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Finite element analysis of Carbon composite sandwich material with agglomerated Cork core

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Abstract

Composite sandwich structures were developed for the hydrofoil sail boat hull using biaxial carbon fabric/epoxy composite facing and agglomerated cork core. These ultra-light weight structures were tested through four point bending tests to characterize their flexural behavior. The material exhibited an initial linear elastic behavior followed by non-linear elastic-plastic behavior. Finite element analysis of the sandwich beams was performed to analyze the flexural behavior of the structure. It was found that the transition from linear elastic to non-linear elastic-plastic behavior is the result of compressive yielding of core material which leads to indentation in the beam. This also causes initiation of failure in the core. A shift in the centroid axis of the beam towards the tensile face was also observed. The sandwich structures made of cross-linked PVC and PMI foam cores were also analyzed for comparison. Further, a parametric study on the effect of areal density and ply angle of the facing fabric and core thickness were performed using finite element method. The parametric study revealed that the transition from linear to non-linear trend is caused by different mechanisms with the change in the mentioned parameters.

Keywords: composite sandwich; ultra-light weight; agglomerated cork; foam cores; flexural behaviour; finite element analysis

1. Introduction

Sandwich composites are special form of laminated composites in which a thick, soft and light weight core is sandwiched between two thin and stiff fibre reinforced plastic skins [1]. The structure thus obtained possesses higher bending stiffness and high strength to weight ratio compared to the monolithic structure. The weight reductions of up to 20% can be achieved by using sandwich structures in the place of monolithic composites [2].With its many advantages, the composite sandwich materials find various applications in the automotive, construction and aerospace industries. The sandwich structures also draw a lot of interest in marine industry, especially in high-speed racing and surveillance [3]. The hulls of the boats used for the high speed racing were mostly made out of aluminum alloys or glass fiber with the traditional core materials like honeycomb or foam core sandwich structures. It has been identified through an analytical design study conducted at ITV (Institut für Textil-

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und Verfahrenstechnik) that, using the carbon fiber in place of glass reduces the weight to a much larger extent and improves the performance and endurance of the hull [4].

Based on the design study, the work presented here had an objective to develop ultra-light weight sandwich material, using thin carbon fibre skin and very recently introduced agglomerated cork as core, for the hydrofoil sail boat hull and to characterize its flexural behaviour. The stress distribution and bending behaviour has been analysed using finite element methods.

2. Experimental

2.1. Material

The composite sandwich structures examined in this study were prepared using NCF (non-crimp fabric), aligned from T700SC-12K carbon fiber for skin. The areal density of the NCF was 550 g/m^2. The NCF was supplied by Saertex GmbH. The core material used was 3 mm thick agglomerated cork (CoreCork® NL10), manufactured by Amorim Corporation. The sandwich was laminated by vacuum assisted resin injection technique using Biresin-CR120/CH-120-6 epoxy resin, supplied by Sika Deutschland, with a stacking sequence of [(0/90) /Cork/ (90/0)]. The nominal thickness of the skin was 0.5 mm, which is comparatively thin considering the traditional skins. The characterization of mechanical properties of skin was performed according to DIN EN ISO 527 standards at ITV and that of core was taken from the manufacturer's product bulletin and literature[5]. Table 1 and Table 2 lists the mechanical properties of the skin and core materials. The fiber volume fraction of the skin material was estimated as 49 %.

Table 1 Mechanical properties of the skin

Property	Average	Std dev
Tensile Modulus, E (GPa)	51.4	0.15
Peak stress, σ (Mpa)	597	56.1
Peak strain, %	2.0	0.42
Shear Modulus, G (GPa)	8.7	0.48
Peak stress, τ (Mpa)	184	28.0
Peak strain, %	8.2	0.36

Table 2 Mechanical properties of the core

Property	Value
Nominal density (kg/m^3)	140
Compressive Modulus (MPa)	51
Compressive strength (MPa)	0.16
Shear Modulus (MPa)	5.9
Shear strength (MPa)	0.85
Poisson's ratio	0.37

