 

# ANALYSIS AND SIMULATION OF THE WIND TURBINE BLADES PERFORMANCE USING NONCONVENTIONAL TESTING TECHNIQUES

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ABSTRACT: The wind turbine blades are components subjected to severe loadings during its service. In this paper were implemented accelerated testing methods to assess the lifespan of products used in the renewable energy industry. This testing instrument is more and more often used by large companies that want as high quality products in as short time possible. Within these types of tests, a special emphasis is put on the accelerated testing techniques. The test laboratories that have modern test equipments and highly qualified personnel is developed more and more. Through blade's failure cycles simulation using Monte Carlo method was determined and graphically represented the reliability indicators. At the finite element analysis for the wind turbine blade were shown the failing mode and the lifespan of the blade using accelerated stresses.
KEYWORDS: wind turbine blade, Monte Carlo simulation, mean life, finite element analysis, accelerated techniques

## 1. INTRODUCTION

The wind energy has been used from the oldest times along the human kind's history, from sailing boats to the wind farms of today, being used as kinetic energy, mechanical or electrical. The notion of turbine is used for any machine with blades that convert the kinetic energy of a fluid into work. In case the kinetic power of the wind is being used the turbine is called wind turbine.

The wind turbine with blades is the most representative between wind installations and the most wide spread because of the superior efficiency. In figure 1 are described the main components of a wind turbine.

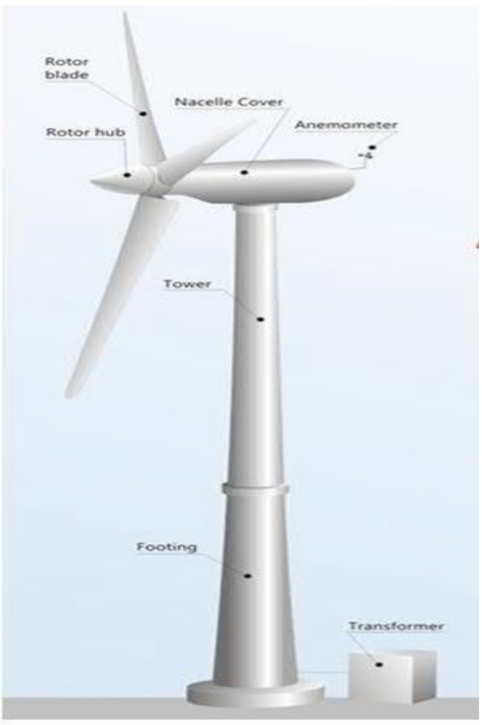


**Figure 1.** The main components of a wind turbine [1]

The working basic and the role for the elements of a wind turbine are as follows [3]:

- The rotor hub – allows for the turbine blades to be mounted, being placed on the wind turbines main shaft;
- The blades are some of the most important elements of the wind turbine and together with the hub form the turbine rotor. The blades are manufactured with the same technology used in the aeronautical industry, from composite materials, that simultaneously ensure low drag, flexibility, elasticity and reduced weight;
- The nacelle has protective function for the turbine's components that are mounted inside (main shaft, gearbox, brake, high speed shaft, the electrical generator, the cooling system for the electric generator and the yaw system);
- The tower – has the function to sustain the wind turbine and to allow for access in case of service and maintenance. Inside are mounted the distribution circuit for the electrical energy produced and the access stairs to the nacelle;
- The main shaft – has low rotational speed and transmits the rotational movement to the gearbox;
- The gearbox is used to increase the rotational speed from the value of the main shaft to a higher value needed by the electrical generator;
- The brake – is a safety device that is mounted on the high speed shaft, between the gearbox and the generator. The rotational speed of the turbine is maintained constant by changing the blade's pitch according to the wind speed and not by breaking the high speed shaft;
- The high speed shaft – the secondary shaft or coupling – has role in transmitting the rotational

movement from the gearbox to the electrical generator;
• The electrical generator – converts the mechanical energy of the high speed shaft into electrical energy;
• The wind vane is mounted on the nacelle and has the role to orient itself permanently after the wind direction;
• The anemometer – device used to measure the wind speed.

The paper presents analysis and simulations of the wind turbine blades. These blades are the main component of a wind turbine with the role of catching the wind energy and transferring it to the turbine rotor. The geometrical and aerodynamic characteristics, the materials used, the blade's internal structure, the number and the length of the blades contributes decisively to the efficiency of the wind turbine [8].

