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# ANALYSIS OF WIND TURBINE BLADES FROM LIGNOCELLULOSIC COMPOSITES SUBJECTED TO STATIC BENDING

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***Abstract***
*This paper presents the results of numerical analysis of stress and strain states which develop in wind turbine blades, modeled from various lignocellulosic composites. A blade structure type NACA 44XX with length 1.5m, power of 2.5kW and a rotational speed of 636 rpm, based on numerical calculations and the aerodynamic theory was designed in Catia program. The model was imported in finite element analysis program - HyperMesh, which were successively awarded four types of elastic properties corresponding to solid wood - oak, lignocellulose composites based on mixture of polyurethane resin and wood particle, glass fiber composite and carbon fibers. Four types of external loads were placed successively in different areas of the longitudinal axis of the blade, simulating wind force. The variation of stress and strain states expressing the advantages and disadvantages of the proposed materials, noting that risk areas of the blade structure can be reduced through various technological ways - through the addition of material thicknesses, changes to the reinforcement of composite layers by introducing layers with higher elastic properties, the introduction of local or global reinforcing elements.*

***Key words:*** *wind turbine blade; lignocellulosic composite; solid wood; bending; stress and strain state.*

## INTRODUCTION

Wind energy is one of the oldest sources of clean energy, a renewable source of energy generated from wind power. Wind energy is the result of the activity of the sun and is formed due to uneven heating of Earth's surface. Every hour the earth receives 1014*kWh* of solar energy, of which about 1-2% is converted into wind energy. The cost of producing electricity by using wind farms represents 75% of the costs using conventional methods. Maintenance does not cost very much (about 4,500 euro) and supplies should be changed every two years. A summary of the risks and damage rates for wind turbines was carried out in 2008 by an insurance company, highlighting the most important risks posed by wind turbines *(http: // www. Asimag.ro/stiri_specialitate/29 ).* Thus 40% of total global damage of wind turbines is due to mechanical faults and failures. The most common mechanical faults occur in the gyroscope system, the gears, bearing as well as on the blades (Xiang 2014; Jensen 2008). The blades damage usually occurs due to fatigue of the materials, vibration,

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overloading, defective materials and impacts (Grasse 2011). The challenge of the wind turbine blade manufacturers is to find constructive solutions to ensure long lengths of blades but stiffer (which not deform under stresses) and simultaneously light (to rotate at a minimum speed of wind about 4 to 5,5m/s) of materials resistant to wear, damage, fatigue and with reduced costs. The thinner turbine blades may be deformed by wind load beyond the maximum allowable deflection, reaching the tower which can lead to damage of the blade and the tower (Puneet 2014). The stress variations from the blade structure occur due to atmospheric turbulence, the accelerations, atmospheric pressure and temperature. Minimum safety coefficient is determined from the condition that permanent deformations do not occur (Xiao 2014). The blades of the wind turbines are subjected to the following external loads: aerodynamic, gravitational, centrifugal, gyroscopic and operational forces (Fig. 1). It was found that high-risk areas of damage are those where the aerodynamic loads acting simultaneously with the structure forces (Fig. 2) (Schubel 2012; Davies 2008).

