

# Mechanical tests, static and modal finite element analysis for MWCNT composite materials

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**Abstract:** *The main purpose of this paper is to develop some numerical experiences based on mechanical tests performed on MWCNT (Multi-wall carbon nanotubes) composites created in our Material compartment using finite element commercial codes (here NASTRAN). The results of numerical simulations are consistent with the laboratory tests and encourage us to continue to improve the models using NASTRAN capabilities in order to obtain a realistic simulation of aeronautical structures made of such composites, considering their special properties.*

**Key Works:** *MCWNT composites, traction tests, bending tests, finite element simulations*

## 1. INTRODUCTION

In this paper we consider numerical finite element simulations on some multiwall carbon nanotubes (MWCNT) and epoxy resin P401 composite. The samples were obtained by ultrasonic homogenization of the epoxy resin with different MWCNT content: 0; 0.5; 2 and 4% CNT, followed by curing at room temperature using triethylenetetramine as curing agent. Ultrasonic homogenization was used as mixing method, as it ensures the optimum dispersion of the carbon nanotubes into the epoxy matrix [1].

Different mechanical tests were performed on three samples of each case: determination of the Young Modulus in traction tests, and determination of flexural modulus in flexural tests. Considering these mechanical tests we developed a set of numerical simulations in order to obtain more information on the way to use these materials in the design of aeronautical structures by comparing them with traditional metal structures.

Several papers as [2], [3], [4], [5] propose methods to deal with the material constants of single or multi-wall carbon nanotubes materials considering their molecular structure.

In this paper we consider only the experimental values of these constants as linear elastic materials and use them in finite element analysis with PATRAN/NASTRAN, first to simulate the laboratory tests, then to evaluate a composed structure that may appear in the aircraft design [6], [7].

For this purpose we performed the numerical simulations in two stages:

a) we tried to reproduce in a finite element commercial code (NASTRAN/PATRAN) the numerical tests performed in our laboratory, and

b) we consider a plate similar with those used in aeronautical structures which includes in a realistic way some MWCNT composite elements and compare this structure with a classical aluminum structure. In this case we perform a modal analysis as well.

## 2. MECHANICAL TESTS

The mechanical test was performed with INSTRON 5982 facility at room temperature. The samples obtained through ultrasonic homogenization are based on epoxy resin with 0; 0.5; 2 and 4% wt MWCNT.

The samples were subjected to tensile and 3 point bending tests. Tensile tests were performed according to ISO 527, using 50 mm/min tensile rate and dumbbell shape specimens [12] and bending tests were performed according to ISO 178, using 2 mm/min speed of test and rectangular specimens [13].

For the traction tests a sample as in figure 1 is considered. Its characteristics are presented in table1.

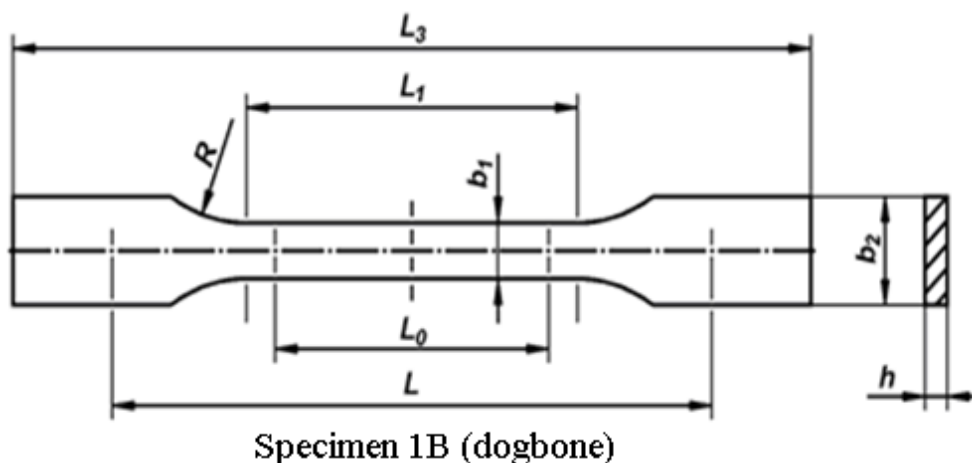


Figure 1. Sample for the traction tests

Table 1. Characteristics of the traction sample

Notation	Dimension (mm)
$L_3$	150
$L_1$	65
$R$	60
$b_2$	20
$b_1$	10
$h$	4
$L_0$	50 $\pm$ 0.5
$L$	115 $\pm$ 1

For the bending tests (fig. 1) the dimensions of the samples are 4mm/10mm/100mm. The distance between the two supports is 64 mm.

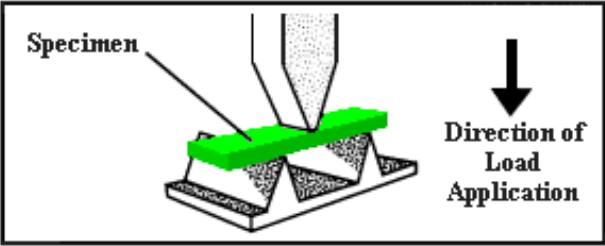


Figure 2. Bending tests

In the following we present some experimental data of tensile test and flexural test for 0% and 2 % wt MWCNT content:

The stress-strain curve of a tensile test in the same case of 0% wt MWCNT content is presented in figure 3.

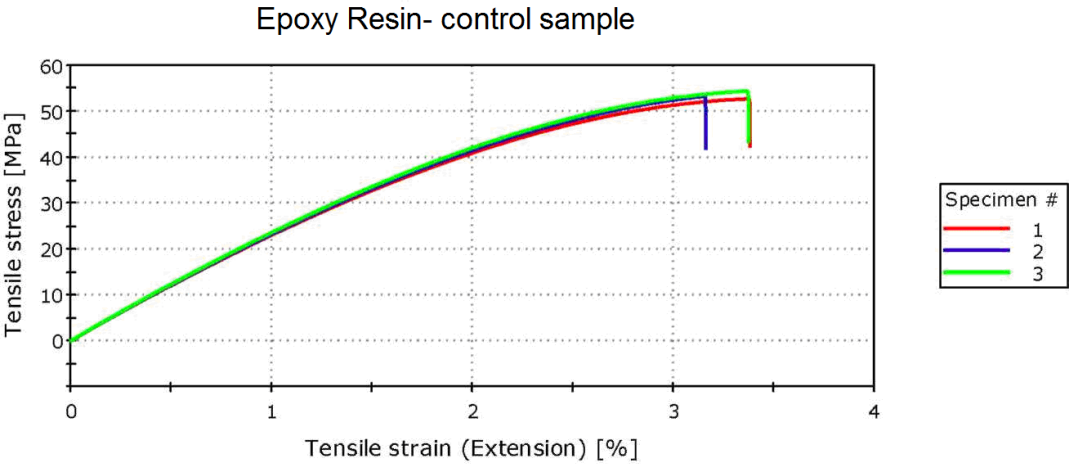


Figure 3. Stress-strain curve for the tensile test for 0% wt MWCNT content

The load extension evolution during bending test for a content of 0% wt MWCNT content is listed below in figure 4.