The wind turbines blade is a complex element and subjected to different forces among which are: the aerodynamic force, the centrifugal force, the gravitational force, vibrations, all of which leading to complex stresses.

In the case study presented in this paper a cyclical mechanical stress shall be applied – bending force. For the cyclical stress most often are used metal components and systems, so the deteriorating phenomena occurring most often are the fatigue. Fatigue deterioration implies a multitude of aspects related to: type of stress, part shape, the surface quality of the part to manufacture, the service environment for the part.

Generally, fatigue can be can be approximated to a process in which the deterioration accumulates into the material following the variable stresses that is subjected to. Fatigue is a local process which manifests itself in different materials used in engineering, like: metal alloys, polymeric and composite materials etc. The wind turbine blade fatigue deterioration is one of the deteriorating factors that impede their operation [7].

The wind turbines blades are subjected to two types of fatigue tests: overall tests; partial tests.

The overall tests: are those tests in which the entire blade is subjected to fatigue loading regime, as close as possible to reality. This kind of tests is usually made with the help of special installations, called test towers. One such tower allows mounting of the blades in conditions similar to the operating ones and then running the blade in a rotational movement at the rated speed. The tower's advantage is that the distribution of forces along the blade is equal to the real operating ones. The measurement of the forces and moments from the blade is usually done with data acquisition systems, so for this a series of sensors shall be mounted along the span and chord. It is to be noticed that, besides the purpose of an actually fatigue test, the blade fatigue test towers fulfil other goals in the research of the loading regime on the blade and the associated components, important elements for the design and manufacture of new types of blades.

The partial tests: are those tests in which the attention is focused on an element or part from the blade. In this direction, on the blade can be applied a force, constant which, although does not represent the real force from the blade, has the property of being equal to the value of the real force. In this way, the testing of the blade at forces that act during the rotation can be realized on a static or dynamic bench.

The loads applied during the accelerated tests for wind turbine blades can be split in three main groups (figure 2):

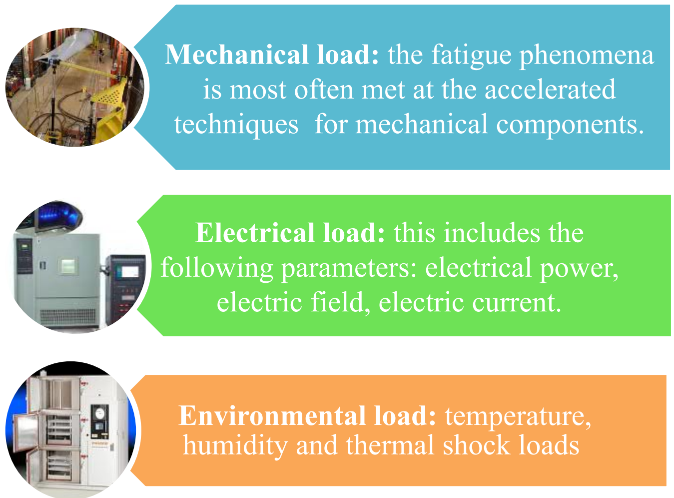


**Figure 2.** The classification of loads applied at the accelerated techniques [10]

Accelerated techniques is used in electronics (resistors, lasers, liquid crystal displays, electronic bounds, switches, relays, cells and batteries) in the study of metals and composite materials, but also for certain components and mechanical assemblies (hydraulic components, tools, bearings). The degree of interdisciplinary of research in the field of accelerated experiments is complex and can include the following industries: manufacturing engineering, the aerospace industry [9], the nuclear industry, the electronic industry, the dental industry, the pharmaceutical industry and the renewable energy industry [5].

## 2. THE GEOMETRIC AND AERODYNAMIC CHARACTERISTICS OF THE WIND TURBINE BLADE

The main characteristics for the wind turbine blade are: the shell made from a sandwich structure (glass fiber and foam); structure comprised of two I profiles, the length of the blade being 28 m; root chord of 2.35 m and tip chord 0.5 m; the blade airfoil is NACA 2412; the twist angle is 5 degrees. The blade is modeled in SolidWorks 2013 and is represented in figure 3.

