An experimental investigation for the effect of blades material and geometry in wind turbine performance using small turbine

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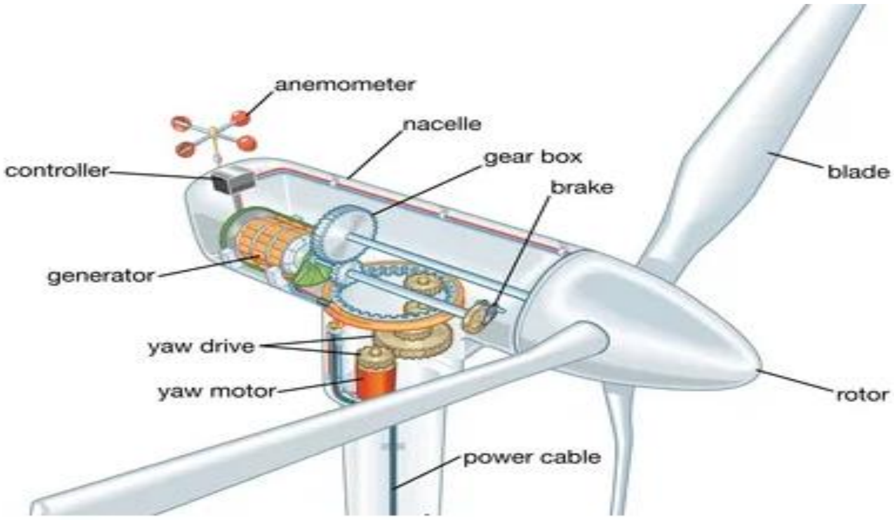
Abstract:

The wind turbine is a device that converts the kinetic energy of wind into electrical energy by generated motion. Wind turbines are an increasingly important source of intermittent renewable energy. As increasing the output power, the turbine rotational speeds increases. There are many parameters that effect on the horizontal axis wind turbine efficiency such as the blade design (geometry), material, and the attack angle. The attack angle is the angle between the blade chord and the wind stream lines. In this research, an experimental investigation was conducted for the effect of changing in the blade design (geometer), material, and attack angle in the small turbine revolution per minute (output power and performance). The optimum blade geometry was narrow width profile and the best attack angle was found 70°. Moreover, epoxy resin imbedded with carbon fiber is the most suitable material for the blade to have better performance.

Key words: Wind turbine, blade geometry, blade design, attack angle, wind speed, blade material, composite material, turbine efficiency.

1. Introduction

A wind turbine is a machine that change the form of wind kinetic energy to electric energy through generators. The generator takes its rotation from the gearbox that connected of the blade rotor as shown in figure 1.1.



. **Figure 1.1. Wind turbine and its schematic drawing**

The importance of renewable energy increases nowadays due to the negative impact of the fossil fuel combustion and emission. Wind turbine on of the most important devices in renewable energy.

Small wind turbines used in many applications range in power from 500 watts to 15 KW depending on the produced electric power. The column height of the wind turbine effects on the produced electric power due to change in the winds speed. Generally, the shaft position determines the classification of the wind turbine. The horizontal wind turbine has parallel axis to the ground as shown in figure 1.2, while the vertical turbine axis is perpendicular to the ground. Practically, the horizontal axis is more efficient than the vertical axis wind turbine.

Figure 1.2. Horizontal axis wind turbine

There are main three parameters that effect on the horizontal axis wind turbine efficiency:

- Blade design (geometry and attack angle)
- Blade material

- Wind speed

Studying the aerodynamics and materials enhancement has developed the wind energy extraction and turbine efficiency.

In respect of blade design, Energy (P) that contained in the wind is expressed in equation (1) as below:

$$\mathbf{P = 0.5\ \rho\ A\ V^3}$$

Where:

- ρ: air density (Kg/ m^3)
- A: exposed area (m^2)
- V: air velocity (m/sec)

According to equation 1; increasing the area of blade that exposed to wind causes increasing in the energy produced from the wind turbine. However, increasing the blade area requires more understanding for the blade geometry. The exposed area is shown in figure 1.3.

