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CHARACTERISATION OF FIBRE GLASS PANELS FOR NAVAL USE

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ABSTRACT

This work examines the characteristic of fiber glass composite panels constructed by Cantieri Arturo Stabile in Trapani (Italy): composite materials are very used in the naval applications, where high stiffness and resistance are required with reduced weight. Experimental tests are executed following ASTM or UNI EN rules, in particular the shear test is executed using a rig constructed to the purpose, designed following the rule *ASTM D 4255-83*. Besides the tests were simulated by analytical methods, by means of Cadec software and numerically by FEM software as *Altair Hyperworks* and *Ansys*, to evidence the error range of the experimental test and to obtain the configuration that can give suitable results also for more complex designs.

The successive phase of optimization is useful to obtain a reduction of the thickness, without compromising the resistance, for a consequent reduction of the production cost and energy saving of the boat during its use.

1. INTRODUCTION

Composite materials are very used in the naval applications, where high stiffness and resistance are required with reduced weight. The characterization of the used panels and the knowledge of the load configuration of every structural part permit the substitution of the common material with FRP composites, in order to exploit the strongly directional mechanical properties. In fact, laminates having the wished behavior may be obtained varying the fiber orientation.

The panels examined in this work are produced by means of a stratified handling process (*Hand-Lay Up*). The glass fibers, having length 25 – 50 mm, containing dry mats, *Chopped Strand Mat (CSM)*, are joined by a binding in order to form a single ply; their length is very little with regard to total one of the handmade; they are oriented in a random way, but are always arranged parallel to the plane of the same ply. The percentage in volume is 25-30% about. The matrix is constituted by polyester resin TS (*thermo set polymers*), consolidated by reticulation.

The experimental executed tests were: traction, shear, interlaminar apparent shear and bending. Because suitable standardization rules are missing for test on random laminates, tests are executed applying the existing rules on composite materials with unidirectional fibers, relatively to specimen dimensioning and to formality of test execution. Used test machines are *Hounsfield* and *MTS*, respectively with load cell 20 kN and 400 kN; a set realized for the shear test (*Shear Test - Method B*) is also used with grasping for specimen shaped on purpose and a central guide for the loading; other sets are used for traction, interlaminar apparent shear and bending. The following elastic characteristics are determined: Young modulus, longitudinal resistance modulus, transversal elasticity modulus, the sliding stress (delaminating), elastic modulus and ultimate strength in bending.

The simulations are executed by Finite Element Method; the used software are: *Altair Hyperworks* to mesh the structures and *Ansys* for the optimization. In relation to geometry of the structure and to the phenomena that are examined, the chosen element is “*shell 91*” with eight nodes for the composite laminated analysis.

2. SHEAR TEST

2.1 Experimental Characterisation

The shear experimental test is executed with refer to rule ASTM D4255-83 [10]. The method can be applied as to laminates with random fibres, as to unidirectional ones. Following the rule, a set was constructed on purpose, enabled to exercise, on the specimen conformed on purpose, a pure shear stress field in both the central free zones. This set is constituted by a base, where are fixed two lateral support, everyone presenting three equidistant holes and a central guide, also it holed, enabled to slide for some millimetres perpendicularly to the base.

