

## **OPTIMIZATION OF THE COMPOSITE MATERIALS OF TANKS USING FINITE ELEMENT METHOD AND STRAIN GAUGES**

**A. STANCIU<sup>1</sup>, I. CURTU<sup>1</sup>, M. STANCIU<sup>1</sup>, S. VLASE<sup>1</sup>**

**Abstract:** The present paper deals with the study of the stress and deformation occurred inside some parts of a storage tank made of composite materials. The paper presents a theoretical approach regarding the mechanical behavior of glass fabric reinforced composite for liquid storage tank. As the most exposed part of the tank is the sight hole, the research was focused upon the stress and deformation of this part, which was subjected to the action of the stored materials pressure. The material used for the structure consists of several layers with different properties. The present paper deals with the study of the stress and deformation occurred inside some parts of a storage tank made of composite materials.

**Keywords:** finite element method, layers, stress, strain gauges, von Mises.

### **1. INTRODUCTION**

Finite element method (FEM) becomes more and more a general method used for solving different types of complex problems concerning both stationary and non-stationary phenomena from all engineering fields but also in other activity and research areas.

As far as the stress and deformation are concerned we may observe that the internal mechanical work is linked to three components of the stress in 2D coordinates, the normal plane component of the stress does not involve the canceling of other strains or stresses.

In order to control the complexity of the problem and “filter” the irrelevant aspects we need to accomplish a suitable mathematical model. This model should consider the fact that we are dealing with an anisotropic material, consisting of several layers and also that the loads and deformations along the contours are difficult to be obtained.

The internal stress and deformation field is locally influenced by the relative

---

<sup>1</sup> *Transilvania University of Brasov, Romania, mariana.stanciu@unitbv.ro, curtui@unitbv.ro*

difference between the constituents' properties, their size, shape and relative orientation as well as by the geometry of the repeating structures that form the composite material

## **2. MATHEMATICAL MODELLING WITH FEM**

This is mostly an ordinary equation or a differential one, developed in space and time. A discrete model with finite elements is generated by help of the variation form of the mathematical model. This stage is called meshing. The FEM equations are solved using an equation solver that will provide a discrete solution.

For example, if the mathematical model is represented by a Poisson equation, the physical achievement can be represented by the heat conduction in a bar or a problem of electric charge distribution. This stage is not always necessary and may be eliminated. The FEM meshing can be done without any reference to the modeled process physical aspects.

## **3. FEM ANALYSIS FOR LIQUID STORAGE TANK**

The paper presents a theoretical approach regarding the mechanical behavior of glass fabric reinforced composite for liquid storage tank.

The model was achieved using MSC Patran preprocessor/postprocessor and MSC Nastran processor. In the preprocessing stage, the finite elements geometric modeling requires the finite element model, which will be finally solvable by help of the programs kit meant for this purpose.

A finite element modeling requires the material behavior modeling, selection and personalization of finite elements, the finite elements structure generation, introduction of boundary conditions and loads. The analysis and solution of the finite element model, elaborated during preprocessing requires the preliminary setting of the solving parameters and the execution of the specific program modules. During this stage, the information and error messages occurred while the program is running should be carefully monitored.

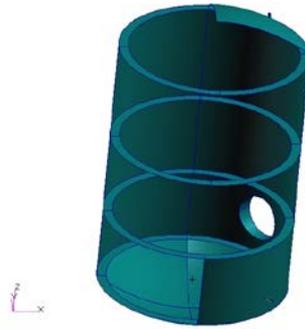
The post processing of the results obtained after solving the finite elements model assumes the visualization of the deformed and animated state of the studied structure and also the visualization of various parameters using lists, diagrams and fields. The results can be easily accessed and the input/output values of the required parameters may be identified at any point of the geometric domain.

The generation of the geometric model using elementary entities was achieved by maintaining the continuity in the passing areas between one entity and the other.

The geometric modeling previous the meshing requires the generation of closed contours consisting of lines for plane areas or surfaces. In figure 1 we presented the detailed model geometry.

According to standards the water density is of  $1000 \text{ kg/ m}^3$ . Considering a safety factor of 1,25 the water density used in calculus is of  $1250 \text{ kg/ m}^3$ . The pressure

was determined upon the 5 sectors obtained after model meshing, taking into account the length of each sector and the water volume.



