP were carried out.

The material of the separate components of sandwich structures were tested and the mechanical properties were obtained. Using the material properties a numerical model of sandwich structure comprising wounded glass fibre and polyvinylester resin facesheets and recycled paper hexagonal honeycomb impregnated in polyvinylester resin was modelled. The Facesheet tension test and three point bending of sandwich structure allowed to verify the FE model of facesheet material and sandwich structure.

The methodology used for investigation of the sandwich structure by changing the thickness of the facesheets in three different conditions such as $t_1 > t_2$, $t_1 < t_2$ and $t_1 = t_2$, this methodology allowed to investigating the strength and stiffness properties at various thickness of the facesheets and distance between the supports. This helped to determine the optimal thickness value of FRP in honeycomb core composite.

In result of the investigation, the optimal thickness value of FRP in honeycomb core composite was purely depends on structure geometry of material or product.

It is also equally important to consider the distance between the supports which influence the thickness variation of the FRP facesheets in honeycomb core sandwich composite.

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