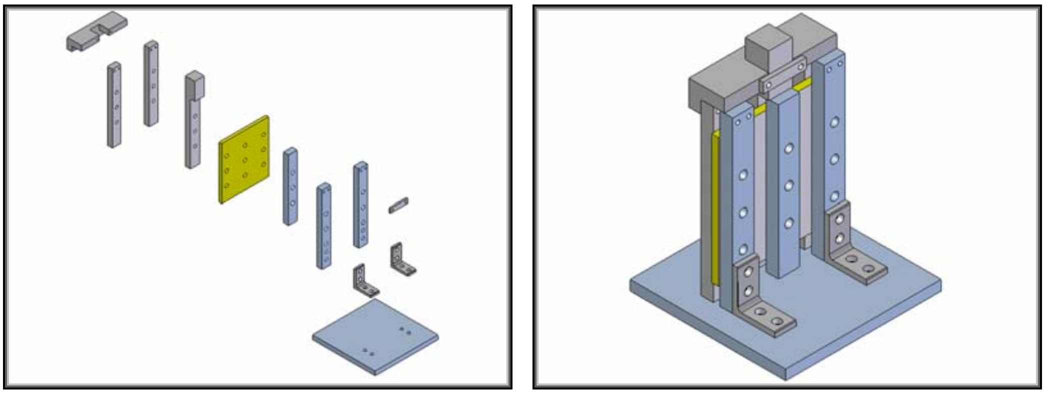


Fig. 1 - Set “*Shear Test Fixture B”*,

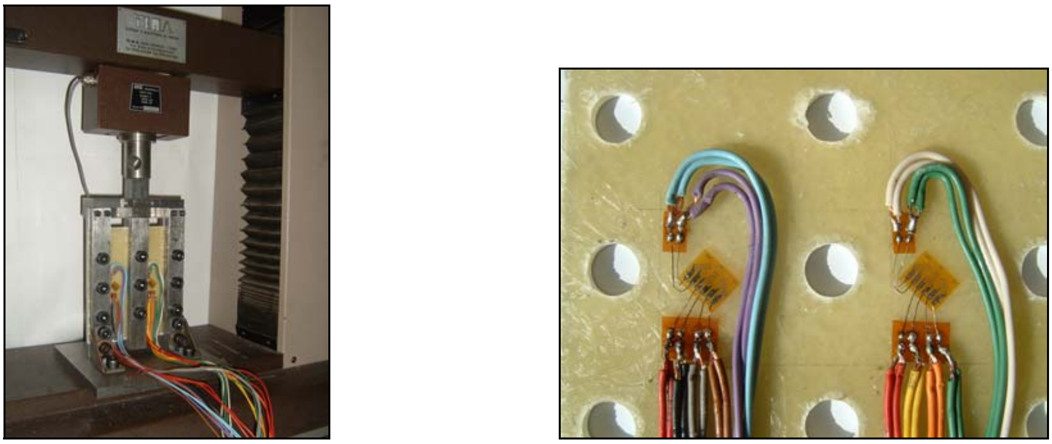


Fig. 2 - Shear test and equipped specimen

The guides tighten the specimen, reporting nine holes by milling machine; in this phase the contact has to occur exclusively for the friction produced by the tightened of the bolts. In the specific case the preload torque was calculated equal to 90 Nm, which value was guaranteed by a dynamometric spanner.

The load was applied by *Hounsfield* machine (Fig. 2) with a speed 1,5 mm/min; it acts in compression on the head of mobile central guide. To acquire properly the strains the specimen are equipped with two rectangular rosettes *E1-30-125RD-350*; all the positioning errors have been offset. The readings are obtained by the *UPM 100* central unit connected to all the grill.

Figure 4 shows the obtained load-strain curves, and table 1 the extra poled value of the shear modulus.

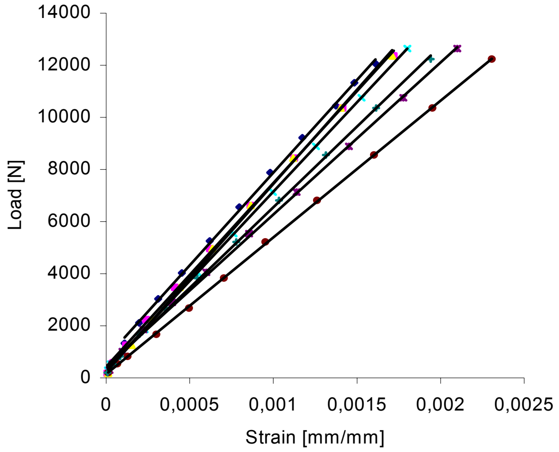


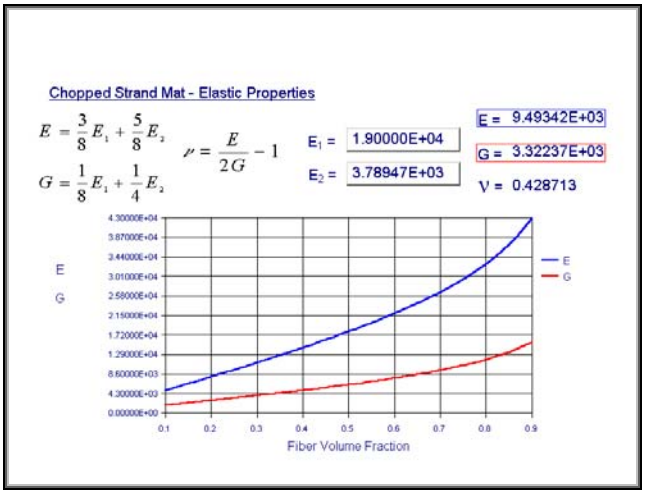
Fig. 3 - ”load-strain” diagram for shear modulus

	Shear Modulus G_{12} [MPa]	
	ER on the left	ER on the right
Specimen 1	2880.53	--------------
Specimen 2	2901.10	2972.94
Specimen 3	2964.78	2527.12
Specimen 4	2397.05	2827.91
Resulting shear modulus: 2909.46		

Tab. 1 – Values of shear modulus

2.2 Numerical Characterisation

The use of automatic calculation tool permits the introduction of the characteristic of the fibres, matrix, their relative percentage, the thickness and the orientation of the reinforcement for everyone layer, so that the behaviour of the laminated and its resistance can be deduced.



