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CHARACTERIZATION OF GRP CONSIDERING THE MECHANICAL MATERIAL PROPERTIES

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ABSTRACT

The absence of raw materials caused industry to search alternatives to traditional materials. In the light of this aim has emerged the concept of composite material. Therefore the realization of structures in the shipping industry and not only, using composite materials is required instead of using classical materials (ferrous and nonferrous). The present paper tries to point out that GRP composite material should be considered in numerical calculations, as an isotropic, orthotropic or anisotropic material. To determine the mechanical character of GRP composite material was used ANSYS finite element program. Taking into account the behaviour of GRP at different loads, a series of experimental modelling were made to verify the mechanical character of GRP. Numerical methodology presented in this paper was well developed and it was experimentally verified, the resulting GRP composite material behaves closer to reality when it is considered in layers in numerical modelling.

KEYWORDS: Composite materials, FEM, stress

1. INTRODUCTION

The absence of raw materials caused industry to search alternatives to traditional materials. In the light of this aim has emerged the concept of composite material. Therefore the realization of structures in the shipping industry and not only, using composite materials is required instead of using classical materials (ferrous and nonferrous).

Research has highlighted that composites are the future, because they combine intelligently the best properties of components, resulting in a material with superior properties.

GRP composites are used in a variety of marine devices that range in size from small yachts, powerboats and fishing trawlers up to large passenger ferries and naval vessels. The usage of GRP composites in marine manufactured in the United States presently exceeds 150.000tons per annum [7]. Composite materials possess many mechanic characteristics which are different from those of ordinary materials. The widespread use of these materials is due to their high strength-to-weight ratio, excellent corrosion resistance, an ability to be moulded into complex shapes and low electromagnetic signature.

From a scientific point of view, composite materials have imposed a new way of approaching the resistance calculations for the determination of the elastic characteristics, which are different from one material to another. A structure which contains composite materials should be studied regarding the load-carrying capacity — the deteriorations that may occur in point of load and behaviour in difficult working conditions (variations of temperature, vibrations, the action of chemical agents, etc.), according to [3], [4], [5].

The analysis of specialised literature in the field of mechanical engineering is at the basis of comparative research between the existing analytical models and the methods of numerical simulation regarding the state of strains and deformations in plates or composite material structures. The results obtained so far in the study of composite materials are significant due to the development of the numerical models that were experimentally verified.

Theoretical models in specialised literature were developed in the mechanics of composite materials, concerning the calculation of strains, the safety coefficient by means of breakage theories specific to composite materials, and the value of the maximum deformation in the case of thin plates made of stratified composite materials.

The most common numerical method used in assessing variable strains is FEM.

Determination of mechanical characteristics is required to perform numerical modelling. For further studies are needed to establish the type of material used: anisotropic, orthotropic or isotropic. Will be analysed in two cases:

1. Plane plates made of GRP considered as formed of successive layers of resin and fibbers, called the "stratified plates". They will have different mechanical properties in two perpendicular directions, this leads to them being considered as orthotropic composites;

2. Plane plates made of GRP considered as made being of a material with identical mechanical properties in all directions, called the 'homogeneous plates. "

To highlight the above, a numerical simulation was performed for cases where the material is considered as stratified and homogeneous. Programs which use FEM have a only predictive character, they are still used in the design of composite structures, because they allow rapid and detailed analysis such as determination of stress and strain in materials under stress and / or thermal, dynamic response structures, geometric and material nonlinearities, fatigue analysis, vibration and oscillation, etc. The most widely used finite element software are: ANSYS, LS-DYNA, COSMOS / M, FEMAP, NASTRAN, etc.

