ANALYSIS OF SAVONIUS TURBINE BLADES WITH ANGLE VARIATIONS USING FEA SIMULATION IN SOLIDWORKS

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Abstract. *The global energy crisis and the need for renewable energy sources have driven the development of wind turbine technology, one of which is the Savonius type turbine. This study aims to analyze the effect of blade angle variations on the structural strength of the Savonius turbine using the Finite Element Analysis (FEA) method in SolidWorks software. Blade models with angles of 0°, 5°, and 10° were analyzed using ABS (Acrylonitrile Butadiene Styrene) material, with evaluation parameters in the form of maximum stress, total deformation, and strain. The simulation results show that the 10° blade configuration produces the most optimal structural performance, with a maximum stress of 61.43 MPa, a maximum displacement of 9 mm, and a maximum strain of 0.002. Compared to the 0° and 5° blades, this configuration shows a more even distribution of stress and strain, thus minimizing load concentration at critical points. Although all configurations produce stresses exceeding the elastic limit of ABS material (±45 MPa), the 10° blade is still recommended as the best design alternative from the aspect of load distribution and structural integrity, with the note that materials with higher mechanical strength are required for practical applications.*

Keywords: *ABS, Blade Angles, FEA Simulation, Savonius, Turbine Blades.*

1. INTRODUCTION

The use of renewable energy is a crucial aspect in responding to global challenges related to the energy crisis and the environmental impacts caused by the use of fossil energy. (Ibn Al Hasyim et al., 2024) Wind energy is an alternative energy source that is clean, unlimited, and can be utilized in various regions. One widely developed wind energy conversion technology is the vertical axis wind turbine (VAWT), particularly the Savonius type (Junaidin, 2017). This type of turbine has the advantage of simple construction, the ability to operate at low wind speeds, and does not require a wind direction tracking system (Amin & Kaloko, 2024).

The primary component determining the performance and reliability of a Savonius turbine is the blade. The blade captures the kinetic energy of the wind flow, which is then converted into rotational mechanical energy. However, during operation, the blade experiences significant and periodic aerodynamic loads, potentially leading to high stress concentrations and structural deformation. (Irwansyah & Anwar, 2023; Karudin et al., 2025) This condition can affect the structural integrity of the blade and shorten its service life. The main problem in this context is the suboptimal blade design, particularly in terms of variations in the blade curvature angle, which directly affects load distribution and the mechanical response of the structure (Mujiburrahman et al., 2023).

As a solution, a computational approach based on the Finite Element Analysis (FEA) method is needed. This is a method commonly used to analyze stress, deformation, and safety factors in mechanical components. By utilizing SolidWorks software, which integrates geometric design and static analysis modules, the evaluation process can be carried out efficiently and accurately (Darsono et al., 2021).

This study aims to analyze the structural strength of a Savonius turbine blade against variations in blade angle using the FEA method. The angles analyzed include 0°, 5°, and 10°. The main parameters analyzed include maximum stress, total deformation, and safety factor. (Alhakiem et al., 2021) The results obtained from this research are expected to contribute to the development of a more structurally reliable Savonius turbine blade design, as well as support the utilization of wind energy on a small scale, especially in urban and rural areas (Arif, 2019).

2. LITERATURE REVIEW

2.1 Savonius Type Wind Turbine

The Savonius type wind turbine is included in the vertical axis wind turbine (VAWT) category which was first developed by Sigurd Savonius in 1922. This turbine consists of two or more half-cylindrical blades arranged opposite each other to form a rotor. (Leni, 2023) The working principle of the Savonius turbine is based on the difference in drag force between the windward side of the blade and the opposite side. The main advantages of this turbine are its ability to operate at low wind speeds, its simple construction, and the absence of a wind tracking system. Although its efficiency is lower than that of a horizontal turbine, the Savonius turbine is well suited for small-scale applications and urban environments (Gomes, 2024).