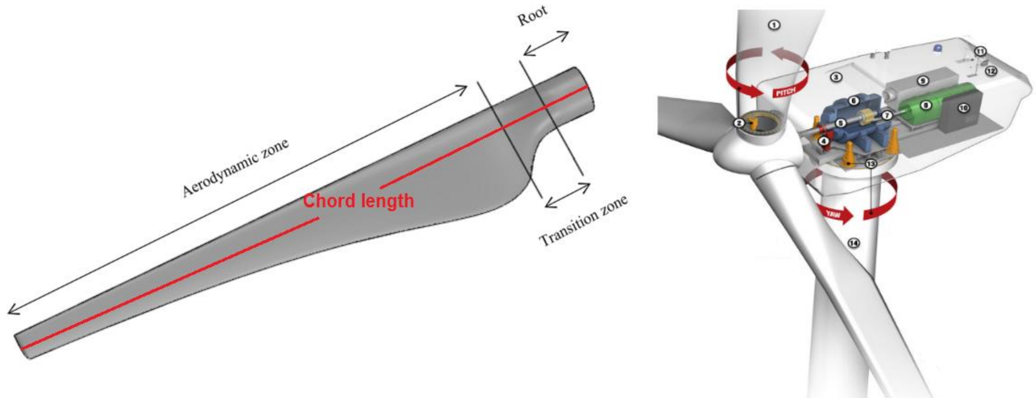


Figure 1.3. Horizontal axis wind turbine

There are two factors effect on the blade design. The first one is the blade geometry. Changing in blade width and length with the same blade profile will have significant effect on the produced power. Moreover, the turbulence in aerodynamics which cause blade tip losses will decrease the turbine efficiency. High tip speed is favorable which often decrease the turbulence losses especially with high lift to drag ratio aerofoils. The tip speed ratio defined according to equation (2):

$$\boldsymbol{\lambda = \Omega\ r\ /\ V_m}$$

Where

- λ: Tip speed ratio
- Ω: rotational velocity (rad / sec)
- r: turbine radius
- V_m: Wind speed

From equation (2); the higher tip speed, the higher produced power. But, the limitations are in increasing the noise level and centrifugal stresses that produced from the differential pressure across the blade. So, we have to utilize the tip speed with different blade geometry.

The second factor is the blade attack angle. As increasing the attack angle, both of lift and drag forces change. The attack angle is the angle between the chord line and the wind direction. It is represented in figure 1.4. The difference between the high pressure and low pressure sides are the main prime mover for the wind blades and it is required to increase the differential pressure as much as possible to increase the turbine efficiency and produced power.

On the other hand and in respect of blade material, there are different blade materials in recent researches that have significant effect on the turbine efficiency. The most traditional blade material is aluminum alloy. However, it has higher weight compared with polymeric or composite materials. The higher weight is not favorable in wind turbine due to its negative effect in rotation friction coefficient but it has the advantage of high strength against the applied loads and long life time.

