COMPARATIVE STUDY OF STRESSES AND STRAINS THAT OCCUR IN STRUCTURAL ELEMENTS MADE OF COMPOSITE MATERIALS CONSIDERING THE MODEL WITH AND WITHOUT LAYERS

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Abstract: Fibreglass-reinforced polyester (GRP) is the most widely used composite material in the ship building industry and requires careful study in point of mechanical characteristics. This article presents the collective experience related to behaviour in different situations of GRP loading. We considered three cases manufacturing for GRP: layers with mechanical characteristics for each layer, composite (the material is considered isotropic but with layers and same mechanical properties for all layers), and isotropic plates.

Keywords: composite materials, stress/displacement, FEM

1. INTRODUCTION

Composites are combinations of two (or more) materials. These are the matrix and reinforcement. The matrix can be constructed of materials: metal, ceramics, polymers. Properties of composites are superior overall properties of each component.

For example, composites, polymer / ceramic have higher modulus than the polymer component but are not fragile like ceramic. Reinforcing fibers can be made of ceramic, glass or polymer. Fibers increase the composite modulus. Strong covalent bonds are established along the fibers gives them a very high modulus in this direction because the tensile and elongation of fibers must move the ties.

The fibers have high modulus on the axis direction but very low along on the perpendicular axis. If the fibers are parallel, the composite modulus depends on the direction that determination takes place. The modulus of elasticity for a composite, matrix + reinforcement, is governed by the mixture rule if the determination occurs along the fibers:

$$E_c = E_f \cdot V_f + E_m \cdot V_m \tag{1}$$

with following terms significance: E_c represents modulus of elasticity of composite, determined along the fibers direction, E_f is modulus of elasticity of fibers, determined the direction of longitudinal axis, V_f is the volume fraction occupied by fibers, E_m is modulus of elasticity of matrix, which normally does not depend on the direction the measurement occurs, V_m is the volume fraction occupied by matrix:

$$V_m = 1 - V_f \tag{2}$$

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Estimation of physical-elastic and mechanical properties of composite material is achieved in a first phase starting from the specific characteristics of the constituents using the mixture rule presented by D. Gay [1].

In general, the technical specification of the resin contains information on physical and mechanical properties of a composite material with a certain percentage of glass fibers. This aspect is covered by European standard ISO 3672-1, and American ASTM D5379 [2], and British BS EN ISO 527 [3 - 5].

For example: M 105 TA AROPOL resin, commonly used in the shipping industry, has separate indications on the tensile mechanical properties, bending and separately thermo-mechanical properties, but also give the properties of a composite with 30% glass disposed in four layers material having a density of 1450 g/m^2. The producer usually indicates the thickness of the resin, scope of application (and credentials with quality certification organizations) and the method of submission the reinforcement.

Composite materials reinforced with fiberglass for the shipping industry are divided into two categories called "E" and "S" depending on the composition of the fibers. The "E" material type is the most commonly used in construction plates, especially because of good water resistance properties.

This paper presents variation of the stresses and strains in a profile formed of a composite plate arranged in the T shape. The composite material was considered in numerical modeling in two ways:

Stratified with mechanical properties on each layer. These properties were experimentally determined for each material (fiber and resin), in Table 1 and 2 are presented the fibers and resin mechanical characteristics [6].

Table 1. Fibers mechanical characteristics.

Fibers Type	Fiber diameter (μm)	Density (g/cm^3)	Longitudinal Elasticity Module (MPa)	Transversal Elasticity Module (MPa)	Poisson's Coefficient
E	7.11	2.60	2.4540e+09	1.8844e+09	0.25

Table 2. Resin mechanical characteristics.

Resin Type	Density (Kg/m^3)	Longitudinal Elasticity Module (MPa)	Poisson's Coefficient
AROPOL M 105 TA	1100	2.9440e+09	0.25

Laminated with unique mechanical properties for composite material. These mechanical properties were also determined experimentally, see Table 3.

Table 3. Laminated mechanical characteristics.

Composite Type	Density (Kg/m^3)	Longitudinal Elasticity Module (MPa)	Transversal Elasticity Module (MPa)	Poisson's Coefficient
GRP	1658	1.8844e+09	1.8844e+09	0.25

2. NUMERICAL MODEL

A numerical model software, specialized in finite element analysis FEM, Solid Works COSMOS/M was used. Meshing was done using SOLID volume elements, resulting a total of 18000 elements and 20622 nods. This numerical model is valuable for both ways of materials considering. The differences witch appears is when we define mechanical properties. For easier understanding we will note:

- case I – profile fabricated from materials considerate on layers, meshed with solid volume elements;
- case II – profile fabricated from one material, meshed with solid volume elements;
- case III – profile fabricated with 2 plates with same mechanical properties like in case II.