2. DAMAGE OCCURRING BETWEEN LAMINAS OF COMPOSITE MATERIALS

Just like metals, stratified composites armed with fibers are sensitive to strain concentrators and lose a large part of their bearing capacity when deteriorated. Two researchers, Kim and Soni [6], [2] have developed a new theory, named after the medium stress criterion. The two researchers assume that delamination occurs as soon as interlaminates medium stress, noted with $\overline{\sigma}_z$, reaches ultimate tensile strength in the normal direction to the stratification plan, $\sigma_z^{(+)}$. Mathematical expression of this stress is as follows:

$$\overline{\sigma}_z = \frac{1}{b_0}\int_{b-b_0}^{b} \sigma_z(y,0)\,dy = \sigma_z^{(+)} \qquad (1)$$

This criterion predicts with good accuracy the initiation and propagation in composite of delamination when normal stress is predominant.

3. NUMERICAL MODEL

In order to establish the type of material, it was necessary to perform a numerical analysis. It was created a 3 - dimensional (3-D) laminate model using ANSYS FE. The parametric finite element what was used is a 3-D SOLID 186 element with eight nodes, with three displacements DOFs per node translations in the nodal x, y, and z directions, figure 1. This element is defined by layer thicknesses, layer material direction angle and orthotropic material properties.

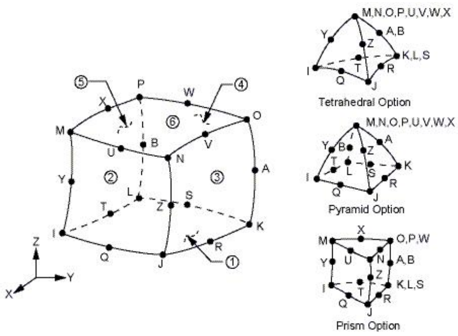

Fig. 1. *3D element with 20 nodes*

To perform the analysis, it is necessary to follow the next steps:

- Selecting a suitable finite element which will be used for meshing; element choice is made depending on the type and geometry of the structure, as well as its available options for post-processing the results;
- Entry the material characteristics E and ν in the database of the program, the material is usually a structural one, but it was used on layered to:
- Modelling and meshing the structure;
- Displacement and load definition is made;
- Data specific to static analysis are introduced;
- The analysis is performed.

The results are studied by means of numerous post processing methods, such as strain maps, displacement maps, graphs, etc.

There have been considered three composite plates having arbitrary geometry, with nine and thirteen layer stacking sequence, Figure 2.

Mechanical properties were determined experimentally for each material and are presented in table 1 [7], [8].

The technical specification of the resin contains information on physical and mechanical properties of a composite material with a certain percentage of glass fibbers. This aspect is covered by European standard ISO 3672-1, and American ASTM D5379.[1]

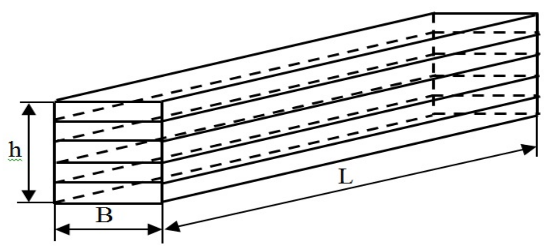

Fig. 2. *Analysed models*

Table 1. *Principal dimensions and characteristic of plates*

Characteristics		Numerical value
Plate size	S_1	L= 300 mm; h= 5 mm; B= 80 mm
	S_2	L= 300 mm; h= 8 mm; B= 50 mm
	S_3	L= 300 mm; h= 8 mm; B= 63 mm
Longitudinal modulus of elasticity		E = 3800 MPa
Poisson coefficient		$\upsilon = 0.25$
Density of fibers		ρ =2300 kg/m^3
Density of resin		ρ =1200 kg/m3
Density of composite		ρ =1658 kg/m^3
Thickness of fiber layer and resin	S_1	$h_{fibbers}$= 0.55 mm; h_{resin}= 0.55 mm
	S_2	$h_{fibbers}$ = 0.61 mm; h_{resin}= 0.61 mm
	S_3	$h_{fibbers}$ = 0.89 mm; h_{resin}= 0.89 mm
Layer number:	S_1	9 - resin + fibbers
	S_2	13 - resin + fibbers
	S_3	9 - resin + fibbers
Force applied:		361.16 N
Percentage of total mass composite reinforcement:		30%

In the loading conditions, it was applied a force of 361.16 N, force determinated experimentally. Boundary conditions were simple edge.