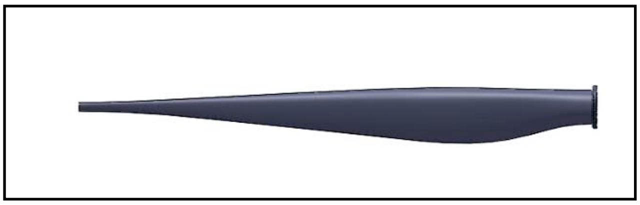

**Figure 3.** The wind turbine blade

For the aerodynamic analysis of the blade airfoil, in figure 4 is described the NACA 2412 airfoil with its main characteristics.

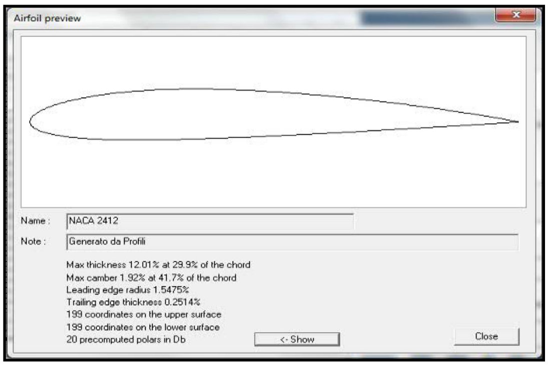


**Figure 4.** The wind turbine blade airfoil – NACA 2412

The main aerodynamic coefficients [2] of the aerodynamic airfoil are the lift coefficient, the drag coefficient. In order to determine the polar of the airfoil, Profili software shall be used. The polar is the curve which describes the variation of the aerodynamic coefficients as function of the angle of attack (figure 5).

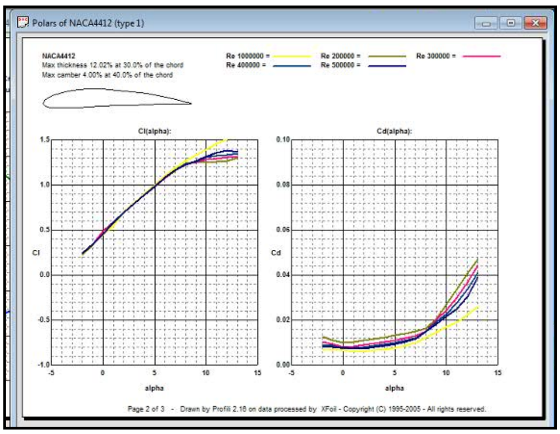

**Figure 5.** The lift coefficient/drag coefficient curve as function of the angle of attack

In figure 6 is drawn the variation of the lift coefficient as function of the drag coefficient. It can be seen that the maximum value of the coefficient is 1.5 at a Reynolds number of 100000, as opposed to the maximum value of the drag coefficient of 0.047 at a Reynolds number of 200000.

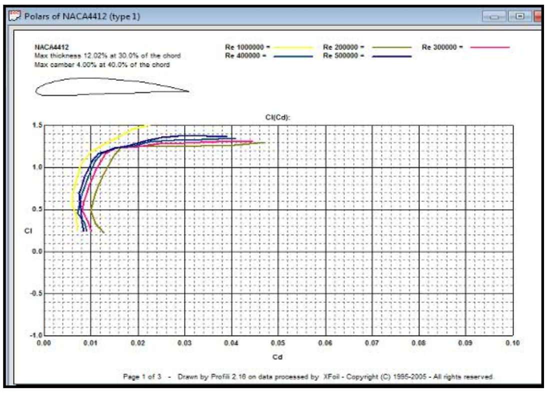

**Figure 6.** The graph of the lift coefficient as function of drag coefficient – for NACA 2412

In the figure 7 is represented the pressure distribution on the NACA 2412 airfoil at 4 degree angle of attack.

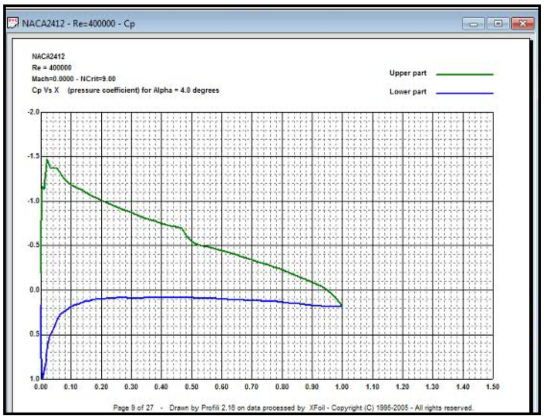

**Figure 7.** The pressure coefficient distribution on the NACA 2412 airfoil at 4 degree angle of attack.

In figure 8 it can be seen that along with the increase of the angle of attack the pressure coefficient from the airfoil's underside increases, because the pressure difference from the upper side increases more and more.