The model has been fixed at one end and the other end it was apply a force of 1000 N. In Figure 1 is presented the geometry with mesh, load and how it was fixed the model. Figure 2 presents the model for profile fabricated with two plates.

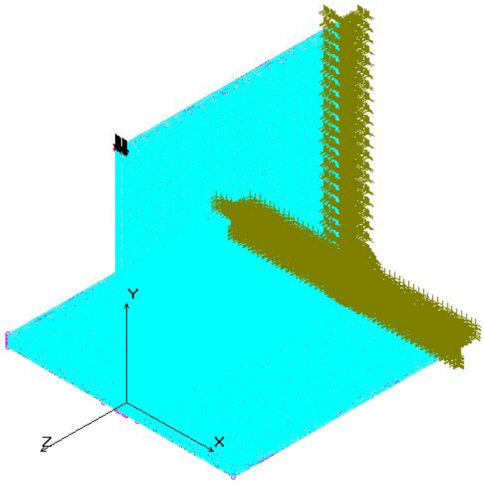

Fig. 1. The meshing model with volume elements layer.

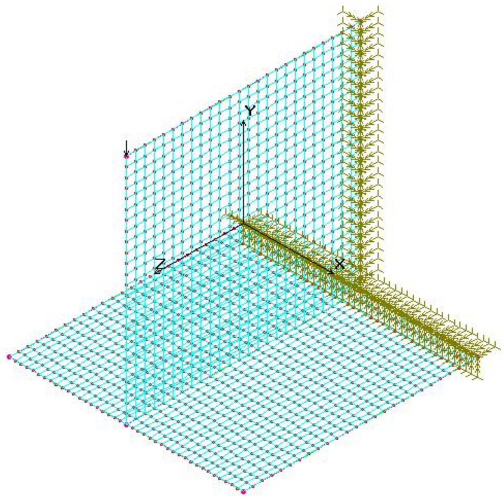

Fig. 2. The meshing model profile fabricated with two plates.

After running the program were obtained variations of displacements and stresses for case I (Figure 3 and 4) and also for cases II (Figures 5 and 6) and III (Figures 7 and 8), the results are presented in Tables 4, 5 and 6.

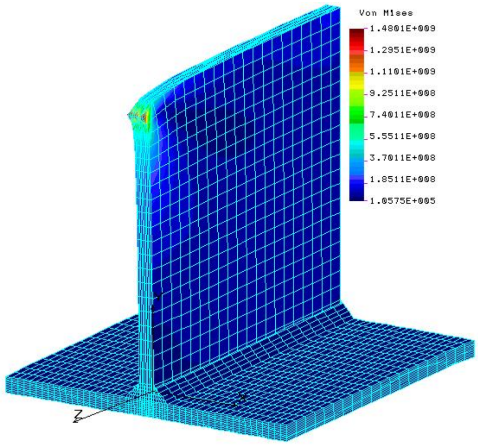

Fig. 3. Stresses variation on profile, case I.

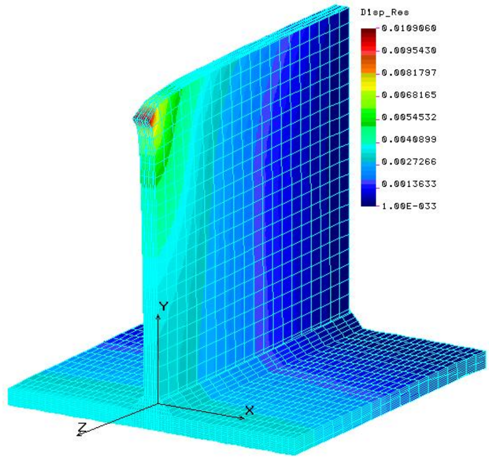

Fig. 4. Displacement variation on profile, case I.

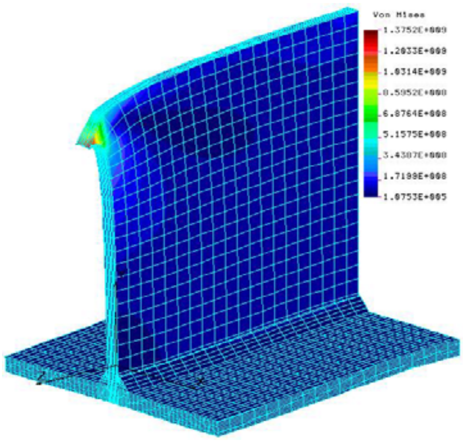

Fig. 5. Stresses variation on profile, case II.