**Fig.1.** Geometric model of the liquid storage tank

Then the model will be analyzed by help of MSC Nastran processor but before running the file we need to do some previous checking in order to validate the finite elements model, as follows:

- determination of the distance between two locations or nodes;
- determination of the angle between two directions determined by three point, one of them being considered as origin;
- identification of common points;
- identification of common lines;
- identification of common nodes and joining them;
- identification of nodes belonging to a selected plane, with the possibility of moving to this plane of the nodes from the adjacent area;
- identification of the common finite elements;
- determination of a finite element distortions;
- identification of the normal in a plane finite elements group and comparing them to a given direction;
- determination of mass properties for the finite elements;
- checking the geometric boundary conditions;
- determination of the loading forces sum in a node.

Then, during post processing, the output data will be associated to both the nodes and the finite elements.

The output data corresponding to the nodes, usually include the problem unknowns, like displacements, temperatures, pressures, velocities.

The output data corresponding to the finite elements are different from one element to another, for example the internal forces, strains, deformation energy.

The tank structure was performed using layered composite materials, with the following positioning of successive layers:

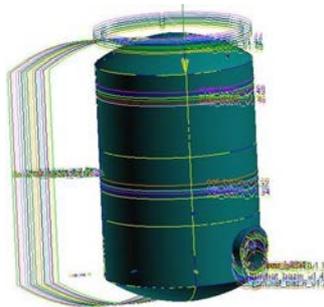
MAT 600 – composite material made of glass fibers (short fibers) in epoxy

resin matrix with specific weight 2x600g /m<sup>2</sup>, thickness 2-2,6mm;

RT 800 – composite material made of glass fibers (woven) in epoxy resin matrix with specific weight 4x 800g /m<sup>2</sup> , thickness 3,2-3,6mm;

MAT 450 – composite material made of glass fibers (short fibers) in epoxy resin matrix with specific weight 2x450g /m<sup>2</sup>, thickness 1,6-2mm.

The structure is made of 8 different layers as shown in figure 2, the arrow representing the succession of the layers starting from the interior towards the exterior of the structure.



**Fig.2.** Succession of material layers MAT-Roving, 8 layers

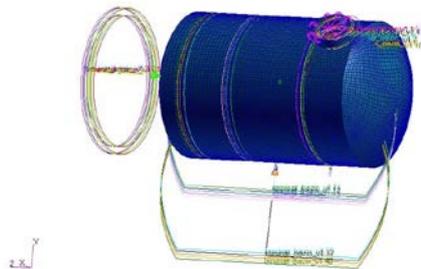
The optimisation tank structure was performed using layered composite materials, with the following positioning of successive layers:

MAT 600 – composite material made of glass fibers (short fibers) in epoxy resin matrix with specific weight 1x600g /m<sup>2</sup>, thickness 2-2,6mm;

RT 800 – composite material made of glass fibers (woven) in epoxy resin matrix with specific weight 2x 800g /m<sup>2</sup> , thickness 3,2-3,6mm;

MAT 450 – composite material made of glass fibers (short fibers) in epoxy resin matrix with specific weight 1x450g /m<sup>2</sup>, thickness 1,6-2mm.

The structure is made of 5 different layers as shown in figure 3, the arrow representing the succession of the layers starting from the interior towards the exterior of the structure.



**Fig.3.** Succession of material layers MAT-Roving, 5 layers

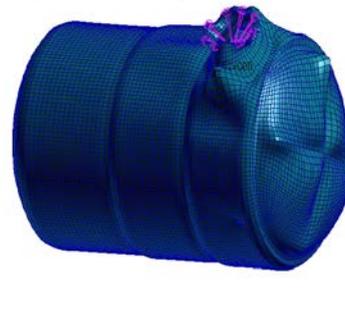
Deformation for two types of materials

Patran 2008r1 28-Apr-09 14:50:23  
 Deform: Default, A1 Static Subcase, Displacements, Translational, (NON-LAYERED)



