Composite Wind Turbine Blade using Prepreg Technology

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ABSTRACT

This paper describes the to design and manufacturing process of a 4500 mm long composite vertical axis Darrieus wind turbine blade (VAWT) and 0.6 m chord with NACA 0021 blade profile, using the autoclave technology. By using the autoclave technology as the manufacturing process, a higher fiber content was achieved which implies a higher specific stiffness and strength, thus leading to lighter blades, compared to a wet hand layup processes. Due to autoclave constrains, four composite blade segments were manufactured to assemble one 4500 mm blade. The composite structure has 3 mm thickness and two composite spar beams, cured at room temperature, are reinforcing the blade inside all along its length. CFD showed a maximum value of 25.4 MPa in the 8 ply configuration of the airfoil and a 2.5 MPa on the leading edge, also a maximum displacement of 4.27 mm localized around the trailing edge end was observed. A maximum Von Mises stress value was 280 MPa and it was located at the airfoil – collar interface, Having a tensile strength of 955 MPa, Hexply M79/42%/200T2X2/CHS-3K preperg was considered appropriate for the manufacturing of this type of structure in the 8 ply configuration.

KEYWORDS: Wind energy, composite structures, autoclave technology, prepreg, structural analysis

1. INTRODUCTION

The international wind energy market showed a new record in 2003 with a growth rate of 15%, reaching an increase of 26% in the last 5 years. Globally, a total power of 8.3 GW was installed. The total installed wind energy power has now reached more than 40 GW, and the average growth in the market during the past five years has been of 26% per year. This illustrates the world's concern regarding the energy supply and consumption in a modern and civilized society and how the use of wind turbines for electricity generation was increased during the past 25 – 30 years [1]. In order to ensure the required shape stability, strength and damage resistance of the VAWT, its blades are produced from long fiber reinforced polymeric composites [2]. In these composites, long fibers ensure longitudinal stiffness and strength, while the resin

matrix is responsible for fracture toughness, delamination strength and out-of-plane strength and stiffness of the composite [3]. Wind turbine blades are long structures that require light, stiff and cheap materials; hence, the choice of materials has usually been strictly limited to composites. Nowadays, blades are still mainly made of glass fibers, carbon fibers slowly becoming a feasible opportunity due to cost reducing from the last years and superior mechanical properties which lead to the possibility of obtaining even larger blades with an increase in energy power; among resins, epoxy is now preferred thanks to its better strength, chemical resistance, adhesion to the fibers, lower thermal shrinkage and easier workability compared to the other low-cost resins [4]. Nevertheless, other materials can be used like aramid, polyethylene and cellulose but they provide lower mechanical properties and lower density. The polymeric composites with the above-mentioned fibers have polymeric matrices, typically thermosets or thermoplastics. Wind turbines blades, during their normal operating cycle (around 20 years), pass through severe environmental conditions e.g. wide range of temperatures, hail, ultraviolet and bird collisions etc. They bear static and dynamic lift, drag and inertial loads so it is important to select the best-suited materials that can withstand these challenges, otherwise they can suffer structural damages and fatigue related issues due to cyclic loading. These problems of fatigue could be resolved by improving the materials characteristics for the blade manufacturing, manufacturing process parameters and blade design and configuration modifications. It is of utmost importance that the blades should be highly rigid, having low weight and must possess rotational inertia, and above all they can resist wear and fatigue. The flapwise and edgewise bending loads cause high longitudinal, tensile and compressive stresses in the material that can lead to fatigue damage. The upwind side of the blades is subjected to tensile stresses while the downwind side is subjected to compression stresses [5]. The blade's shape stability should corresponds to the minimum deflection area under wind loads. This can be achieved by increasing the moment of inertia of the blade, using a corresponding blade design, and by increasing the flexural stiffness of the blade material. The flapwise bending is countered by the use of spars, internal webs or spar cabs inside the blade, while the edges of the profile carry the edgewise bending. There are two primary blade designs that are used for VAWT that operate on different principles: Savonius type and Darrieus type [6]. Savonius type uses aerodynamic drag from wind to rotate the blades and to produce power. This type of blade is however rugged and simplistic thus reducing the costs due to their ease of manufacture, less maintenance and can resist longer in harsh environments. On the other hand, Darrieus type designs, uses wind lift forces to rotate the blades. These blades have an airfoil shape which ensure the air traveling along the leading edge with greater speed than the air on the trailing edge, creating an area of lower pressure on the outside of the blade, thus it can spin faster than the speed provided by the wind resulting in higher efficiency. However, this higher efficiency is attenuated through a higher production cost [7].
During blade designing phase some aerodynamic factors must be taken into account: the airfoils shape which define the cross sectional areas which are defined by suction and pressure sides, the flatwise direction which denotes the lines that are perpendicular to the chord line, edgewise the parallel ones; and also denotes the lines that are perpendicular to the rotor plane, lead-lag the in-plane lines. Nevertheless, the design strategy for the composite blades considers aerodynamic loading, assessed via computational fluid dynamics and variable structural properties including prepreg material, thickness and layup sequence of the blade airfoil and design and of the two "I" shaped reinforcing spars.