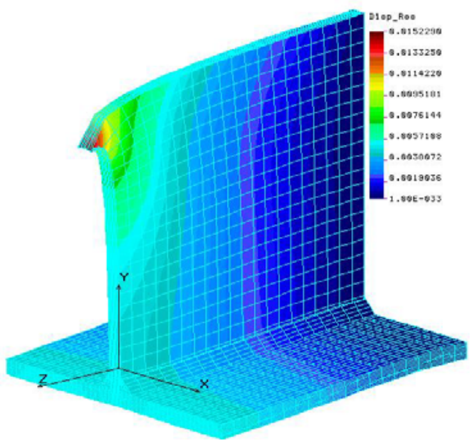

Fig. 6. Displacement variation on profile, case II.

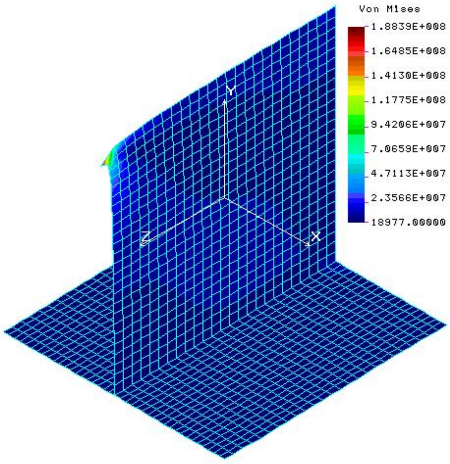

Fig. 7. Stresses variation on profile, case III.

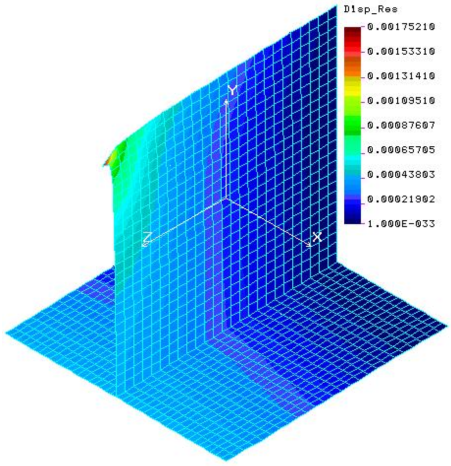

Fig. 8. Displacement variation on profile, case III.

After running the models a few nodes were chosen arbitrarily as can be seen in Figure 9, where tensions are obtained on the x and z axes.

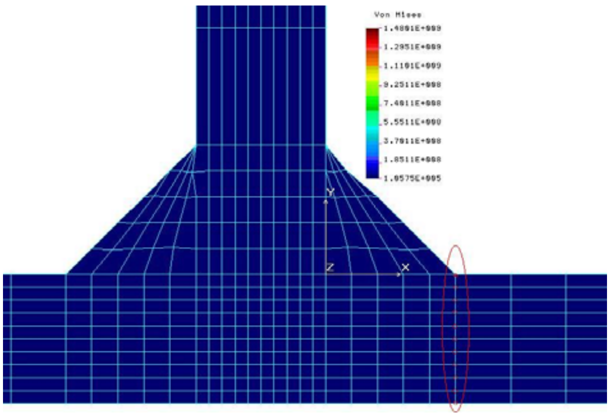

Fig. 9. Nodes near by considered zone.

3. RESULTS AND DISCUSSION

After the model was numerical calculated in tables below is the presented the results (Table 4 – 6 and Figures 10 and 11).

Table 4. Normal stress variation for case I and case II.

Thickness of layers [m]	Case I		Case II	
	Normal stress [MPa]			
	Axe x	Axe z	Axe x	Axe z
0.0000	1.28E+04	1.28E+03	1.40E+04	2.19E+03
0.0005	1.38E+04	1.24E+03	1.62E+04	2.33E+03
0.0010	1.39E+04	1.03E+03	1.31E+04	5.96E+02
0.0015	1.40E+04	8.44E+02	1.00E+04	1.11E+03
0.0020	1.41E+04	6.88E+02	1.32E+04	4.05E+02
0.0025	1.43E+04	5.61E+02	1.65E+04	1.87E+03
0.0030	1.46E+04	4.55E+02	1.51E+04	1.20E+01
0.0035	1.48E+04	3.62E+02	1.37E+04	1.94E+03
0.0040	1.51E+04	2.81E+02	1.55E+04	3.59E+02
0.0045	1.55E+04	2.15E+02	1.73E+04	1.22E+03
0.0050	1.58E+04	1.73E+02	1.75E+04	1.06E+03

Table 5. Normal stress variation for case III.

