# ANALIZA MATERIJALA ZA IZRADU LOPATICA VETROTURBINA

## ANALYSIS OF MATERIALS FOR MAKING WIND TURBINE BLADES

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*U poslednjih nekoliko godina primećenoje izrazito povećanje interesa za obnovljive izvore energije, pri čemu je iskorišćavanje energije vetra najbrži činilac proizvodnje energije iz obnovljivih izvora. Povećanje snage i veličine vetroturbina otvara polje istraživačima, da pronađu optimalan način upravljanja i iskorišćenja besplatne energije vetra. Uzimajući u obzir dostupnost ovih izvora energije, mogućnost konzervacije energije i korišćenja novih tehnologija u cilju uštede energije dolazi do manje zagađenosti i smanjenja emisije ugljen-dioksida. U radu su analizirani tehnički materijali koji se koriste za izradu lopatice vetroturbina. Prikazani su istorijski počeci kada su korišćene drvene lopatice, a zatim je fokus usmeren na metalne lopatice izrađene od čelika i aluminijuma. Razmatrane su i lopatice od fiberglasa koje imaju bolje karakteristike ako se uzme u obzir zamor materijala, one su lakše za rad, male mase, dobrih karakteristika i većina modernih turbina ih koristi. Zatim je prezentovan proces proizvodnje lopatica. Unutrašnjost lopatica se ispunjava slojevima fiberglasa koji se popunjavaju epoksi smolom. Da bi se poboljšala krutost dodaje se sloj drveta između slojeva fiberglasa. Dve strane lopatica se spajaju korišćenjem tečne epoksi smole. Poseban osvrt je dat za materijale lopatica u malim turbinama. Ove turbine se koriste kao primarni, ili sekundarni izvor energije. Ukoliko se koriste kao primarni tada im se dodaje baterija. Vetrogeneratori malih snaga od 300 kW do 2MW, se koriste za punjenje akumulatora i skladištenje energije dobijene na takav način. Predstavljeni su materijali koji se koriste za izradu lopatica ovih malih vetroturbina, kao što su: drvo, metali, polimer ojačan staklenim vlaknima, polimeri ojačani prirodnim vlaknima i nanokompozitni materijali. Nakon toga diskutovane su detaljno njihove osobine.*

***Ključne reči:*** *energija vetra; vetroturbina; materijali; lopatica.*

*In the last few years, a marked increase in interest in renewable energy sources has been observed, whereby the use of wind energy is the fastest factor in the production of energy from renewable sources. Increasing the power and size of wind turbines opens the field for researchers to find an optimal way of managing and using free wind energy. Taking into account the availability of these energy sources, the possibility of energy conservation and the use of new technologies in order to save energy leads to less pollution and reduction carbon dioxide emissions. In the paper, the technical materials used for the manufacture of wind turbine blades are analyzed. The historical beginnings when wooden blades were used are shown and then the focus is on metal blades made of steel and aluminum. Fiberglass blades were also considered, which have better characteristics if material fatigue is taken into account, they are easier to work with, light mass, good characteristics and most modern turbines use them. Then the production process of blades was presented. The inside of the blades is filled with layers of fiberglass that are fulfilled with epoxy resin. To improve rigidity, a layer of wood is added between the layers of fiberglass. The two sides of the blades are joined together using liquid epoxy resin. A special review is given for blade materials in small turbines. These turbines are used as a primary or secondary energy source. If they are used as primary, then a battery is added to them. Wind generators of small power from 300 KW to 2 MW are used to charge batteries and store the energy obtained in such a way. The materials used to make the blades of these small wind turbines such as wood, metals, polymer reinforced with glass fibers, polymers reinforced with natural fibers, and nano-composite materials are presented. After that their properties in detail were discussed.*

***Key words:*** *wind energy; wind turbine; materials; blade.*

## 1 Introduction

Scientists are constantly searching for new forms of energy, even though we have available natural energy sources that we do not use enough. Such energy sources that we usually called renewable are wind, solar energy, wave energy, tidal energy, hydro energy, geothermal energy and others. One of these natural sources of energy is surely wave energy. In scientific circles, there has long been a controversy about whether it is worth investing in this type of energy [1].

Taking into account that there is an increasing demand for non-renewable energy sources, and that they are being consumed more and more, the need to use renewable energy sources arises [2].

