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A DESIGN APPLICATION OF CORED POLYSTYRENE COMPOSITE MATERIAL TO NAVAL CONSTRUCTION

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Abstract. This paper presents a study of the distribution of stresses and strains acting on a prismatic ferry that makes use of an idealized composite [1] to naval employment. The structural arrangement of the ferry is minimized in order to achieve the limit of the minimum dimensions and thicknesses able to resist deformation and maximum stresses. This minimum structural arrangement was chosen in order to study the limits of the recently developed material. Calculation of stresses and strains on the vessel is conducted with the aid of a software-based on Finite Element [2] and [3] method. In order to proceed to the stresses and strains calculations the ferry was subjected to different loading conditions: one of hogging and another of sagging, assuming the same load capacity in both situations. The basic structural arrangement adopted in a base composite element is formed by two faces and an expanded polystyrene core. Equally spaced shear webs connect both laminated faces. These reinforcements and both faces are laminated with fiber glass impregnated with epoxy resin. In defining the minimum dimensions of the elements a rule of thumb [4] is used in order to start to search for the modeling of the minimum geometry and generate the results. Results of stress distribution and deformation of the hull structure are presented. It is also computed the total weight of the structure in order to compare with another structural weight. So, these same dimensions previously defined for the ferry are also used to define a structure based in a core of Divinycell® to compare the total structural weight. At last, it is concluded that the present structure [1] has a weight consistent with the lower density Divinycell, but with a much lower price than the composite structure cored with Divynicell®.

1 INTRODUCTION

The possibility of developing a material able to maximize their strength and minimize weight has always attracted researchers in the field of shipbuilding. Throughout history it has been made available some materials that meet very well their high requirements of strength with low weight. It was from the search for these materials that have arisen composites like fiberglass, carbon fibers and Kevlar, all destined both to solid and cored construction.

Among these materials, fiberglass is surely the most popular and affordable cost. Although it has more modest requirements of tensile strength, modulus of elasticity and weight, its low cost makes it very attractive for shipbuilding.

The Kevlar® and carbon fibers have higher levels of tensile strength and modulus of elasticity. They have also the lowest densities. Specifically, the Kevlar® fiber (aramid) has the highest specific resistance measured by the ratio between the tensile strength and the specific weight. However, both options reach much higher levels of cost, making the decision about the best material dependent on the characteristic that one wants to optimize in each case.

To improve even more these requirements of each material in the solid construction is that it is usual to add a core in between two faces made with each one of these materials. There are several types of cores such as the honeycombs, balsa wood, divinycell, polyurethane, and other such as polystyrene, which will be applied to the structure of a prismatic ferry in this work. The composite material is made up of fiberglass impregnated with epoxy resin in the lamination of the external and internal surfaces separated by a core of expanded polystyrene. Several shear webs connect the faces.

2 PROBLEM DEFINITION

In order to make possible the production and analysis of results is that the composite is applied to the structural arrangement of a rectangular prismatic barge, which floats in calm and deep waters with the following main dimensions:

- length over all: 20.00 m,
- molded beam: 4.00 m,
- molded draught: 2.13 m,
- maximum draft: 0.50 m,
- displacement at full load: 41.0 tf,
- light draft: 0.023 m,
- light displacement: 1.812 tf,
- load capacity: 39.188 tf.

The base plate of composite material that covers the entire barge and bulkheads have their arrangement as shown in Figure 1 below, which shows a sheet of 1 meter long by 4 meters wide. In order to view all the details of the structural arrangement the drawing is not in true scale, it is just a sketch.

The ferry has eight compartments separated by seven watertight bulkheads. In order to simulate the conditions of hogging and sagging is that the ferry will have four of its compartments alternately loaded, once its extreme compartments, after its central compartments as shown in Figure 2.

As implied by the load capacity and molded draft above, there is a load distributed at the bottom of each loaded compartment of 0.9796 tf/m², and a hydrostatic pressure at the bottom and in the wetted side. The Figure 3 shows the hydrostatic pressure acting on the side and on the ferry´s bottom. For these loading conditions is that the distributions of stresses and strains in the structure of the ferry will be calculated.