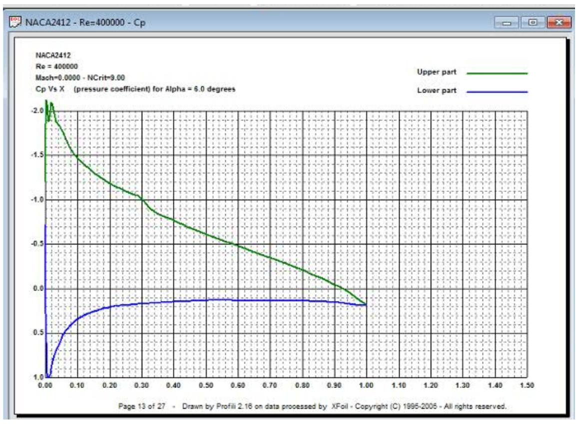

**Figure 8.** The pressure distribution coefficient on the NACA 2412 airfoil at a 9 degree angle of attack

## 3. THE SIMULATION OF THE FAILURE CYCLES FOR THE BLADE THROUGH THE MONTE CARLO METHOD USING THE ACCELERATING TECHNIQUES

A great insight into the reliability of applications is presented by statistical modeling through the Monte Carlo method that makes it possible to reduce the multitude of reliability problems at a small number of computing schemes. These computational algorithms can be solved quite easy with the help of computer assisted reliability software [4].

ALTA software use Monte Carlo simulation for generating data sets (cycles to failure) that can be analyzed directly in a standard folio. It can also use the SimuMatic utility to automatically perform a large number of reliability analyses on data sets that have been created via simulation. Monte Carlo utility provides randomly generated data sets based on a specified model, distribution and parameters [6].

Using the parameters (β=8.128; k= 1,34990476649312E-57; n= 12.611) and the two accelerated levels (11000 KN and 12000 KN), it is simulated with the help of ALTA7 software the values for the number of cycles to failure in accelerated conditions (Fig. 9).

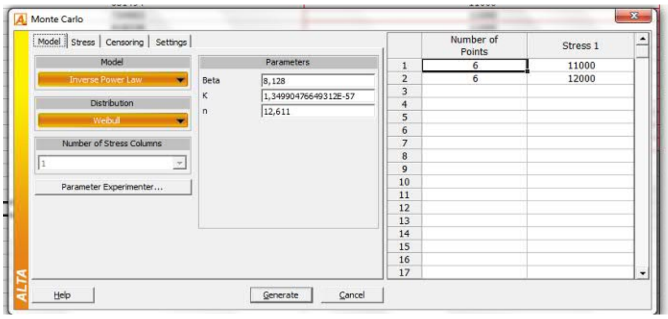


**Figure 9.** The simulation using the Monte Carlo method of the data in accelerated conditions for the blade

In figure 10 are failure cycles determined for the two accelerated regimes. These accelerated regime data shall be extrapolated for the normal test regime (10000kN) of the wind turbine blade using the accelerating factor.

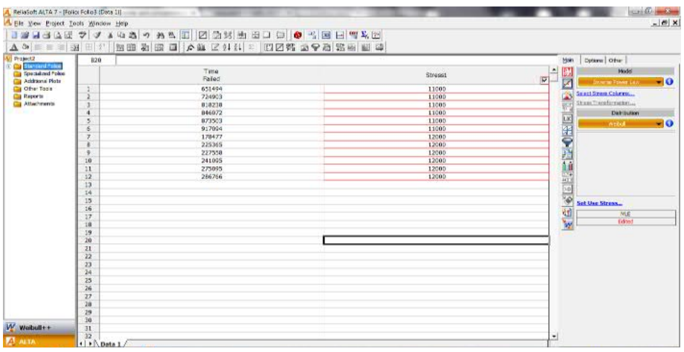

**Figure 10.** Time to failure of the data in accelerated conditions for the blade

It was determined the reliability indicators (the reliability function and unreliability function) depending on the number of cycles to failure in normal testing condition (Table 1).