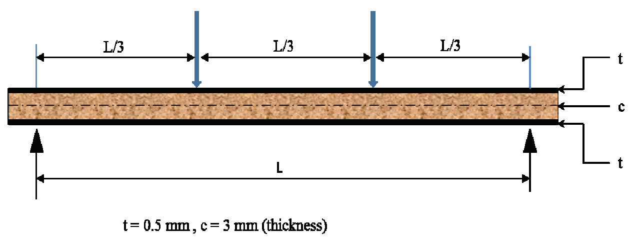
2.2. Test Specimen and procedure

Composite sandwich panels with nominal thicknesses of 4 mm were tested in this study. The panels were cut into required specimen dimensions and tested according to the DIN EN ISO 14125 standard. Five replicates of the specimens were prepared and tested for its static flexural properties by four point bending test.

The sandwich specimens were tested on a 20 kN universal testing machine with loading points at the third and two-third span of the specimen (Fig 1a). The test was conducted at a testing speed of 3 mm/min. The loading pins and the supports had a diameter of 10 mm to prevent local indentation failure on the beam.

3. Finite element modeling of sandwich beam behavior

Numerical simulations were carried out to compare with the experimental measurements of the flexural behaviour of the composite sandwich beams. The simulations of the four point static bending test of the composite sandwich beams have been carried out using Straus7® finite element program [6]. The skin material was modelled as 8-noded plate elements with mechanical properties obtained from the ITV-coupon tests results listed above and representing the actual layup. The core material was modelled as 16-noded layered brick elements. The skin was assumed to be perfectly bonded to the core, eliminating detachment of skin and core. The plate elements had aspect ratio of 1.0 and the brick elements between 3.1 and 3.3. The skin was modelled as linear elastic laminate material with linear stress–strain relationship and the core as isotropic material with non-linear stress– strain relationship. The finite element model was carried out simulating the specimen and the loading set-up in the actual experimental conditions. Due to symmetry, only one -half of the sandwich beam was modelled to reduce the computational time. Fig. 1b shows the numerical model used to simulate the 4-point static bending tests of the composite sandwich. Non-linear analyses were conducted considering the combined effect of the linear elastic behaviour of the skin and the non-linear behaviour of the core material and the large displacements of the sandwich beams before failure.



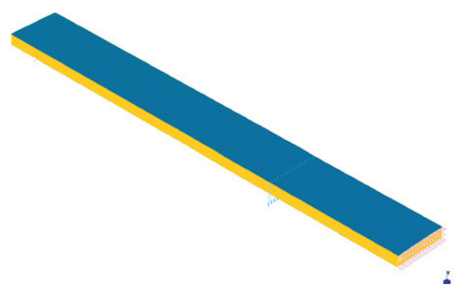


Fig. 1. (a) Schematic illustration of the four-point bending test; (b) Numerical model for 4-point bending simulation

4. Experimental results and discussion

The 4-point bending tests of the sandwich beams showed a non-linear load-displacement relationship. The typical load-displacement relationship is shown in the Fig 2a. It can be observed from the Fig 2a that the load capacity of the specimen increased linearly with deflection until a load of 20 N. After this load, a slight decrease in stiffness can be observed. This could be due to the core shearing. On further increase in load, the load capacity dropped non-linearly with deflection. This could be due to the skin wrinkling or local de-bonding. The sandwich beam failed abruptly beyond this due to the compressive failure of skin as shown in Fig 2b. It can be observed from the Fig 2b that the compressive failure in the skin displaced the beam further from the right hand side top loading roller. However, no crack was observed in the core. The possible reason for this could be because of the soft nature of the core, unlike normally used stiff foam cores [7].

5. Finite element method predictions and comparison with experimental results

The finite element prediction showed a good correlation in the flexural behavior of the sandwich beams with that of the experimental results within the linear elastic region (Fig 2a). The solution diverged from that of experimental beyond the elastic region of the core. This could be due to the heterogeneity of agglomerated cork. However, interestingly the predictions revealed the reasons for the transition of the beam behavior from linear to non-linear. It was observed that at 20 N of the applied load the predicted results deviated from the experimental load-displacement curve. The out-of-plane stress contour diagram (Fig 3) at 20 N load shows the region of compressive yielding in the beam. The out-of-plane stress plot (Fig 4a) of the beam revealed that the peak compressive stress of the core has been reached and beyond which the core undergoes compressive yielding. This phenomenon of compressive yielding leads to non-linear regime. The plot (Fig 4b) between the planes of the sandwich beam along its span showed a deflection in the centroid towards the tensile face below the load application point. This reveals the local indentation phenomena below the point of load application, making the problem more complex.