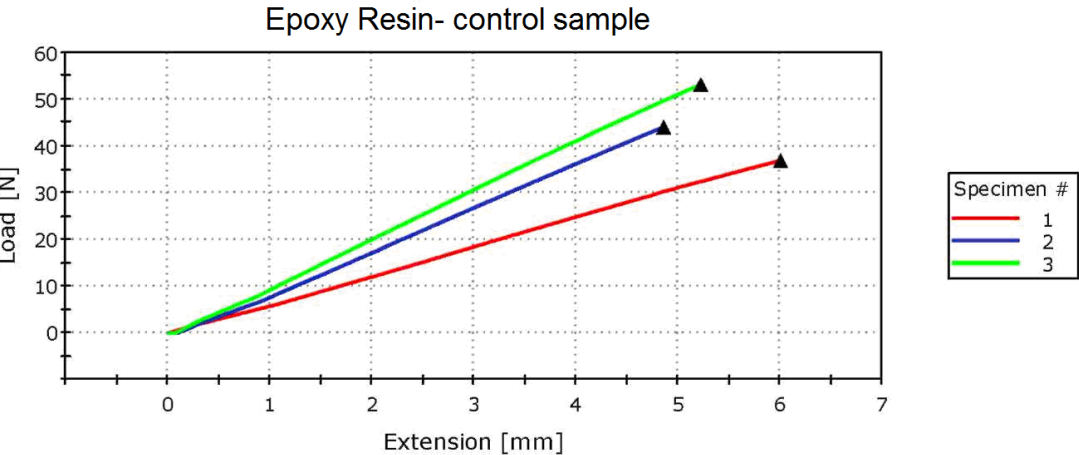


Figure 4. Load extension evolution during bending test for a content of 0% wt MWCNT content

The stress-strain curve of a tensile test in the same case of 2% wt MWCNT content is presented in figure 5.

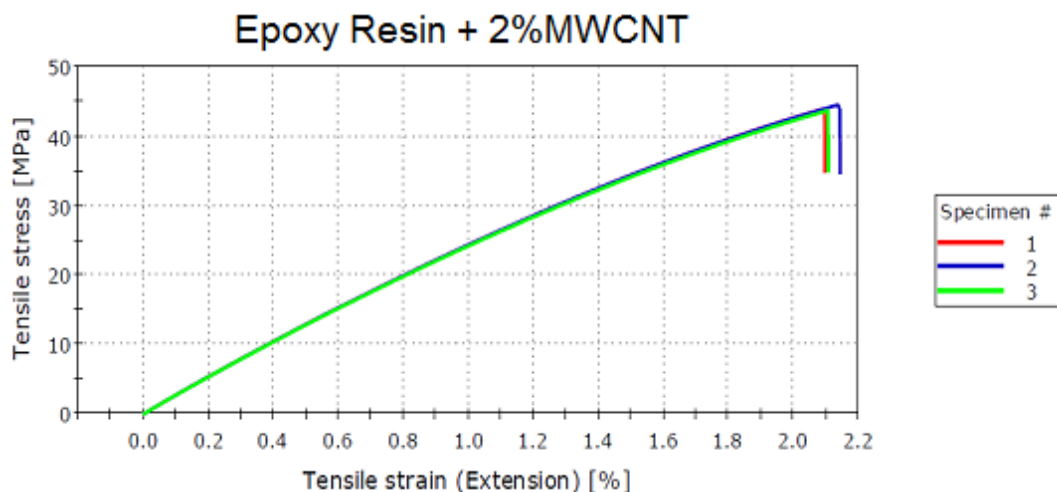


Figure 5. Stress-strain curve for the tensile test for 2% MWCNT content

The load extension evolution during bending test for a content of 2% MWCNT content is listed below in figure 6.

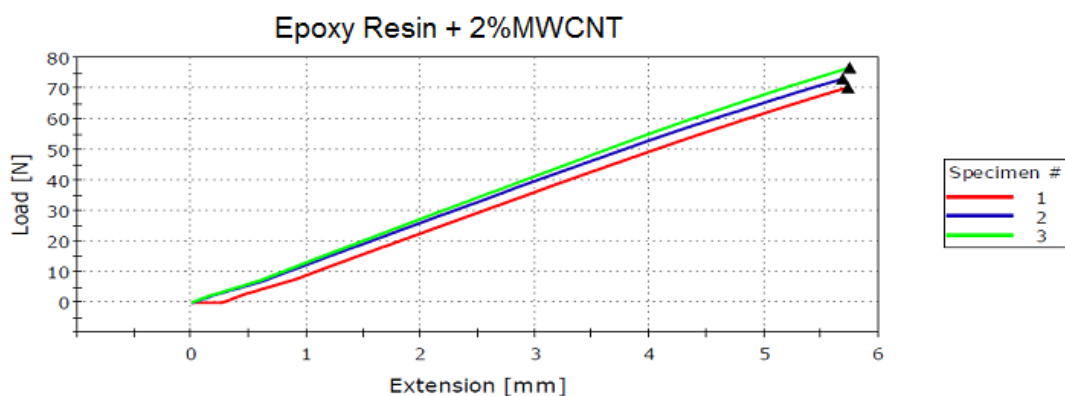


Figure 6. Load extension evolutions during bending test for a content of 2% MWCNT content

The mean values of Young modulus obtained by mechanical tests are presented in Table 2.

Table 2. Mechanical tests values of Young modulus

MWCNT content	E (Young Modulus) (Tensile test) MPa	E Modulus (Flexural Strain test) MPa
0%	2461	6767
0.5%	2663	6736
2%	2605	6390
4%	2563	6250

As a conclusion, experimental data shows that the 0,5% wt and 2% wt contents improve the elastic characteristics of the materials, especially for the tensile test.