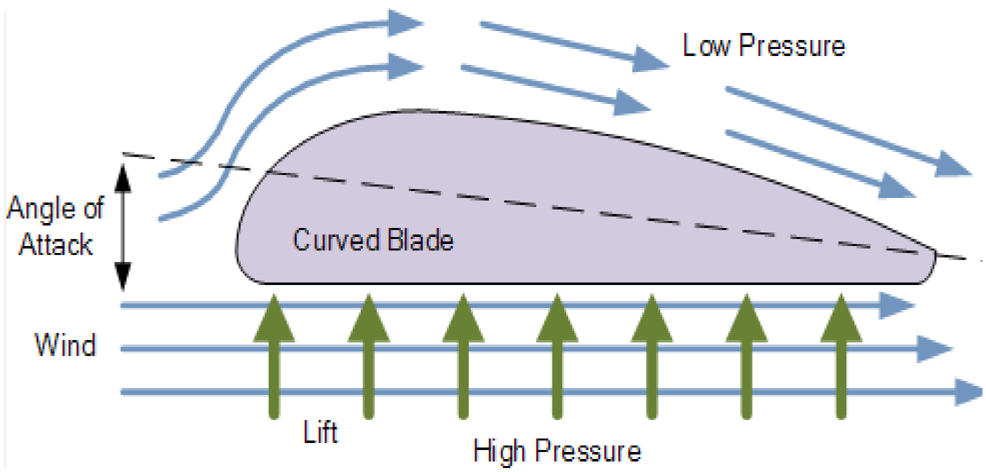


Figure 1.4. Blade attack angle

Nowadays, the composite materials are used widely in wind turbine blades. A composite material is a combination of two materials with different specifications. The engineered composite have mixed properties between mixed materials as shown in figure 1.5. The most favorable composite materials in turbine blades are epoxy resin carbon fiber and epoxy resin – glass fiber. These materials are lighter than metals and chemically stable.

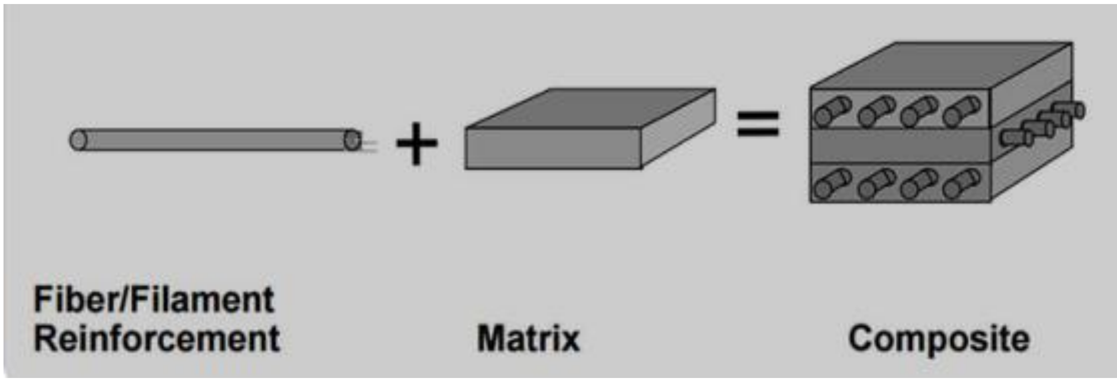


Figure 1.5. Composite materials

Changing in blade materials cause changing in the mechanical properties; stiffness, ductility, and weight. Consequently, the blade which is manufactured from the ductile material will have more twist and bend during rotation as shown in figure 1.6. Thus, the turbine efficiency will be effected.