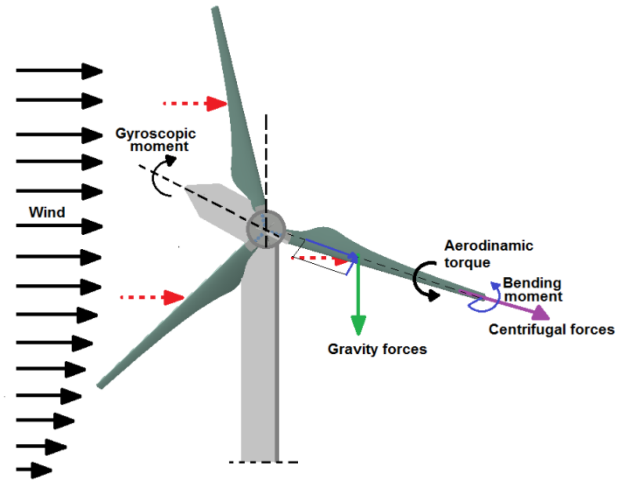



***Fig. 1.***
***Bending load of blade***

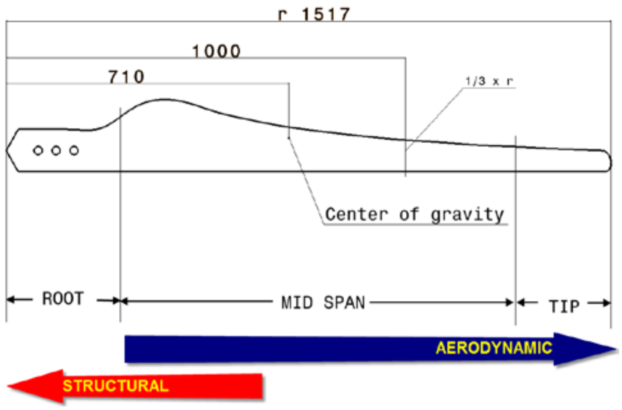



***Fig. 2.***
***The main regions of wind blade and prevailing loading***

In the blade construction are used composite materials to simultaneously provide mechanical strength, flexibility, elasticity and light weight. Of these, the most used are composites based on fiberglass and carbon fiber (Hiromasa 2008).

**OBJECTIVE**

The objective of the research is to evaluate the stress and strain state of the wind turbine blade modeled from lignocellulosic composite, fiberglass composite, carbon fiber and solid wood. The analyzed structures are subjected to bending in static condition. The results revealed that the hypotheses related to application points of forces are very important in calculus because influence the magnitude of displacement and the stresses. Moreover, the paper evaluates in terms of stresses and strains, feasibility of wind turbine blades made from bio-composites such as solid wood and lignocellulosic composites.

## MATERIAL AND METHOD

### Geometry of wind blade

In the finite element analysis, a NACA 44XX profile (The National Advisory Commitee United States for Aeronautics) with geometric shape resulting from aerodynamic and mechanical calculation based on Betz's formulas was studied:

$$c_{opt} = \frac{2\pi r}{n} * \frac{8}{9C_L} * \frac{U_{wind}}{(V_r} \; ; \quad (1)$$

$$V_r = \sqrt{V_v^2 + U^2} \; . \quad (2)$$

where: *r* is the radius of the blade (represents the length, in *m*); n- number of blade; $C_L$ – the lift coefficient; λ - the local velocity at the tip of the blade (*m/s*); $V_r$ – local wind speed (*m/s*); U – wind speed (*m/s*); $U_{wind}$ – the wind speed for which is designed the blade; $C_{opt}$ - optimal size of chord (profile). Using a commercial program to choose the profiles of blade, radius and the tip speed ratio, it was generated a model for wind turbine blade with 2,5*kW* power, rotational speed of 636*rpm*, wind speed of 9*m/s* and the efficiency of 0.3, which was designed in Catia (Fig. 3). The radius of the blade is 1,5*m*.