Also, the experimental data shows that higher concentrations of the MWCNT decrease the E Modulus for flexural strain test.

It is important to mention that the values obtained can be influenced also by the specimen achievement procedure. The dumbbell and rectangular shape specimens were cut from larger plates using milling procedure. Mechanical intervention was necessary to obtain dimensions in the tolerance limits mentioned in the standard, intervention that can influence the mechanical performance of the material. Future experimental work will use special molds in order to form, directly, specimens of required geometry and dimensions.

### 3. NUMERICAL EXPERIENCES

#### 3.1 Numerical simulations of mechanical tests

Reproducing the laboratory tests in PATRAN/NASTRAN we intend to better understand how we can use the finite element commercial code to model the possibility of using such materials in designing different aeronautical structures.

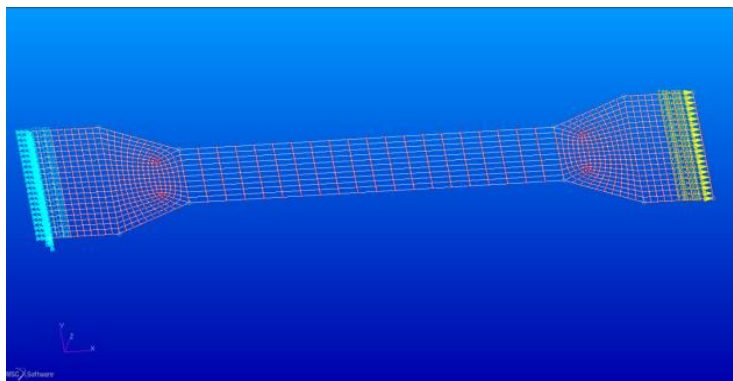
In this stage we introduce only a homogenous material characterized by a Young modulus equal with the mean value obtained by the laboratory experience and a Poisson ratio common for non-metallic materials, because the experimental tests indicate a large interval with a linear stress strain behavior as one can note in figures 3 and 4.

Moreover, comparing the tests with different MWCNT content, one can note that introducing the nanotubes in the epoxy resin the “linear character” of the stress-strain diagram is strengthened, although the mechanical characteristics are not significantly improved (see table 2).

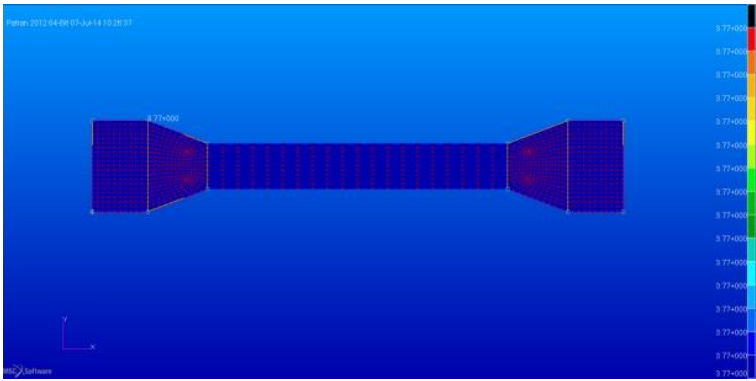
##### 3.1.1 Traction tests

Different aspects of the finite element model of the sample described in figure 1 are presented in figure 7:

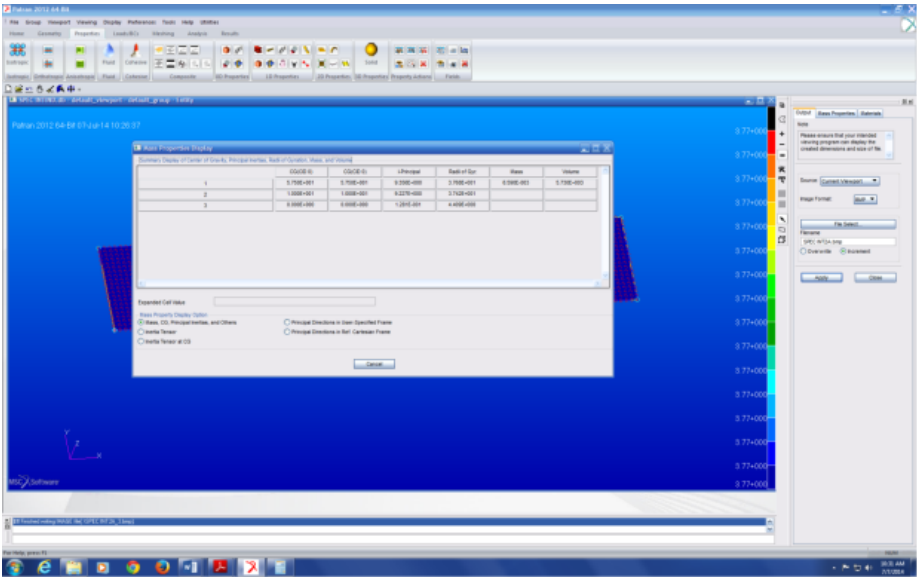
- a) finite element mesh with the boundary conditions and applied forces,
- b) element thicknesses,
- c) the mass distribution and the geometry for the 2% samples, and the for the 4% samples.



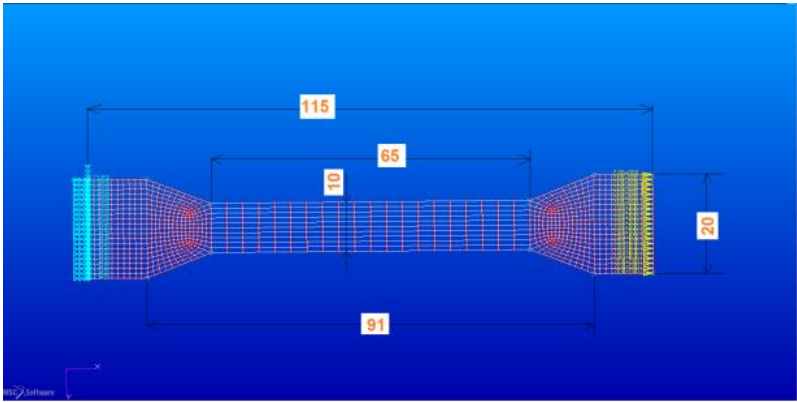
a) Finite element mesh with the boundary conditions and applied forces



