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Design, Modelling, and Finite Element Analysis of Wind Turbine Blades for Sustainable Energy Generation

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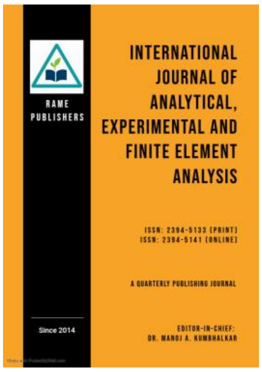

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Abstract: The increasing global emphasis on sustainable energy solutions has driven advancements in wind turbine technology. This study focuses on the design, modelling, and finite element analysis (FEA) of wind turbine blades to assess their structural and aerodynamic performance. A key aspect of the research is the comparative evaluation of different manufacturing materials, including fiberglass, carbon fibre composites, and aluminium alloys, to determine their impact on strength, weight, and durability.

The methodology involves developing a detailed 3D CAD model of the wind turbine blade in SolidWorks, ensuring precise geometric representation. The model is then imported into ANSYS Workbench for structural and aerodynamic analysis under realistic operating conditions. The blade is subjected to various loading scenarios, including wind pressure, centrifugal forces, and gravitational effects, to analyse key performance parameters such as stress distribution, deformation, and fatigue life. Additionally, material-specific simulations will be conducted to compare mechanical behaviour and longevity.

The expected results aim to highlight the advantages and limitations of different materials in wind turbine blade applications. By assessing structural integrity and fatigue resistance, the study will provide insights into material selection for improved efficiency, reliability, and sustainability in wind energy generation. The findings will serve as a reference for engineers and manufacturers in developing cost-effective and high-performance wind turbine blades for future renewable energy projects.

Keywords: Wind Turbine Blades, Finite Element Analysis, Sustainable Energy Generation, Structural Analysis, Composite Materials, Stress Distribution, Deformation Analysis, SolidWorks Modelling, ANSYS Simulation, Renewable Energy, Load Analysis.

1. Introduction

Wind energy has emerged as one of the most promising renewable energy sources, offering a sustainable and environmentally friendly alternative to fossil fuels. As the global demand for energy continues to rise, concerns over climate change, air pollution, and the depletion of non-renewable resources have accelerated the shift toward cleaner energy solutions. Wind energy, being abundant, widely available, and cost-effective, plays a crucial role in the transition to a more sustainable energy future.

Wind energy is harnessed through wind turbines, which convert the kinetic energy of moving air into mechanical power, ultimately generating electricity. This process eliminates greenhouse gas emissions and reduces dependence on conventional power generation methods such as coal, oil, and natural gas. Unlike fossil fuels, which require extraction and combustion, wind energy relies on natural atmospheric movements, making it a clean and renewable source of power. With continuous technological advancements, wind energy has become increasingly efficient, making it one of the fastest-growing energy sectors worldwide.

The importance of wind energy is reflected in its numerous economic, environmental, and social benefits. Economically, wind power has become one of the most cost-competitive sources of electricity, with lower operational and maintenance costs compared to conventional power plants. The increasing deployment of wind farms has also created job opportunities in manufacturing, installation, maintenance, and research, driving economic growth in many regions. Governments worldwide are investing in wind energy infrastructure, providing incentives and subsidies to promote its adoption.

From an environmental perspective, wind energy significantly reduces carbon footprints by lowering greenhouse gas emissions, thereby mitigating the effects of global warming. Unlike fossil fuel-based power generation, wind turbines do not release pollutants such as carbon dioxide (CO_2), sulfur dioxide (SO_2), or nitrogen oxides (NO_x), which contribute to air pollution and respiratory diseases. Additionally, wind power reduces water consumption associated with traditional thermal power plants, making it a more sustainable choice in regions facing water scarcity.

Socially, wind energy enhances energy security by reducing reliance on imported fuels and increasing domestic energy production. It supports rural development by enabling the establishment of wind farms in less populated areas, providing additional income for landowners and local communities. The decentralization of wind energy systems allows for distributed power generation, improving grid stability and resilience against power shortages or disruptions.