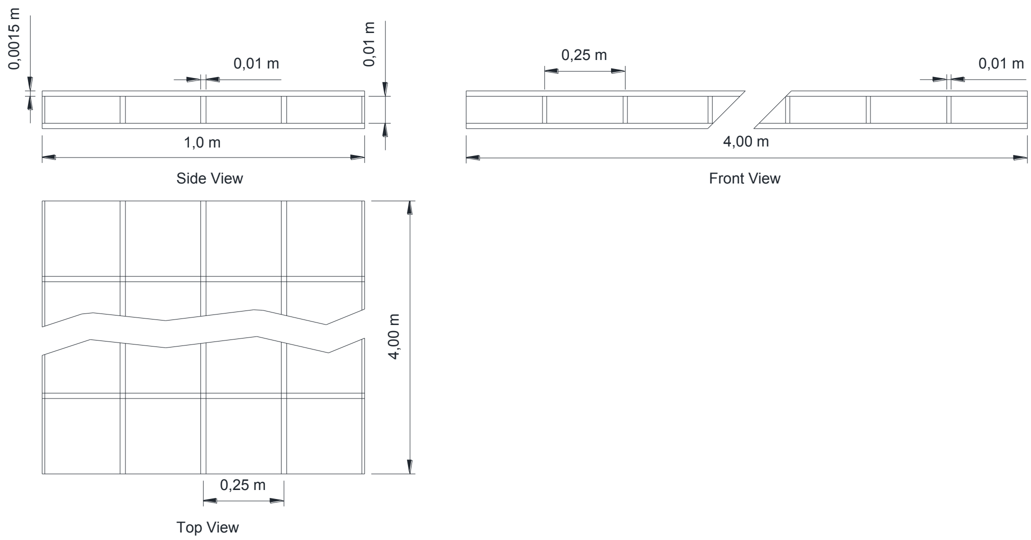

Figure 1 – Structural Arrangement of the base plate element

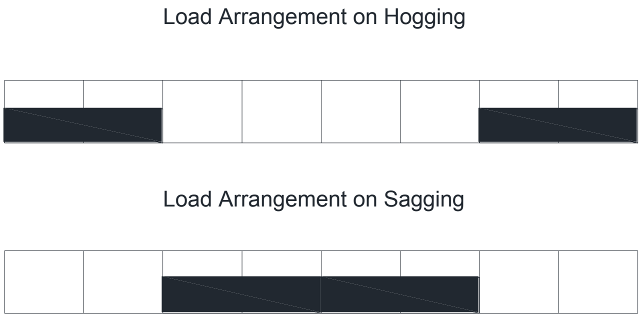

Figure 2 – Load Arrangement on the two simulations

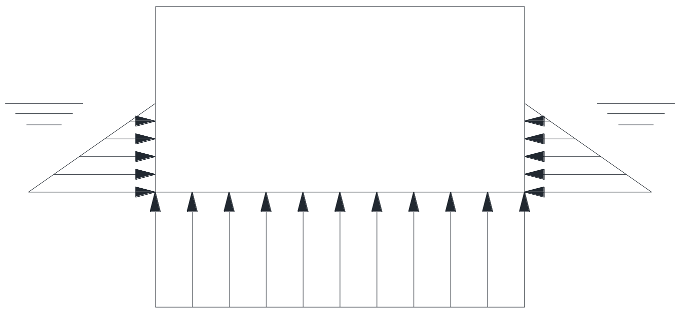

Figure 3 – Hydrostatic Load acting on the Hull

3 COMPUTATIONAL SIMULATION

3.1 Structural arrangement and geometry

The geometry of the vessel considered in the computational simulation of the problem is for a prismatic rectangular ferry of 4000 mm of breadth, 2013 mm of depth and 20,000 mm of length overall. The hydrostatic pressure of the water acting on the vessel´s side and bottom is due to the draft and was considered with a height of 500 mm. From Figure 4 to Figure 6 it is showed the geometry and dimensions of the idealized vessel and the height of the water pressure.