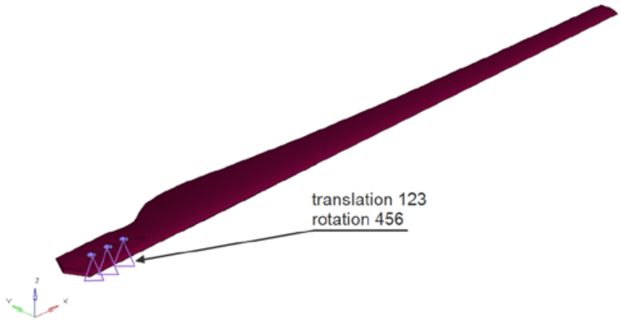



***Fig. 3.***
***Geometrical model of the wind blade***

### Materials

Stresses and strains of blade were analyzed with finite element method using HyperWork package from HyperMesh software. Due to complexity of aerodynamical load from point of view of mathematical description, the finite element analysis was approached through equalization of dynamical load with static ones. We have considered four types of elastic materials whose elastic properties are presented in Table 1 and 2, because to change dynamic and mechanical properties of wind turbine consist of modifying the material, which the blade is made of (Jureczko 2005).
Carbon fiber composite and fiber glass composite are two tipical materials for turbine blade (Ashwill 2008). The lignocelulosic compozite made of polyester resin with oak particles in fraction volum to 1:1 studied by (Stanciu, Terciu, Curtu 2014) and oak solid wood represents two lignocelulosic materials which were analysed in these paper.

### Types of finite element

Depending on the used material, the structure was modeled as a solid body, being meshed in solid-type finite elements tetra10 – in case of solid wood (Fig. 4, a) and as a beam structure with thin walls and closed profile NACA 44XX, in case of composites (Fig. 4, b), in which case we used shell type elements (quad 4). In Tabel 1, the symbol E represents elasticity modulus in longitudinal direction, G – shear modulus and ν - Poisson coefficient. The indices 1, 2, 3 represents the direction of fibers: 1 – longitudinal direction (along of radius), 2 – transversal direction (in chord direction), 3 – thickness direction. For wood, the indices coresponds to the main section – longitudinal (1 or L), radial (2 or R) and tangential (3 or T) (Table 2).

*Table 1*

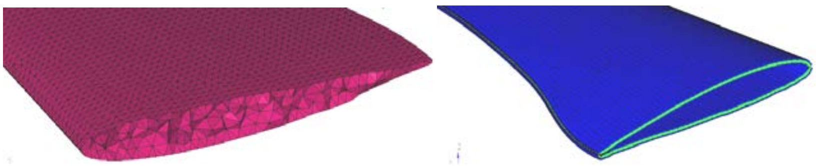
***Elastic properties of composite materials used in FEA for each type of modeled structures***

| Materials | Density Kg/m$^3$ | No. of layers | Thickness [mm] | Young`s Modulus | | | Shear Modulus | | | Poisson Coefficient | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $E_1$ [MPa] | $E_2$ [MPa] | $E_3$ [MPa] | $G_{12}$ [MPa] | $G_{21}$ [MPa] | $G_{13}$ [MPa] | $\nu_{12}$ | $\nu_{21}$ | $\nu_{13}$ |
| Carbon fibre composite | 1500 | 12 | 4,2 | 16200 | 15100 | 4300 | 3100 | 3100 | 2800 | 0.3 | 0.3 | 0.03 |
| Fiber glass composite, | 2400 | 3 | 1,1 | 10000 | 10000 | | | | | 0,25 | | |
| | | | 2 | 48000 | 35000 | | | | | 0,3 | | |
| | | | 1,1 | 10000 | 10000 | | | | | 0,25 | | |
| Lignocellulosic composite (Stanciu, 2014) | 1300 | 5 | 0,86 | 4711 | 2786 | - | 1746 | 1032 | - | 0,349 | | |
| | | | 0,8 | 4012 | 4012 | - | 1464 | 1464 | - | 0,337 | - | - |
| | | | 0,86 | 2786 | 4711 | | 1032,6 | 1746 | | 0,349 | | |
| | | | 0,8 | 4012 | 4012 | - | 1464 | 1464 | - | 0,337 | - | - |
| | | | 0,86 | 4711 | 2786 | - | 1746 | 1032 | - | 0,349 | | |