2.2 Turbine Blades

The blades are the primary components directly responsible for capturing the wind's kinetic energy. The blade design affects the magnitude of the force received and the efficiency of energy conversion. In Savonius turbines, the blades are typically curved in a semi-cylindrical shape, but modifications to the blade curvature angle can significantly impact pressure distribution and airflow (Leni et al., 2025). The blade structure must be able to withstand aerodynamic loads and centrifugal forces during operation, so material strength and geometric design are crucial factors (Dharma & Masherni, 2017).

Following are several types of pressure:

1. Static Pressure

Static pressure is the pressure acting perpendicular to the surface of an object without considering the fluid's motion. In the context of wind tunnels, it represents the potential energy of the fluid at a given point and is often used to understand the pressure distribution on the surface of a test object such as an airfoil, vehicle, or building. Static pressure distribution plays a crucial role in determining aerodynamic forces, such as lift and drag, that influence the aerodynamic performance of a design. Static pressure measurements are performed using pressure taps installed along the surface of the test object to generate detailed pressure distribution data (Astuti et al., 2023).

2. Dynamic Pressure

Dynamic pressure is the pressure generated by fluid motion and represents the fluid's kinetic energy. Its value depends on the airflow velocity and air density. Dynamic pressure is a key parameter in wind tunnel experiments, as it affects the airflow velocity within the tunnel. Dynamic pressure measurement is crucial for calibrating flow conditions to meet experimental requirements, such as simulating laminar or turbulent flow (Algifari & Adrian, 2023).

2.3 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) is a numerical approach used to analyze the physical behavior of a structure under specific loading conditions. FEA divides the geometry into small, interconnected elements (meshes), then solves numerical equations for each element to obtain stress distributions, deformations, and other mechanical responses. In the context of turbine blade structural analysis, FEA enables efficient and accurate evaluation of the blade's strength and resistance to wind pressure. By utilizing software such as SolidWorks Simulation, the modeling and analysis processes can be performed in a single, integrated platform (Setiyana & Kurniawan, 2020).

2.4 Finite Element Analysis (FEA)

SolidWorks is a parametric-based computer-aided design (CAD) software commonly used in mechanical design and engineering. One of its key features is the SolidWorks Simulation module, which allows users to perform finite element analysis (FEA) directly on the designed 3D model. (Allasselcida & Leni, nd) This module supports various types of structural, thermal, and dynamic simulations, and provides visualization of stress distribution, displacements, and safety factors in a component or assembly (Usma et al., 2024).

SolidWorks Simulation offers the advantage of integrating geometric design and simulation processes, facilitating iterative analysis during product development. SolidWorks provides high flexibility in evaluating the resistance of mechanical structures to various loads and supports design validation prior to manufacturing. In the context of wind turbine blade analysis, this software is capable of providing accurate results in identifying critical stress points and deformation behavior due to wind pressure (Rahman et al., 2022).

2.5 Finite Element Analysis (FEA)

Several previous studies have discussed the effect of blade design variations on Savonius turbine performance. Saha et al. (2008) stated that modifying the blade angle and shape can improve the turbine's aerodynamic efficiency. Al-Abadi et al. (2016) in their study showed that changes in blade angle affect the distribution of forces and pressures in the turbine. Meanwhile, Rautray et al. (2020) used an FEA approach to evaluate the maximum stress on turbine blades and emphasized the importance of structural analysis in design development. However, studies that specifically link blade angle variations with structural strength aspects through FEA simulations are still limited, thus creating a relevant research gap for further study.

3. RESEARCH METHODS

This research falls into the category of computational simulation-assisted experimental design studies. The approach used involves three-dimensional (3D) modeling in SolidWorks software and structural strength analysis using SolidWorks Simulation features. This process aims to validate that the wind tunnel design has adequate strength and stability for use as a testing medium for Savonius-type wind turbines.