b) Element thicknesses

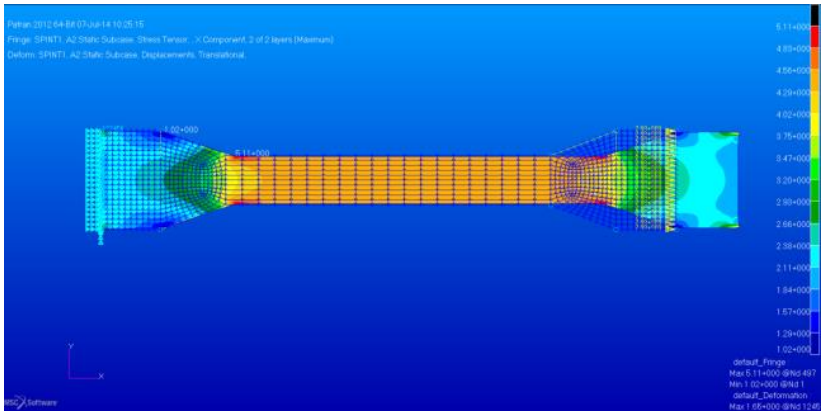


c) Mass distribution

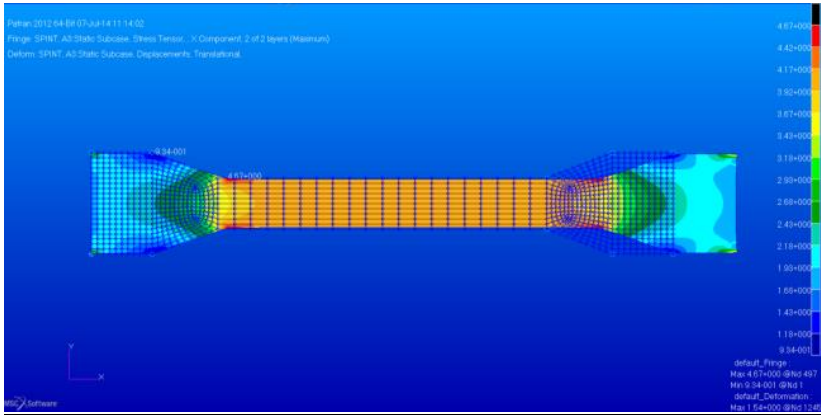


d) Geometry of the traction sample

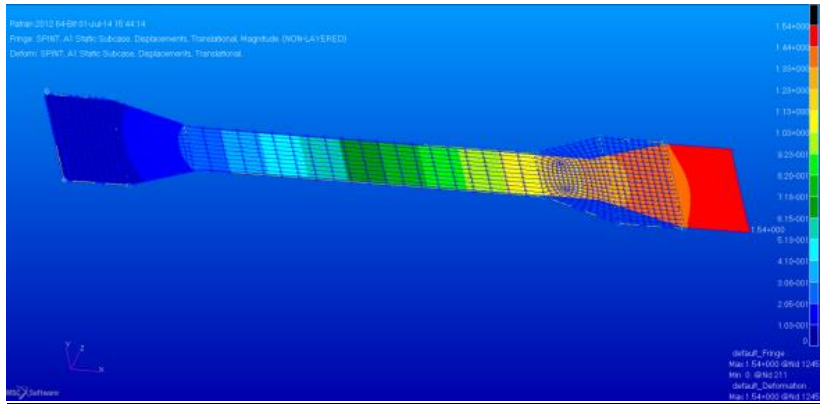
Figure 7. Finite element model for traction tests for 2% sample (mean values)



a) Stresses and displacements for 2% MWCNT



b) Stresses and displacements 4% MWCNT



c) Displacements for 4% MWCNT

Figure 8. Numerical results of PATRAN/NASTRAN simulations for 4% MWCNT

The results of PATRAN/NASTRAN simulations are presented in figure 7 and Table 3.

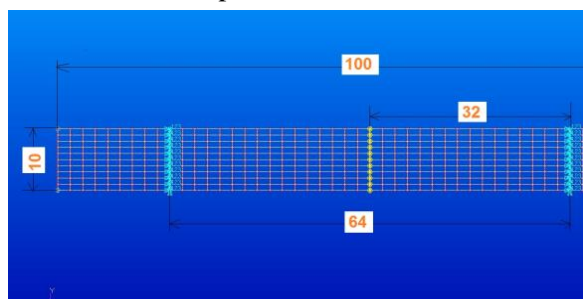
Table 3. Results of PATRAN/NASTRAN simulations.

MWNCNT content	Young Modulus E (mean value) (Mpa)	Poisson ratio	Applied Forces (daN)	Stresses (Mpa)		Displacements (mm)	
				Lab tests (MPa)	Numerical results MPa	Lab tests	Numerical results
2%	2605	0.33	165.792	43.96	45.6 in the middle region(see fig.6 a)	2.18	1.65 see figure 8a
4%	2563	0.33	148.777	40.21	41.76 in the middle region (see fig.6 b)	1.99	1.54 see figure 8 b),c)

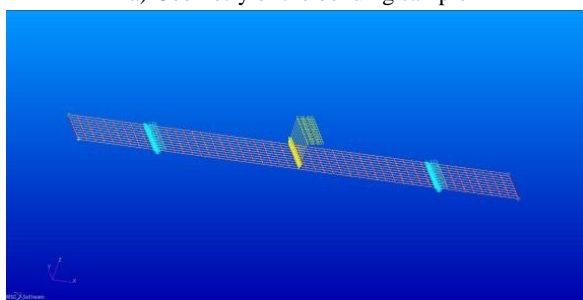
Comparing the values of stresses and displacements obtained in lab tests and those obtained as results of PATRAN/NASTRAN simulation one can state *that the numerical simulations are consistent with the lab tests for the traction case.*

### 3.1.2 Bending

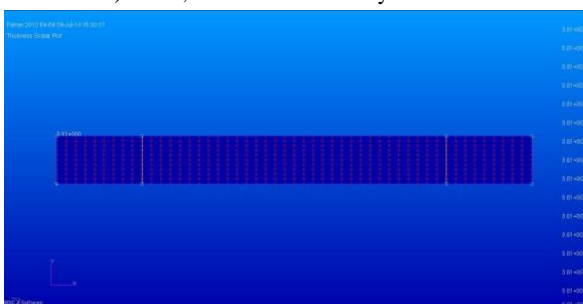
Different aspects of the finite element model of the sample described in figure 1 are presented in figure 9: a) geometry of the bending sample, (b)- finite element mesh with the boundary conditions and applied forces, (c) element thicknesses and (d) the mass distribution for the 2% samples, and for the 4% samples.