Figure 4: Cross section of the boat and height of water column – dimensions in "mm"

Figure 5: Side view and dimensions of the prismatic vessel – dimensions in "mm"

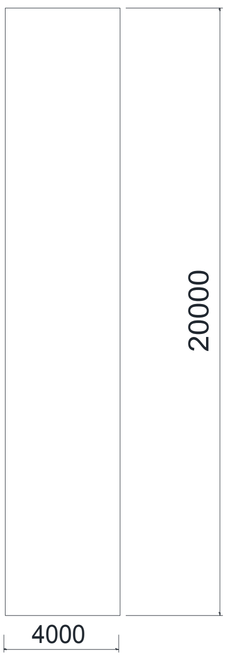

Figure 6: Top View – dimensions in "mm"

3.2 Computational modeling

The computational modeling was based on the finite element method [2], [3] and the vessel was represented by 35183 Solid elements. The Solid element is an eight-node element for modeling three-dimensional structures and solids. It is based upon an isoparametric formulation that includes nine optional incompatible bending modes. The incompatible bending modes significantly improve the bending behavior of the element if the element geometry is of a rectangular form.

A 2 x 2 x 2 numerical integration scheme is used for the Solid. Stresses in the element local coordinate system are evaluated at the integration points and extrapolated to the joints of the element. An approximate error in the stresses can be estimated from the difference in values calculated from different elements attached to a common joint. This will give an indication of the accuracy of the finite element approximation and can then be used as the basis for the selection of a new and more accurate finite element mesh [5].

The Solid element model is a general state of stress and strain in a three-dimensional solid. All six stress and strain components are active for this element. The Solid element stresses are evaluated at the standard 2 x 2 x 2 Gauss integration points of the element and extrapolated to the joints [5]. See reference [3] for more information.

For that reason, the vessel was divided into eight internal compartments, with bottom and deck in the same dimensions. Watertight bulkheads that divide the compartments can be seen in Figure 7, while the side walls, deck, bottom and front cover are as shown in Figure 8. There is a hydrostatic pressure (Surface Pressure Load) acting on the wetted side of the vessel with linear variation through the 0.5 m of water column. This preliminary deformation of the side walls is showed in Figure 9.