2. RESEARCH GOAL AND METHODOLOGY OF WORK

The goal of the present paper was to design and manufacture a vertical axis wind turbine, made out of three 4500 mm identical thermoset composite blades. The final 2 kW VAWT will be assembled and mounted in COMOTI's Sf. Gheorghe site. All CAD models were developed with SolidEdge ST4 and SolidWorks 2010. The technology chosen to manufacture the wind turbine blades was the autoclave technology due to its higher process performances including overall cured material properties.
In the proposed blade design, the airfoil profile has a constant chord (600 mm) along the length of the blade (4500 mm). Four individual sectors, having the following dimensions 1125 x 600 mm will be manufactured and join using three collars (as marked blue in Fig. 1), to form one of the three VAWT blades. Two 4500 mm long composite reinforcing spars will be positioned inside each blade, offering stability to entire blade during operation. Each "I" shaped composite reinforcing spar will be bonded to the blade with

Araldite adhesive. Furthermore, each composite blade has two connection points (metallic inserts in two of the composite collar, as indicating in Fig. 1) on one of its broadsides for assembly to the rotor through metallic supporting struts (Fig. 10a). A 1:9 scale model was manufactured using two layers of glass fibers and one of carbon fiber on a foam core and assembled on a vertical axis to emphasize the overall aspect of the larger model (Fig. 10b).

3. RESULTS AND DISSCUSIONS

3.1. Numerical simulations (static and modal analysis)

Due to the low ratio between the blades dimensions, 4500 x. 600 mm and the thickness of composite layers, around 3 mm, the composite structure was modeled with SHELL elements. The investigated solution is characterized by the use of a single metallic insert on the composite collar, presented in Fig. 1. The load is composed of dynamic pressure caused by wind of 40 m/s, 1 MPa.

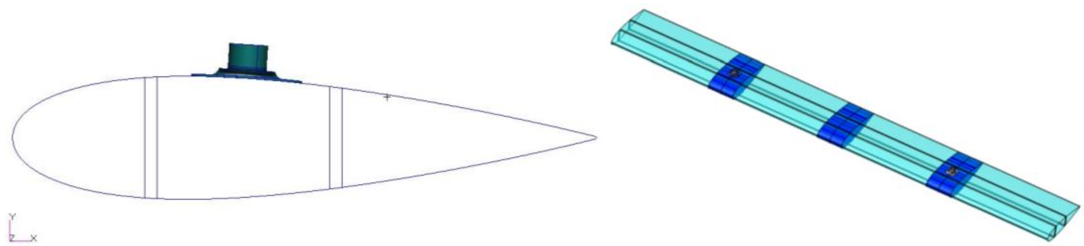


Figure 1. Composite wind turbine blade assembly

The use of composite materials has involved new approaches in terms of material's strength, mainly due to their mechanical properties. Evaluation of tensile strength was made based on empirical consideration criteria, and these can be considered a generalization of classical failure theory, in case of laminar materials defining a yielding surface in the stress space in a similar way defining the flow area in the case of elastoplastic materials.

Strength Analysis

The main tension distribution and the displacements for the first collar is shown in Fig. 2.