Chopped Strand Mat - Elastic Properties

$$E = \frac{3}{8}E_1 + \frac{5}{8}E_2 \qquad \nu = \frac{E}{2G} - 1$$

$$G = \frac{1}{8}E_1 + \frac{1}{4}E_2$$

E_1 = 1.90000E+04

E_2 = 3.78947E+03

E = 9.49342E+03

G = 3.32237E+03

ν = 0.428713

Fig. 4 –Analytical values of modules (*Cadec*)

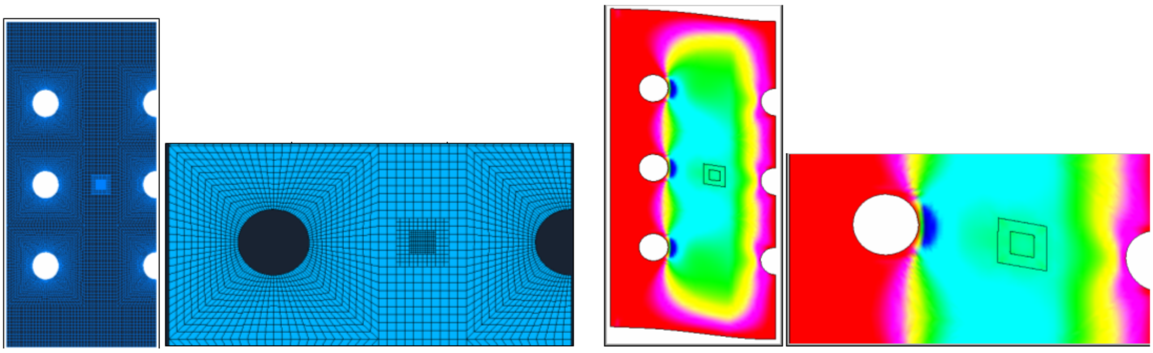


Fig. 5 – Model mesh and stress map

A specific calculation code for this purpose is the module "*HyperLaminate,*" of *Hyperworks*, furnished by *Altair.* Besides elastic properties are obtained also by *Cadec* [8] to obtain an analytical comparison (Fig. 4). The specimen is reproduced exploiting the symmetrical load and constraint geometry, the shear test was simulated and the investigation was focused fitting the mesh in the zone of strain gauge application (Fig. 5). Table 2 shows the results of the three methodology of study: analytical, experimental and numerical one.

Methodology	Shear Modulus G12 [MPa]
Analytical	3320.0
Experimental	2909.5
Numerical F.E.M.	2949.8

Tab. 2 – Obtained values by the three methodology of study

3. TENSILE TEST

This test was conduced following the rule ASTM D 3039 [1]. Five specimens were subjected to strain, at constant velocity, by the action of a unidirectional load applied normally to the section. The tests were executed using *Hounsfield* machine equipped to test fibreglass composites. The crossbar speed was 2 mm/min; the recording of the strain was acquired by an extensometer connected to *UPM 100*, enabled to register the applied loads and to furnish the corresponding strain. Fig. 7 shows load – strain curve obtained by experimental tests of the five specimens.