Case III	
Thickness of plates [m]	Normal stress [MPa]
0.0050	1.8839E+002

Table 6. Displacements on the three cases.

Case	Displacement [m]
I	0.0109060
II	0.0152290
III	0.0017521

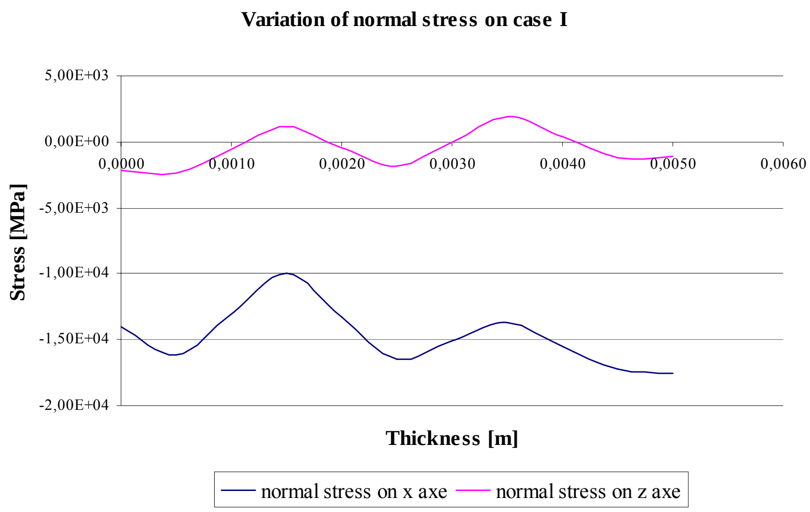

Fig. 10. Variation of normal stress on case I.

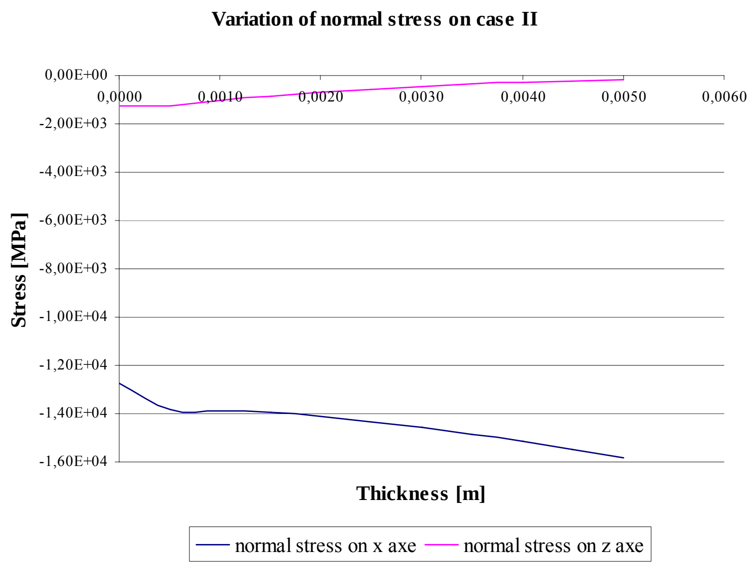

Fig. 11. Variation of normal stress on case II.

4. CONCLUSIONS

Taking in consideration tables 4 and 5 we can conclude the biggest value of stress appears when the profile is considerate meshed on layers with different mechanical properties. This can be explained by the fact that through this layer with different material properties result has better strength characteristics. It can be seeing it from Figure 10 and 11 and Table 6. Using the mesh/FEM as in first case are obtained tensions which may lead to more accurate sizing of structures made of GRP. The method used in case III can be taken in consideration for usual calculus of GRP structures.

In Table 7 are presented all the results for the three cases considered in this study and the percent of variation in these results.

Table 7. Comparison between maxims of normal stress between cases (base is profile fabricate with plates).

Case	Normal stress [MPa]	Percent on normal stress (%)	Displacements [m]	Percent on displacements (%)
I	1.480e+03	7.9	0.011	5.5
II	1.375e+03	7.3	0.015	7.5
III	1.883e+02	0	0.002	0

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