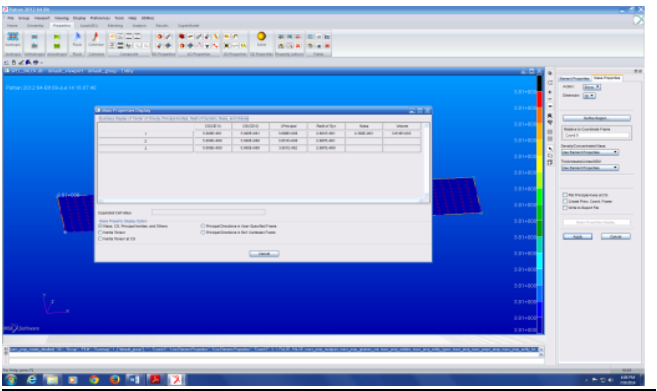
a) Geometry of the bending sample



b) Mesh, forces and boundary conditions



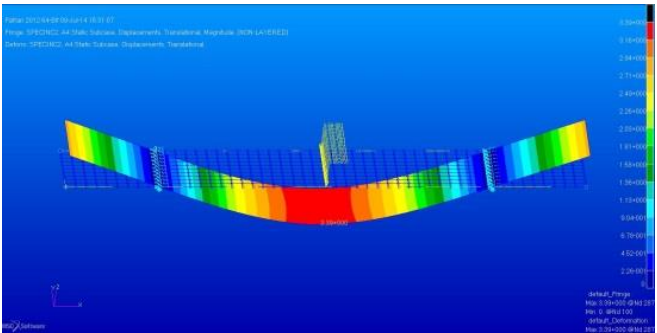
c) Element thicknesses



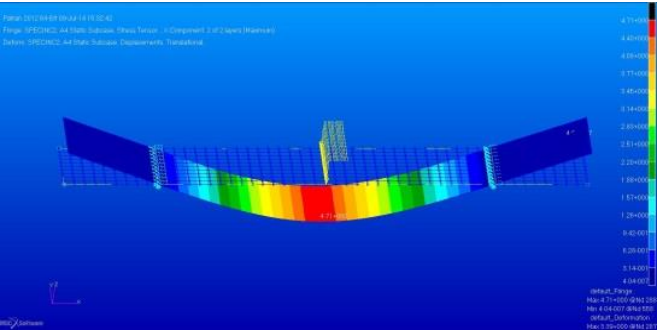
d) Mass distributions

Figure 9. Finite element model for bending tests for 2% sample (mean values)

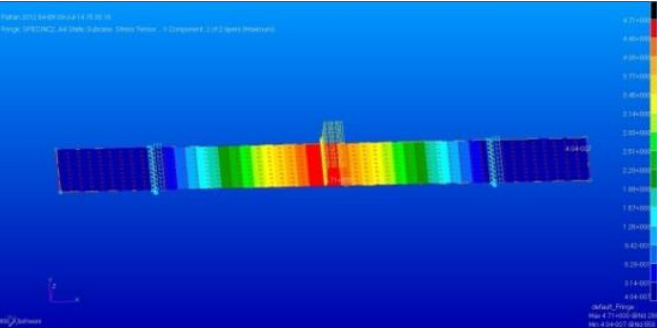
The results of PATRAN/NASTRAN simulations are presented in figures 10, 11 and Table 4.



a) Displacements



b) Stresses and displacements



c) Stresses

Figure 10. Bending results for 2% MWNCT

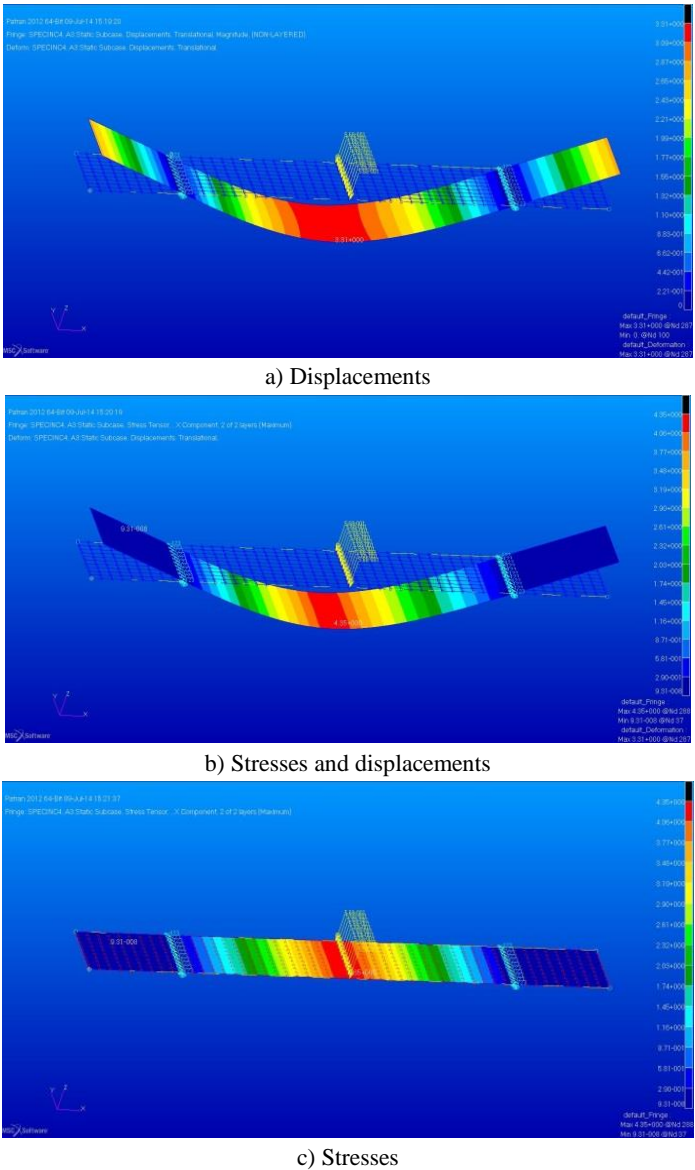


Figure 11. Bending results for 4% MWCNT

Table 4. Results of PATRAN/NASTRAN simulations

MWCNT content	Young Modulus E (mean value) (Mpa)	Poisson ratio	Applied Forces (daN)	Stresses (Mpa)		Displacements (mm)	
				Lab tests (MPa)	Numerical results MPa	Lab Tests	Numerical results
2%	2605	0.33	7.326	76.23	47.1	Not available for significant comparison	3.39
4%	2563	0.33	6.246	69.98	43.5	Not available for significant comparison	3.31

The laboratory experiences and the numerical simulation results reveal some differences for the bending case and that fact implies that the constitutive equations have to be improved considering NASTRAN capabilities to model plastic materials.

