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DIFFERENT FAILURE MODES ASSESSMENT TO IMPROVE THE SANDWICH COMPOSITE PANEL STIFFNESS WITH HONEYCOMB CORE FOR MARINE STRUCTURES APPLICATION

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Graphical abstract
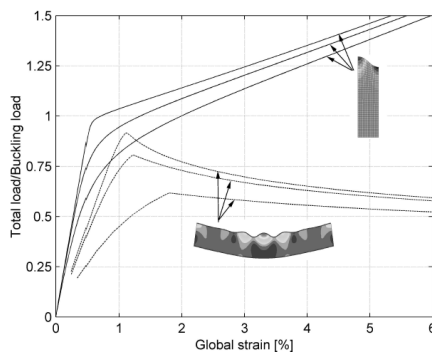
Abstract

This research paper focuses on the prediction of different failure modes to improve the sandwich composite panel with honeycomb core for application in marine structures. Marine, automotive and aerospace industries are continually trying to optimize material performance in terms of strength and weight. Success has been achieved through the growth of high performance materials, including fibrous composites such as ceramics, new alloys, and carbon fiber composites and through the use of structural concepts such as sandwich composite panel construction. Sandwich composite panel construction with honeycomb core consists of three components: two facing sheets, the core that fill the space between the facing sheet and the core-to-facing bonding adhesives. The facing sheets of a sandwich panel can be compared to the flanges of an I-beam element, as they carry the bending stresses to which the beam is subjected. With one facing sheet in compression, the other is in tension. Similarly the honeycomb core corresponds to the web of the I-beam that resists the shear loads and vertical compressive load to the face sheet. This paper presents a model for prediction of different failure mode of face sheet and core material. The obtained results of this model were compared with experimental results and presents that it is a simple and good model.

Keywords: Sandwich Panel, Failure Mode, Honeycomb Core, Marine Structure
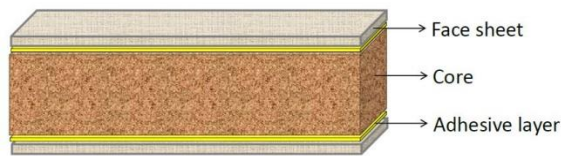
1.0 INTRODUCTION

This research paper deals with the structural behaviour of laminated composite hull plates in high speed light craft. Composites made of fiber-reinforced plastic (FRP) is often superior to steel and aluminium as building material for high speed light craft (HSLC) due to a low weight/strength ratio. The hight specific strength of glass fibers together with the superior specific stiffness offered by carbon and other high modulus fibers has led to an increasing use of these materials in fast marine vessels, such as ferries, special military ships and high performance sailing and power boats. The knowledge of the material behaviour, strength and fatigue of FRP composites is still limited. Most designs are based on boat building experience rather than structural analysis, which is often too expensive to perform.

A sandwich panel is indeed formed by three parts (Figure 1):
- Two faces that are usually thin if compared to the thickness of the entire sandwich panel. The external layers confer high flexural and in-plane stiffness to the sandwich panel.
- A central core that is usually thick, light and weaker than the external faces (the core typical thickness varies between 3 mm and 60 mm).
- Two adhesive layers between the sandwich external faces and the internal core.

The requirements for the materials forming the sandwich external faces depend on the specic structural application, but the most common speci_cations are: high stiffness to achieve high exural rigidity, high tensile and compressive strength, impact resistance, surface finish, environmental resistance (chemical, UV, heat, etc.), wear resistance. Composite materials, metals, wood and polymers are among the most common materials used to build the external face sheets of sandwich structures [1]. The bending behaviour of marine composite hull plates is characterised by a remarkable geometrical non-linearity due to large panel sizes and relatively high lateral loads [2,3,4].

Figure 1 Typical cross section of a sandwich panel formed by two external face sheets and an internal core connected by adhesive layers

Pronounced lateral deflections introduce inplane displacements and membrane strains in the faces as well as shear deformation in the core. Thus, the classical Kirchhoff plate theory is not sufficient to describe this kind of response. Reissner & Mindlin [5,6] introduced a theory governing finite deflections of sandwich plates with isotropic faces and cores. Based on Reissner's theory, Alwan [7] solved the nonlinear bending problem of rectangular sandwich plates by means of double trigonometric series with simply supported edges. Kan and Huang [8] derived a large-deflection solution of clamping sandwich plates by applying a perturbation technique. However, none of the above solutions are easy to use in practice.