With growing investments in research and development, wind energy technology has advanced significantly, leading to more efficient, durable, and cost-effective wind turbines. Modern wind turbines are designed with improved aerodynamics, advanced composite materials, and digital monitoring systems to maximize energy capture and operational efficiency. The expansion of offshore wind farms, where wind speeds are higher and more consistent, has further increased the potential for large-scale energy generation.

As the world moves toward achieving carbon neutrality and sustainable energy goals, wind energy will continue to play a critical role in meeting global electricity demand. By improving turbine design, optimizing material selection, and enhancing structural efficiency, researchers and engineers are working to make wind energy even more viable for widespread adoption. This study focuses on one of the key components of wind turbines—the blade—which directly influences energy efficiency and system performance. Through detailed design, modeling, and analysis, this research aims to contribute to the ongoing advancements in wind energy technology, ultimately supporting a cleaner and more sustainable future.

2. Literature Review

Extensive research has been conducted on the structural analysis, material optimization, and performance enhancement of wind turbine blades using computational techniques such as Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD).

Kavan Mevada [1] performed a comprehensive finite element analysis of wind turbine blades using various materials, including structural steel, epoxy-carbon, E-glass, S-glass, and aluminum alloy. The study evaluated stress distribution, deformation characteristics, and weight reduction potential. The results demonstrated that epoxy-carbon composites exhibited superior mechanical performance due to their high strength-to-weight ratio, reduced deformation, and enhanced structural integrity, making them highly suitable for wind turbine blade applications.

Prado and Branner [2] developed a detailed two-dimensional finite element model to investigate the structural behavior of wind turbine blades, particularly focusing on the load-carrying box girder. Using publicly available geometric and material data, the study identified critical stress concentration regions and deformation patterns under operational loading conditions. Their findings contributed significantly to the optimization of blade structural design and material selection.

Elsherif et al. [3] conducted a material selection study for wind turbine blades by integrating CFD and FEA techniques. Aerodynamic pressure loads obtained through CFD simulations were applied to finite element models for structural assessment. The study compared fiberglass-reinforced plastic and carbon-fiber composites, concluding that carbon-fiber composites offered superior strength and lower deformation, thereby enhancing blade performance and reliability.

Shiv N. Prajapati and Manish Kumar [4] investigated the structural response of a wind turbine blade based on the NACA 4420 airfoil profile. Their dynamic finite element analysis examined stress concentrations and deformation behavior under varying loading conditions. The study highlighted the importance of optimizing blade thickness and composite layup configurations to improve fatigue resistance and structural strength.

Appadurai and Fantin Irudaya Raj [5] explored the influence of composite materials on wind turbine blade performance using finite element analysis. Their comparative study demonstrated that hybrid composite structures provided enhanced stiffness, improved fatigue resistance, and reduced overall weight. These characteristics contribute significantly to increasing blade efficiency and operational lifespan.

Yamina et al. [6] performed structural modeling and stress analysis of a 61.5-meter wind turbine blade designed for high wind-speed environments. Through finite element simulations, the researchers evaluated stress distributions, deformation characteristics, and potential failure mechanisms. The study revealed that optimized material layering and structural modifications substantially improved blade durability and operational efficiency under extreme loading conditions.

Navadeh et al. [7] investigated the vibrational behavior of wind turbine blades using finite element analysis. The research focused on determining natural frequencies, mode shapes, and dynamic responses under varying wind conditions. The results emphasized the critical role of material stiffness and damping characteristics in minimizing vibration-induced damage and extending blade service life.

Kim and Cho [8] examined the static bending behavior of wind turbine blades reinforced with graphene platelets. Their finite element model evaluated blade deflections under different crack lengths and locations. The results indicated that graphene-reinforced composites exhibited greater resistance to crack propagation and enhanced structural durability compared to conventional fiberglass materials.

Nachtane et al. [9] evaluated the structural performance of composite wind turbine blades under critical loading conditions using finite element analysis. The study focused on identifying failure-prone regions and investigating intralaminar damage mechanisms. Employing the Tsai–Hill failure criterion, the researchers assessed various spar and web configurations and proposed optimized designs to improve blade structural integrity.