4. NUMERICAL MODEL AND RESULTS

After running, the program stresses the variation for each layered flat plate, Figures 3 - 5.

Results for S_1 (stratified plates):

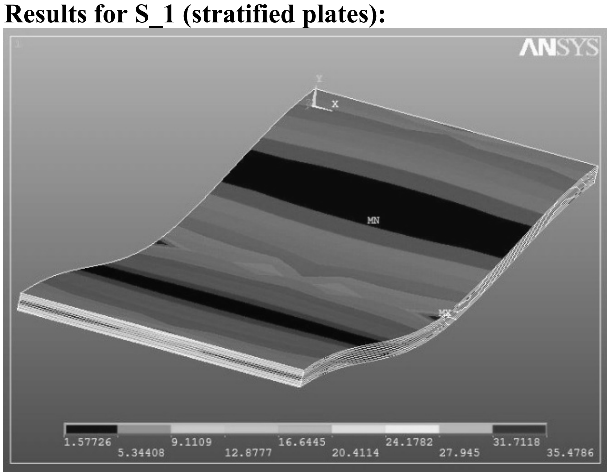

Fig. 3. *Stress variation*
Maximum stress = 35.47 [MPa]

Results for S_2 (stratified plates):

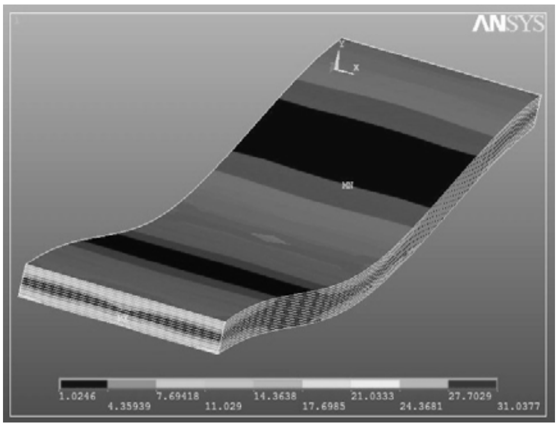

Fig. 4. *Stress variation*
Maximum stress = 31.03 [MPa]

Results for S_3 (stratified plates):

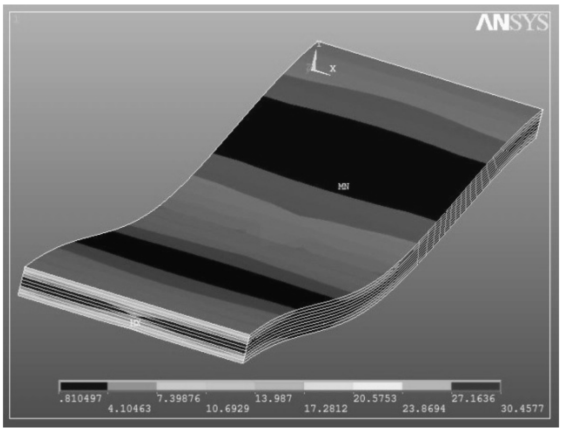

Fig. 4. *Stress variation*
Maximum stress = 31.03 [MPa]

Results for S_3 (stratified plates):

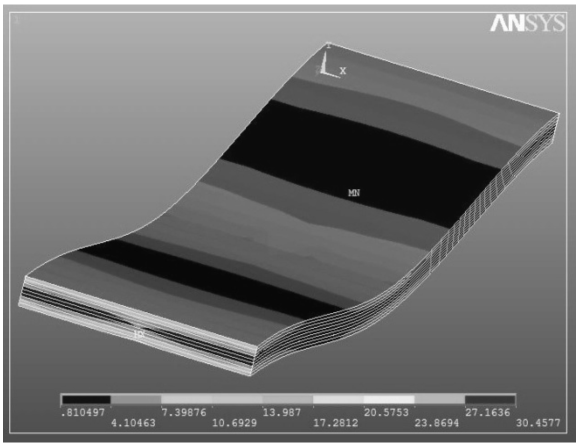

Fig. 5. *Stress variation*
Maximum stress = 30.45 [MPa]