### 3.2 Model of possible aeronautic structure

Consider a reinforced plate that can be used as separating wall in an aircraft cabin. It may be a metallic structure, but we investigate now the possibility to be made of aluminum bars and nano composite plates. Taking into account the encouraging results of simulations of the laboratory mechanical tests we model such a plate and investigate the consequences of using it for such a separating wall in order to obtain a lighter structure. We compare the results obtained for this plate with a classical plate with aluminum panels. The geometry of the considered plate is described in figure 12.

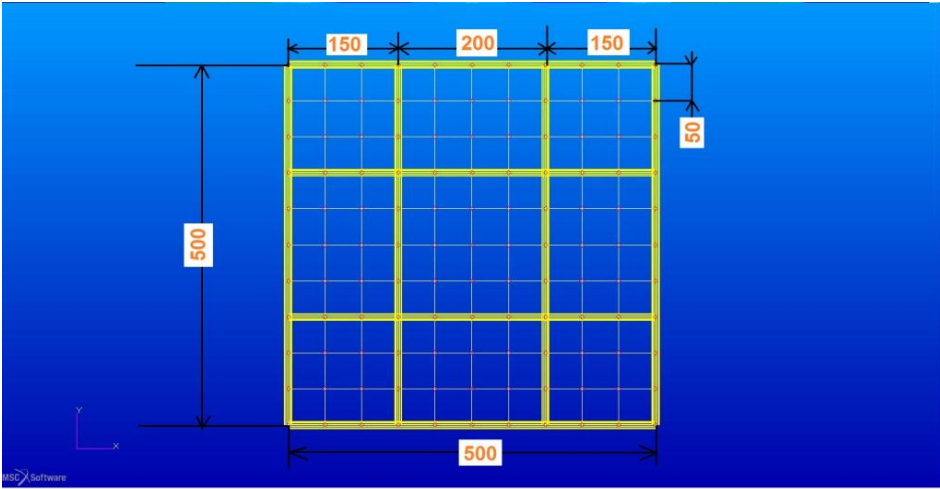


Figure 12. Geometry of a reinforced plate

The principal characteristics of the model are presented in table 5 and in figure 13.

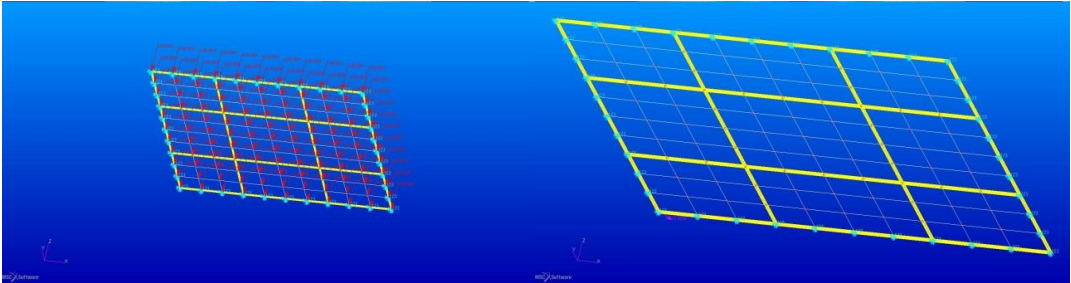


Figure 13. Loads and boundary conditions for the reinforced plate a) distributed pressure, b) inertial loads

Table 5. Geometrical characteristics of reinforced plate

	h (mm)	E (daN/mm <sup>2</sup> ) panels	panels density g/mm <sup>3</sup>	E (daN/mm <sup>2</sup> ) beams	beams density g/mm <sup>3</sup> beams	FEM Mass (Kg)
MCWNT 2%	4	260.591	0.00115	7300	0.0027	1.286
MCWNT 4%	4	256.351	0.00115	7300	0.0027	1.286
aluminum	4	7300	0.0027	7300	0.0027	2.198

We considered two load cases: 1) a uniform distributed pressure  $p=0.0004\text{daN/mm}^2$  (which corresponds to a total force of  $100\text{daN}$ ) and 2) initial loads with  $n_x=9$ ,  $n_y=6$ ,  $n_z=-6$ .

The plate is simply supported on its boundary. The results of the numerical simulations are presented in table 6 and in figure 14.

Table 6. Results

	Maximum displacement case 1(mm)	Maximum displacement case 2 (mm)	Von Misses maximum Stress case 1 daN/mm <sup>2</sup>	Von Misses maximum stress case 2daN/mm <sup>2</sup>
MCWNT 2%	47.8	3.54	1.35	0.098
MCWNT 4%	48.3	3.58	1.35	0.094
aluminum	1.72	1.49	6.8	0.587