**Table 1.** Reliability indicators of blade

| The number of cycles to failure in normal conditions | Reliability Function | Unreliability function |
|---|---|---|
| 2138645 | 0,94387 | 0,05613 |
| 2386354 | 0,86402 | 0,13598 |
| 2655241 | 0,78331 | 0,21669 |
| 2700490 | 0,70242 | 0,29758 |
| 2726760 | 0,62147 | 0,37853 |
| 2888976 | 0,54049 | 0,45951 |
| 2997116 | 0,4595 | 0,5405 |
| 3099072 | 0,37852 | 0,62148 |
| 3199546 | 0,29757 | 0,70243 |
| 3296382 | 0,21668 | 0,78332 |
| 3359216 | 0,13597 | 0,86403 |
| 3436231 | 0,05612 | 0,94388 |

Using the computed values for the reliability function has been made a graph of the variation of the reliability a function of the number of cycles until failure in normal regime (figure 11).

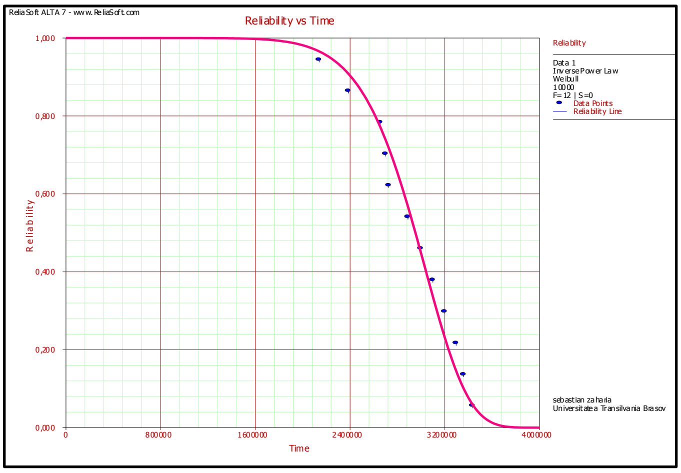


**Figure 11.** Reliability function

The Unreliability vs. Time (cycles to failure) chart show how the unreliability (probability of failure) changes with time (figure 12).

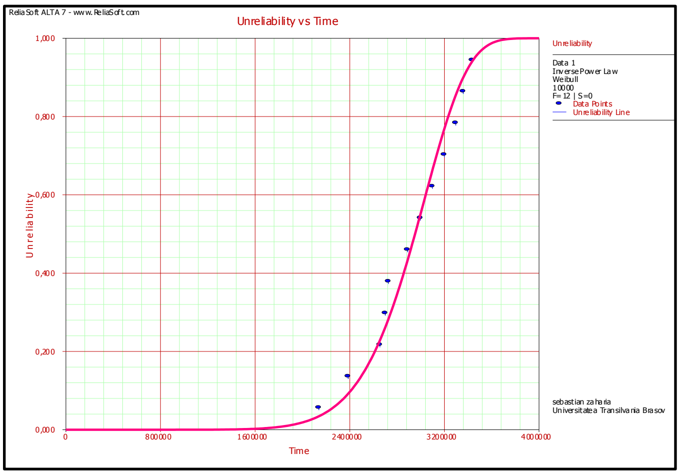


**Figure 12.** Unreliability function

The probability density function chart displays the relative frequency of failures as a function of time at the specified use stress level of 10000 KN (figure 13).

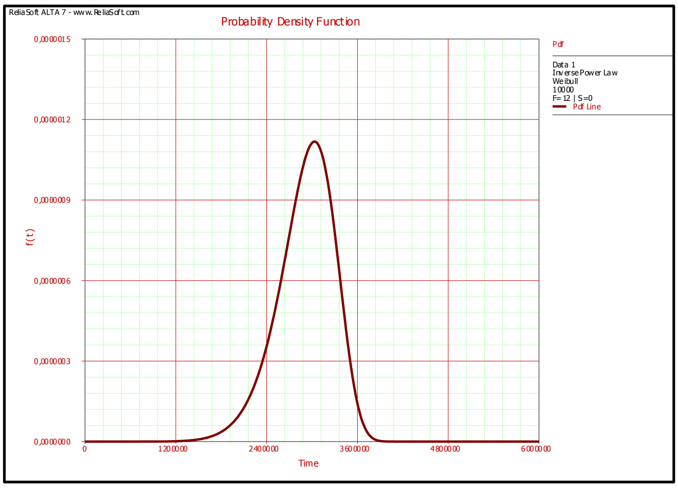


**Figure 13.** Probability density function

The rate of failure describes the failure probability at a given moment for an element of a system which is in a good working state until that moment. The Failure Rate - Time chart displays how the failure rate (in failures per unit time) changes with time at the specified use stress level of 10000 KN.