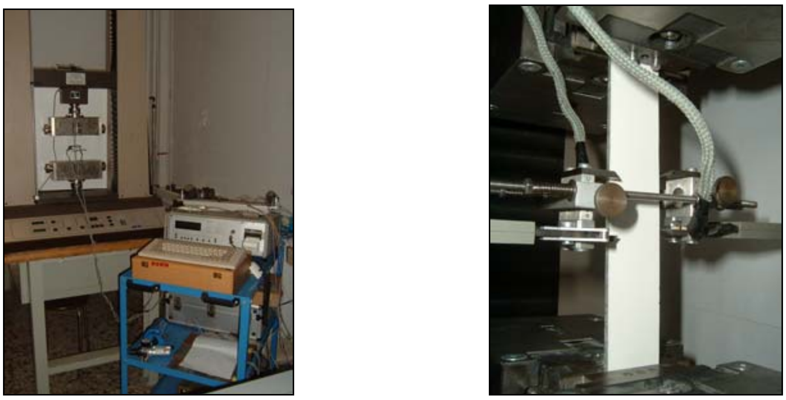


Fig. 6 - Housfield, UPM 100, and specimen equipped by extensometer

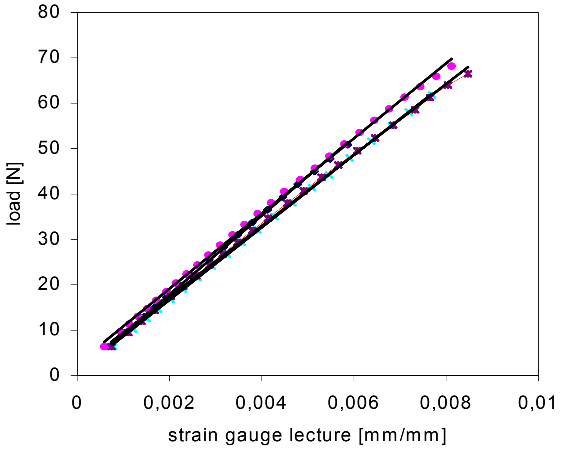


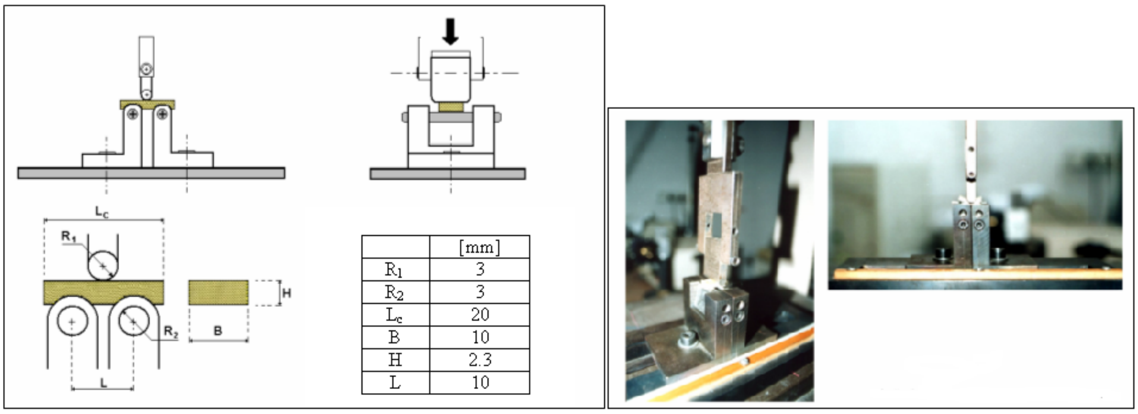
Fig. 7 – Load - strain diagram

Young Modulus [MPa]	
Specimen 1	8670.8
Specimen 2	8618.2
Specimen 3	---------
Specimen 4	8541.1
Specimen 5	8114.3
Young Modulus E_{random}=8486.4	

Tab. 3 - Values of Young modulus

4. DELAMINATING STRENGTH

The delaminating is the more frequent mechanism of damage of composites with polymeric matrix. The same nature of composite laminates does that they contain layers or place having less resistance in correspondence of the joining surface between the plies or of fiber/matrix interface. Under the effect of shear stress, delaminating and de cohesion phenomena are verified in these zones, with greater probability in correspondence of the corners and of the component edges. The fracture due to interlaminated sliding is systematic in enough short specimens, subjected to three point bending test (*short-beam shear test*), the test was performed with reference to rule *UNI EN 2563,* relative to bending test for composites with unidirectional fibres [3]. The method permits the determination of the composite resistance under parallel action to the plies plane. Short specimens with rectangular cross section are used for this characterisation in bending on two supports, as fig. 8 shows. The load is applied on the specimen centre by means of a punch connected to 2000 N load cell. The test is able to furnish qualitative information on the behaviour of the fibres – matrix interface and to measure the resistance to interlaminar sliding (ILSS- *Interlaminar Shear Strength*). If the shear stresses in a point of the specimen mean plane reaches the interlaminar sliding resistance of the composite before that the traction component reaches the value of tensile resistance in the material, the damage occurs by a delaminating mechanism. It does not occur in long specimens, where the fracture, under tensile strength, occurs in a point of the external lower surface.



