ANALYTICAL STUDY OF COMPOSITE PANEL FOR MANUFACTURING BOATS BY THEORY OF HETEROGENEOUS SECTION

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Abstract
This job aims analyze the bending of a composite sandwich panel idealized for marine applications by means of the classical theory of Solid Mechanics. The composite panel basis of this study is proposed by Ribeiro, Wahrhaftig and Nascimento [1]. Mathematical simplifications were made to fit the employed theory with the panel. The developed analytical formulations aimed at the calculation of normal stresses in bending and is based on classical concepts of heterogeneous section. Some numerical simulations are performed in the panel to analyze outcome on dimensional variations induced. The formulation developed adequately describes the behavior of composite structural analysis. This enables pre-design and directing more complex stages of more sophisticated computational models.

1. Introduction.

The research related to composite materials in vessels are stimulated mainly by the fact that reducing the weight of these allows for greater load capacity, fuel economy, increased acceleration, increased vessel stability, increased strength and structural rigidity. Moreover, the composites require less maintenance and can be adapted to meet the specific requirements of each case performance, what allow more design flexibility. For military applications, composite materials offer the best features of the radar camouflage and good protection against shrapnel. During the last years there has been a growing interest in the marine industry for composite materials and their use for primary structures.

The primary structures are part of the structure that resists the longitudinal efforts of vessel. Fonseca [2] defines these efforts as the bending stresses along its length, which tend to establish the hull deformations called hogging and sagging. These efforts are most important to consider the structural study. Because of them is that the hull structure must be strengthened and more particularly robust along the length of the two regions further away from the longitudinal neutral plane of the vessel.

However, any part that composes the hull, ship draft, which is the proposed use of the sandwich panel of the present study, also will have to resist the secondary and tertiary efforts, helped by support structures and joints. It is noteworthy that we should not neglect the need to meet the basic conditions for the existence of a safe floating medium, namely, strength, tightness and buoyancy. In a preliminary assessment, sandwich panels with web, the inner panel joints, the joints between panels and support structures must have the structural capacity to meet the core requirements of vessels.

In the constant quest to beat themselves to growing challenges of industrial activity, the science and technology of materials evolved in surprising ways in recent decades. The emergence of composite materials was a natural to take advantage of desirable characteristics of different materials in one piece progress, giving the set properties, what isolation materials would not be possible to obtain. Wood and steel were gradually abandoned, then modifying the classical canon of the shipbuilding industry, causing a severely industrial revolution that changed the way the boats are designed and produced, says Di Bella [3].

Mouritz [4], in turn, reports that were the composites virtually unheard as a structural material is only used in "non-critical" applications. However, the military needs that arise in the context of World War II favored a slight breakthrough and composites have been used in the construction of small vessels of the U.S. Navy. With the observation of positive characteristics such as strength, durability and ease of repair, the application was extended to other types of military vessels of the 40s until the 60s. In recent years, the improvement of the design, fabrication and mechanical performance of composites of low cost have led to an increased use of composite materials for large patrol boats, hovercraft, minesweepers and corvettes, and there was a continuous evolution of length of warships built entirely of composite materials between the years 1945 and 2000.

In this direction, Romanoff [5] adds that the demand for lighter structures, safer and modular has stimulated the need to study new materials and structural configurations in the design and manufacture of marine structures. Another important fact is the possibility of the design of the composite can be integrated (simultaneously) on the structural component project. With this, we incorporate into the spiral design, proposed by Evans in 1959, the option to develop, for each single case, a structural component optimized to be applied to the particular condition of analysis.

For Atkinson [6] the main advantage obtained currently with the use of composite materials in manufacturing of sandwich panels for boats, compared with conventional materials (typically metal, wood or fiberglass) is the significant reduction of total system weight built. This reduction can achieve up to 50% for structural applications and 75% for non-structural applications, providing an increase of speeds reaching up to 50.0 knots (93.0 km/h) for fast ferries.

For this reason, weight reduction is one of the main design goals of a vessel and an important indicator of its quality. Rawsom [7], for example, sets the ideal design, i.e., the optimized design, as the one that can lead to the minimal structure in terms of weight, but capable of withstanding the loads imposed. Although the weight always has a significant aspect in assessing the feasibility of a vessel, the overall cost, which includes ease of manufacture and maintenance, is characterized as the main deciding factor. The cost of a project, for example, can increase quickly if non-standard sections or special quality materials are used. On the other hand, it may happen that the fabrication some material will be more difficult and more expensive due the machinery employed. Even so, it is possible to achieve economic viability of a project adopting administrative and managerial measures to enable the increasing standardization of elements to be used, improving the geometric optimization of parts depending on the specific internal forces, establishing a line of production to achieve economies of scale and, finally, structural systems to support the use of non-special materials and already established in the market, either in the same genre or similar applications.