Results for H_1 (homogenous plates):

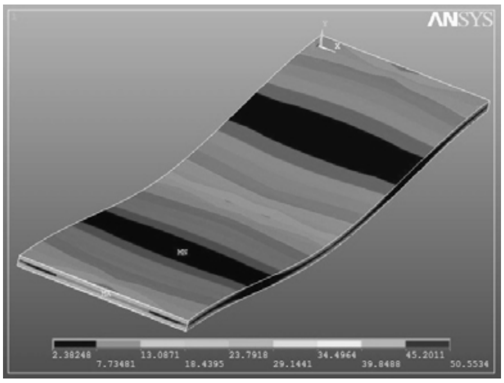

Fig. 6. *Stress variation*
Maximum stress = 50.55 [MPa]

Results for H_2 (homogenous plates):

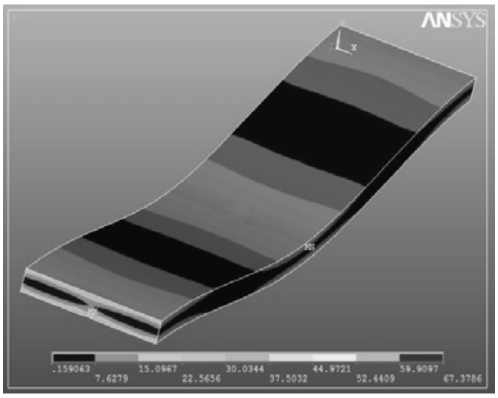

Fig. 7. *Stress variation*
Maximum stress = 67.37 [MPa]

Results for H_3 (homogenous plates):

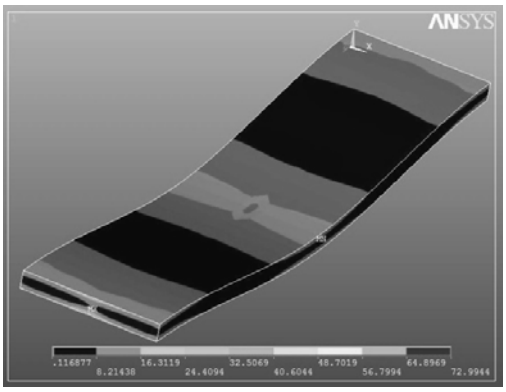

Fig. 8. *Stress variation*
Maximum stress = 72.99 [MPa]

Model		Displacement maximum [mm]	Stress maximum [MPa]
GRP plates made of "layers"	S_1	8.95	35.47
	S_2	3.44	31.03
	S_3	2.75	30.45
GRP plates made of "homogeneous"	H_1	15.60	50.55
	H_2	6.22	67.37
	H_3	4.92	72.99

5. EXPERIMENTAL RESULTS AND COMPARISONS

To validate the numerical results, experimental measurements have been performed on the same type of plane plates. The method used to determine the maximum stresses and deformations in plates made of GRP was the prevalent TER (tensometric electric resistive).

Electrical tensometry is the method of measurement of deformations and of elongations of a solid body, through transducers that convert mechanical deformation variations in variations of an electrical quantity. As method, electrical tensometry is part of the general methods of electrical measurement of non-electric quantities.

Resistive transducer used in tensometry is a resistor built from one or more metallic conductors connected in series, with a very small diameter (0.015...0.02 mm), having a wasteful resistance whose values are usually between R = 50Ω and R = 1000Ω. Due to its small shape and size (figure 9), the resistive transducer is also named strain gauge or tensometric stamp [9] .

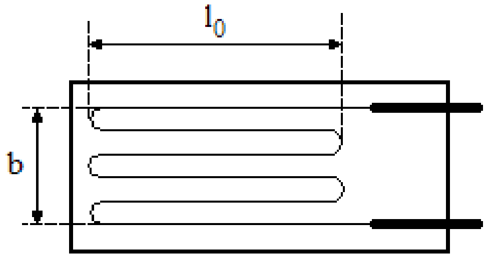

Fig. 9. *Resistive transducer*

5.1 Experimental verifications

For the present research, the same plates were chosen, to determine the stresses and specific deformations and to compare them with numerical values.