Wind power is used to create mechanical energy which is then converted into electrical energy. A typical power conversion system consists of a wind turbine that usually has three fiberglass blades, a shaft, and a generator. The kinetic energy of the wind at the entrance to the wind turbine is converted into mechanical energy that is used to drive the generator shaft. One end of the generator shaft is connected to the output from the wind turbine, while the other end is connected to the input to the generator. It is necessary to harmonize the number of revolutions of the wind turbine, which is several tens of times per minute, and the generator, which is achieved by using a reducer. Increasing the power and size of wind turbines opens the field for researchers to find an optimal way of managing and using wind energy [3, 4].

The direction of further energy use is towards the increasing inclusion of renewable energy sources. The European Union plans that by 2023 as much as 25% of the total energy used will be from renewable energy sources, and American scientists believe that in California it will be possible to use 20% from renewable sources, while the Union of Scientists from this field believes that it will be possible to obtain 20% of the total energy used from renewable sources by 2023 [5, 6].

The transition to renewable energy sources such as small hydropower plants, solar power plants, biomass and geothermal energy plants, as well as wind energy, is also encouraged by the fact that the price of initial investment has decreased significantly in the last thirty years, while the prices of oil and natural gas continue to fluctuate regularly [7].

The paper analyzes the materials used for the production of small and large wind turbine blades, their properties and the methods of production the same.

## 2 Overview of wind energy

Almost all renewable energy comes from the sun. The sun radiates 1015 kWh per square meter towards the earth. About 2% of this energy is converted into wind energy, which is about 50-100 times the amount of energy that is converted into biomass energy [8].

Wind is a horizontal flow of air masses that is caused by differences in temperature and pressure and the tendency to equalize them. Wind characteristics are influenced by many geographical factors, the best places are ocean coasts and open seas. The influence of the wind is felt at heights of up to 100 meters. The speed of the wind depends on the objects on the ground; the height and the configuration of the terrain and the speed of the wind mean the flow near the earth surface [9].

Wind energy is one of the most used renewable energy resources, which is applied for different applications. Energy produced by wind power refers to the process of electricity production using the wind. Namely wind hits a turbine’s blades and causing them to rotate. That changes the kinetic energy to rotational energy, arises shaft moving as connected generator.

Energy obtained from wind currently provides around 10% of the world's energy supply. Its presence in the renewable energy sector surely will increase. With existing technologies, optimizing the efficiency of wind turbines is crucial as appropriate choice of materials.

The global wind industry in year 2021, had capacity of almost 94 GW. It led to total installed wind turbine capacity close by 837 GW. Yet this growth needs to quadruple by the end of the 2030 for course toward 1.5C pathway and net zero by 2050. [10].

## 3 Specificity of wind turbines

Wind turbines are energy converters that transform the kinetic energy of wind in mechanical energy. Those turbines can be installed in both single and wind farm (group of wind turbines). Wind turbines on Figure 1 are shown.

*Figure 1: Wind turbines [11]*

Wind generators produce electricity usually at wind speeds from 3 m/s to 25 m/s. Production is profitable if the wind blows at a speed of 6 m/s, 2800 hours. It is necessary to determine the location at heights of 30 to 50m.

For households, wind turbines with a power of several tens of kW are interesting. They are used as a primary or secondary source of energy. If they are used as a primary source then a battery is added to them, [12].

Wind generators of small power from 300 kW to 2 MW are used to charge batteries and store the energy obtained in such a way.

The technologies of wind turbines are constantly improving and getting bigger, with specially designed blades, improved electronics and advanced software solutions. Global winds are caused by uneven heating of air masses in the atmosphere. There is unequal warming at the equator and the poles.

Warm air at the equator rises and is characterized by lower atmospheric pressure. Cooler air flows at the equator at heights of 1 to 10km. Due to the earth's rotation and Carioles acceleration, sources and sinks of global winds appear.

Local winds operate in the lower layers of the atmosphere. Typical examples are sea and mountain winds. They are influenced by the relief of the terrain; the wind is more intense at the top of the hill than at the foot. The tunnel effect between two hills accelerates the wind up to 30%.

Windmills harness the power of the wind and then use a generator to convert the kinetic energy of the wind into electricity. Their efficiency also depends on the design of windmills.

The blade is a crucial part of the wind turbine, which determines its output power by its size and shape. The choice of material when designing the blade is important because 20% of the production cost of a turbine falls on those two parameters.

