Composite Solutions for Deck Catamarans

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The paper is treating the strength analysis of the main deck structure of an inland navigation catamaran for 30 passengers. The main deck should have high stiffness and high strength to resist to external loading and endure high stresses from combined bending and torsion loads. Different materials for sandwich structure of the deck have been analysed by using the Finite Element Method in order to determine the solution which accomplish better designing criteria regarding allowable stress and deformations and total weight.

Key words: sandwich composites, shipbuilding, FEM modeling

The beginning of the 21st century is the era of using unconventional materials like composites. In the special fields, like transport means, where the weight is a very important parameter, the using of lightweight structures is a challenge that allows achieving good performances.

A major step forward in shipbuilding shows that it is now technically possible to build ships, whose structure can be totally or partial made out of advance materials such as carbon or glass fibre, while meeting classification societies' safety requirements [1,2].

Composite materials also bring other advantages, like a reduced cost for maintenance (plastic materials do not rust) and an increased life cycle of the vessel.

As far as the new materials demonstrates the good characteristics and many benefits specific for ship, shipbuilders have to keep up with the new materials construction technologies and methods are concerned.

In the future do to research extension will be developing some more advances designed to not only to increase the performances of ships but to also create safer, more effective vessels.

Main composites advantages versus metallic materials (unlimited choice of material, high range of mechanical characteristics, light material, absence of corrosion and good ageing behaviour in marine environment, non magnetic property, low thermal conductivity, high electrical resistivity, transparency to electromagnetic waves, low attenuation of acoustic waves) recommend them to be used, prior to steel.

Until now, composites applications on ships are used for: superstructures, decks, watertight doors, hatches, tanks, masts, rudders, rudder stocks, fins, hand rails, gratings, waterjet tunnels, propellers, shafts line or also for ship repair (e.g. SPS system) [3,4].

The most used composite structures are made as sandwich type which is a special class of composite materials that is fabricated by attaching two thin but stiff skins (usually high stiffness laminate that is to meet the required strength) to a lightweight but thick core (with generally low strength). The high thickness of the core very often can provide high bending stiffness with a low density material.

In [5] the fundamental mechanical properties, including stiffness, strength and fatigue performance of the composite structures used in marine applications are studied. The structure was optimized to be stiffest and strong enough to have a significant factor of safety upon the design load.

Sandwich structures have to be analysed to obtain an optimum design for transferring bending loads and can be either metal structures (built of aluminium skins and honeycomb or metal-foam cores) or polymer structures (built of composite skins and polymer foam cores). In [6] analysis to soften stress concentration in areas of the catamaran deck to fatigue-induced cracking due to operational loading is performed. Since laminate and core have different thickness and Young's modulus, the flexural rigidity is often used to describe the sandwich overall elastic property.

The classification societies (BV, ABS, DNV-GL) [7-10] are concerning requirements according to the numerical calculus of catamaran decks. The analysis includes evaluation of wave loads for particular sea conditions, ship hull stress occurred due to waves and structural responses.

In order to compare the importance of material selection on the final ship design, this paper analyzes seven building media (steel, aluminium and five composite sandwiches) when used in the construction of the main deck.

The deck is designed to conform to accepted Rules requirements and standard building practices. The design of the ship hull starts from a scantling according to classification societies requirements and can be followed by a finite element structural analysis, for further improve.

For the sandwich structural design, as design parameters are used: material properties for skins and core, thickness of the skin and core, ratio of skin thickness/core thickness, fiber orientation angle. In this paper, the deck stiffness and strength is the priority for the sandwich design. The sandwich skin should have high stiffness and high strength to resist to external loading and endure high stresses from bending.

Deck description

This study of the deck structure of an inland navigation catamaran for passengers is performed by considering different material types. Because the target is to obtain the small draft and relatively high speed, these characteristics can be obtained by reducing the total light ship weight by using as much as light materials. The passengers are carrying in a salon placed on main deck and in another open salon on upper deck (fig. 1).

For the flexibility in deck arrangements, the pillars or other similar supporting structures have been avoided, the structure being supported only on the outline of the deck.