2.0 METHODOLOGY

2.1 Structural Design

The structural design criteria, which should be taken into consideration in the design phase of sandwich and single-skin hulls, are listed in the following:

- Global hull bending, shear and torsion deformations.
- Panel deflections.
- Stresses in the skins or in the laminates.
- Stresses in the core.
- Skin wrinkling.
- Global panel stability.

Prior to the choice of hull type, the assets and the drawbacks involved in manufacturing and design of either single skin or sandwich should be taken into consideration. The two concepts are outlined in the following, in addition to the FRP design rules imposed by some of the leading authorities, in order to provide the reader with an overview of the two different building concepts and to give an idea of the limits of the design rules [9].

The properties required for the core material depend on the structural applications and variations. Typical requirements can include low density, high stiffness and strength perpendicular to the sandwich faces, energy absorption, high shear modulus and strength, thermal and acoustic insulation, thermal and chemical stabilities for manufacturing. Many different materials are currently employed in the core of sandwich panels: among these the most common are balsa wood, polymers (PVC, SAN), and metals (aluminum). Also, different core morphologies have been applied, such as: homogeneous foam core, corrugated core, honeycomb (Figure 2) [10, 11].

The use of sandwich panels has improved the performance of many structures, as it has allowed the realization of larger and lighter applications. The aircraft industry is a clear example where the use of sandwich panels leads to extended lifetime and weight saving [12].
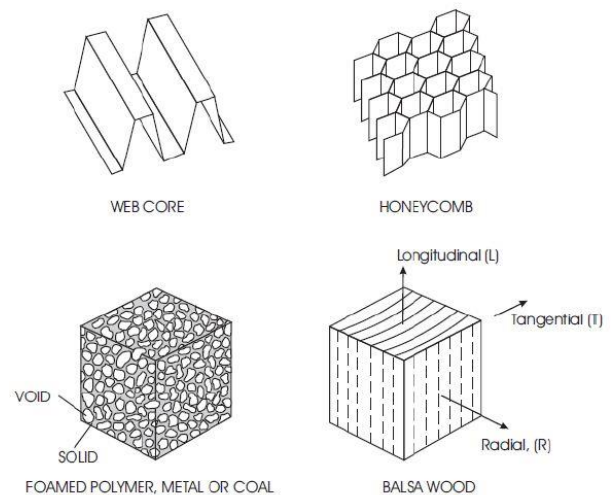
Figure 2 Examples of different common core types (Carlsson. 2010) [11]

The sandwich panels are popular in high performance applications where weight must be kept to a minimum. For example aeronautical

structures, high speed marine craft and racing cars. In the most weight_critical applications, composite materials are used for the skins, cheaper alternatives such as aluminium alloy, steel or plywood are also commonly used. Materials used for cores include polymers, aluminium, wood and composites. To minimize weight these are used in the form of foams, honeycombs or with a corrugated construction (Figure 3) As well as mechanical requirements, core materials may also be selected based on there are resistance or thermal properties.
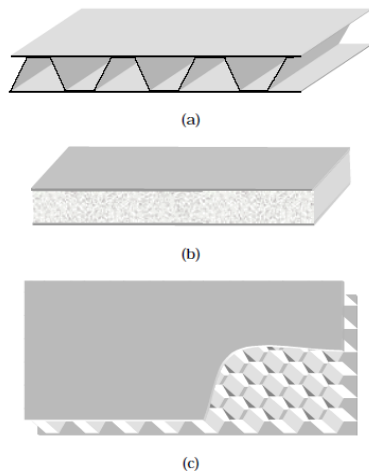
Figure 3 Sandwich panels with (a) corrugated (b) foam and (c) honeycomb core

The most common and some unorthodox techniques employed to manufacture sandwich components for structural applications, as well as the recent developments and future trends in terms of both materials and processing routes are comprehensively reviewed by Karlsson [13].

3.0 SANDWICH HULL DESIGN AND FAILURE MODES

Designers of sandwich panels must ensure that all potential failure modes are considered in their analysis. A summary of the key failure modes is shown below [14]:

3.1 Strength

The skin and core materials should be able to withstand the tensile, compressive and shear stresses induced by the design load as shown in Figure 4. The skin to core adhesive must be capable of transferring the shear stresses between skin and core.
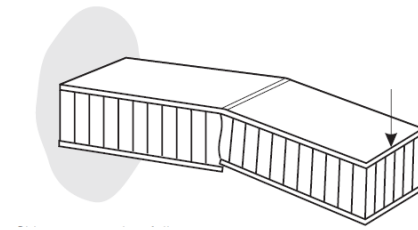
Figure 4 Skin compression failures