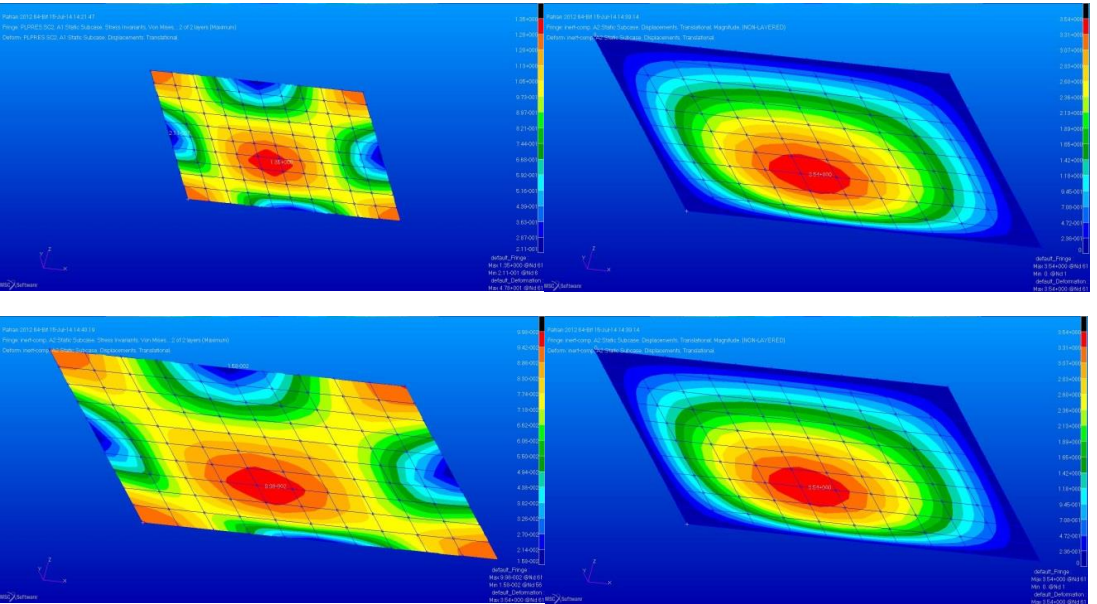


Figure 14. Von Misses stress and displacements for a plate with 2%MCNT panels and aluminum beams for an uniform pressure and inertial loads

As it we expected the plate composed of nanocompozite panels and aluminum beams is lighter than the aluminum plate as we can see in table 4 and the values of displacements and stresses presented in table 5 indicate that such a structure may be used in structures as separation walls in an aircraft cabin.

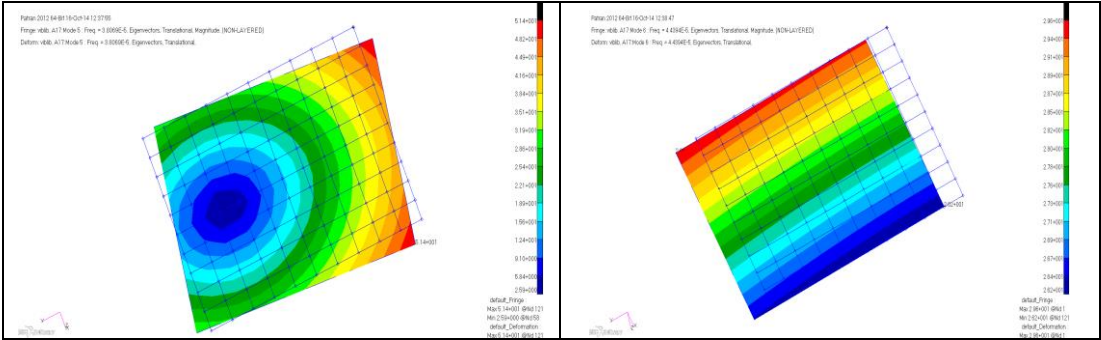
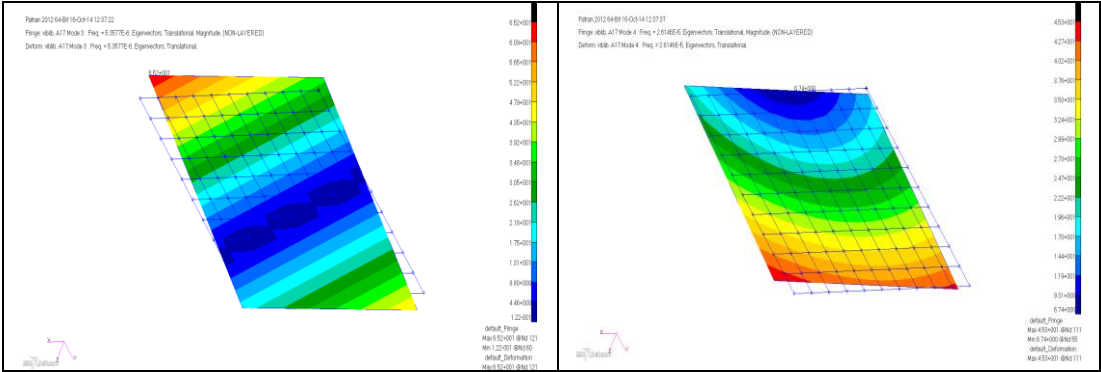
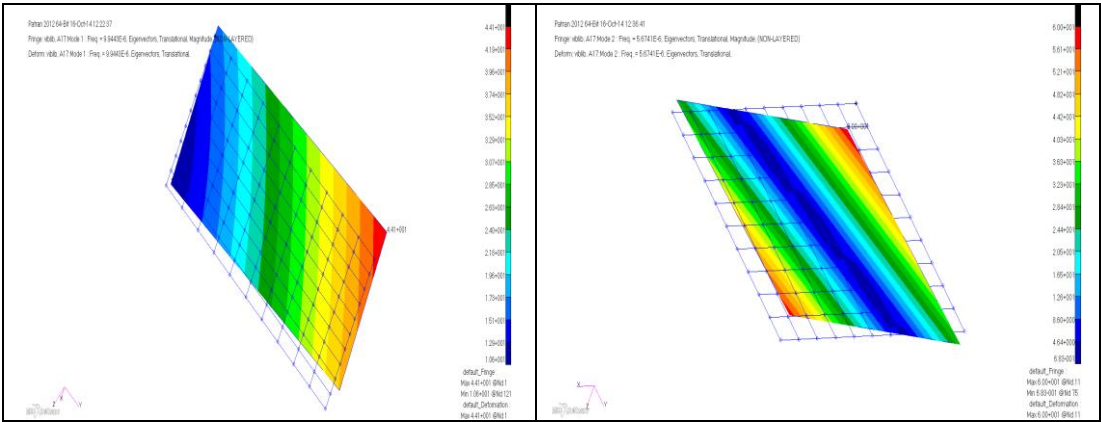
We also performed a modal analysis on this structure with the following results.

For the 4% MWCNT plate with aluminum beams we obtained the following 10 frequencies (6 rigid and 4 elastic) see table 7 and figure 15.