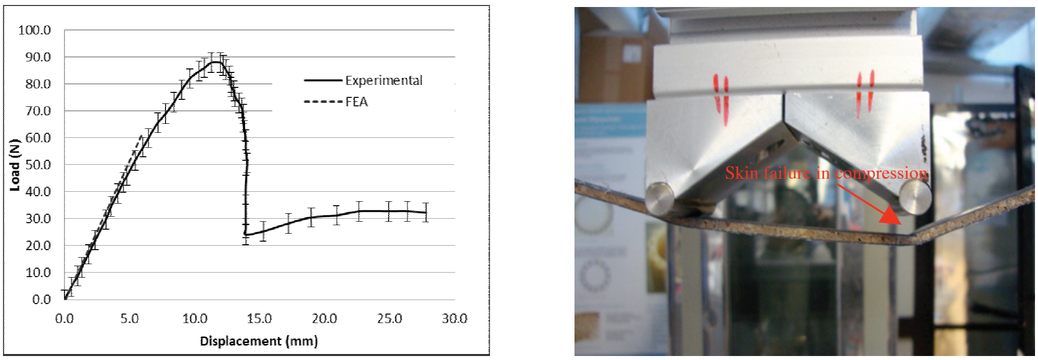


Fig. 2. (a) Load-Displacement curve for sandwich beams; (b) Sandwich failure due to skin failure in compression

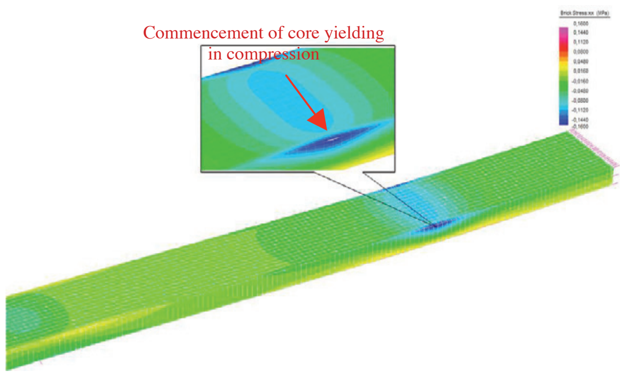


Fig. 3. Predicted core yielding in compression

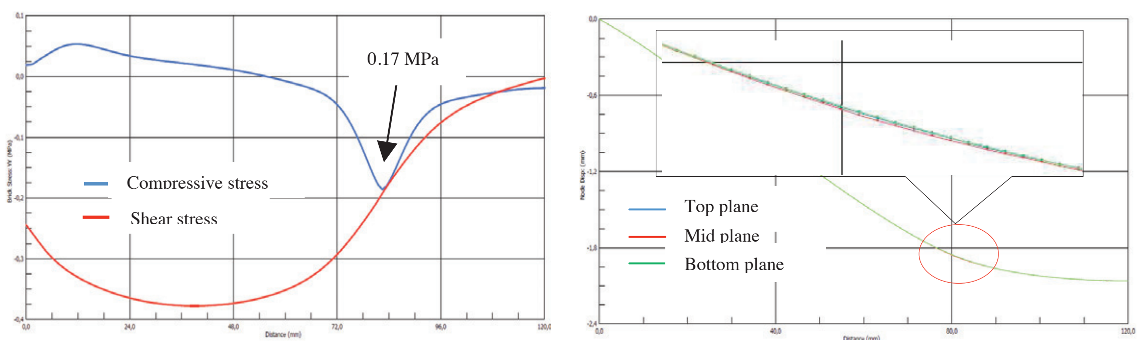


Fig. 4. FE predictions at 20 N load (a) Stress distribution along the span of the specimen; (b) Shift in the centroid axis towards tensile face

Sandwich beams made of cross-linked PVC and PMI foam cores with similar skin materials were also analyzed for comparison. The behavior of the foam cored sandwich materials were also similar regarding the compressive yielding phenomenon (Fig 5). This could be because of the similarity in the internal structures of closed cell foam cores and cork material [7].