The research was conducted in the computer-Aided Design (CAD) Laboratory, Mechanical Engineering Program, Muhammadiyah University of West Sumatra, from March to July 2025.This research goes through several stages as in the research scheme below:

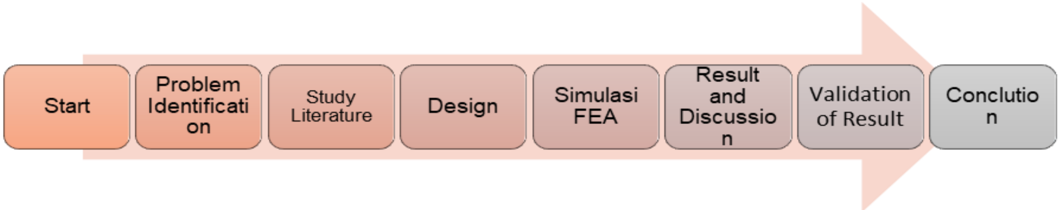


Figure 1. Research Scheme

3.1 Problem Identification

This stage aims to identify the main problem underlying the research, namely the suboptimal structural strength of the Savonius turbine blade design due to angular variations. Researchers observed potential damage due to high stress concentrations and excessive deformation.

3.2 Literature Study

At this stage, relevant references and scientific literature were collected and reviewed, covering the basic concepts of the Savonius turbine, blade design, the finite element method (FEA), and the use of SolidWorks software as a simulation tool. This study serves as the theoretical basis for formulating the design and simulation.

3.3 Model Design

This stage involves the three-dimensional (3D) modeling process of a Savonius turbine blade with three angle variations (0°, 5°, and 10°) using SolidWorks software. The geometry specifications and technical parameters are adjusted to relevant experimental standards to ensure the validity of the model.

3.4 FEA Simulation

At this stage, a simulation process is performed using SolidWorks Simulation. A wind pressure load is applied to the blade surface to analyze the structure's response to the loading. Parameters analyzed include maximum stress (von Mises), total deformation, and strain.

3.5 Results and Discussion

The simulation results are analyzed and interpreted to evaluate the structural performance of each blade angle variation. The discussion is conducted by comparing the mechanical parameters generated from each model to determine the most structurally optimal angle.

3.6 Validation of Results

This stage aims to verify the simulation results by comparing them to material mechanics theory and secondary data from relevant literature. This validation is essential to ensure that the simulation results are reliable and accurately represent real-world conditions.

3.7 Finish

At this stage, conclusions are formulated based on the results of FEA simulations and analyses conducted on Savonius turbine blades with angle variations of 0°, 5°, and 10°. The conclusions obtained reflect the effect of angle variations on the strength of the blade structure and the most optimal design potential. In addition, this stage also highlights the contribution of research to the development of Savonius-type wind turbine designs and provides recommendations for further research, both in terms of geometry variations, materials, and in-depth experimental testing.

4. RESULTS AND DISCUSSION

4.1 Results

In the context of designing reliable components for capturing and converting wind energy, a thorough understanding of the mechanical response of structures to real loads is required. In Savonius-type wind turbines, the blades are the primary elements that determine the system's effectiveness and resilience to periodic aerodynamic stresses. Blade resistance to stress, deformation, and strain is a crucial focus to ensure optimal long-term performance. To address this challenge, a simulation study was conducted to evaluate the strength of blade structures with three variations in bending angle.

The stage begins with designing a three-dimensional model of the blade using SolidWorks based on uniform geometric specifications. The geometric specifications of the Savonius blade used in this study are shown in Table 1.

Table 1. Turbine Blade Dimensions

No	Parameter	Mark	Unit
1	Bottom diameter	20	cm
2	Thickness of spoon	2	mm
3	Blade diameter width	10	cm
4	Radius	7.7	cm
5	Spoon height	20	cm

These dimensions were designed to ensure compatibility with laboratory-scale wind tunnel facilities and to simplify the fabrication process. After the 3D model was completed, the blade angles were varied to 0°, 5°, and 10°, as shown in Fig.Figure 2. to analyze its influence on structural response using the Finite Element Analysis (FEA) method to analyze the von Mises stress distribution, total deformation, and strain due to wind pressure.