Also under the design it is worth noting the consideration of Levy Neto [7], mentions that when the mathematical modeling of the mechanical behavior of composites is more difficult and labor intensive when compared to traditional isotropic structural materials (metal, for example). By technology consolidation, the latter allow relative ease in predictability of behavior by widely known methods.

2. Characteristics of the panel and general considerations of structural behavior.

The Figure 1 shows a three-dimensional image of the composite panel used in this study.

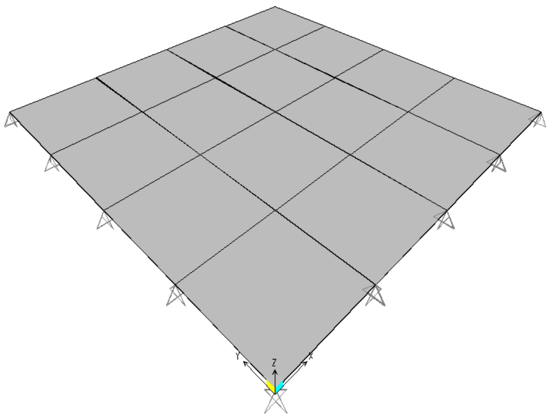

Figure 1. 3D Finite Element Model.

The board has webs in both directions, longitudinal and transverse. The analytical development will be carried out in the plan , considering the central cross section of the panel, so the section will only webs in one sense and will be supported on the sides, in encounters with webs. The geometry of the section can be seen in Figure 2.

For the skin plates, edges and webs, we adopted the fiber glass of reinforced type E, FRP. To fill the gaps in the core, we used the expanded polystyrene, EPS. Were also evaluated some other materials for forming the core as seen in Table 1.

From the point of view of the general considerations of structural behavior is important to mention that in a structure with web-core, web separating the skin plates. Webs are usually performed in only one direction and are spaced 10 to 100 times the thickness of the skin plate. Therefore, the webs in the core produce a continuous support for the skin plates in the longitudinal direction of the web and produce a stand supported on stretches in the transverse direction. Thus, the web-core panel is the highly orthotropic, says Romanoff [5].

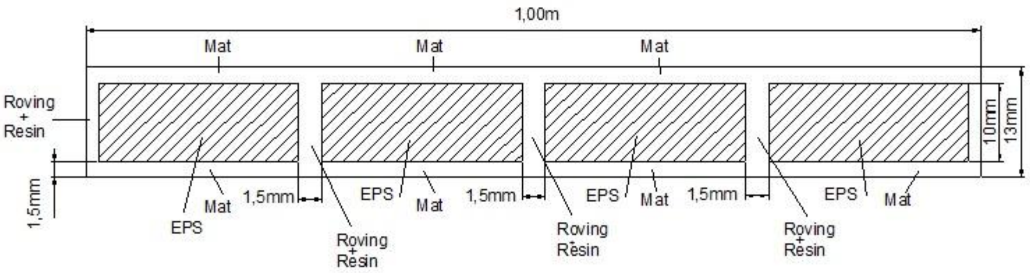

Figure 2. Geometry of the studied cross section.

Propriety	Renicell 240 (PVC)	Balsa LD7	Honeycomb PP30-5	EPS 3	EPS 3 with shear webs
Specific Gravity (kg/m³)	240	90	100	14	38
Compression Strength (MPa)	4.00	5.40	1.62	0.06	179.26
Compression Modulus(MPa)	131.00	1847.79	72.39	- -	151684.66
Tensile Strength (MPa)	3.30	7.00	1.21	0.12	206.84
Shear Strength (MPa)	2.50	1.60	0.52	0.06	75.84
Shear Modulus (MPa)	96.53	96.53	13.79	3.31	- -

Table 1. Mechanical properties of different core materials (Ribeiro, Wahrhaftig e Nascimento [1]).

According to Atkinson [6], the loads applied to a sandwich structure are supported by internal forces of traction and compression of the skin plate material. The core material when attached to the skin plates, transfers shear for surface materials, causing the sandwich to work as a homogenous structure. The web arranged thus provides integrity to the construction and has the important effect of stabilizing the coating materials. The result is that the materials disposed in the skin plates of the panel should have conditions to meet the structural requirements of high tension and compression. The conditions of use and other attributes regarding the final application of the product is that will determine the choice of materials to be used.

An important consideration which directly relates to the study with regard to the treatment of structural composite is made by Mendonça [8]. He states that when the behavior of a sandwich beam can be analyzed in a first approximation, with the use of classical theories of beams, since two precautions are taken: I- must, clearly, consider the different properties of the material involved, and II- must consider the effect of transverse shear in the deflections. This means that one should use the Timoshenko theory or higher-order in the transverse shear tract. As the transverse shear tract is not part of the scope of this now study, the possibility is complementation to the next job.