The experiments were carried out in the laboratory of the Department of Strength of Materials and the aims were to compare theoretical and practical results and to determine errors to validate numerical modelling.

Model and experimental stand

The experimental stand is composed of the following elements, figure 10:
1 - strain gauge device Spider 8 (from Hottinger); 2 - laptop Catman Express 3.1 software; 3 - composite specimen; 4 - strain gauge marks; 5 - mass weighing 36.115 kg; 6 - wire strain gauges.

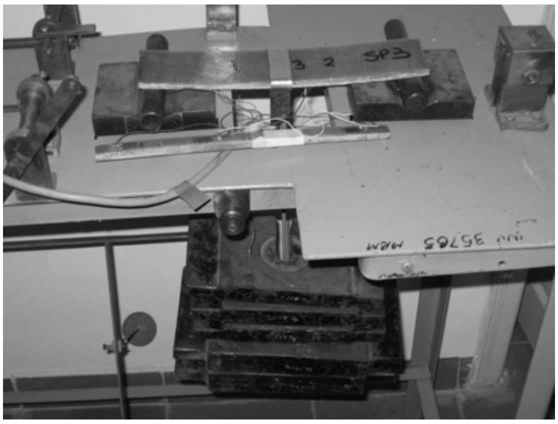

Fig. 10. *Experimental model*

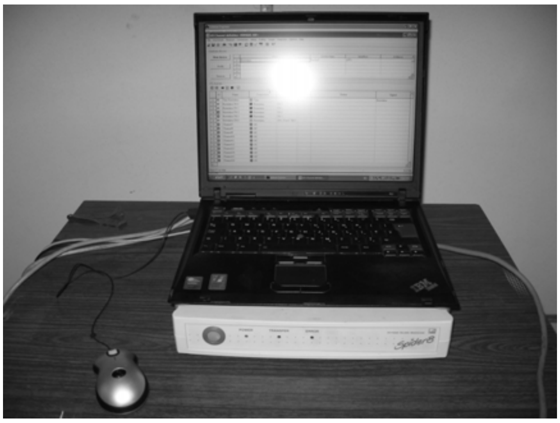

Fig. 11. *Laptop Catman Express 3.1*

The three strain gauges of the three-plane plate were placed between layers as shown in Figure 12. The marks of strain gauges were oriented at 0^0 - 90^0 - 45^0.

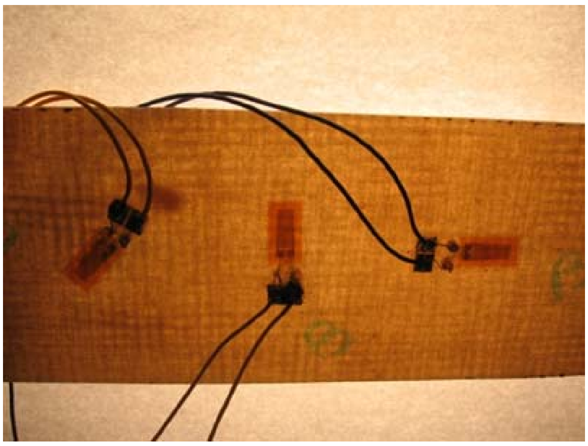

Fig. 12. *Location of the three tensometric marks between plate layers*

Deformations were measured in the marks, on plate thickness, using a strain gauge transducer. Measurement results are presented in Table 2.

Experimental models	Stress on thickness plates [MPa] measured on marks	
	Mark_1	Mark_2
SP_1	1.47E+06	1.07E+06
SP_2	1.82E+07	3.54E+07
SP_3	3.18E+05	3.69E+06

Comparative values regarding the variation mode of the normal stresses for each separate mark (Figures 13, 14, 15).