**Fig.4.** Deformation for 8 layers

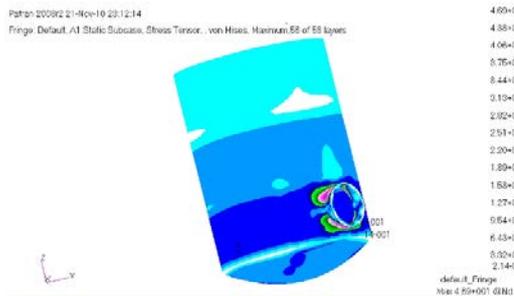
Patran 2008r2 26-Sep-10 13:01:31  
 Deform: Default, A1 Static Subcase, Displacements, Translational, (NON-LAYERED)



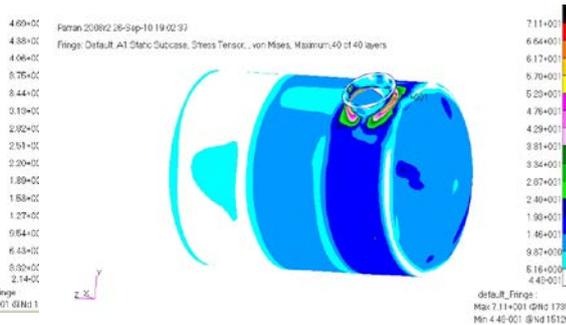
**Fig.5.** Deformation for 5 layers

Deformation for type of materials MAT- Roving, 8 layers, has a maximum variation of 1,25mm; deformation caused by model optimized type-Roving of 5 layers, has maximum variation of 2.52mm, with a deformation will damage it double the first MAT-Roving.

In figure 6 and 7 is presented the maximum Von Misses stress distribution for all layers



**Fig.6.** The maximum Von Misses stress distribution for 8 layers, MAT-Roving material



**Fig.7.** The maximum Von Misses stress distribution for 5 layers, MAT-Roving material

The maximum stress was at layer 5, last material 71,1 MPa for Von Misses comparison with first material it is 46,9 MPa.

### 3. DETERMINATION OF STRAINS USING STRAIN GAUGES

Electric strain measuring, whose fundamental concepts were established approx. six decades ago, had a fast and wide development due to its important benefits: the method is non-destructive so the shape and size of the measured part or structure are not changed; allows performing of measurements in real working conditions; The tank is made of a material called MAT which consists of non-woven glass fiber impregnated with non-saturated ortophthalic polyester resin and Roving.

The tank structure was performed using layered composite materials, with the following positioning of successive layers:

MAT 600 – composite material made of glass fibers (short fibers) in epoxy resin matrix with specific weight  $2 \times 600 \text{g/m}^2$ , thickness 2-2,6mm;

RT 800 – composite material made of glass fibers (woven) in epoxy resin matrix with specific weight  $4 \times 800 \text{g/m}^2$ , thickness 3,2-3,6mm;

MAT 450 – composite material made of glass fibers (short fibers) in epoxy resin matrix with specific weight  $2 \times 450 \text{g/m}^2$ , thickness 1,6-2mm.

*Table 1 Mechanical Characteristics of the Materials*

No	Type of material	Elastic modulus $E_{11}$ [MPa]	Elastic modulus $E_{22}$ [MPa]	Poisson's coefficient $\nu$
1.	MAT 600	10000	10000	0,25
2.	RT 800	48000	35000	0,25
3.	MAT 450	10000	10000	0,25



**Fig. 8.** Strain gauges on the tank

In order to determine the strains occurring for the three strain gauges that were used, we determined the static zero, making the difference between the value pointed out by the device and the next measurements made both after filling the tank with water (figure 8) during three stages and then emptying it by the same method. We determined only compression strains for all the recordings performed in the areas where the strain gauges were attached.

The unit loading  $\sigma = E \cdot \varepsilon$  daN/mm<sup>2</sup> or Kg/mm<sup>2</sup>, where:  $\varepsilon$  – specific length  $\varepsilon = \Delta l / l$ ;  $\sigma$  - unit loading; E - Young's elastic modulus, the constant for the fiber has values between  $(0,06-0,10)10^6$ .

After we determined static zero for each measuring point, we started filling the tank with water in three stages, each stage representing 1/3 of the recipient volume, determining by help of the MK device, the

structures stress for each of the three fillings.

In Table 2 we presented the stress in the material during the filling, after taking static zero out.