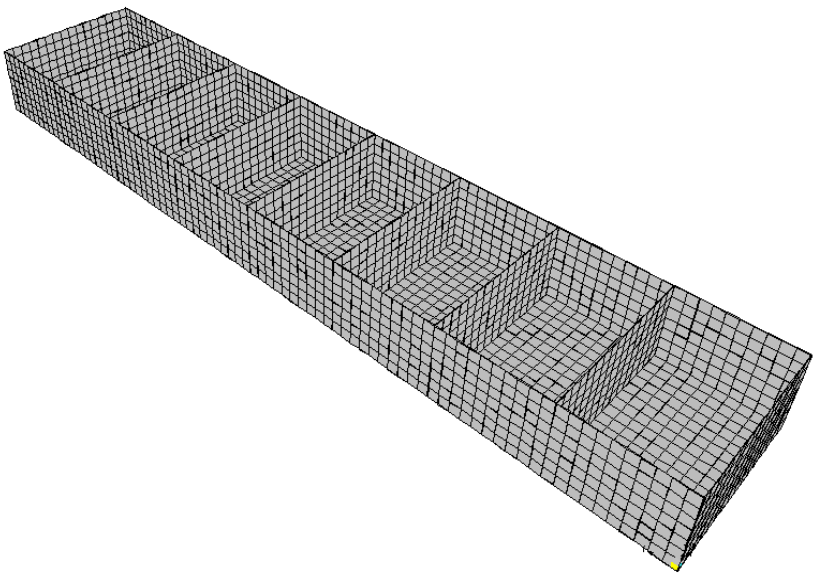

Figure 7: Partial model of the boat – Internal view

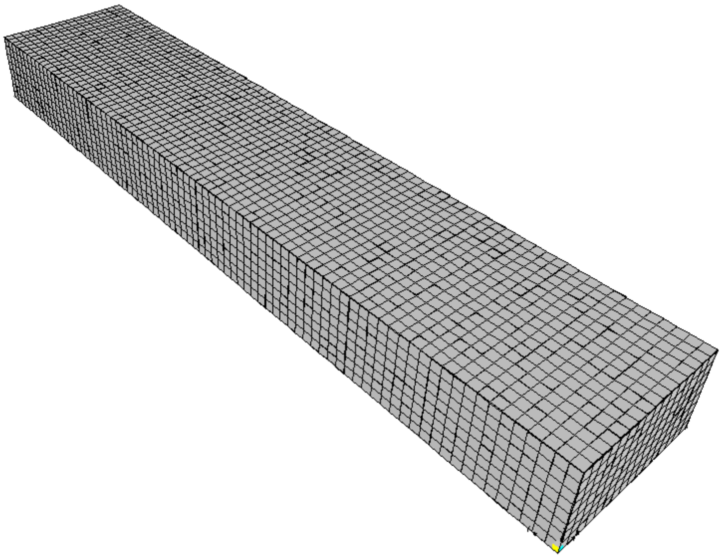

Figure 8: Complete model of the closed vessel

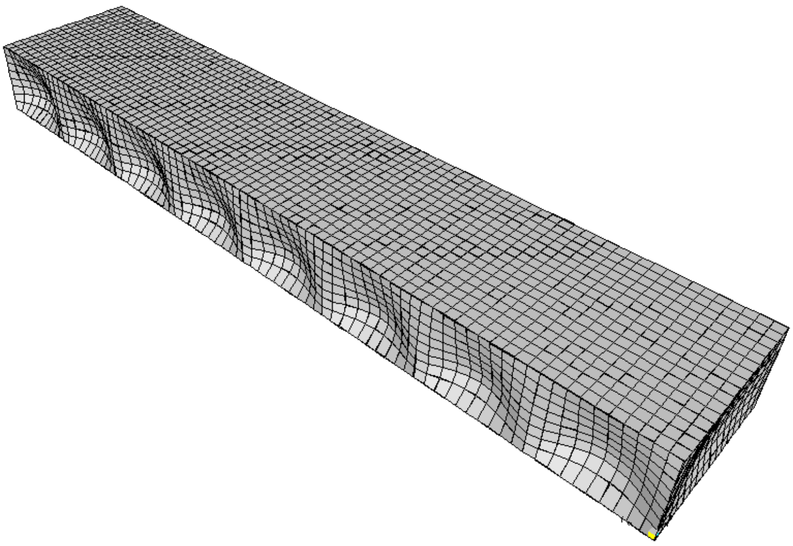

Figure 9: Deformed side of the structure by external pressure – Complete model (no scale)

4. RESULTS

Results were generated considering two different loading conditions, one of hogging and another of sagging. So in the figures to come it will be used the following nomenclature:

COMB1: Hogging, which means that the four extreme compartments are loaded with the same draft of 0.5 m deep.

COMB2: Sagging, which means that the four middle compartments are loaded with the same draft of 0.5 m deep. Both loading conditions are represented in Figure 2.

Results are presented for the stresses and strains acting in the whole vessel, that is, bottom, deck, sides, front and back cover.

So, for COMB1 and COMB2 the results for the maximum tensile stress in the deck and bottom are presented in table 1.

Regarding the results of the deformed structure, results of maximum strain obtained by the software shows 66 mm due to hydrostatic pressure at the front cover (Figure 12) and 30 mm for the sides (Figure 13). Table 1 condenses these results of stresses (C = Compression; T = Tension) and Table 2 for the strains. Table 3 shows the mechanical properties of interest for fiberglass impregnated with epoxy resin.

Table 1: Maximum Stresses

Condition	Max. Tensile Stress (Deck)	Max. Tensile Stress (bottom)
COMB1 (Hogging)	55 MPa (T)	343 MPa (C)
COMB2 (Sagging)	159 MPa (C)	628 MPa (T)

Table 2: Maximum Strains

Position	Maximum Elongation
Sides	30 mm
Front Cover	66 mm

Table 3: Mechanical Properties of interest for fiberglass with epoxy resin [7]

Property	Value
Tensile Strength	715 MPa
Compressive Strength	570 MPa
Shear Strength	70 MPa
Poisson´s Ratio	0.22

The overall deformation of the vessel in both loading conditions of hogging and sagging are sketched in Figure 10 and Figure 11. Maximum value in the first loading condition was of 22mm, while for the second it was of 30 mm. It is to be observed that epoxy resin impregnating fiberglass can elongate up to about 5 %. Maximum relative observed sag was of 2.6%. Remembering that it was tried to maintain all dimensions of the structure minimized.