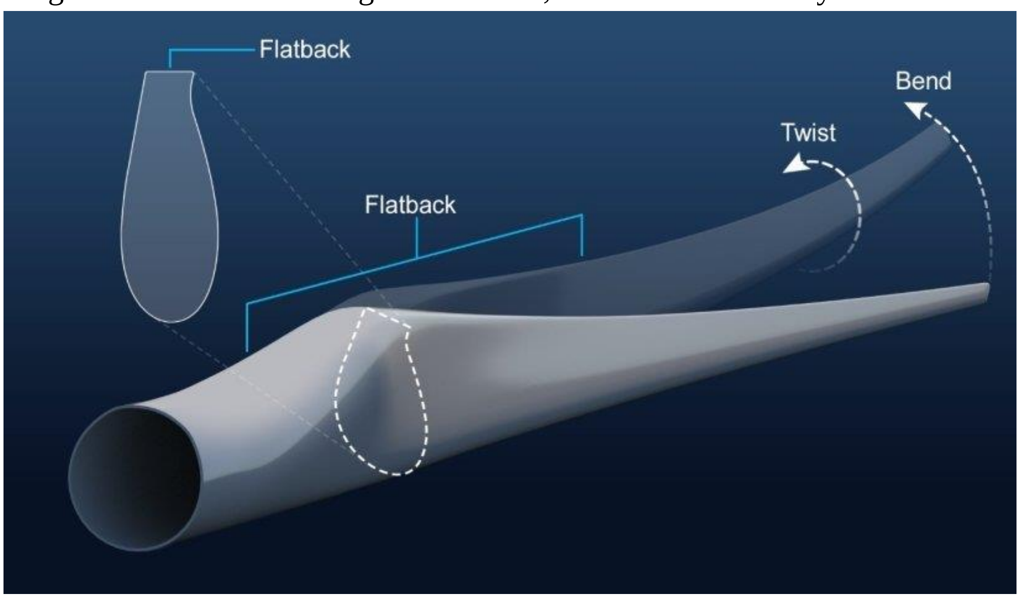


Figure 1.6. Blade twisting and bending with wind load

In this research, an experimental investigation was applied for the wind turbine output power (represented in RPM) with changing the blade geometry (width), attack angle, and blades materials.

2. Materials Preparation and Research Methodology

In order to investigate the effect of blades material and geometry (design shape and attack angle) in wind turbine performance; prototype model of small wind turbine was manufactured with different blade width and blade materials. The turbine efficiency is expressed by the turbine rotational speed in RPM. The tests were conducted in respect of the following:

- Different blade design and calculated tip speed ratio with the same blade materials and wind speed.

- Different attack angle with the same blade materials and wind speed.
- Different blade materials with the same blade width, attack angle and wind speed.

2.1. Experimental setup

The 10KW wind turbine was fabricated with the following specifications as shown in figure 2.1:

- No of blades: 3
- Rotor diameter: 5.5 cm
- Blade length: 25cm
- Blade design: as per figure 2.1 (conventional design).

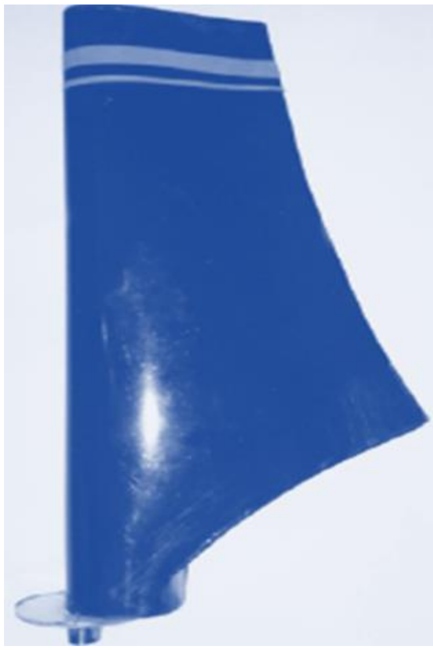
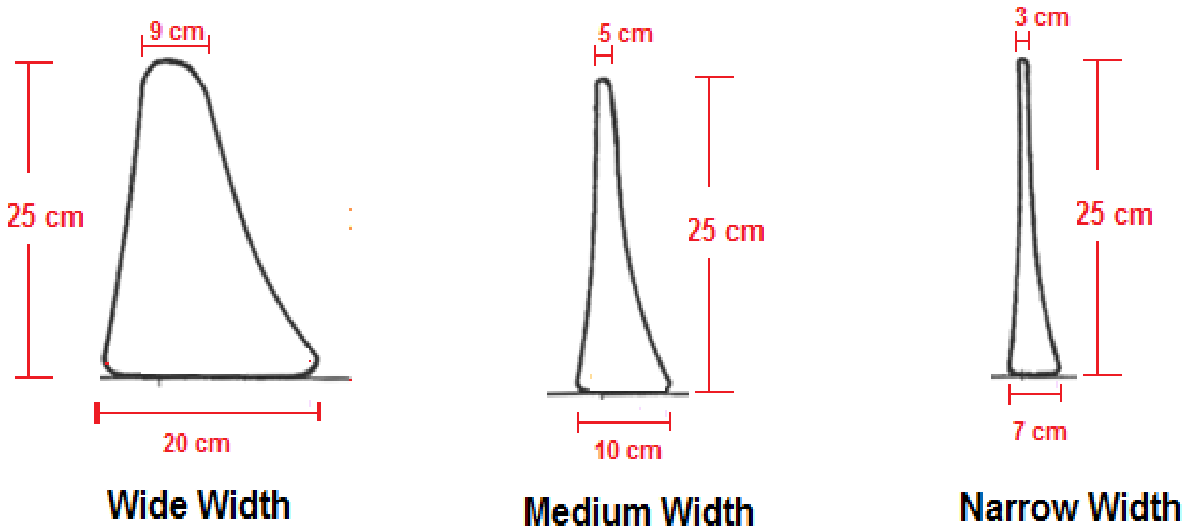