	[mm]
R_1	3
R_2	3
L_c	20
B	10
H	2.3
L	10

Fig. 8 - Short beam shear test

The parameter determining the transition from interlaminar sliding fracture mode to traction one is the ratio L/H. In fact the traction strength [MPa] can be calculated as:

$$\sigma = \frac{3PL}{2BH^2} \tag{1}$$

And the shear strength [MPa]:

$$\tau = \frac{3P}{4BH} \tag{2}$$

where: B [mm] = specimen width; H [mm] = specimen thickness; P [N] = acting load; L [mm] = support distance. Resolving (1) and (2) respect to the load and equalling, one obtains:

$$\frac{\sigma}{2\tau} = \frac{L}{H} \tag{3}$$

it gives the condition for the interlaminar damage:

$$\frac{\sigma}{2\tau} \rangle \frac{L}{H} \tag{4}$$

Following the rule, five specimens are tested fixing the crossbar speed equal to 1 mm/1'. Fig. 8 shows the shape and the dimensions of the specimens used in the tests. The data are recorded by the software *LABVIEW* and are shown in fig. 9.

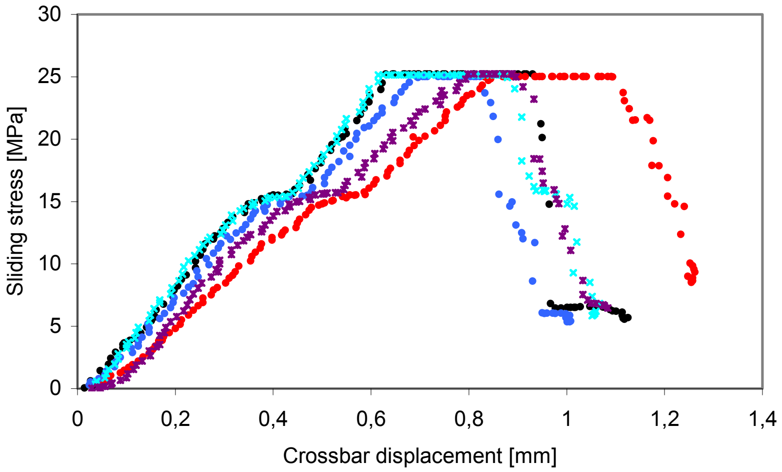


Fig. 9 – Sliding stress versus crossbar displacement for the five tested specimens

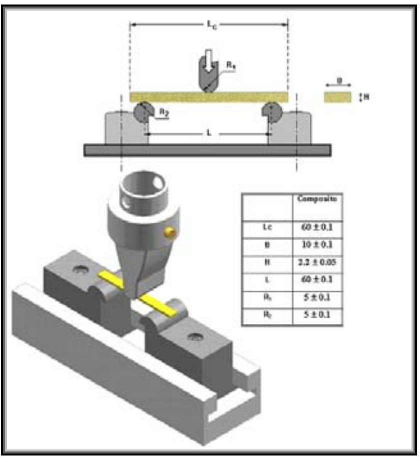
The mechanical behaviour of resistance to interlaminar apparent shear in composite material is defined by the following parameters:

$$\tau = \frac{3P_r}{4BH} \qquad (5)$$

τ [MPa] = sliding stress; P_r [N] = Maximum load in the instant of the fracture of the first ply. The tests give a result of 25.2 MPa for the sliding stress in fibreglass composite.

5. BENDING TEST

The panels in composite laminate are very used for the realisation of elements subjected at predominating bending solicitation. The three point bending test is performed with reference to rule *UNI EN 2562*, regarding the test in laminates with unidirectional and random fibres [2]. Also in this case the data were monitored by *LABVIEW* software.



	Composite
Lc	60 ± 0.1
B	10 ± 0.1
H	2.2 ± 0.05
L	60 ± 0.1
R1	5 ± 0.1
R2	5 ± 0.1

Fig. 10 – Supports: shape and adopted geometry

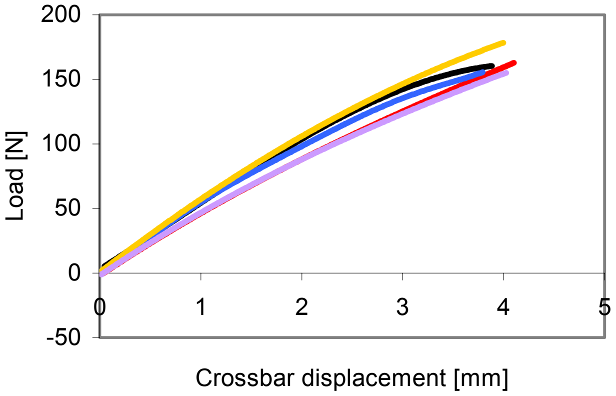


Fig. 11 – Bending stress versus crossbar displacement for all the five specimens

Particular attention is put to the shear, because it can induce damage for delaminating instead than bending; the condition assuring the bending damage is, by (3):