One of the most important advantage using sandwich composite (with core made out of polyester, foam of

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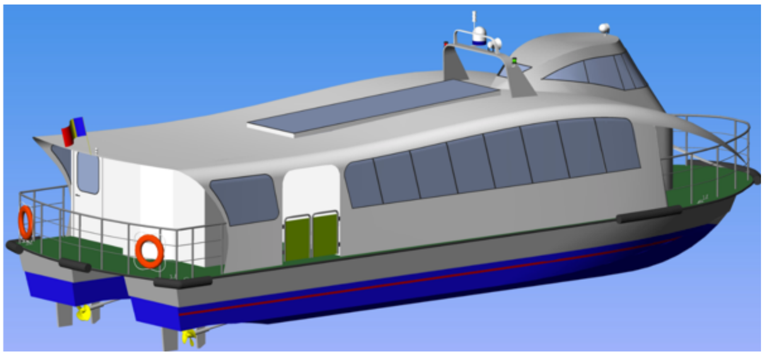

Fig. 1. Inland navigation catamaran made out of composites

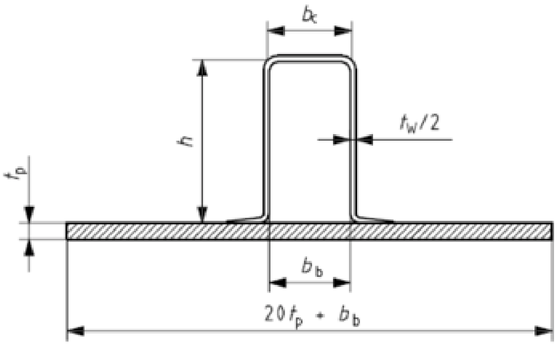

Fig. 2. Geometry of the transverse section [5]

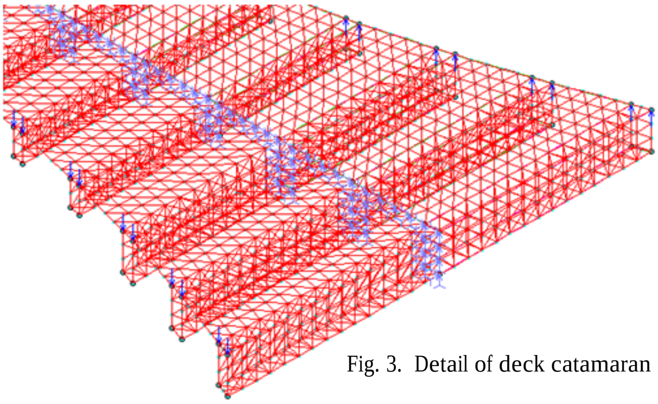

Fig. 3. Detail of deck catamaran

Table 1

STIFFENERS CHARACTERISTICS AND LOADS

Type	Frame	Fi
		[N]
U150x75x5	0-2, 19-22	-3433
U40x40x5	3-18	-28
U250x100x5	23-25	2543

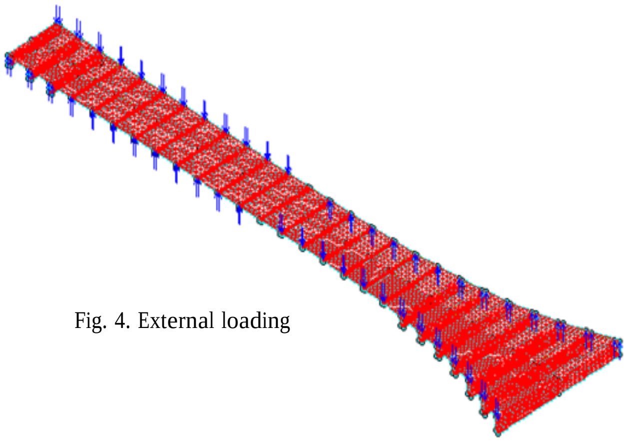

Fig. 4. External loading

polymers) is related to achievement the stiffness so that to remove the internal stiffeners. The stiffness is the most important factor of the catamaran panels to assure a good weight penalty.