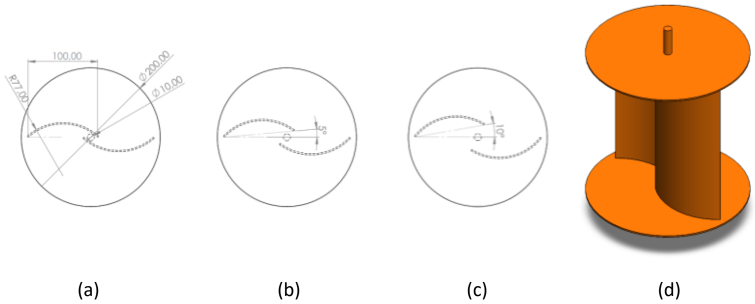


Figure 2. Savonius Turbine Design (a) Angle 0°(b) Angle 5°(c) Angle 10°(d) 3D Turbine

A. Turbine0°

1. Stress

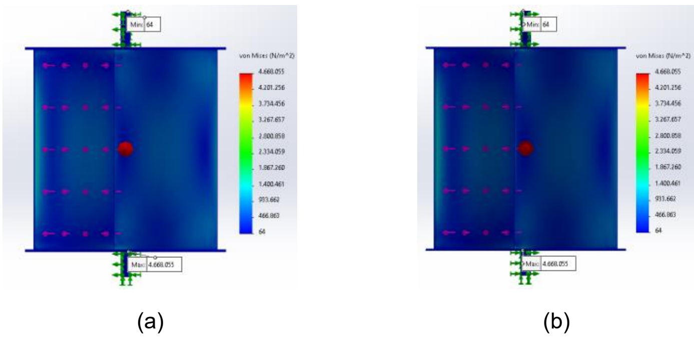
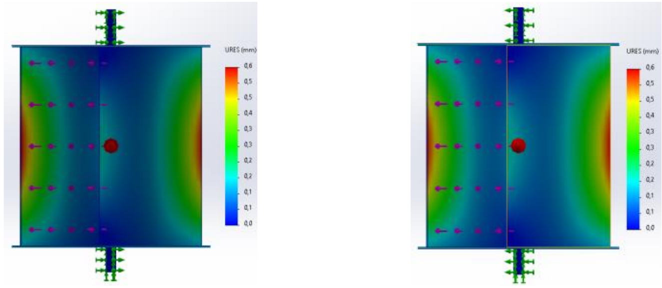


Figure 3. Von Mises Stress Turbine 0°(a) Saction 1(b) Saction

Based on the results of finite element simulation (FEA) on the Savonius turbine blade with an angle of 0°, Visualization using the von Mises stress criterion shows the distribution of maximum and minimum stresses that occur in the turbine structure when given a work load. The maximum stress value is located in the rotor center area with a value of 4.668 MPa, while the minimum stress of 64 N/m3 occurs at the end of the clamped shaft (fixed support). The even stress distribution and no excessive concentration in the outer area indicate that the turbine structure design is relatively safe for the given load, but special attention needs to be given to the center area because it is the focus point of the rotating force and the main torque load.



(a) (b)

Figure 4. Turbine Displacement 0°(a) Saction 1(b) Saction 2.

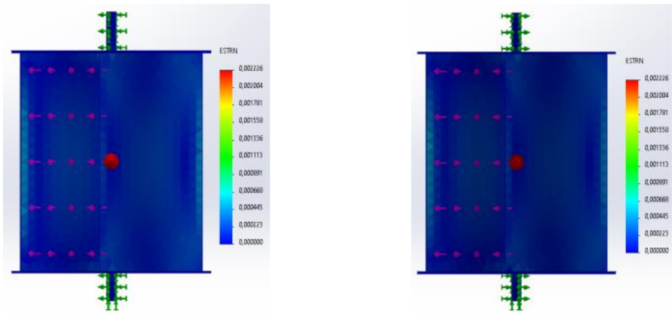
2. Displacement

The displacement distribution shows that the center of the blade experiences the greatest displacement due to wind pressure, indicated by the red color with a maximum displacement value of 0.6 mm and occurs in the center left side area of the structure, marked in red. In contrast, the minimum value of 0.0 mm occurs at the fixed support points at the top and bottom, indicated by the blue color.

The displacement distribution is symmetrical, with a color gradient indicating a decrease in deformation from the center of force toward the support area. The direction of the external force is indicated by the pink vector acting horizontally, while the fixed support is visualized by the green lock symbol.