**Table 2 Stress in the material during filling**

Filling stages	$\varepsilon$ for gauge no.1	$\varepsilon$ for gauge no.2	$\varepsilon$ for gauge no.3
Static zero	0	0	0
1/3	-118	-139	-247
2/3	-168	-233	-243
3/3	-163	-180	-214

In Table 3 we presented the stress in the material during emptying the tank.

**Table 3 Stress in the material during emptying**

Emptying stages	$\varepsilon$ for gauge no.1	$\varepsilon$ for gauge no.2	$\varepsilon$ for gauge no.3
Static zero	0	0	0
1/3	-7	-91	-69
2/3	-9	-127	-49
3/3	-20	-90	-25

The difference between static zero for the device and the loading value represents the specific length  $\varepsilon$ .

If after the tank filling we find that the value with respect to static zero is increasing, this means that the material is tensed.

If the value diminishes, as it happened in the present case, both for filling and for emptying the tank, then the material is compressed.

Measuring by strain gauges analysis brings a significant contribution to the experimental researches results that determined the mechanical properties of the composite materials and to the finite element modeling by emphasizing the maximum stress in certain material areas.

#### 4. CONCLUSIONS

MAT type material resists much better to the applied loads (considering all directions), the values are smaller in comparison to the efforts occurred in the roving.

Following the experimental researches and also the studies based on FEM we conclude that the material thickness is oversized.

In this respect we decided that we may reduce the number of layers from 8 to 5, namely we may give up to one of each type of material.

This leads to costs diminishing, weight loss and not last to less exposure of the working personnel to toxic wastes.

In our case we find that the tank is not subjected to great strain, meaning it is oversized. It might be made of less layers, with smaller thickness, fact that leads to lower fibers and resin consumption and as a follow, lower costs.

We performed a comparison between the strains in this material using several methods:

- Using strain gauges;
- Using finite element method and NASTRAN program;
- Experimental tests upon samples made of the same material as the studied tank.

The compared results lead us to the conclusion that this material, for the stated dimensions will in fact resist to a 40 times greater stress than those to which it was statically subjected.

Based on the obtained results we may draw some interesting conclusions concerning the shape and size optimization methods for the designed elements, considering the stress and strain magnitude and distribution, the vibration own modes and frequencies.

#### REFERENCES

- [1]. Alămoreanu, E., Constantinescu, D.M., *Design of laminated composite plates*, Romanian Academy Publishers, Bucharest, 2005.
- [2]. Enescu, I., Stanciu, A., *Finite elements*, Transilvania University Publishers, 2007, ISBN 978-635-947-7.
- [3]. *MSC/NASTRAN for WINDOWS, Version 2.0*, Users manuals.
- [4]. Sims G. D., Broughton W., R., *Glass Fiber Reinforced Plastics—Properties, Comprehensive Composite materials, vol. 2*, ISBN 0-080437206, pp. 151-197.
- [5]. Stanciu A., Cotoros D., *Simulation of Mechanical Properties for Fibre Reinforced Composite Materials, Theoretical and Experimental Aspects of Continuum Mechanics*, WSEAS Cambridge, UK, Febr.2008, ISBN 978-960-6766-38-1, ISSN 1790-2769.
- [6]. Stanciu A., Cotoros D., *Study Concerning the Mechanical Tests of Mat&Roving Fiber Reinforced Laminated Composites*, 5th Wseas International Conference on Applied and Theoretical Mechanics (MECHANICS '09) Puerto De La Cruz, Tenerife, Canary Islands, Spain December 14-16, 2009.
- [7]. Teodorescu, H., *Basic concepts and mechanics of polymeric composite materials*, Transilvania University Publishers, Brasov 2007.
- [8]. Stanciu, A. E., Purcărea, R., Curtu, I., Cotoros, D., *Analysis Of Mechanical Properties Of Roving And Mat-Roving Composites Subjected To Bending*, 3rd Int. Conf. Advanced Composite Materials Engineering COMAT, 27-29 october 2010, ISSN 1844-9336, vol. II, pp.288-292.
- [9]. Thompson, E. G., *Introduction to the Finite Element Method. Theory. Programming and Applications*, New York, Wiley & Sons Publishers, 2004.