Tarfaoui et al. [10] investigated the mechanical behavior and damage evolution of large composite wind turbine blades subjected to severe wind loading. By applying finite element simulations and the Tsai–Hill failure criterion, the study analyzed damage progression and load-bearing capacity. The findings provided valuable insights into improving blade structural resilience and enhancing resistance to critical loading conditions.

The reviewed literature demonstrates that significant progress has been made in the structural analysis and material optimization of wind turbine blades through the application of FEA and CFD techniques. Most studies have focused on evaluating composite materials, stress distributions, deformation characteristics, vibration behavior, and failure mechanisms. Advanced materials such as carbon-fiber composites, hybrid composites, and graphene-reinforced structures have shown considerable potential for improving blade performance and durability.

However, there remains a need for further investigation into the combined effects of material selection, blade geometry, and loading conditions on the overall structural performance of wind turbine blades. In particular, comparative studies involving advanced composite materials under realistic operating conditions are limited. Therefore, the present work aims to model and analyze a wind turbine blade using finite element techniques to evaluate its structural behavior and identify design parameters that can enhance strength, durability, and operational efficiency.

3. Results and Discussion

The results obtained from the structural analysis of the wind turbine blade and discusses their significance with respect to geometry, material properties, boundary conditions, and applied loading. The analysis was performed after completing the modelling and meshing stages, providing insight into the mechanical behaviour of the blade under pressure loading with the root region fixed. The study mainly focused on deformation, stress distribution, and strain, which are essential parameters for evaluating the structural stability and performance of wind turbine blades under operational conditions.

Since wind turbine blades are continuously subjected to aerodynamic forces, understanding their structural response is important to prevent excessive deformation, stress concentration, and premature failure. The interpretation of results considered not only the numerical values obtained from the analysis but also the variation of response along the blade span, from the fixed root to the free tip. In addition, the performance of different materials such as E-Glass fibre, Kevlar fibre, and Epoxy Carbon was compared to evaluate their suitability for blade applications in terms of strength, stiffness, and deformation resistance.

3.1 E-Glass Fibre

The total deformation result of the E-Glass fibre blade illustrates the displacement distribution across the blade under the applied loading condition. The maximum deformation recorded was 6.1433×10^{-5} m. The contour plot shows a gradual variation in deformation along the blade span, represented by smooth colour transitions from red and yellow to green and blue. This indicates a uniform transfer of deformation without any abrupt localized distortion.

The deformation pattern demonstrates that the blade experienced controlled elastic behaviour under the applied load. The relatively low deformation value suggests that the E-Glass fibre material provided adequate stiffness and structural stability. E-Glass fibre is known for its balanced mechanical properties, including good strength, stiffness, and ease of manufacturing, making it a widely used material in wind turbine blade applications.

The analysis also indicates that the blade design remained structurally stable throughout the loading condition, with no excessive deflection observed. Such controlled deformation is desirable because excessive bending can reduce aerodynamic efficiency, increase fatigue effects, and shorten the operational life of the blade. Therefore, the obtained results confirm that the E-Glass fibre blade can effectively withstand the applied loading while maintaining structural integrity and reliable performance.