Figure 2.1. Blade design

- The selected blades materials were aluminum, epoxy resin- glass fiber, and epoxy resin- carbon fiber. Each material was tested individually.
- Blade width: three blades were fabricated for each material. The wider blade has the largest width, while the narrow has the smallest width. Blades dimension are illustrated in figure 2.2.
- Twist angle: zero (straight conventional profile)



. **Figure 2.2. Blades width**

2.2. Instruments used

Several instruments were used to record the parameters as below:

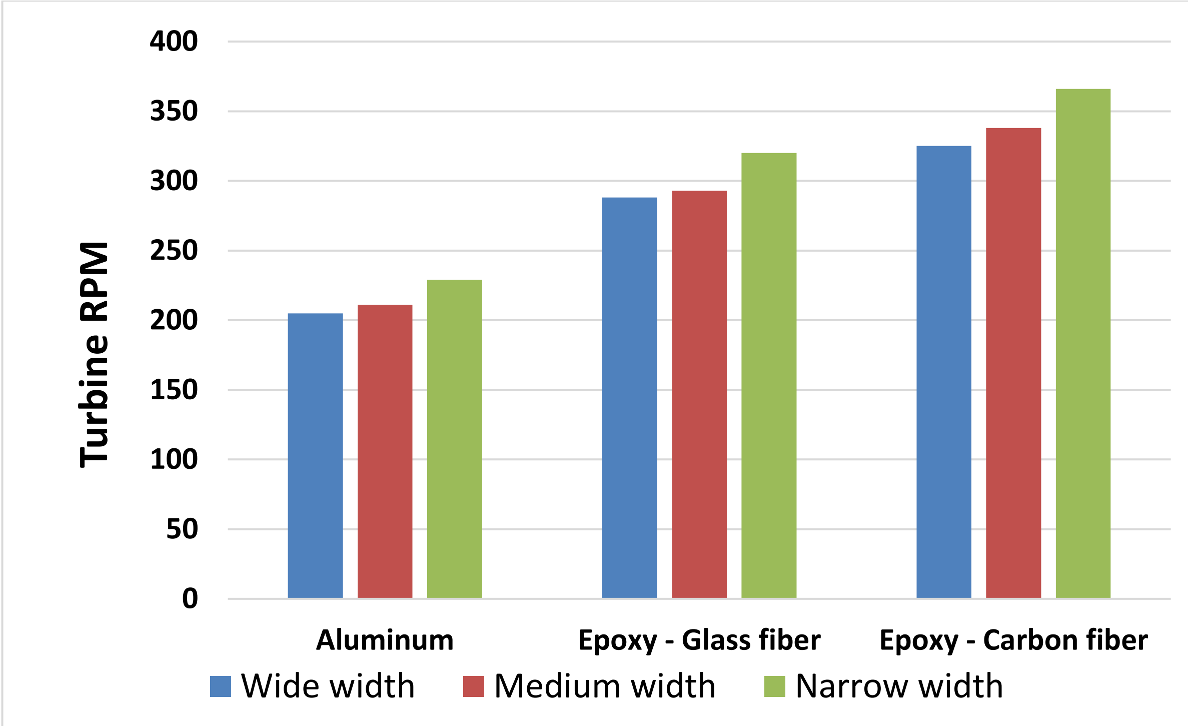
- Anemometer: used to measure the wind speed in (m/sec), wind direction, and pressure.
- Key phasor: used to measure the rotational speed of the wind turbine axis (RPM). The measured rotation speed is the indication of wind turbine efficiency. When the turbine rotational speed increases at the same wind speed, the turbine efficiency increases. So, the efficiency will be expressed in terms of turbine RPM (revolute per minute).
- Digital inclinometer: used to measure the blade attack angle (°)

3. Results and Discussion

Each set of blades mentioned above were installed on the rotor hub of the wind turbine. It was installed above 45m from sea level in Hurghada in Egypt. This location was selected because of its high wind speed which may reach to 10 m/sec in some days. All the measured parameters were recorded and compared with each other in respect of the following factors.