The deck structure is a panel stiffened with transverse stiffeners. The deck is extended from frame No.0 to frame No.25. The geometry of transversal stiffeners is tall top hat, built according to [5] as illustrated in figure 2.

The initial deck structure is a panel concerning a plate of 24 mm with transversal stiffeners (figs. 3 and 4).

In order to obtain a light structure, the following material versions for deck have been analysed:

M1 - Whole structure made out of steell E_x=210 GPa; μ_{xy}= 0.3

M2 - Whole structure made out of aluminium E_x=69 GPa; μ_{xy}= 0.33; G_{xy}= 27 GPa

M3 - Plate made out as sandwich. The sandwich core made of honeycomb, sandwich skins and stiffeners made of Epoxy - Eglass - Wet.

M4 - Plate made out as sandwich. The sandwich core made of PVC - Foam_60 kg/m^3, sandwich skins and stiffeners made of Epoxy - Eglass - Wet

M5 - Plate made out as sandwich. The sandwich core made of PVC - Foam_80 kg/m^3, sandwich skins and stiffeners made of Epoxy - Eglass - Wet

M6 - Plate made out as sandwich. The sandwich core made of SAN - Foam_81 kg/m^3, sandwich skins and stiffeners of Epoxy - Eglass - Wet

M7 - Plate made out as sandwich. The sandwich core made of SAN - Foam_103 kg/m^3, sandwich skins and stiffeners made of Epoxy - Eglass – Wet.

The thickness of the stiffeners is of 5 mm.

For the versions with sandwich system for the deck plate, the core has the thickness of 20 mm and the skins thickness is of 2 mm.

For all versions, the dimensions of the stiffeners are described in table 1.

Fem analysis

The 7 structural material versions have been analyzed in static loading by using Ansys [11] package, to investigate the gain in weight reduction by fulfilling the Rules criteria regarding deck deflection (from serviceability reason was limited to 10 mm) and stress.

The loading resulting from torsion of catamarans in oblique waves was reduced to punctual forces placed at the end of each transverse, as it is illustrated in figure 7. The values of these forces, notted with F_i, are illustrated in table 1.

The mesh of the structure model has 3862 elements: SHELL 3L with one layer for modeling the stiffeners and SHELL 3L with three layers for modeling the deck plate sandwich. In table 2 the material characteristics for each type of material used in analysis are presented.

Along the symmetry plane of the deck structure, boundary conditions have been considered as: anti-symmetry conditions.

In table 3, the maximum vertical displacements, the highest equivalent stress and the mass for each material version are illustrated. As it is seen, the structure M1 (steel structure) has the smallest maximum displacement, equal to 0.109mm.

Among the structures with sandwich system (M2-M7) the smallest value of maximum displacement is 4.2361 mm, for M5 (sandwich core made of PVC - Foam_80 kg/m^3, sandwich skins and stiffeners made of Epoxy - Eglass - Wet).

In figures 5, the areas with the maximum displacement and stress map for M5 structure are illustrated.

	Material	Characteristics
Layered structure of stiffeners, Sandwich skin	Epoxy - Eglass - Wet	E_x=3500 MPa E_y=E_z=9000 MPa μ_{xy}= μ_{xz} =0.28; μ_{yz}=0.4 G_{xy}= G_{xz} =4700 MPa G_{yz}=3500MPa; ρ=1850 kg/m^3
Sandwich core	Honeycomb	E_x=1MPa; E_y=1 MPa E_z=255 MPa μ_{xy}= 0.49; μ_{xz} = μ_{yz}=0.001 G_{xy}= 1 MPa; G_{xz} =37 MPa G_{yz}=70 MPa ρ = 80 kg/m^3
	PVC - Foam_60 kg/m^3	E_x=102MPa μ_{xy}= 0.3; G_{xy}= 39.231MPa ρ = 60 kg/m^3
	PVC - Foam_80 kg/m^3	E_x=70 MPa; μ_{xy}= 0.3 G_{xy}= 26.923 MPa ρ = 80 kg/m^3
	SAN - Foam_81 kg/m^3	E_x=60 MP; μ_{xy} = 0.3; G_{xy}= 23.077 MPa ρ = 81 kg/m^3
	SAN - Foam_103 kg/m^3	E_x=85 MPa; μ_{xy} = 0.3 G_{xy}= 32.692 MPa ρ = 103 kg/m^3