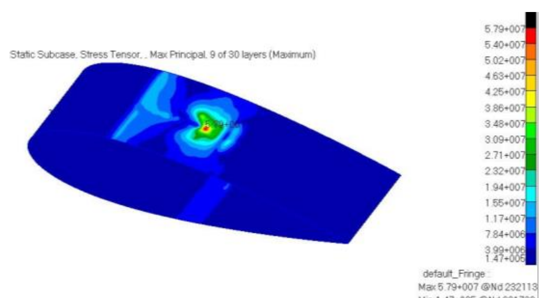


Figure 2. Main strain distribution [Pa] –first collar (maximum on all 8 layers)

The maximum main strain value is 58 MPa and is located in the contact region between the collar and the metallic insert (Fig. 2). The maximum strain value for the spars and collar exterior surface is 82 MPa (Fig. 5) and for the contact region between the insert and the collar is 73 MPa (Fig. 6).

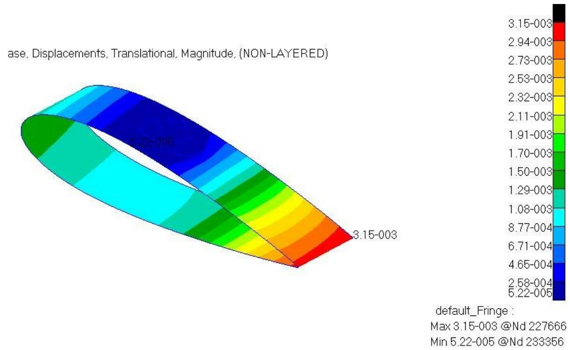


Figure 3. Total displacement [mm]

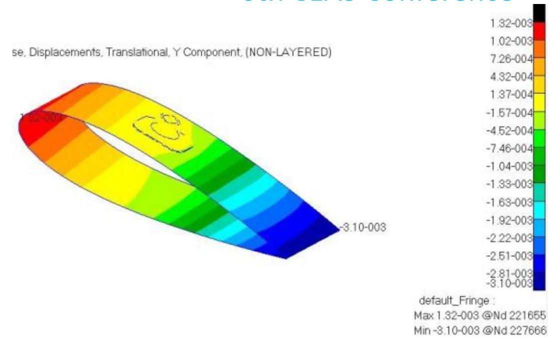


Figure 4. Displacement on OY [mm]

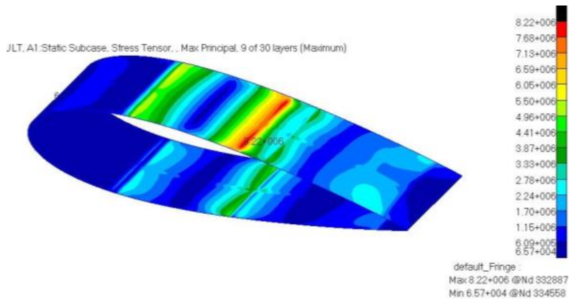


Figure 5. Main strain distribution [Pa] – second collar (maximum on all 8 layers)

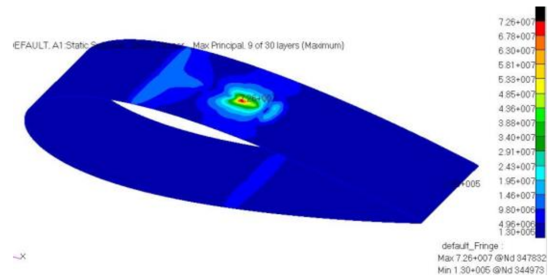


Figure 6. Main strain distribution [Pa] – third collar (maximum on all 8 layers)

As for the airfoil, the maximum displacement is 4.27 mm and is localized near the trailing edge end (Fig. 7).