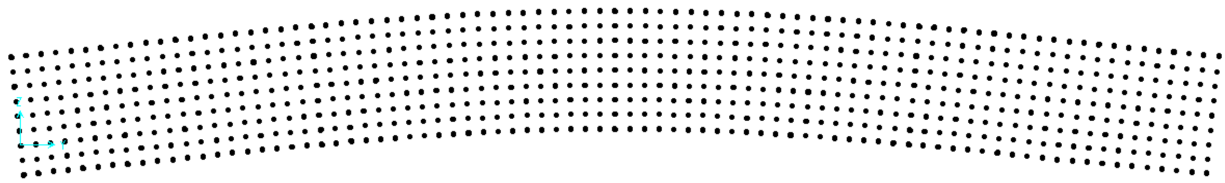

Figure 10: Deformation in Hogging – 22 mm

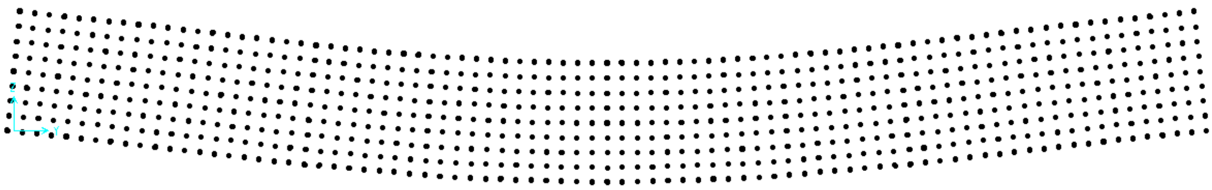

Figure 11: Deformation in Sagging – 30 mm

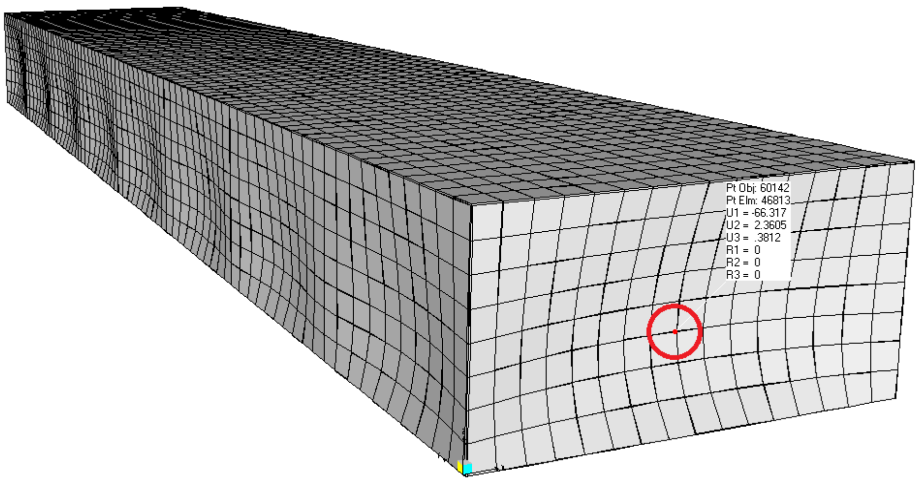

Figure 12: Deformation from pressure – Front Cover – 66 mm

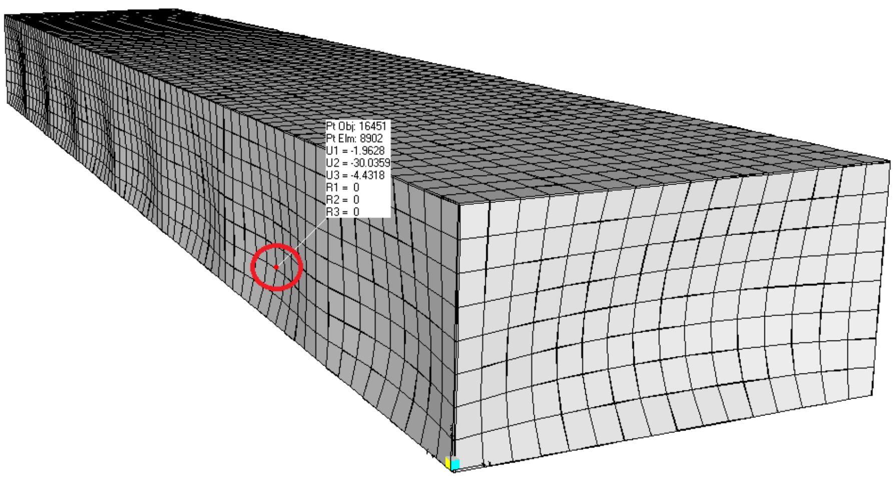

Figure 13: Deformation from pressure – Side – 30 mm

5. WEIGHT COMPARISON WITH A DIVINYCELL® STRUCTURE

Section 4 shows several good results obtained for a structure that was thought to be in their minimal dimensions. But it is also desirable to make some comparisons with other commercial materials.