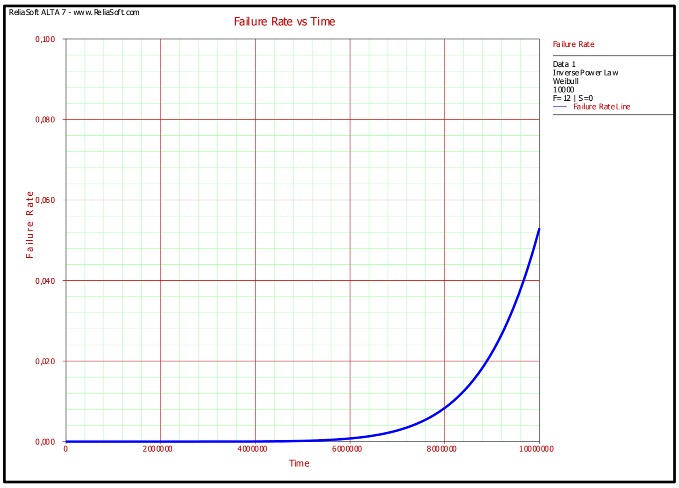


**Figure 14.** Failure rate

The Quick Calculation Pad (QCP) provides you with a quick and accurate way of gaining access to some of the most frequently requested reliability results in ALTA software. The main scope of accelerated techniques is to determine the life time in normal testing conditions. Using the data resulted from Monte Carlo simulation using accelerated techniques we can determine the mean number of cycles to failure of the blades in normal testing conditions. Following the simulation of accelerated data using the Monte Carlo method for the blades from wind turbine, we obtained the value of 2912243, which represents the mean number of cycles until failure (figures 15).


**Figure 15.** The determination of the number of cycles to failure of the blades in normal testing conditions

## 4. FINITE ELEMENT ANALYSIS FOR THE WIND TURBINE BLADE

The finite element method has become shortly a computational instrument necessary and convenient for any engineer. In this paper the software Ansys15 has been used for the accelerated regime analysis of the wind turbine blade. In figure 16 is presented a first step of the finite element analysis, more exactly the mesh generation of the blade. The blade is fixed similarly with the fixing during operation and at the other end a 11000 kN force is applied according to the first level of acceleration (figure 17).

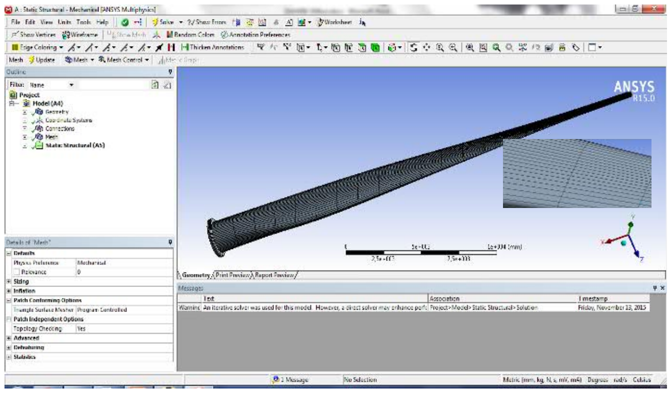


**Figure 16.** Mesh details on blade

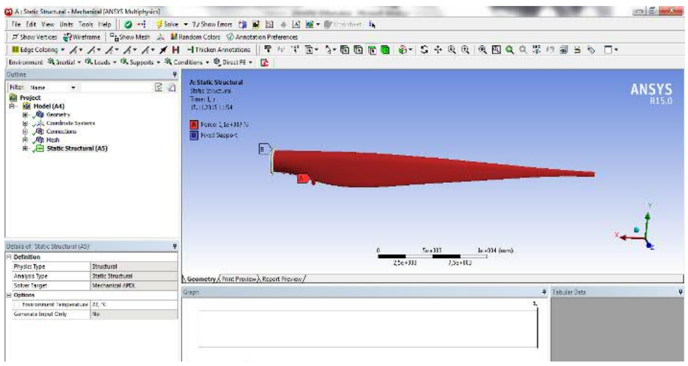


**Figure 17.** Loads and support on blade

The Equivalent (Von Mises) stress is often used in determining whether an isotropic and ductile metal will yield when subjected to a complex loading condition. Equivalent stress distribution along the blade is described in figure 18.