Table 2
MATERIALS CHARACTERISTICS

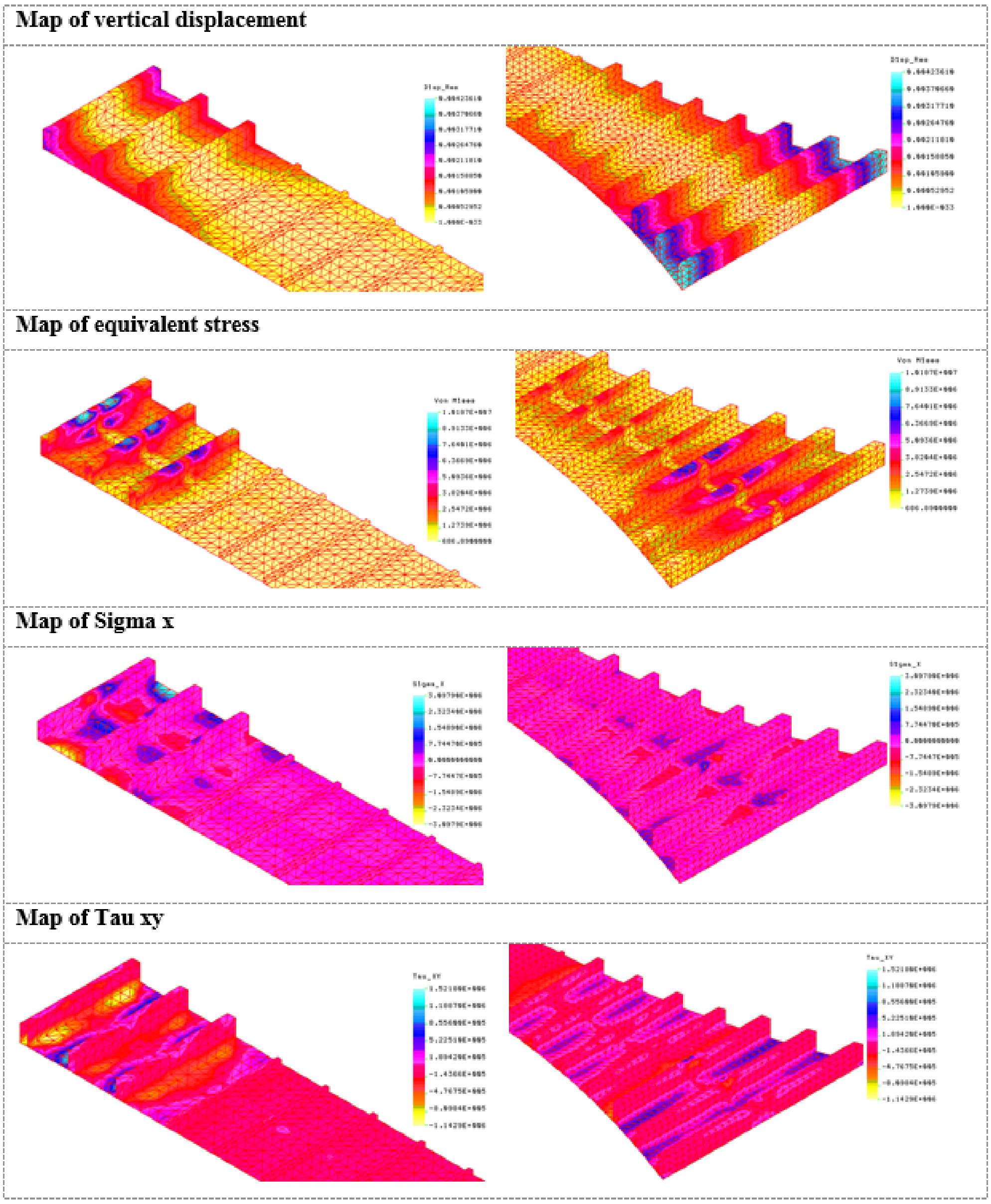

Fig. 5. Map of displacements and stresses in the hot spot areas

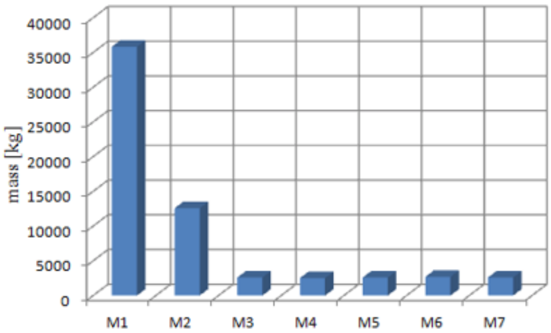

Fig. 6. The variation of mass versus type of deck structure

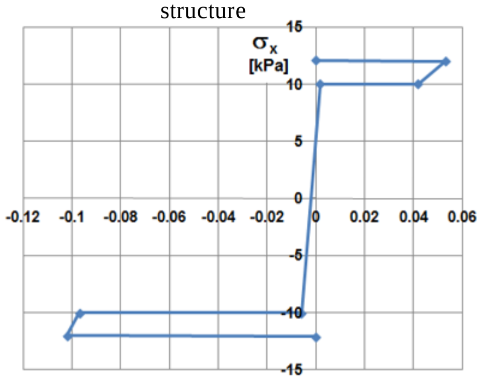

Fig. 7. The variation of normal stresses (σ_x) in the point with the maximum equivalent stress

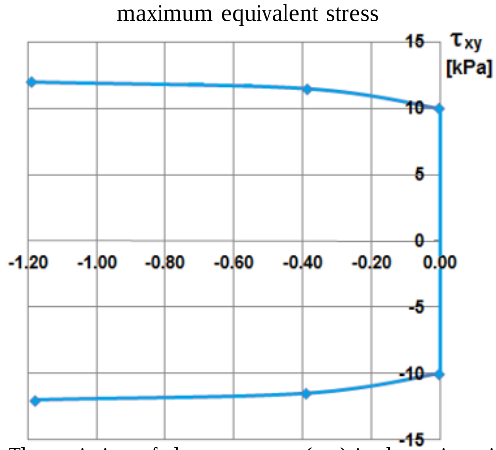

Fig. 8. The variation of shear stresses (σ_{xy}) in the point with the maximum equivalent stress

In figure 7, the variation (in KPa) along plate thickness (24 mm) of the normal stresses (parallel with x axis) is illustrated. As it is seen, a leap of 0.0402 KPa in the stress variation in the skin-core interface is seen.

In figure 8, the variation (in KPa) along plate thickness of the shear stresses (in plane xy) is illustrated. As it is seen, a leap the stress variation between the skin-core interfaces is constant in the core.

Conclusions

Following to the FEM analysis, the results obtained for the 7 deck structure versions to the external loading have been presented.

By comparison with the metallic structures it is observed that the using of the composite sandwich versions leads to a structure having the performances: lighter (M5) and stiffer for the same dimensions, and off course a better strength. Additionally, the operation and maintenance cost of the vessel is to be analysed. Layered composites for skins are applied to fully utilize the strengths of the intrinsic components while minimizing any compromise resulting from inherent properties of any one of the elements. By using optimizing techniques and arranging composites during design, the resulting structure will be better suited and with good performances not only for ship deck application, than selecting a single material, such as aluminum or steel. When the sandwich composites are selected, the reinforcements, like transverses or other type of stiffeners, can be removed.

Table 3

MAXIMUM VERTICAL DISPLACEMENTS, EQUIVALENT STRESS AND MASS

Version	w_z [mm]	Equivalent stress [MPa]	Mass [kg]
M1	0.10911	9.5645	3584
M2	0.33093	9.5257	1257
M3	4.3406	10.249	260
M4	4.2682	10.206	251
M5	4.2361	10.187	260
M6	4.2784	10.212	269
M7	4.253	10.197	260

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