The relatively small maximum displacement values indicate that the structure has adequate stiffness and is capable of withstanding the working loads without excessive deformation. These results indicate that the design is within structurally acceptable deformation tolerances.

3. Strain



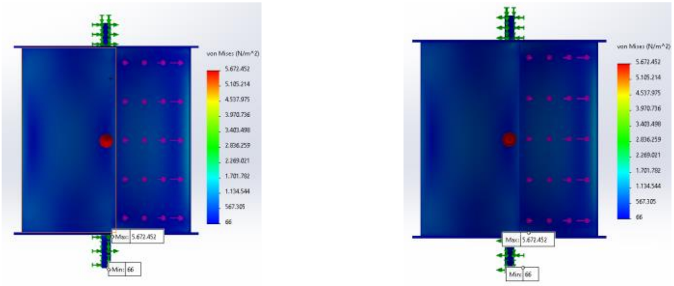
(a) (b)

Figure 5. Turbine Strain 0° (a) section 1 (b) section 2

In the Savonius turbine blade model with a 0° angle, the strain distribution in the structure under static loading is visualized in a color-coded contour scale. The maximum strain value is 0.002226 and is localized in the center of the structure, right around the point of force application. This region is highlighted in red, indicating the highest deformation relative to the initial length. Conversely, minimum strains approaching 0.000000 are detected in the upper and lower fixed support areas, shown in blue. The strain distribution spreads symmetrically from the center of the load outward, in line with the direction of the external force represented by the pink vector acting horizontally. The fixed support conditions (in green) limit the displacements, so most of the strains are concentrated in the free area exposed to the force. The relatively low maximum strain value indicates that the structure remains within the elastic zone of the material, with no indication of plastic deformation or permanent damage. These results support previous findings from stress and displacement analysis and confirm that the structure is capable of operating elastically under the given loading conditions.

B. Turbine5°

1. Stress

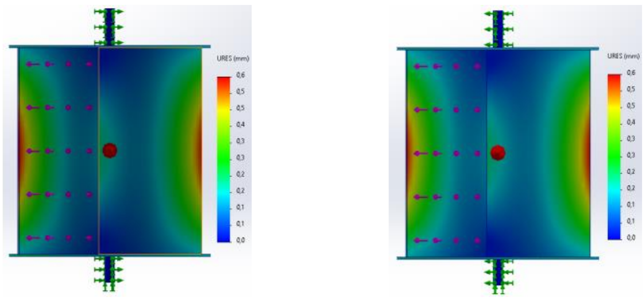


(a) (b)

Figure 6. Von Mises Stress Turbine 5° (a) Section 1 (b) Section 2

In the model with a blade angle of 5°, the von Mises stress simulation shows a maximum stress value of 5.67 MPa and is localized in the center area of the structure around the point of force concentration, as indicated by the red color. Meanwhile, a minimum stress of 66 N/m² appears in the area around the bottom support and the edge of the structure. The external force is applied horizontally from right to left, indicated by the pink force vector, resulting in a relatively symmetrical stress distribution pattern. Referring to the yield strength of ABS material which ranges between 30–45 MPa, the maximum stress value generated is still far below the failure limit, so the structure can be said to work in the elastic zone and is safe from permanent deformation. Thus, the use of ABS in this design shows stable structural performance with a sufficient safety factor against the applied loads.

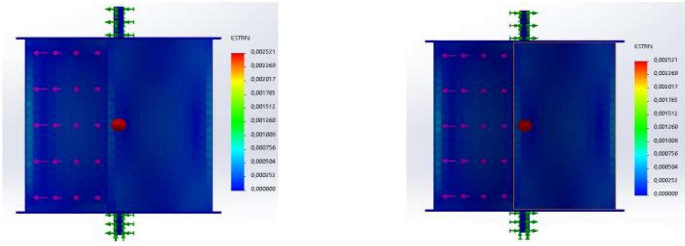
2. Displacement



(a) (b)