Another consideration that aligns with this study is established by Romanoff [5]. He says that the analysis of composite structures requires a homogenization of the panel section. The treatment by homogenization of the panel was first proposed by Libove and Hubka for corrugated core sandwich and by Holmberg for web-core sandwich. Since then, several authors have analyzed the web-core sandwich panel through this technique. The main benefit of this method is that the different elasticity or stiffness are transferred to a homogeneous equivalent stiffness of the sandwich plate, significantly reducing the number of unknowns of the problem of bending, simplified analyzes.

3. Mathematical solution and numerical simulation.

With the fulcrum in the geometry of the section proposed by Ribeiro, Wahrhaftig and Nascimento [1], were attributed to the cross section dimensions literal values, representing the unknowns of the problem relative a generic section, as shown in Figure 3. By Steiner`s theorem and taking as reference the median plane parallel to the *zx* plane of the cross section, were obtained the moments of inertia for the part of the panel formed by the skin plates as well for the core consisting by the filling material together with the boards and webs of the section.

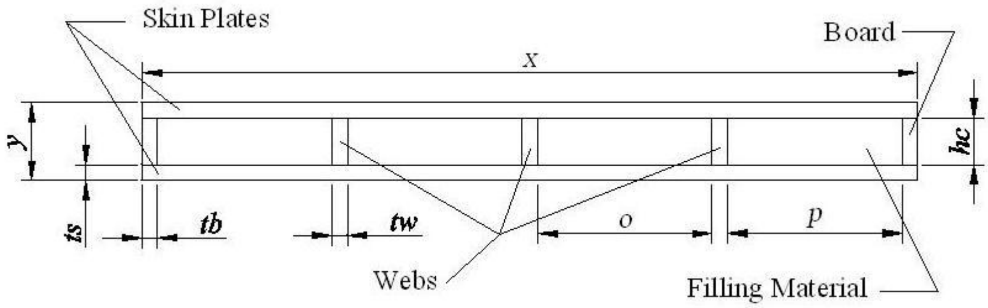

Figure 3. Parameters for the mathematical development.

Therefore, to the plates skin one has:

$$I_{TS} = 2\left(\frac{xt_s^3}{3} + \frac{y^2 x t_s}{4} - \frac{yxt_s^2}{2}\right) \tag{1}$$

To the lateral boards and webs one has:

$$I_{TW} = 2\left[\frac{t_b\left(y-2t_s\right)^3}{12}\right] + 3\left[\frac{t_w\left(y-2t_s\right)^3}{12}\right] \tag{2}$$

Finally, one has for the filling material:

$$I_{TF} = 2\left[\frac{o\left(y-2t_s\right)^3}{12}\right] + 2\left[\frac{p\left(y-2t_s\right)^3}{12}\right] \tag{3}$$

Once defined the inertias to homogenized section, was used the theory for bended pieces as stated in Timoshenko [10] for obtaining the equations to the maximum stresses to the different materials, as shown below.

$$\sigma_{x1} = \frac{My}{I_{eq}} \quad \text{and} \quad \sigma_{x2} = n\frac{My}{I_{eq}} \tag{4}$$

where M is the bending moment, I_{eq} the inertia of homogenized area, n the relation between the modulus of elasticity and y the variable in relation at the point of interest.

To evaluate the suitability and versatility of the equations developed in this work, have been done some numerical simulations. The loading conditions adopted also followed what was stipulated by Ribeiro, Wahrhaftig and Nascimento [1], with the adoption of a corresponding pressure to a water column with 2.0 m high. As the panel is square and its dimensions in plan are 1.0 m x 1.0 m, the total of the distributed linear load is approximately 20,000.00 N/m.
By the boundary conditions adopted one has a typical behavior of a beam in flexion simply supported at both sides. Therefore, the maximum bending moment is given by:

$$M = \frac{qx^2}{8} \tag{5}$$

where *q is* the loading rate and *x* is the span (or variable in this problem).

Thus, the maximum moment induced by loading is 2,500.00 Nm. As the cross section has two orthogonal axes of symmetry, the neutral line is located in the centroid of the section.

In the first simulation was varied the height core *hc*. By varying the height core also vary the distance from the skin plate to the neutral line and the height of the boards and webs. It was found that with the increase of the height core significantly increases the inertia of the composite, reducing the stresses in the material, Figure 4.

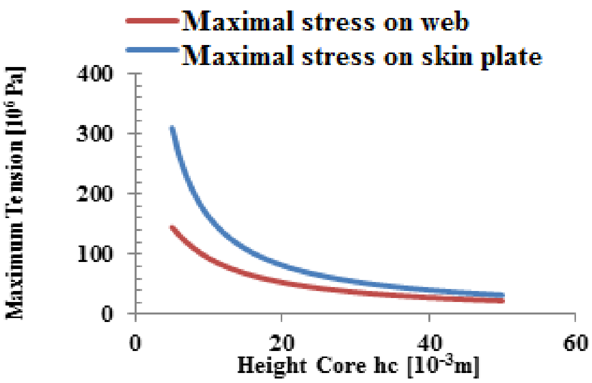

Figure 4. Simulation 1 – Variation of the height core *hc*.