*Table 2*

***Elastic properties of solid wood used in FEA for each type of modeled structures (Curtu, 1984)***

| Materials | Density Kg/m$^3$ | Young`s Modulus | | | Shear Modulus | | | Poisson Coefficient | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $E_L$ [MPa] | $E_R$ [MPa] | $E_T$ [MPa] | $G_{LR}$ [MPa] | $G_{LT}$ [MPa] | $G_{RT}$ [MPa] | $\nu_{TR}$ | $\nu_{LT}$ | $\nu_{RT}$ | $\nu_{TL}$ | $\nu_{RL}$ | $\nu_{LR}$ |
| Solid wood (oak) | 750 | 14000 | 2200 | 830 | 1320 | 910 | 440 | 0.34 | 0.41 | 0.83 | 0,036 | 0,07 | 0,43 |



***a)*** ***b)***

***Fig. 4.***

***Meshing in finite element structure: a) Solid elements tetra 10; b) shell finite elements - quad4***

**Loading structure**

Loading structure was performed for four different cases of force application: case 1 - the force applied to the free end, with a value of 100*N* (Fig. 5, a); case 2 - force applied to one third of the blade length from the tip (Fig. 5, b); case 3 - force applied to the gravity center of the structure (Fig. 5, c); case 4 - uniform distributed forces over the entire length of the blade with the equivalent value of 100*N* (Fig. 5, d) and case 5 - distributed force by a linear law as shown in Fig. 5, e. Finite element analysis was run for each load case separately and for each type of material used in the blade structure.

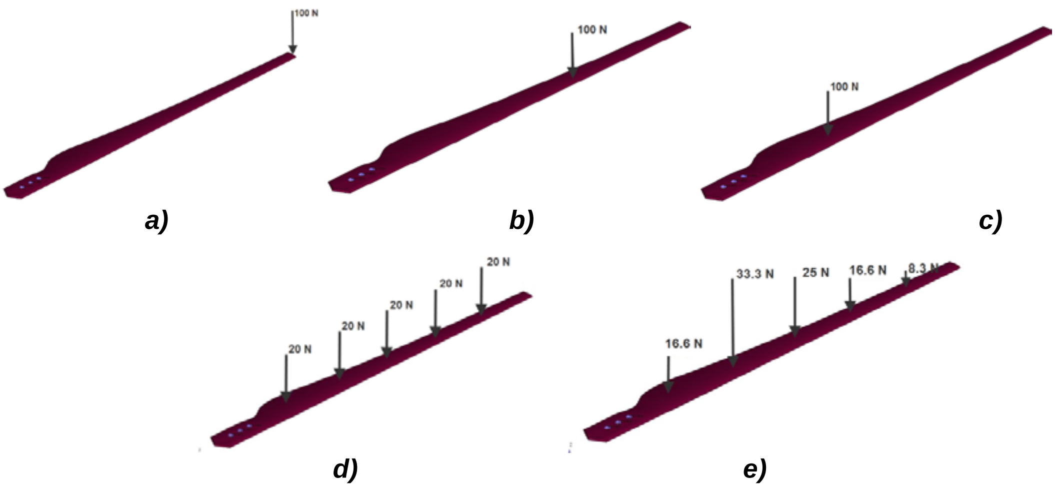



***Fig. 5.***

***External load applied on blade structure: a) case 1; b) case 2; c) case 3; d) case 4; e) case 5***

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## RESULTS AND DISCUSSION

### Static analysis - stress and strain state

It is noted that the blade material plays an important role in the analysis of stresses and strain states. The solid wood and the lignocellulosic composite presents the largest bending deformation, unlike the blade made of fiber glass or carbon fiber composite. In Table 3 and 4 are presented the results of the five types of loading in accordance with studied materials, in terms of the stresses and the displacements. Analyzing the stresses and strains highlights that the way is applied the load and the elasticity of material influences the static behavior of the structure: the largest displacements being recorded when concentrated force is applied on the tip of blade or at one third from tip. Thus, it's found that displacements are approximately three times lower in case of carbon fiber composite compare to wood or six time lower compare to lignocellulosic composite (Fig. 6 and 7) .