Figure 7. Turbine Displacement 5° (a) Saction 1 (b) Saction 2

Figure 7 shows the distribution of total displacement (URES) in the structure due to static loading with fixed restraint conditions at the top and bottom. The maximum displacement value recorded was 0.6 mm, which occurred on the left side of the center of the structure, marked in red on the contour map. Meanwhile, the minimum displacement value of 0.0 mm occurred in the fixed support area, marked in dark blue, indicating that there was no movement at that point according to the specified boundary conditions. The pink force vector indicates the force acting horizontally from left to right. The displacement distribution shows a symmetrical pattern with a color gradation from red to blue, indicating that deformation decreases from the center of force towards the support. The maximum displacement value of 0.6 mm is still within the elastic limit for materials such as ABS (Acrylonitrile Butadiene Styrene), which has an elastic modulus between 1.5 and 2.5 GPa. This indicates that the structure did not experience plastic deformation and remains safe for use under the analyzed loading conditions.



(a) (b)

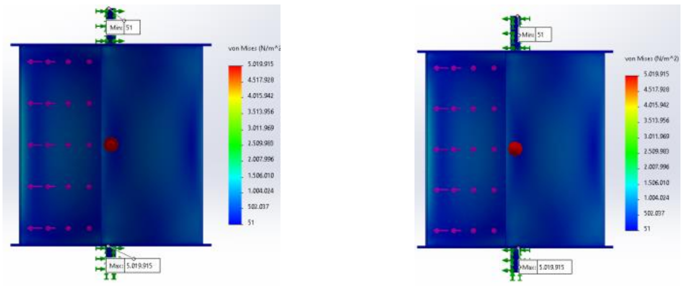
Figure 8. Turbine Strain 5° (a) Saction 1 (b) Saction 2

3. Strain

Figure 8shows the strain distribution (ESTRN) in the structure as a result of static loading simulation with ABS material and fixed support conditions at the top and bottom. The maximum strain value recorded is 0.002521, which occurs around the center area of the structure where the force is focused, marked in red on the contour. Meanwhile, the minimum strain value approaching 0.000000 is found in the support area and the edge of the structure, marked in dark blue. The external force vector in pink indicates a horizontal force applied from left to right. The strain distribution pattern appears symmetrical, indicating a uniform response of the structure to the loading. This maximum strain value is still within the elastic limit of ABS material, which has a yield strain limit of around 0.04–0.06 depending on the composition and condition of the material. Thus, the simulation results indicate that the structure remains operating within the elastic zone without experiencing permanent deformation, and the design can be said to be safe for the applied load.

C. Turbine 10°

1. Stress

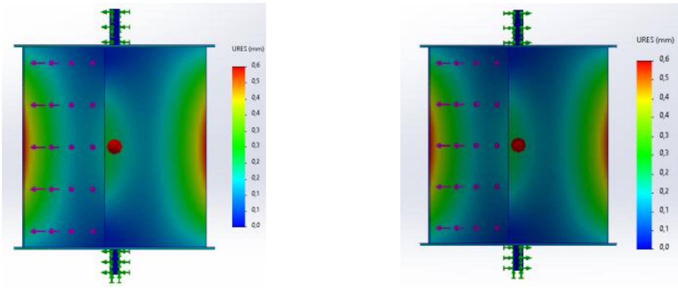


(a) (b)

Figure 9. Von mises Turbine 10° (a) Saction 1 (b) Saction 2

The von Mises stress simulation in Figure 9 for a blade with a 10° angle shows a maximum value of 5,019.915 N/m² (5.02 MPa) and is localized in the center of the structure, right at the main contact area of the force, which is visualized in red as an indication of the highest stress zone. In contrast, the minimum stress of 51 N/m² is distributed in the upper support area, indicated by the dark blue color on the contour map. The loading direction is visualized by the pink force vector that acts horizontally from left to right, resulting in a symmetrical stress distribution pattern from the load side to the support side. Based on the characteristics of ABS material, which has a yield strength ranging from 30 to 45 MPa, the maximum stress that occurs is still far below the failure threshold. This indicates that the structure is in a safe condition, operating in the elastic zone, and does not show any indication of material failure due to the applied load.