3.1. Effect of blade design on the wind turbine efficiency

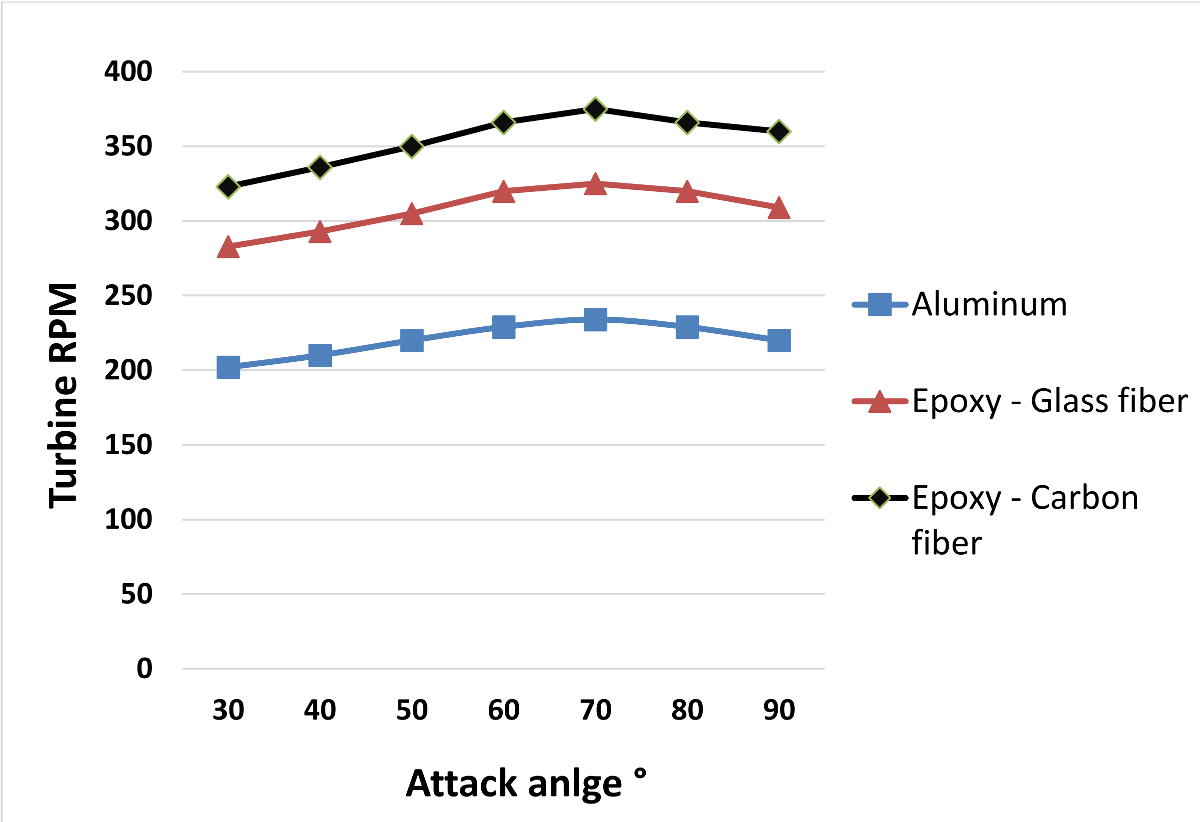
The results in figure 4.1 showed that at different blade design and calculated tip speed ratio; the optimum design is the narrow blade width. This is due to lighter weight and low drag coefficient for the narrow blade width compared with larger ones. These results were at constant attack angle (60°), wind speed (6 m/sec), and same materials.