The performance of the wind turbine blade mainly depends on the aerodynamic profile, angle of the blades and materials. Wind turbine blades are exposed to different working conditions, like dust and shiny environment, heavy rainfall and snowfall, high wind velocities in the rugged topography, changes in the temperature, moisture, and ultraviolet radiation. Also they are subjected to high fatigue that results in crack formation and growth [13].

New solutions for small wind farms, adapted to populated areas, are tulip-shaped wind turbines, manufactured by company Flower Turbines (Netherlands). They implement more technological innovations, because innovative aerodynamic solutions and adaptive design are used for turbines. Constructively, they contain two special blades, and are currently produced in three different blade heights, ie. 1, 3 and 6m. They do not disturb the appearance of urban environments, do not make more noise from the wind that drives them, and start to produce electricity at wind speeds of 1.2 m /s, and grouping more of them increases their efficiency by 20 – 50% [14].

## 4 Materials for wind turbine construction blades

Wind turbine blade constructions require materials with specific characteristics. The certain relevant properties of the most used materials for wind turbine blades are presented in table 1 [13].

*Table 1: Properties of materials for wind turbine blades [13]*

| Material | Density kg/m$^3$ | Young's modulus GPa | Breaking strength MPa | Breaking strain | Cost per kg in $ |
|---|---|---|---|---|---|
| Wood | 400-625 | 0.5-2.5 | 40-90 | 0.5-1.5 | 0.3-5 |
| Steel | 8000 | 200 | 200-1000 | 3-5 | 0.6-2.5 |
| Aluminum | 2500 | 70 | 50-300 | 4-12 | 2.5-5 |
| Glass fiber | 2660 | 30-80 | 2000-3500 | 2.5 | 2-3 |
| Varbon fiber | 1600 | 100-1000 | 380-6200 | 1.6 | 7-90 |
| Plant fiber | 1350-1550 | 73 | 400-1500 | 1.4-3.2 | 1-3 |
| Nanocomposite | Depends upon type of constituents | | | | |

Wooden turbines mainly for educational purposes are used. The wood is strong, easily bendable and available.

A metal blades are made from steel, which is quite expensive and heavy, and from aluminum, which is also expensive but lighter. The use of aluminum allows easier work, but material fatigue may occur.

In Figure 2 the metal wind turbine blade is presented.

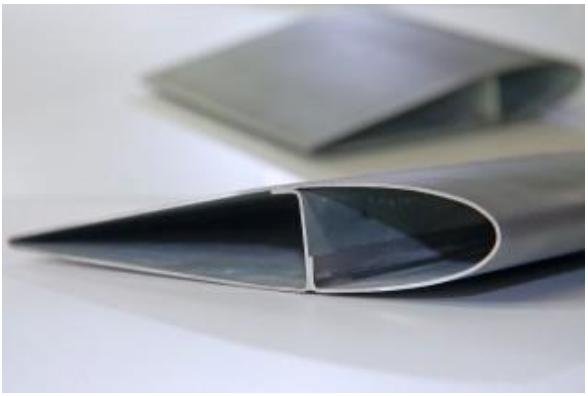

*Figure 2: Metal wind turbine blade [11]*

Wind turbine blades dominantly are made of composite materials that combine high-tensile-strength fibers, with polymer resins to form glass- or carbon-fiber-reinforced polymers (GFRP, or CFRP). These turbines account for approximately 8% of the overall composite market. Composite materials are used for blades because they nave superior properties, as strength, lightweight, and durability. Between 80% and 90% of the blade mass consists of composite material, where 60% to 70% is reinforcing fibers and the other 30% to 40% is resin. Certain changes in the design and material choices for wind turbine blades could lead to greater recyclability [15].

Fiberglass blades have better performance when material fatigue is considered, they are easy to form, light mass, good performance and most modern wind turbines around rhe world use such fiberglass blades. The standard fiberglass blades in Figure 3 are shown.

Wood blades are laminated with weather resistant coatings. Special tapes made up of polyurethane or aluminum are used to keep the tip of the blade safe against wind erosion. But the cost of laminating blades is not little [13].

The inside of the blades is filled with layers of fiberglass that are filled with epoxy resin. To improve rigidity, a layer of wood between the fiberglass layer is added. The two sides of the blades are joined together using liquid epoxy resin.