Table 7. MSC.NASTRAN JOB CREATED ON 28-MAY-14 AT 15:10:56  
OCTOBER 16, 2014 MSC.NASTRAN 11/25/11 PAGE 7  
SUBCASE 1  
REAL EIGENVALUES  
(BEFORE AUGMENTATION OF RESIDUAL VECTORS)

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	-3.90E-09	6.25E-05	9.94E-06	1.00E+00	-3.90E-09
2	2	-1.27E-09	3.57E-05	5.67E-06	1.00E+00	-1.27E-09
3	3	-1.13E-09	3.37E-05	5.36E-06	1.00E+00	-1.13E-09

4	4	2.70E-08	1.64E-04	2.61E-05	1.00E+00	2.70E-08
5	5	5.72E-08	2.39E-04	3.81E-05	1.00E+00	5.72E-08
6	6	7.78E-08	2.79E-04	4.44E-05	1.00E+00	7.78E-08
7	7	1.13E+03	3.37E+01	5.36E+00	1.00E+00	1.13E+03
8	8	2.60E+03	5.10E+01	8.12E+00	1.00E+00	2.60E+03
9	9	3.63E+03	6.02E+01	9.59E+00	1.00E+00	3.63E+03
10	10	8.05E+03	8.97E+01	1.43E+01	1.00E+00	8.05E+03



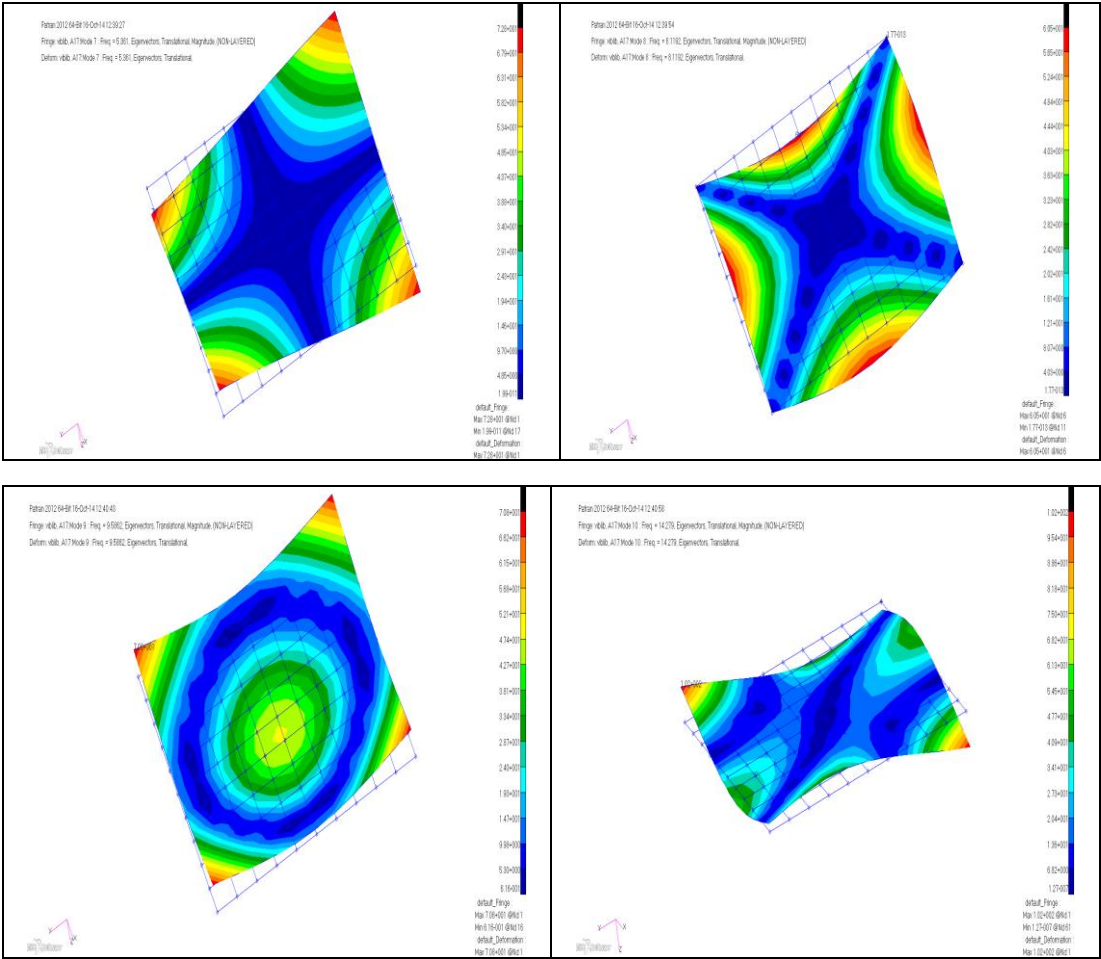


Figure 15. Normal modes for 4% MWCNT plate -6 rigid modes and 4 elastic modes.

In Table 8 we present a comparison between the frequencies of a metallic structure with two composed plates.

Table 8. Natural frequencies for the composed plate

MODE NO.	MWCNT plate		Aluminum plate	Notes
	2%CNT	4%CNT		
1	3.97E-05	9.94E-06	6.14E-05	Rigid modes
2	2.45E-05	5.67E-06	1.78E-05	
3	1.97E-05	5.36E-06	1.74E-05	
4	4.41E-06	2.61E-05	1.64E-05	
5	2.90E-06	3.81E-05	6.38E-05	
6	2.15E-06	4.44E-05	1.04E-04	
7	<b>5.39E+00</b>	<b>5.36E+00</b>	<b>8.31E+00</b>	Elastic modes
8	8.16E+00	8.12E+00	1.22E+01	
9	9.64E+00	9.59E+00	1.48E+01	
10	1.43E+01	1.43E+01	2.13E+01	

Analyzing these data we note that the first free elastic frequency for the mixed plate is smaller than the aluminum plate, but its value is not too small (almost 50% smaller). So the conclusions about using such kind of structures for different types of interior structures in aircraft design still stand.

#### 4. CONCLUSIONS ABOUT THE POTENTIAL USE OF SUCH MATERIALS IN THE PROCESS OF DESIGNING AERONAUTICAL STRUCTURES

As stated above the results of the finite element numerical simulations of the MCNWT materials are in a convenient relation with the laboratory tests and further tests (experimental and numerical) may be developed in order to consider using such materials in aircraft design. So, from table 3 one can note that in the traction case the differences between the lab tests and the numerical simulations results are round 4%. The differences for displacements can possibly be explained by the fact that all numerical simulations consider a linear isotropic elastic model and these materials are in fact nonlinear and not isotropic. Same arguments may stand for the differences for the bending case (table 4). But the main conclusion is that after some more evaluations we may consider such materials to be integrated in complex structures used for aircraft design.

To have a more complete evaluation maybe compression tests are necessary followed by a buckling analysis of composed plates [8], [9], [10].

#### ACKNOWLEDGEMENT

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