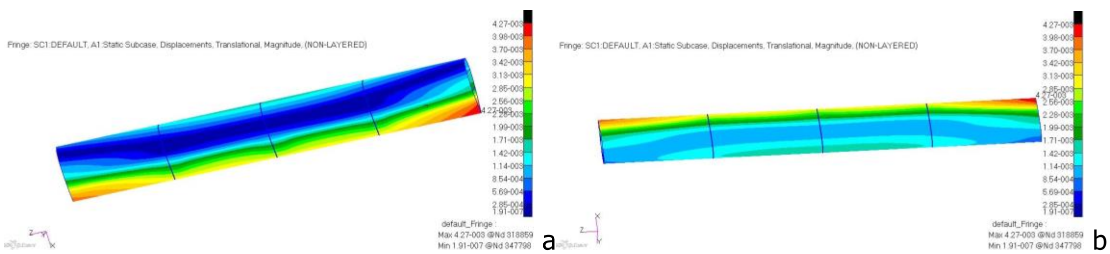


Figure 7. Maximum displacement for the airfoil at (a) trailing edge and (b) leading edge

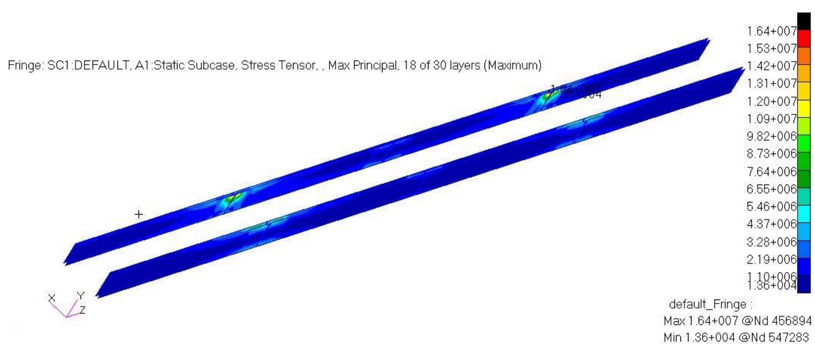


Figure 8. Maixmum stress on the 4500 mm length spars

Von Mises stresses for te metallic inserts are shown in Fig. 9.

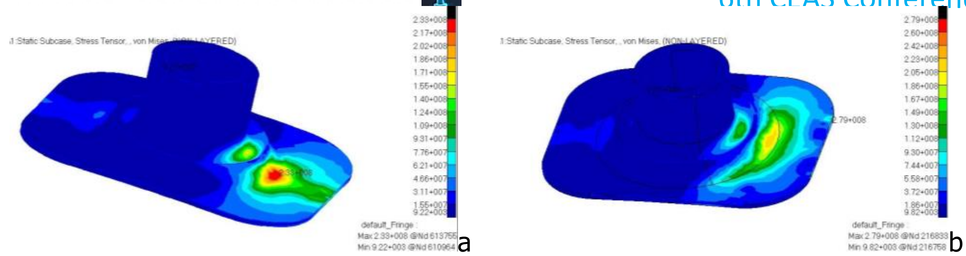


Figure 9. Von Mises maximum stresses for (a) metallic insert locked in XOY plane – 233 MPa and for (b) metallic insert locked on all three directions – 279 MPa

It was proposed a material with a yield limit of at least 500 MPa, and a minimum safety factor of 1.82. We will use the Al7075 alloy with a yielding stress 503 MPa and a safety factor of 1.82 which is an adequate value, maximum Von Mises stress being located only on a reduce area fig.9 b). According the IEC 61400-1[xx] the maximum safety factor for unfavorable load is 1.35 which is smaller than safety factor of proposed solution, 1.82. . Since the tensile / compression strength of the material used is 955 MPa for carbon fiber Hexply M79/42%/200T2X2/CHS-3K, it appears that there are no problems with the failure of the composite material for the configuration used. The overall maximum failure indice value calculated based on the Tsai-Wu criterion is 0.113, indicating that the probability of failure is very small (failure occurs for a failure indice value greater than 1). The actual frequency of the first vibration mode is 23 Hz, 10 times the nominal frequency, and there are no problems with overlapping the working mode with its own frequencies.

3.2. Mold design and manufacturing process

The manufactuiring of a vertical Darrieus wind turbine with three identical blades (Fig. 10), symmetrically placed at an angle of 120°, is the main purpose of this paper. The three blades are NACA 0021 type, with a length of 4500 mm and a 600 mm chord. For their fabrication, an 8 ply configuration was proposed. Prior to one step autoclave manufacturing protocol and process, mould (1125 x 700m mm, weight 66 Kg) was designed using SolidEdge ST4 in order to obtain airfoil blade final acceptance tolerances (figure 11). The parameters of the VAWT are presented in Table 1.