The second simulation was performed by varying the thickness of skin plate. Increasing the thickness of skin plate, the stress drops rapidly and asymptotically, as can be seen in Figure 5.

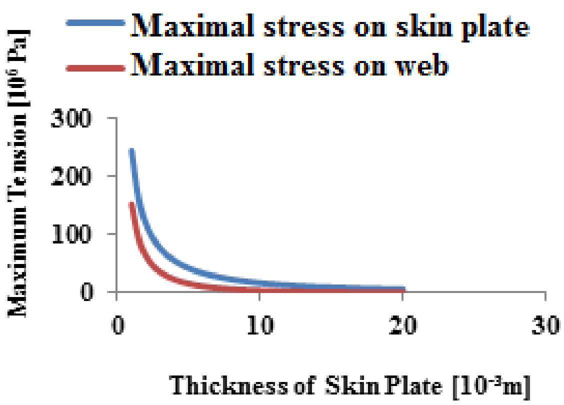

Figure 5. Simulation 2 – Variation of the thickness of the skin plate.

In the third simulation, ranged up the thicknesses of boards and webs, having their values been increased until 0.015 m. Unlike previous simulations, there was only a small variation of stress in the skin plate, lateral boards and webs, as can be seen in Figure 6. This occurred in function of a little "sensitivity" to bending of the elements that act compensating shear effort near the neutral line. For future studies, the analyzes of the shear stress can be magnified to these elements.

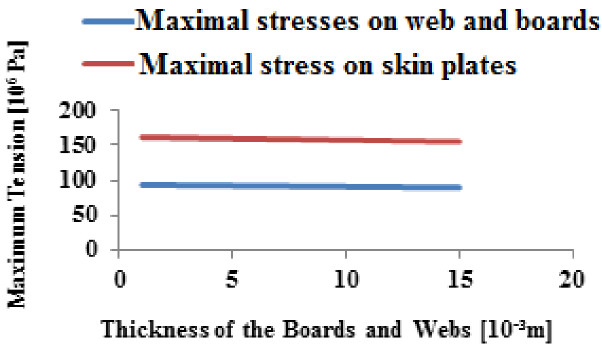

Figure 6. Simulation 3 – Variation of the thickness of the boards and webs.

In the last simulation it was decided to vary the length between supports. In this case, as there was an increase of the area that receives the distributed loading generated by the pressure from hydrostatic water column, it was necessary also to vary the total load in proportion to the area to keep the same load distributed. So that, the span was varied from 0.5 m to 2.0 m, and could be observed that the normal stresses increase as a quadratic parabolic function, as observed in Figure 7, which is in accordance with the provisions of Eq. (5).

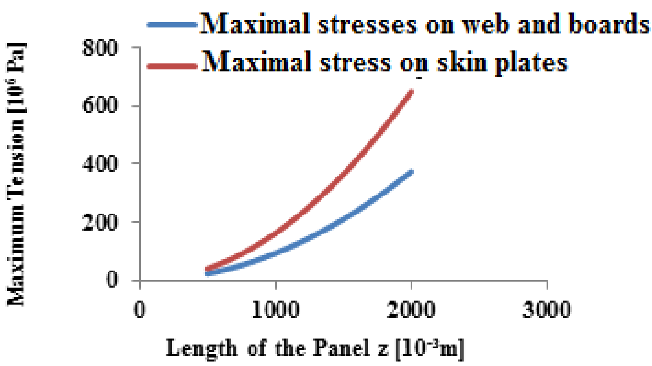

Figure 7. Simulation 4 – Variation of the length of the panel.

4. Final considerations

Essentially, to evaluate the behavior of structural components subject for bending is useful to examine the "sensitivity" of the stresses in function on the geometry of the elements. Particularly in applications involving composites, there is the peculiarity that in the same structural element, there are regions with different mechanical properties and distinct behaviors to be evaluated.

It is worth highlighting the importance of establishing, from the knowledge of material properties and geometry of the elements employed, an analytical formulation for determination of the normal stresses in bending, adopting typical conditions loading of marine engineering. It is noteworthy that the mechanical behaviors based on the classical theories of Solid Mechanics were confirmed.

The mathematical development based on the heterogeneous section theory allows to obtain equations relatively simple which produce reliable results and can be used for pre-dimensioning structural components of a vessel, before developing more complex computational models, decreasing the time of analysis, contributing for improving the quality and for reducing the final cost of the projects.

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