***Table 3***

***Variation of displacement with type of loading and type of materials***

| **Loading** | **Displacement *mm*** | | | |
|---|---|---|---|---|
| | ***Carbon fiber*** | ***Fiber glass*** | ***Lignocellulosic*** | ***Solid wood*** |
| **Case 1** | 120,051 | 192,348 | 668,862 | 381,393 |
| **Case 2** | 35,647 | 55,853 | 171,806 | 120,252 |
| **Case 3** | 8,050 | 12,471 | 27,774 | 31,785 |
| **Case 4** | 19,348 | 30,352 | 89,718 | 67,344 |
| **Case 5** | 27,132 | 42,731 | 133,298 | 92,057 |

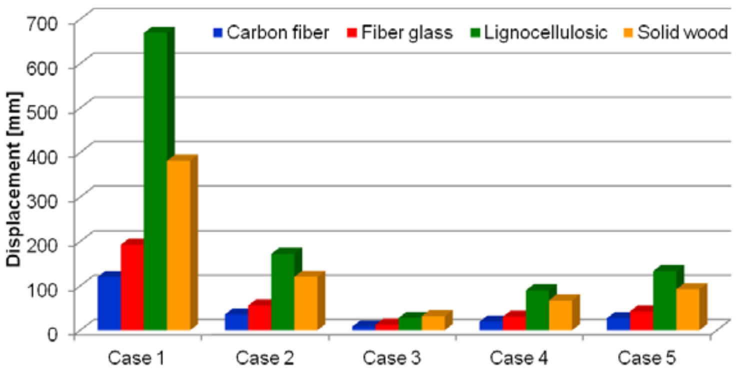
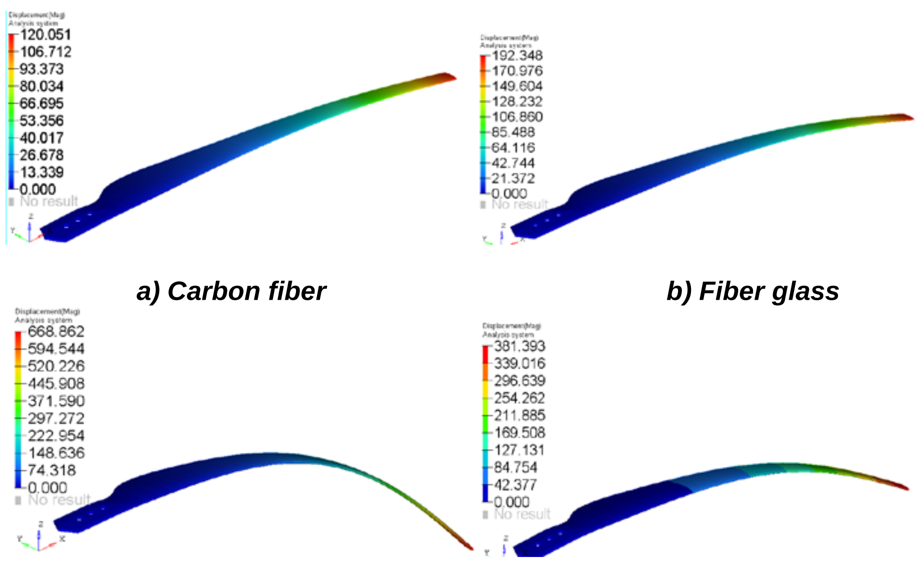