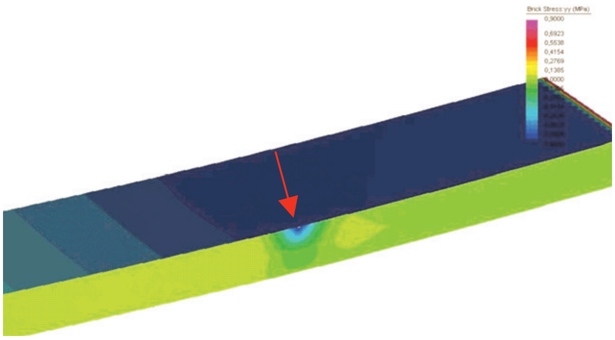


Fig 5. Predicted core yielding in compression for PVC foam core

A finite element parametric study on the beam was also carried out by changing the layup (+45/-45), areal density (254 g/m^2) of the skin material and thickness (5 mm) of the core material to analyze the effect on flexural behavior. The properties of the materials used were taken from the coupon test results reported elsewhere [8]. The study revealed that due to +45/-45 layup and lighter fabric, the contribution due to shear was more than that of tensile and compressive properties of the skin. Hence, the beam had less load-bearing capacity in the elastic region. As a result the core reached its peak compressive stress at much lower loads. The increase in thickness of the core did not showed pronounced effect within the elastic regime. This may be due to very small difference in the thickness between the above mentioned sandwich beams.

6. Conclusions

The flexural behavior of ultra-light weight sandwich composite material has been studied experimentally and numerically. The following conclusions could be drawn from the study.

1. The experimental load-displacement curve showed an initial linear elastic behavior and then a non-linear elastic-plastic behavior of the sandwich beams in flexure.
2. The beam failed due to shear failure of the core followed by the compressive failure of the skin.
3. The finite element predictions had good correlation with experimental results in the elastic regime.
4. The finite element predictions revealed that the core compressive yielding leads to the non-linear regime of the beam in flexural behavior.
5. The compressive yielding causes stress localization and indentation in the beam.
6. The shift in the centroid axis towards the tensile face confirmed the local indentation below the load application point.
7. The parametric study revealed the change in the material parameter affects the mechanism of the load distribution within the sandwich beams.

It is obvious from the conclusions that the further focus should be made on finding solutions to the stress localization and local indentation for these ultra-light weight thin sandwich beams. Also, these local effects should be included into the finite element prediction to analyze the behavior till failure. The work is in progress in partnership with Straus7-Germany to implement these effects in the finite element code and also to model the interface between skin and core and the interface between cork agglomerates.

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References

[1] Zenkert D., Ed., The Handbook of Sandwich Construction. London: Engineering Materials Advisory Services Ltd., 1997.

[2] Allen H.G., Analysis and Design of Structural sandwich panels. Oxford: Pergamon Press, 1969.

[3] Y.D.S. Rajapakse., “Marine Composites: Foreward”, Composites: Part B 35 (2004) 447–450.

[4] Fritz F. “Hydrofoil-Segelboot der International Moth Klasse Auslegung und Fertigung in Faser-Kunststoff-Verbundbauweise”, Diploma Thesis, Institut für Textil- und Verfahrenstechnik, University of Stuttgart, 2010.

[5] Carvalho P., Alves C., Freitas M. Reis L., "Mechanical behaviour of Sandwich beams manufactured with Glass or Jute Fiber facings and Cork Agglomerates as Core", Materials Science Forum, vol. 636-637, pp. 245-252, 2010.

[6] Straus7., Straus7 Release 2.3.6 finite element analysis system. Sydney, Australia: Straus7 Software, 2005.

[7] Silva et al. "Cork: properties, capabilities and applications”, International Materials Reviews, vol 50 no.6, pp 345-365, 2005.

[8] S.Sathis Kumar, Geiger R .,"Herstellung und Kennwertermittlung von Faserverbund Sandwich Strukturen für den Einsatz in einem Hydrofoil Segelboot der Moth Klasse”, Master Thesis, Institut für Textil- und Verfahrenstechnik, University of Stuttgart, 2010.