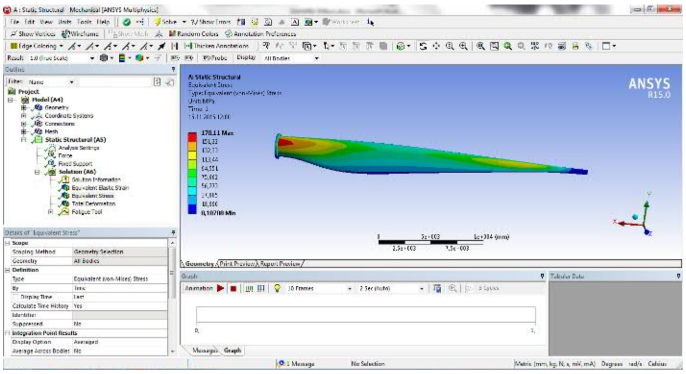


**Figure 18.** The distribution equivalent tensile stress

The strains of the wind turbine blade are in the 0-387 mm domain, it can be seen that the maximum strain is attained at the end of the blade.

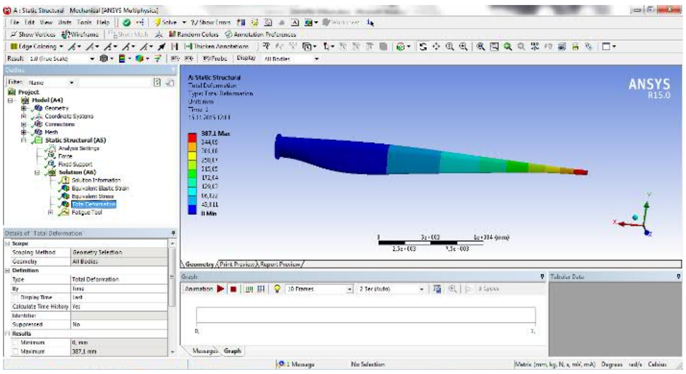


**Figure 19.** Total deformation

With the Fatigue Tool module from the Ansys15 software can be obtained information about the places where failures can occur.

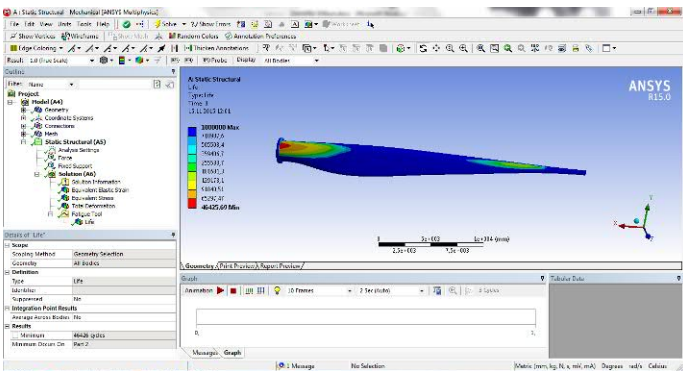


**Figure 20.** The fatigue life of blade

## 5. CONCLUSIONS

At some components from renewable industry (blade), for which a high reliability is estimated, the determination of the life time and of the reliability parameters, under normal stress conditions, implies a long testing period. If a blade requires, for example, $10^8$ cycles to cause a failure from fatigue in normal use condition, by using an accelerated techniques we can obtain the same result in $10^5$ cycles. For the case study (blade of wind turbine) under analysis, figure 15 shows the mean number of cycles to failure from Monte Carlo simulation under use conditions. We can observe that, by using the accelerated life tests, the testing time has been reduced by 5.56 times. Monte Carlo simulation using the cycles to failure of the blades is a method commonly used and allows a first opinion on the lifespan and reliability indicators. The finite element analysis can get information on strains, tension and on the lifespan of the blade.

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