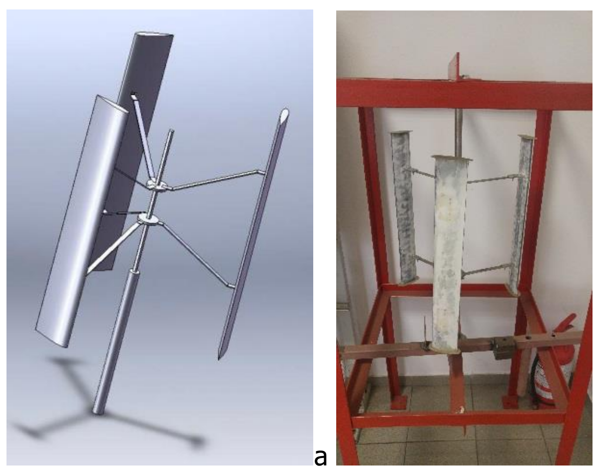


Figure 10. (a) The CAD model of the VAWT with 4500 mm long blades; (b) Scaled (1:9) VAWT mounted on a metallic support

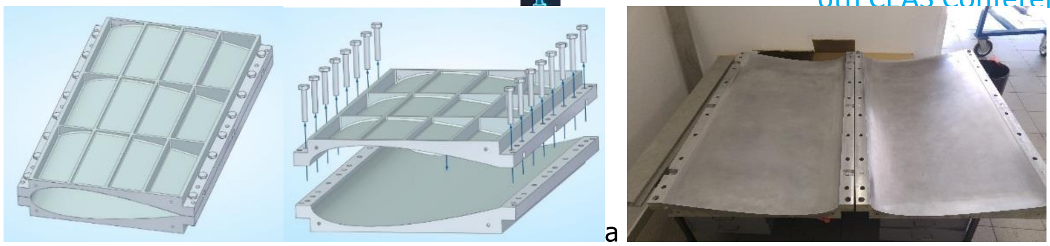


Figure 11. (a) CAD model of the mould (b) manufactured two piece aluminium mould

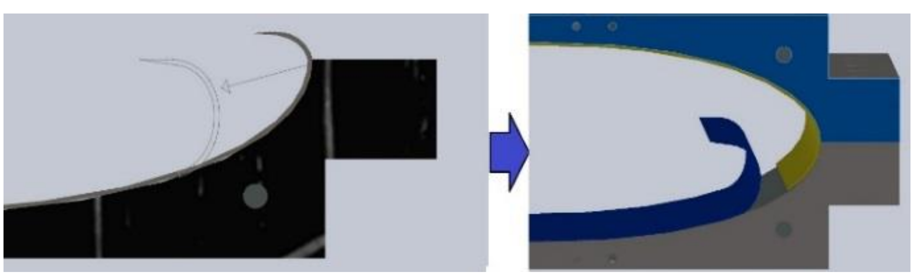
Figure 12. COMOTI's autoclave

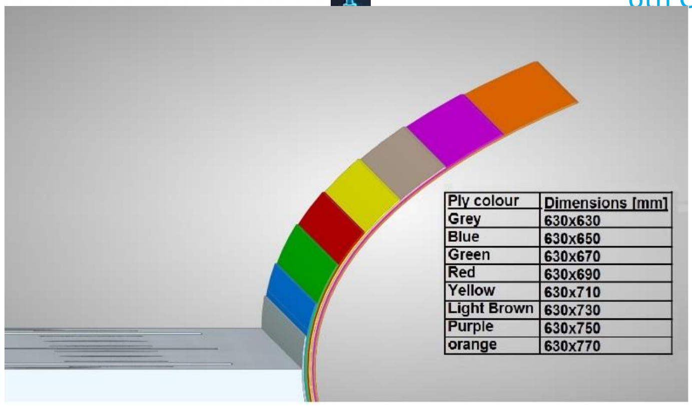
Usable diameter [mm]	1500
Usable length [mm]	2500
Maximum pressure [bar]	20
Maximum temperature [ºC]	400
Loading agent	Aer
Maximum load	20 kg composite 100 kg aluminium 350 kg steel

Table 1. VAWT parameters

Rotor diameter [m]	3.6
Rotor height [m]	4.4
Number of blades	3
Chord [m]	0.6
Turbine area [m^2]	16
Wind velocity [m/s]	8