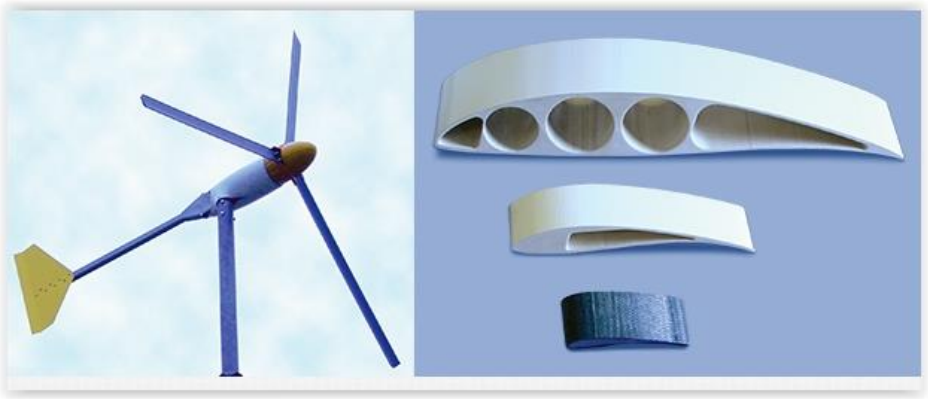

*Figure 3: Fiberglass blades [16]*

The blade is baked for 8 hours at a temperature of 70 degrees. In Figure 4 production of blades is shown [17].

*Figure 4: Production of blades [16]*

Before delivery, turbine blades are subjected to static and dynamic tests. They are exposed to 1.3 times the maximum permissible loads.

To simulate 20-year material fatigue, the vanes are mounted on test beds that vibrate two million times, before durability is tested in a final static test. The blades are painted white and sent to wind farms.

Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP), Natural Fiber Reinforced Polymer (NFRP) and nanocomposites are types of materials relative frequently used in the manufacturing of small wind turbine blades. In the design of wind turbine blade, it is very important to consider the specific strength and specific stiffness of materials [13].

Company Siemens Gamesa has developed first recyclable blades. Blades are set on a wind turbine at the Kaskasi offshore wind farm in Germany. It is the first commercial installation technology of recyclable wind turbine [18].

Scientists at the Michigan State University have created a distinct turbine material that can be revived and recycled into new turbine blades. The new turbine material they have made by combining glass fibers with a plant-derived polymer and a synthetic one [19].

The main trend in wind turbine development is the increase in size in order to reduce the leveraged cost of energy and offshore placements. Consequently, with increasing size, the weight of the rotor blades increases and gravitational loads managed the design. Also longer blades deflect more, so that structural stiffness and the stiffness-to-weight is very important. In addition, the turbine designed to be in operation for about 20–25 years are under the influence of the active high-cycle fatigue loads [20].

## 5 Conclusion

The need for energy is increasing. Numerous efforts are being made to use renewable sources of energy such as wind. Present energy crisis confirms exactly that fact.

Wind turbines have been used long for the production of electrical energy from renewable sources. Design and development in the field of wind turbine structures have been the subject of

numerous engineering studies. The optimization and improvement of such systems are the main tasks.

Technologies for making turbines, i.e. their blades, are constantly being developed and make improved. Wind turbine blades have been made of steel and aluminum alloys earlier. In order to bring better characteristics, fiberglass as an optimal material for wind turbine blades is widely used today. Most rotor blades today are made of plastic-reinforced-glass (fiberglass). Other materials that have been tried include composites and carbon fiber reinforced polymer. As rotor size increases on larger turbine, more and more attention will be paid to the fatigue strength of the materials.

Metals have moderate strength and fatigue properties. They are not preferred for blades because of limitations linked with the manufacturing process and fatigue strength. Composites are widely used materials for small wind turbine blades. GFRP is commonly used composite because of its many desirable properties, such as high specific strength and specific stiffness, easy availability, low cost and easy production. In addition, the use of CFRP is also in increasing trend, because of its higher strengths, but its usage is limited due to high cost and less availability. Nanocomposites and NFRP as new generation materials are also applicable for the specific construction of wind turbine blades.

Wind turbines reach the end of their design lifetimes over the next years and therefore significant quantities of blade material will need to be recycled. Designs of these turbines over time have evolved to in size and efficiency increasing, which lead to greater generating electric energy capacity.

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