2. Displacement

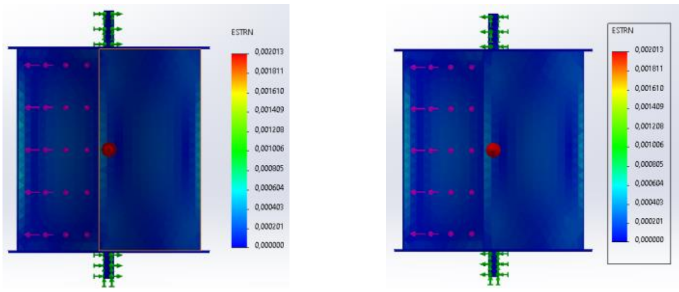


(a) (b)

Figure 10. Turbine Displacement 10° (a) Saction 1 (b) Saction 2

Figure 10 shows the simulation results showing that the maximum displacement value reaches 0.6 mm, located on the left and right sides of the structure, which is marked by the red color on the contour. Meanwhile, the minimum value of 0.0 mm is in the support area, as indicated by the dark blue color. The distribution of displacement forms a symmetrical pattern, with a color gradation from red → green → blue indicating that the deformation spreads evenly from the point of force application towards the direction of restraint. With reference to ABS material which has an elastic modulus of around 1.5–2.5 GPa, a displacement of 0.6 mm is still relatively low and indicates that the structure is within the elastic limit. This indicates that the design is able to withstand the given load without experiencing permanent deformation or structural failure.

3. Strain



(a) (b)

Figure 11. Turbine Strain 10° (a) Saction 1 (b) Saction 2

Finite element analysis (FEA) results showing the equivalent strain distribution (ESTRN) in an ABS (Acrylonitrile Butadiene Styrene) structure due to loading from the left side. The color scale on the right depicts strain values ranging from 0.000000 (dark blue) to 0.002013 (red), where most areas of the structure experience low to moderate strains, ranging from 0.000000 to 0.001006. The maximum strain point of 0.002013 is marked in red located in the center of the structure, possibly due to stress concentration in certain geometries such as holes or joints. The direction of the force is indicated by the pink arrow from left to right, while the supports (restraints) are visualized with green symbols on the right side and the top and bottom of the structure. Based on the mechanical properties of ABS material which has a maximum strain before breaking of around 0.04 (or 4%), the maximum strain value of 0.002013 (or 0.2013%) is still far below the safe limit, so it can be concluded that this structure is still in a safe condition against deformation.

4.2 Validation of Results

The results of this study are in line with the findings of Al-Abadi et al. (2016), which showed that variations in blade angle in Savonius turbines have a significant influence on the pressure distribution and mechanical response of the structure. The study stated that blades with a certain curvature angle are able to distribute aerodynamic loads more evenly, thereby reducing stress concentration at critical points. In addition, Rautray et al. (2020) through a finite element simulation (FEA) approach also found that blade geometry with angle modification has a positive influence on stress and strain distribution patterns, without increasing the risk of excessive deformation. This finding strengthens the results of the current study, where blades with an angle of 10° were shown to have the most even stress and strain distribution despite experiencing greater displacement, but still within the elastic limit. Thus, validation of these simulation results confirms that blade designs with angle variations, especially 10°, provide advantages in terms of structural strength and resistance to loading.

CONCLUSION

Based on the results of Finite Element Analysis (FEA) based simulations of Savonius turbine blades with angle variations of 0°, 5°, and 10°, it can be concluded that blade geometry plays an important role in determining the structural response to aerodynamic loading. The material used in this analysis is ABS (Acrylonitrile Butadiene Styrene), which although commonly used in engineering prototypes, has an elastic limit of around 45 MPa. From the simulation results, the blade with an angle of 10° shows the best structural performance with a more even distribution of stress and strain, and maximum displacement that is still within the elastic limit of the material, although the maximum stress value still exceeds the elastic limit of ABS. This indicates that the 10° blade design is more effective in distributing the load, thereby reducing the risk of stress concentration at critical points. However, because all blade configurations produce stresses above the elastic limit of ABS, the use of this material is not recommended for long-term applications without reinforcement or selection of stronger materials. Therefore, a blade with a 10° angle can be recommended as the optimal design in terms of load distribution, with the note that improved structural performance can be achieved through further material development or geometry engineering.

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