3.2 Stiffness

The sandwich panel should have sufficient bending and shear stiffness to prevent excessive deflection as shown in Figure 5.
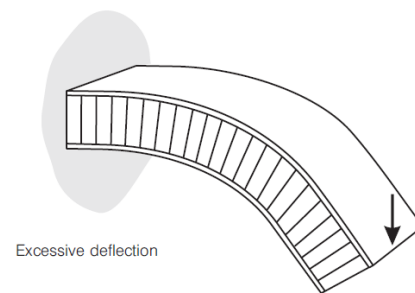
Figure 5 Excessive deflection

3.3 Panel Buckling

The core thickness and shear modulus must be adequate to prevent the panel from buckling under end compression loads as shown in Figure 6.

Figure 6 Panel buckling

3.4 Shear Crimping

The core thickness and shear modulus must be adequate to prevent the core from prematurely failing in shear under end compression loads as shown in Figure 7.
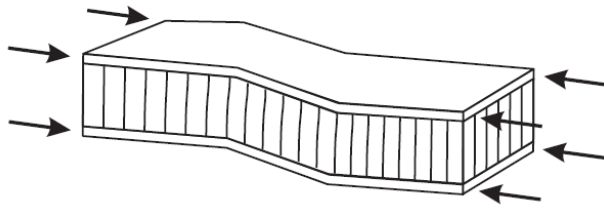
Figure 7 Shear crimping

3.5 Skin Wrinkling

The compressive modulus of the facing skin and the core compression strength must both be high enough to prevent a skin wrinkling failure as shown in Figure 8.
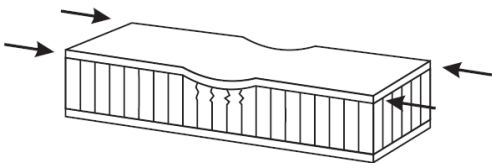

Figure 8 Skin wrinkling

3.6 Intra Cell Buckling

For a given skin material, the core cell size must be small enough to prevent intra cell buckling as shown in Figure 9.
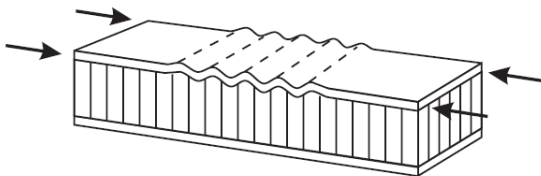

Figure 9 Intra cell buckling

3.7 Local Compression

The core compressive strength must be adequate to resist local loads on the panel surface as shown in Figure 10.
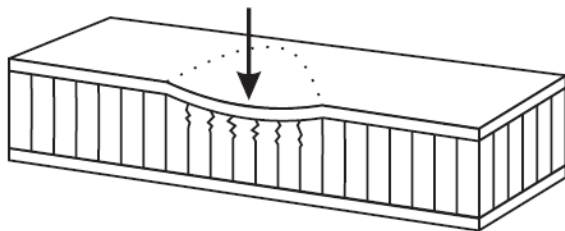

Figure 10 local compressions

The structural design criteria for sandwich plates in FRP hulls provided by Bureau Veritas, BV15, and Det Norske Veritas, BV16 (Figure 11) are listed in following Eqs. 1, 2.

- Minimum thickness, tmin, of the faces:

$$\text{BV:} \quad t_{\min} = 0.6 \cdot 10^{-3} \cdot \sqrt{0.97 L_{wl} + 10} \tag{1}$$

$$\text{DNV:} \quad t_{\min} = 10^{-3} \cdot \frac{1.5 + 0.09 L_{wl}}{\sqrt{\dfrac{\sigma_{nu}}{1.6 \cdot 10^{8}}}} \tag{2}$$
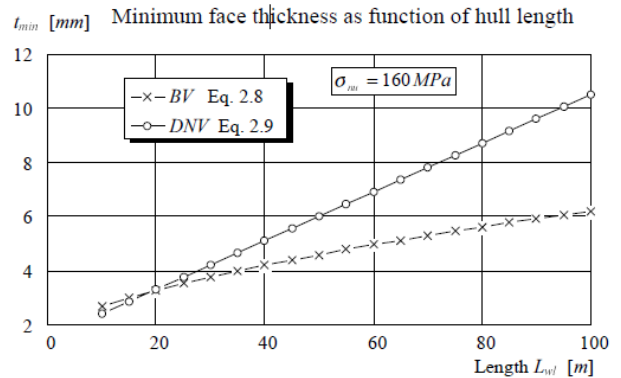

Figure 11 Minimum face thickness required by bureau Veritas and Det Norske Veritas [16]

The primary advantage of using the sandwich concept in a FRP hull instead of a stiffened single-skin structure is the built-in flexural stiffness of the sandwich, which makes the stiffener system unnecessary. The bending and the in-plane stresses are mainly carried by the faces, whereas the shear stresses are taken by the core. The building of an FRP sandwich hull requires, however, more technical skills and advanced technology than building a single skin hull.