A number of 16 plies were cut (a set of each plies for each half-mould) form the M79 prepreg having the following dimensions: 8 plies with 1125 mm in length and width between from 630 to 770 mm, and 8 plies with 1125 in length and width between 630 to 490 mm. Each set of 8 plies were previously bond together before laying on each of the half-moulds. Prior to closing the mold, the plies folded at the edges of the first half-mould were pulled 100mm inward to allow for longer plies of the second half-mould to fold on the first half-mould (Fig. 13). After closing the mold, the plies were stretched, forming both the leading and trailing edges. An inner vaccum bag was build-up and wrapped around a layer of release film, then placed inside the mould. The entire mould was then covered in a breather cloth and the assembly was inserted into an external vaccum bag. The inner vacuum bag and external vacuum bag were bond together, connected to autoclave's vacuum lines and cured (Fig. 14).





Ply colour	Dimensions [mm]
Grey	630x630
Blue	630x650
Green	630x670
Red	630x690
Yellow	630x710
Light Brown	630x730
Purple	630x750
orange	630x770

Figure 13. Each set of 8 prepreg plies placed on each half-mould prior to closing the mould and vacuum bag assemby

Figure 14. Vacuum bag assembly

The curing cycle was selected considering prepreg technical sheet and the properties of the mold (90°C temperature, XXX HOUR , 2 bar pressure, vacuum), and it is showed in Fig. 15. After the curing cycle, the components were allowed to cool over night until ambient temperature to avoid the internal tensions in the structures when they are released from the molds.

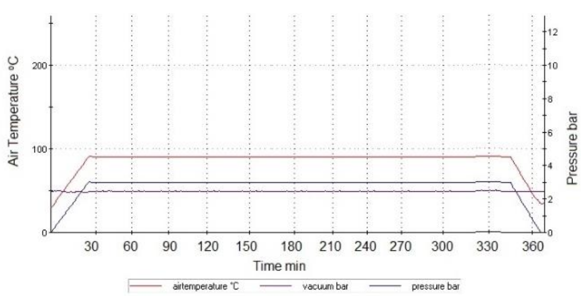


Figure 15. Graphic representation of the curing cycle

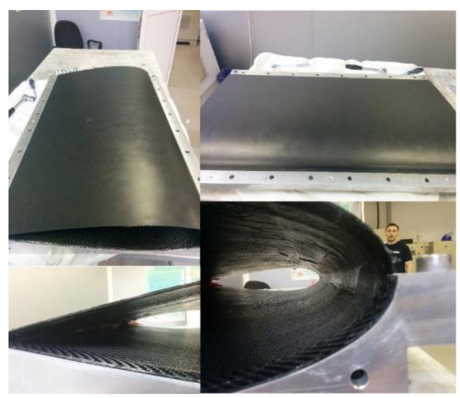


Figure 16. A composite blade sector

A manufacturing protocol was established for a section of a composite spars (300 mm in length). Namely, in order to manufacture the spar from the leading edge, glass fiber, epoxy resin, a Ø18 mm x 120 mm (3 mm thick) pipe and two welded metal plates were required (Fig. 16). The spar consists in a three part ensemble: two soles (which will attached to the airfoil) and a central piece, connected to the two soles, as presented in Fig. 17 a.

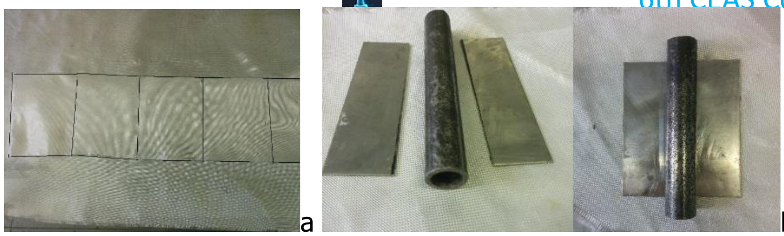

a b

Figure 17. The glass fiber cloth (a) and metallic parts (b)