***Fig. 6.***

***The variation of the displacements related to materials and the cases of loading***



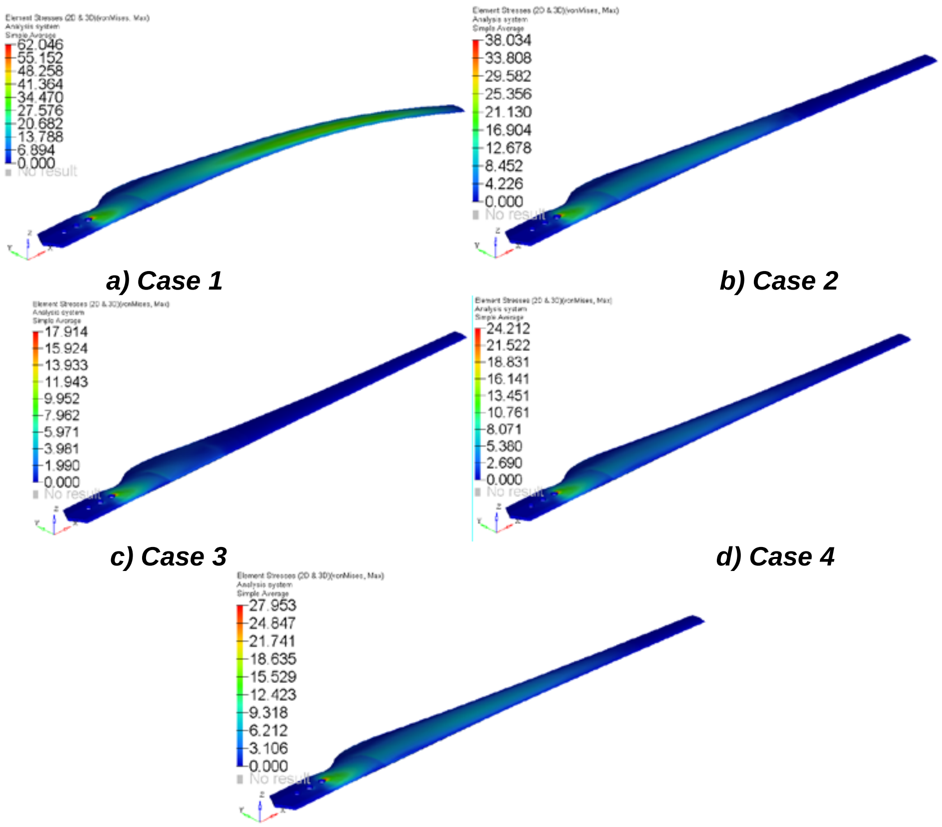

***a) Carbon fiber*** ***b) Fiber glass***

***c) lignocellulosic*** ***d) solid wood***

***Fig. 7.***

***The displacements variation in case 1 of loading***

The stresses obtained in case of the blade made from solid wood are higher than admissible stresses of 10*MPa*, but is around of 100*MPa* which represent flexural strength of oak wood (Curtu 1984). In case of lignocellulosic composite, 60*MPa* represents the flexural strength. The concentrated forces applied to the free end and to one third of the blade length from the tip may causes some damage of the wind blade because the stresses exceed the admissible stress (Table 4). The strength of the blades made from carbon fiber and fiber glass composites is superior compare to lignocellulosic composite and solid wood. The flexural strength for the carbon fiber composite is around 140*MPa* and for fiberglass is around 120*MPa* (Gulaski 2014; Amer 2014; Huang 1990). The results show that, in static condition, the blade resist to external loading for each studied cases (Fig. 9). Taking into account that the wind turbine blade is subjected to cyclic forces (variable and aerodynamic) and complex loading, the flexural strength decreases with 40 to 80% from the results obtained in static analysis. The maximum value of the stresses von Mises regardless the material, is obtained in case of forces applied on the tip of the blade (case 1). In all cases, the maximum stress is recorded in area of fixed the blade. It can be noticed that the blade made of solid wood (oak) recorded von Mises stress appropriate with carbon fiber composite. For short radius of blade, the laminated solid wood can be use with success in wind turbine structure.