The most common production method of a sandwich hull is to make use of a female mold and proceed as for the single skin hull. After the outer skin has been formed in the mold the core, usually PVC foams but also aluminum or resin-impregnated honeycomb, is bonded to the skin employing an adhesive, which is most often the resin used for the skins. Next, the core material is tapered before the inner skin is applied to the core.

Asymmetric sandwich panels with skins of differing thickness are subjected to various degrees of damage via quasi-static indentation before compressive loading to failure.

These are compared with panels with skins of equal thickness. The experiments show that the asymmetric panels experience an improvement in strength with small amounts of indentation compared with undamaged asymmetric panels, and for more severe damage, show greater residual strength than the symmetric panels [23, 24 and 25].

4.0 RESULTS AND DISCUSSION

Results of response calculations by application of the above methods are compared to numerically compute finite difference results and experimental results from Bau et al. [17].

The following parameters are discussed: deflection and in-plane strains and shear strains calculated in the middle of the plate and along the x-axis for y=b/2. The results are shown in Figures 12, 13, 14.
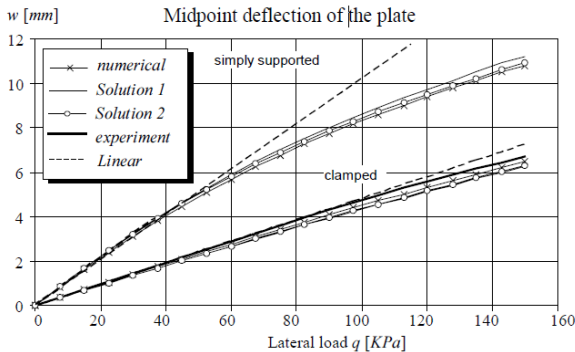
Figure 12 Midpoint deflections w of a clamped and a simply supported sandwich plate

The geometrical non-linear behavior is most pronounced for the simply supported plate illustrated in Figure 12, where the lateral deflection in the centre of the plate is plotted against the lateral load q. The analytical results are almost identical and quite accurate (about 3 percent) compared to the numerical results and the experimental data.
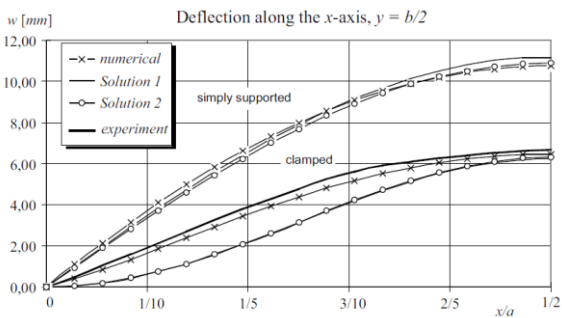
Figure 13 Deflection, w, along the axis, y=b/2, clamped and simply supported. Lateral load q=150 kPa

The deflection along the x-axis is considered in Figure 12, the analytical solutions are not accurate in the clamped case, whereas, for the simply supported case, the deflection curves agree well with the numerical results.
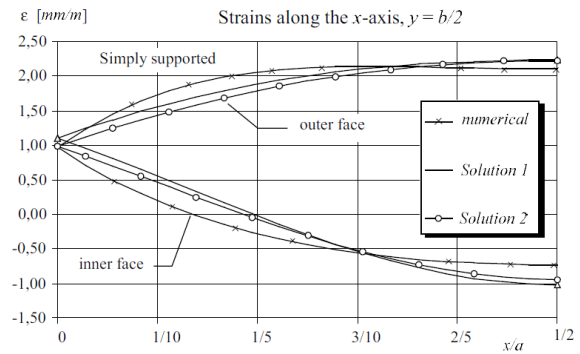
**Figure 14** Strains ε_x, along the x-axis, y=b/2, simply supported. Lateral load q=150 kPa