. **Figure 3.1. Effect of blade design on the wind turbine efficiency**

3.2. Effect of attack angle on the wind turbine efficiency

The results in figure 4.2 showed that at different attack angle; the optimum attack was found 70°. Generally, increasing the attack angle cause increasing in the lift force. However, more increasing in attack angle (above 70°) cause high drag and turbulence loss around the blades aerofoils. These results were at the same blade width (narrow width), wind speed (6 m/sec), and same materials.



. **Figure 3.2. Effect of attack angle on the wind turbine efficiency**

3.3.Effect of blade materials on the wind turbine efficiency

The results in figure 3.4 showed that the optimum blade material was found epoxy resin – carbon fiber. Generally, this is due to lighter weight and low mechanical friction during rotation. Moreover, epoxy carbon fiber blade were better than epoxy glass fiber due to high ductility and tip bending which cause high energy conversion and high lift coefficient. These results were at the same blade width (narrow width), wind speed (6 m/sec), and attack angle (60°).

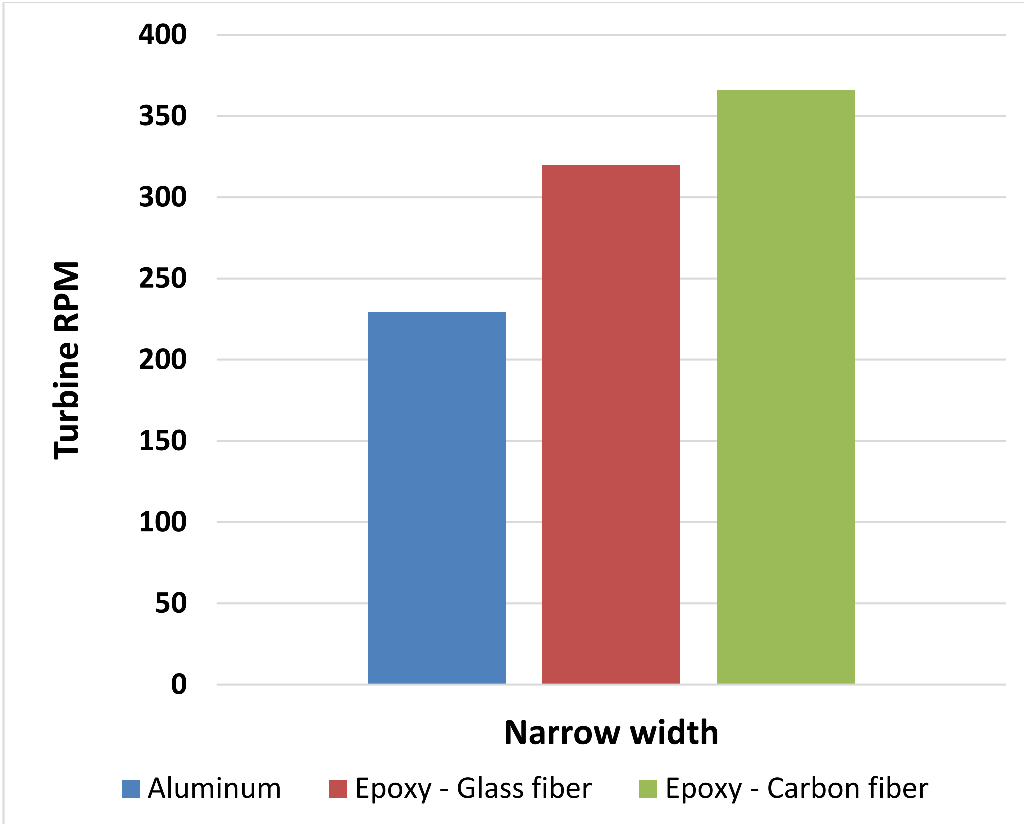


Figure 3.3. Effect of blade materials on the wind turbine efficiency

4. Conclusion

Finally and after completion the experimental setup and testing, it was concluded that the optimum blade geometry was narrow width profile for all blade materials and attack angles. This is due to its high lifting force coefficient and lighter weight. Also, the most probable attack angle was found 70°. If the attack angle increase slightly, the drag force increases and the produced power decreases. Moreover, epoxy resin imbedded with carbon fiber was found the most suitable composite material for the blade due to its high ductility and light weight.

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