It is made here a comparison of the total weight of this structure to the same structure, cored with Divinycell®, which is a very used commercial core material. There are several densities of Divinycell®, but the lowest density was chosen for comparison.

A comparison of stress and strain results would also be desirable, with another structure cored with Divinycell®, for example, but this was not done. An additional computer simulation for the distribution of stresses and strains in the material would consume another amount of time, which could impair the publication of the article.

However, it is fully possible to compare the weight of the two structures. The calculated weight to the present vessel, using expanded polystyrene was previously mentioned and is equal to 1.816 tf.

As the ferry is prismatic in all directions, its light weight can be calculated for each linear meter of the structure. Figure 14 shows 1 linear meter of the Divinycell base plate. It is to be noted that the thicknesses of the internal and external faces in the Divinycell® structure are equal to the ones at the base plate employing expanded polystyrene as the core, as well as the thickness of the core itself. The only noticeable difference is that the reinforcements at the Divinycell® structure are external to the plate.

The Divinycell® plates are available with various densities from 38 kg/m³ to 250 kg/m³. Adopting the lower density, it can be listed the following weights that make up the plate of 1 m long x 4 m wide:

- Divinycell® plate 1 m x 0.01 m x 4 m = 1.52 kgf,
- weight of external reinforcements in the transverse direction = 1.03 kgf,
- weight of external reinforcements in the longitudinal direction = 1.03 kgf,
- internal / external fiberglass faces of the plate = 21.6 kgf,
- inner lining of reinforcements (Divinycell®) = 0.12 kgf,
- total weight = 25.3kgf.

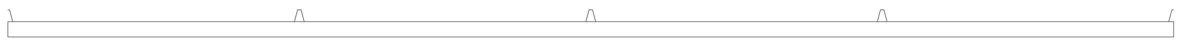

Figure 14 – Base plate using Divinycell®

The arrangement of the expanded polystyrene base plate is the same, but there are internal reinforcements, instead, and there is no need to soften the reinforcements, giving them the trapezoidal form, just like in the Divinycell® plate. So, the weight of linear meter of expanded polystyrene plate of the base structure is:

- Base polystyrene plate core 4 m x 1m x 0.01 m = 0.56 kgf,
- weight of the inner glass fiber reinforcements = 5.76 kgf,
- internal / external fiberglass faces of the plate = 21.6 kgf,
- total weight = 27.9 kgf.

Note that the weight of the two structures is approximately equal. However, the lower density of Divinycell has much more limited use than the high, and has much higher price than the structure that uses the polystyrene, once the present plate has insignificant price compared to the price of the Divinycell® plate [6].

6. CONCLUSIONS

Stresses and strains acting on a prismatic ferry reinforced with sandwich fiberglass panels were numerically simulated. Results of stress and strain along the vessel were produced, showing that all stresses and strains were inside the limits of the mechanical properties of the material, although the structure was kept next to minimal. So, some deformations next to the limiting strain is totally acceptable. The same can be said about the level of the stresses.

When comparing the weight produced with a similar structure using a core of Divinycell® of 38 kg/m³ dense, it was observed that the weight of the present structure is very close to the weight of the structure using Divinycell®. Although expanded polystyrene is about 33% of the specific mass of Divinycell®, fiberglass shear webs makes the weight of the present structure a bit higher.

Although the present material makes a structure a little heavier, the less dense Divinycell® also has lower mechanical properties, and if this was analyzed, maybe this density was not used.

This material was also analyzed just after the register of the patent [1] in 2013 [8]. Now and then it was showed that it is light and stiff, although expanded polystyrene has very poor mechanical properties. Shear webs reinforce the weaknesses of the expanded polystyrene, mainly shear strength.

At last, the presented composite material is becoming a good option for construction of small and medium sized vessels. The research is to be continued with an experimental investigation about mechanical properties and about the variation of the resistance to impact loads in function of distance between shear webs.

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