Figure 14 shows that the analytical solutions have good agreement with the numerical solutions, but slightly conservative results for both the inner and outer faces. In the clamped case, the maximum strains are found at the edge, and the analytical results are about 35 percent lower than the experimental/numerical results. In the centre of the plate, the analytical methods predict strains approximately 20 percent higher.
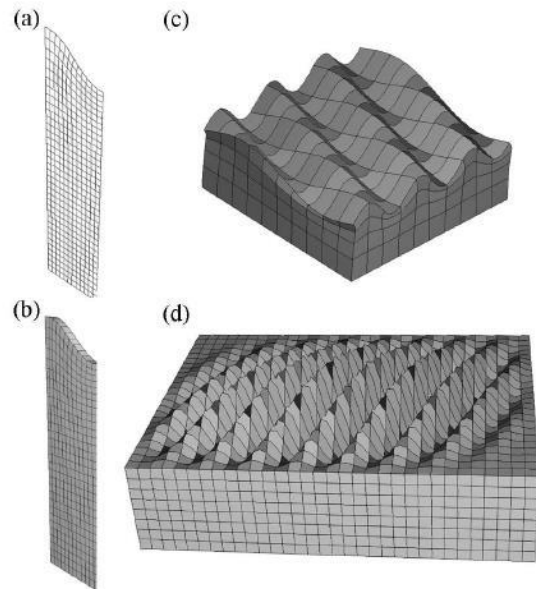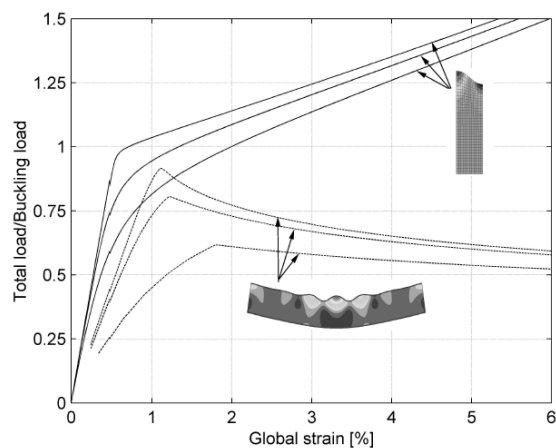
Figure 15 Different types of finite element models used for wrinkling analysis. a)2-dimensional model for single cell, b)3-dimensional model for single cell with surface element, c)3-dimensional model with periodic boundary conditions and d)3-dimensional model for the small sandwich surface

Figure 15 shows the different types of finite element methods for wrinkling analysis as 2-dimensional model for single cell, 3-dimensional model for single cell with surface element, 3-dimensional model with periodic boundary conditions and 3-dimensional model for the small sandwich surface. The stiffness was measured as 40 percent compared to the 8 percent found above. A typical load deflection for the

experiment is shown in Figure 16 [18]. This incorrect value was used by in the numerical and analytical models. Failure consisted of buckling of the walls in all specimens [19, 20, 21, 22]. The location of the buckling varied between successive specimens and was randomly distributed through the depth.
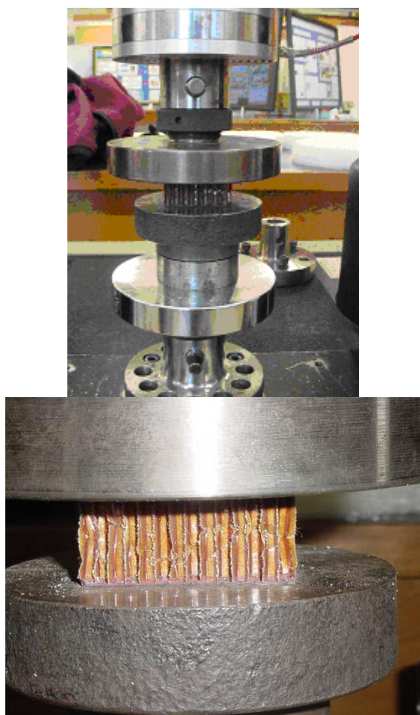
Figure 16 Compression test, showing a fracture line through specimen[18]

Figure 17 Non-linear curves for two different models of finite element method

Figure 17 shows the Non-linear curves for two different models of finite element method. The continues lines show the equivalent paths for non-linear wrinkling and desh lines show a sandwich panel beam under initial bending moment.

4.0 CONCLUSION

This research focuses on the prediction of different failure modes to improve the sandwich composite panel with honeycomb core for application in marine structures. For the simply supported case, the strains are reasonably accurate, whereas in the clamped case, the strains are overestimated in the plate centre and underestimated near the plate edges. The shear strains in the core are underestimated. Experiments showed that the damaged area should be modelled with 8 percent of undamaged coremodulus, compared with 40 percent [18].

Acknowledgements

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