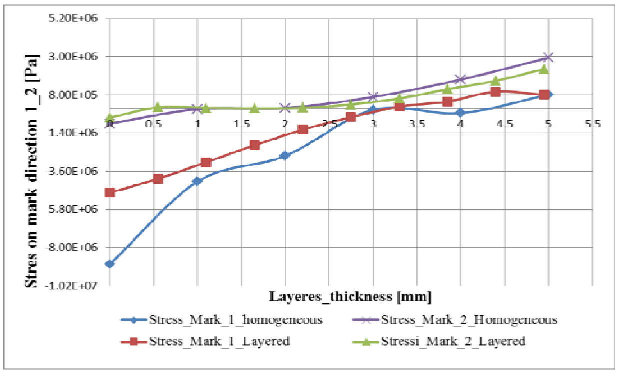

Fig. 13. *Variation stress on the mark zone [Pa]*

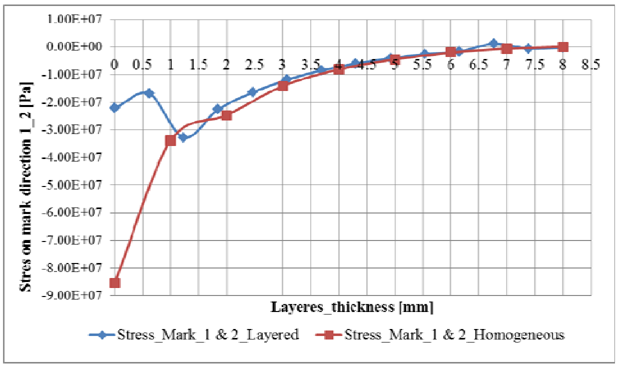

Fig. 14. *Variation stress on the mark zone [Pa]*

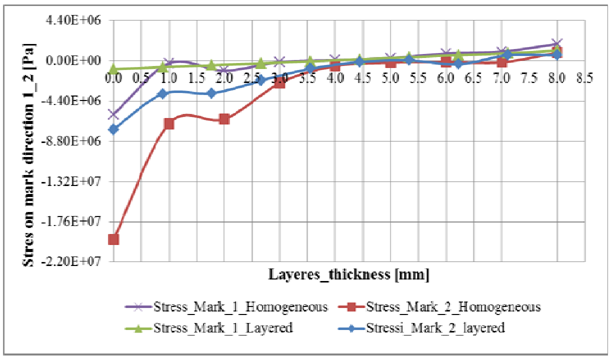

Fig. 15. *Variation stress on the mark zone [Pa]*

Table 3. *Comparisons between numerical and experimental results*

Type of material	Measure method		Stress on thickness plates [MPa] measured on marks		Deviations (measured / calculated) **[%]**)	
			Mark_1	Mark_2	Mark_1	Mark_2
Experimental GRP	Measured	SP_1	1.47E+06	1.07E+06		
		SP_2	1.82E+07	3.54E+07		
		SP_3	3.18E+05	3.69E+06		
GRP plates made of "layers"	Calculation	S_1	1.38E+06	1.12E+06	6 %	5%
		S_2	1.69E+07	3.28E+07	8%	8%
		S_3	3.06E+05	3.63E+06	4%	2%
GRP plates made of "homogeneous"	Calculation	H_1	1.33E+06	1.31E+06	11%	**18**%
		H_2	1.63E+07	3.28E+07	12%	8%
		H_3	2.71E+05	3.08E+06	**17** %	**19%**

6. CONCLUSIONS

Because the literature does not provide specific data for a detailed calculation of structures of composite materials in layers, was preferred the FEM analysis for the study of interlaminar stress for of GRP plates with experimental validation.

The analysis of interlaminar stress in static conditions was useful in determining the mechanical character of the GRP material.

The results revealed that isotropic composite material was excessively rigid, which means inefficient use of material properties.

Numerical and experimental results obtained lead to the conclusion that the study can be used to predict behaviour plates / structures made of GRP.

Experimental validation of numerical results obtained by acceptable deviation induces the conclusion that the numerical procedure was well developed and numerical results are correct.

Acknowledgements

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