***a) Case 1*** ***b) Case 2***

***c) Case 3*** ***d) Case 4***

***e) Case 5***

***Fig. 8.***
***Stresses von Mises in case of fiber glass composite***

***Table 4***

***Variation of stresses von Mises with type of loading and type of material***

| **Materials/Loading Cases** | **The maximum stress von Mises MPa** | | | | | **Flexural strength *MPa*** |
|---|---|---|---|---|---|---|
| | **Case 1** | **Case 2** | **Case 3** | **Case 4** | **Case 5** | |
| ***Carbon fiber*** | 117,836 | 72,194 | 33,926 | 45,901 | 53,013 | 140 |
| ***Fiber glass*** | 62,046 | 38,034 | 17,914 | 24,212 | 27,953 | 120 |
| ***Lignocellulosic*** | 83,627 | 51,282 | 24,169 | 32,653 | 37,693 | 60 |
| ***Solid wood*** | 117,885 | 72,819 | 34,336 | 46,383 | 53,541 | 100 |

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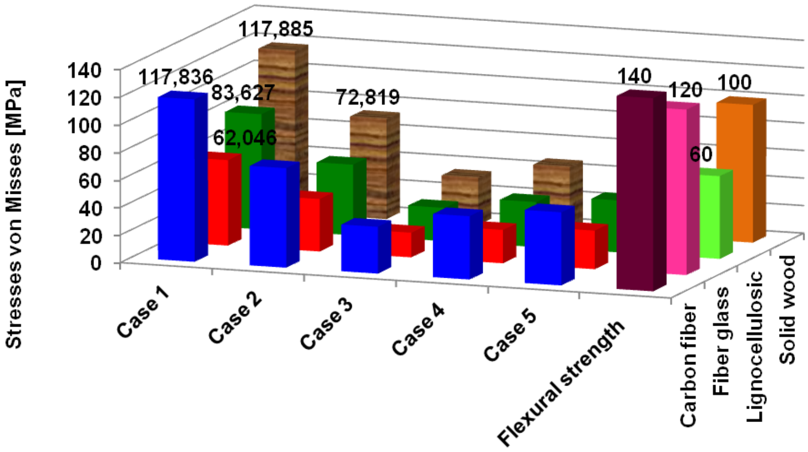


***Fig. 9.***
***The stresses von Misses variation against the type of loading, material and flexural strength of each material***

If it is neglected the fixed area of the blade because the practice show that zone is safe, it can be noticed that in area B and C from Fig. 9 are the most stressed, exactly the region where the aerodynamic and structural loading overlap. In the next studies, structural optimization of the wind turbine blade will be investigated.

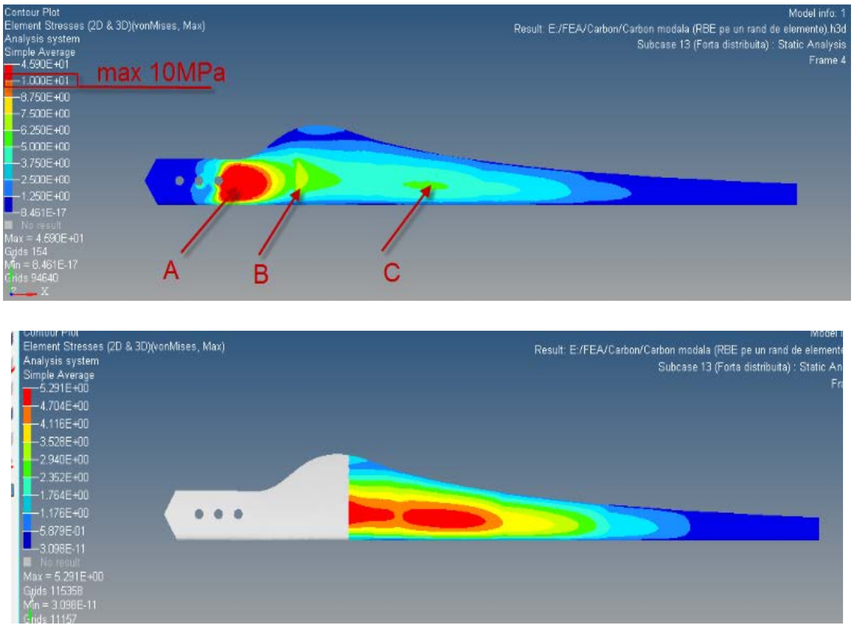


***Fig.10.***
***The stresses region with maximum risk due to superposed the static and dynamic loading***

## CONCLUSIONS

In this study, the posibilities of using new materials for wind blades preformance were investigated by means of static analysis of the structures subjected to static bending. In reality, the external loading are not constant, contrary they varying in time. So, the loading variation can be expressed in deterministic way as sinusoidal variations, complex periodic or transitional to a random variations.