After curing the two soles and the central piece, an Ø18 mm hole was made on one of the soles to allow the spar to be attached to the turbine’s shaft. After the hole was performed, the central piece was mounted on the sole and an adhesive layer (Araldite) was applied and allowed to cure for 24 hours, after which, the second soul was bonded. After the spar was assembled, it was inserted into the blade at a distance of 142 mm from the leading edge (as shown in Fig. 18 b). The placement of the two spars within the composite blade, were realized according to Fig. 19. Each blade sector will be firstly bonded to the spars, one by one, after which they will be secured with a collar made out of 5 layers of carbon fiber and epoxy resin, cured at room temperature. Fraza cu gaura de prinderea pe

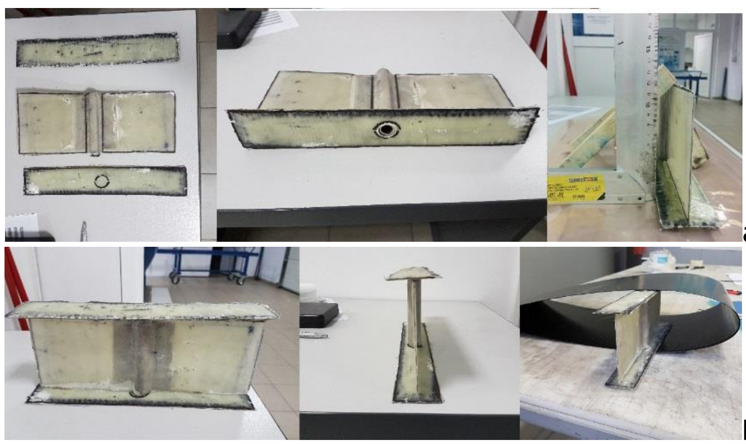

a
b

Figure 18. (a) The three components that assemblies the spar and (b) inserting the spar within the blade, near the leading edge

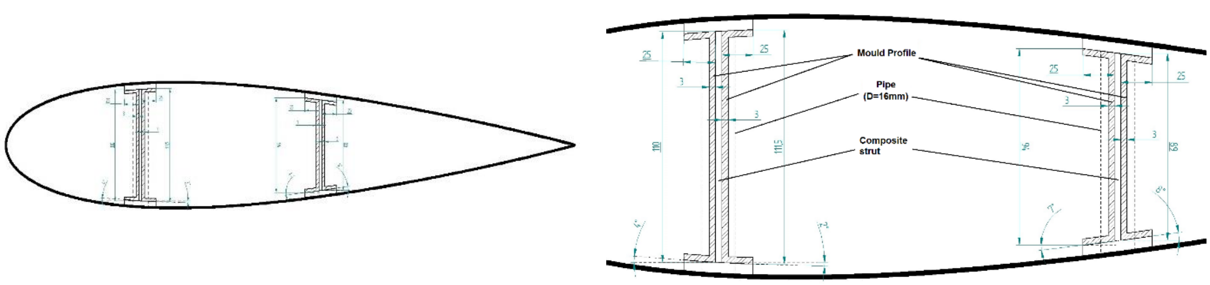


Figure 19. Spar dimensions and positioning

The four composite sectors manufactured with autoclave technology are presented within Fig. 18. The two spars will be manufactured out of carbon fiber according to the manufacturing trial previously presented.

Figure 19. Vertical axis wind turbine composite blades

4. CONCLUSIONS

The autoclave technology involves substantially higher costs than room temperature curing, due to the need of precursor materials (prepregs) whose cost sometimes exceeds the room temperature curing process, and due to the storage conditions of the prepregs. On the other hand, using autoclave technology, components with high structural properties are obtained. The stress analysis results showed that there are no problems with the failure of the composite material for the configuration used. The overall maximum value of the yield value calculated based on the Tsai-Wu criterion is 0.113, indicating that the probability of failure is very small (the yield is for a yield value greater than 1). The actual frequency of the first vibration mode is 23 Hz, 10 times the nominal frequency, and there are no problems with overlapping the working mode with its own frequencies. Using M79 prepreg material, a 1,82 safety factor was obtained. According to the stress analyses, 2 mm thickness is enough for the composite blades to withstand the loads while having the two spars bonded inside the structure. Four composite sectors were manufactured via autoclave technology for the assembly of one wind turbine composite blade. The two spars are under development and will be bonded to the structure.

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