$$\frac{\sigma}{2\tau} \langle \frac{L}{H} \qquad (6)$$

Fig. 10 shows the supports shape: the load punch advances at a constant speed 2 mm/1' permitting the specimen deformation until the fracture in correspondence of the lower surface. Fig. 11 shows the bending stress in function of crossbar displacement for the tested specimens. Mechanical behaviour in bending of a composite is defined by the following parameters:

- *Ultimate strength in bending σ_{flx}*: is defined as the ordinate of the curve strength-strain where one has the damage of the first ply, it is determined by the following relation:

$$\sigma_{flx} = \frac{3P_r L}{2BH^2} \tag{7}$$

Where: P_r [N] = value of the load producing the damage of the first ply and the same significance of the other symbols.

	Ultimate strength in bending σ_{flx} [MPa]	Young modulus in bending E_{flx}[MPa]
Specimen 1	150.9	9765.90
Specimen 2	150.8	9399.75
Specimen 3	144.7	9328.18
Specimen 4	166.0	9568.60
Specimen 5	165.0	9234.80
σ_{flx} = 148.8 MPa; E_{flx} = 9321 MPa		

Tab. 4 – Values obtained in bending test

- *Elastic modulus in bending E_{flx}* : It is calculated drawing the curve load – strain and taking at least five values in the linear part of the curve. Elastic modulus is the slope of the curve load – strain in the part where the composite material is not still deformed; it can be calculated by:

$$E_{flx} = \frac{P_r L^3}{10BH^3(d_2 - d_1)} \tag{8}$$

Where: d_1 [mm] = crossbar displacement when the load is 1/10 than fracture one; d_2 [mm] = crossbar displacement when the load is the half than fracture one.

The measures of bending resistance of laminated composite materials are effected using specimens having L/H ratio such as the fracture occurs to traction of the fibres, hence one can expect a bending resistance value similar to traction one. In reality the tests involve a different stress distribution in the composite material, so that both the stresses values are not in correlation.

6. FEM OPTIMISATION

The goal function is the research of the optimal sequence of packing for a given type of plies, in order to reduce the actual thickness, preserving the mechanical properties. In first approximation a polyester matrix drowning the same percentage of glass fibre than random one, forms the substitutive composite in order to obtain the same specific weight.

Vary elementary load conditions were studied in order to single out the suitable configurations in term of stiffness. Relieving the displacements of some points of the fibreglass model, the corresponding values of the deformations are used as state variable, or design requirement, for the numerical simulation. This state variables furnishing the values of maximum lowering, produce an admissible dominion of suitable configurations for the thickness greatness.

The optimal configuration of structural naval components, subjected to several load conditions, also simultaneously, was obtained after several analyses. The numerical problem is treated in the following way:

- *Individuation of the employing element type.*
- *Division of the structure in an adequate number of elements.*
- *Application of load and boundary condition.*
- *Solution of the equation deriving from the model.*
- *Results interpretation.*

The optimisation was conduced for simple and regular panels, by making the hypothesis of linear behaviour, obtaining successfully the thickness reductions of 24% about. The stratified laminate has a thickness 3.15 mm, against a value of starting 5.5 mm for the random laminate.

7. CONCLUSIONS

The experimental analyses permitted the comparison and the validation of the both analytical and numeric FEM models in order to raise the confidence levels, in a certain tolerance field, for future studies on more complex structures in composite material. In particular the pure shear test has given strain values, obtained by rosettes, in a good accordance with numeric ones. The interlaminar shear test and bending ones give an analogous good accordance between numeric, experimental and theoretical ones.

The optimisation phase permitted a strong reduction of the panels thickness, by an adequate orientation of the plies. The weight reduction produces less immersed volume, hence less wave resistance, but also a less wetted surface and less friction resistance, with consequent energy saving. It can be obtained without compromising the stiffness and the resistance of the handmade, thus guaranteeing the boat security in the respect of RINA rule.

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