The risk reduction of the wind turbine blades can be prevented during the conception and design; by judicious choice of the most suitable solutions and proper materials according to some optimization criteria; ensuring the qualitative manufacturing process, by proper selection of processes and technological equipment; conserved - using appropriate methods of transportation, handling, storage and operation; maintained - through proper operation and proper maintenance program and regularly monitor the structural integrity of the blades by appropriate means.

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**REFERENCES**

Amer C, Sahin M (2014) Structural Analysis of a Composite Wind Turbine Blade. World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering Vol:8(7).

Ashwill Th, Paquette J (2008) Composite materials for innovative wind turbine blades, http://windpower.sandia.gov/other/SAMPE2008-Ashwill.pdf.

Curtu I, Ghelmeziu N (1984) Mecanica lemnului si materialelor pe baza de lemn. Ed. Tehnica Bucuresti.

Davies GAO, Ankersen J (2008) Virtual Testing Of Realistic Aerospace Composite Structures. J Mater Sci (2008) 43:6586–6592.

Grasse F, Trappe V, Thoens S, Said S (2011) Structural health monitoring of wind turbine blades by strain measurement and vibration analysis. Proceedings of the 8th International Conference on Structural Dynamics, EURODYN 2011, Leuven, Belgium, 4-6 July 2011.

Gulasik H, Coker D. (2014) Delamination Debond Behaviour Of Composite T - Joints in Wind Turbine Blades. Journal of Physics: Conference Series 524:1742-6596.

Hiromasa Kawai, Kazutoshi Michishita, Akira Deguchi (2008) Design Wind Loads on a Wind Turbine for Strong Wind. BBAA VI International Colloquium on: Bluff Bodies Aerodynamics & Applications Milano, Italy, July, 20-24 2008.

Huang Hou-Cheng (1990) Static and Dynamic Analysis of Plates and Shells. Academic Press.

Jensen Find Mølholt (2008) Ultimate strength of a large wind turbine blade. PhD Thesis Danemarca ISBN 978-87-550-3634-5.

Jureczko M, Pawlak M, Mezyk A (2005) Optimization of wind turbine blades, Journal of Materials Processing Techonology 167:463 – 471.

Puneet Malhotra (2014) Advanced Blade Testing Methods for Wind Turbines. Masters Theses February 2014, University of Massachusetts – Amherst, http://scholarworks.umass.edu/theses.

Schubel PJ, Crossley RJ (2012) Wind Turbine Blade Design. Energies 2012 (5):3425-3449.

Stanciu MD, Terciu OM, Curtu I (2014) Compozite Lignocelulozice – Aplicatii in Industria Automobilelor. Ed. Universitatii Transilvania din Brasov. DOI: 10.13140/2.1.2368.0323, pp. 238.

Xiang Li, Zhibo Yang, Xuefeng Chen (2014) Quantitative Damage Detection and Sparse Sensor Array Optimization of Carbon Fiber Reinforced Resin Composite Laminates for Wind Turbine Blade Structural Health Monitoring. Sensors 2014, 14(4):7312-7331.

Xiao Chen, Wei Zhao, Xiao Lu Zhao, Jian Zhong Xu (2014) Failure Test and Finite Element Simulation of a Large Wind Turbine Composite Blade under Static Loading. *Energies* 2014, 7:2274-2297; doi:10.3390/en7042274.