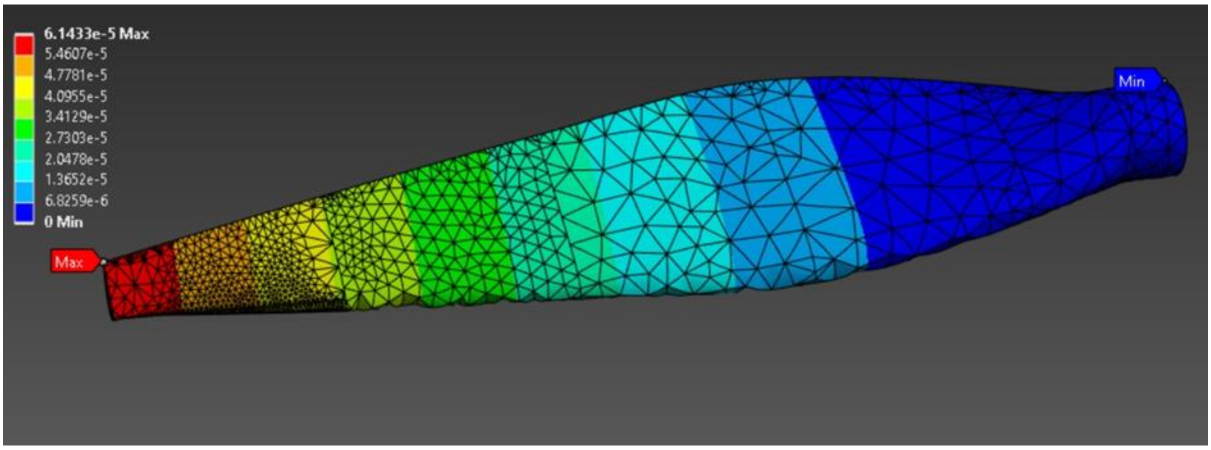

Figure 1. Total deformation result of E-glass fibre

The equivalent stress result for the E-Glass fibre blade is shown in figure 3.2, with the stress values expressed in Pa. The maximum equivalent stress is 4.0062e5 Pa, while the minimum stress is 74.286 Pa. The contour plot indicates that the highest stress occurs in the mid-to-tip region of the blade, where the red zone is visible near the area marked as maximum stress. This region is more highly loaded because of the combined effect of bending and the transfer of force along the blade span. The stress distribution gradually changes from dark blue near the root to green, yellow, and red toward the region of maximum stress. This pattern shows that the blade does not experience uniform stress, which is expected in a cantilever-type structure under pressure loading. The lower stress near the root and the higher stress away from it suggest that the blade geometry and loading condition create a stress concentration zone in the central portion of the blade, where structural demand becomes more significant.

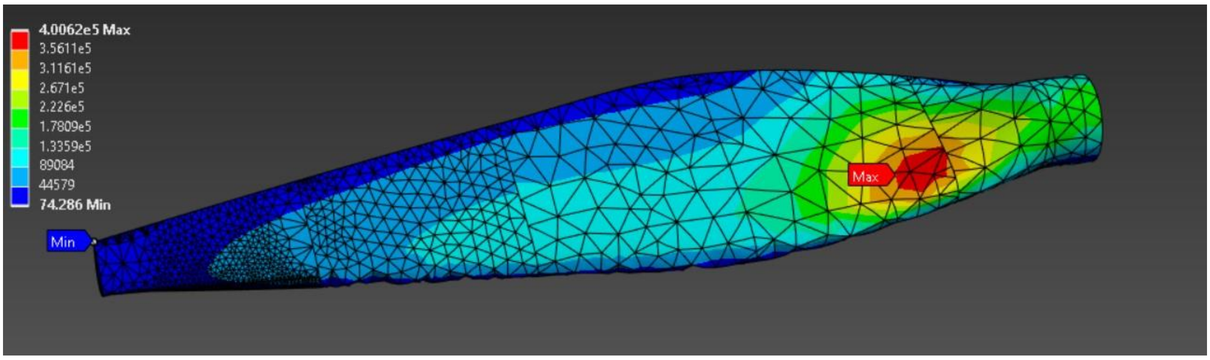

Figure 2. Equivalent stress result for the E-Glass fibre

The result also suggests that the E-Glass fibre blade can sustain the applied load without excessive localized failure, as the stress remains distributed over a broad region rather than being concentrated at a single sharp point. Since E-Glass fibre is known for its good tensile strength and structural reliability, this stress response indicates that the material is suitable for wind turbine blade applications where resistance to cyclic loading is important. The mesh pattern visible in the figure further confirms that the stress field was captured across the entire blade surface, supporting the validity of the analysis. The equivalent stress result shows that the E-Glass fibre blade experienced moderate stress levels with a clear peak in the loaded region.

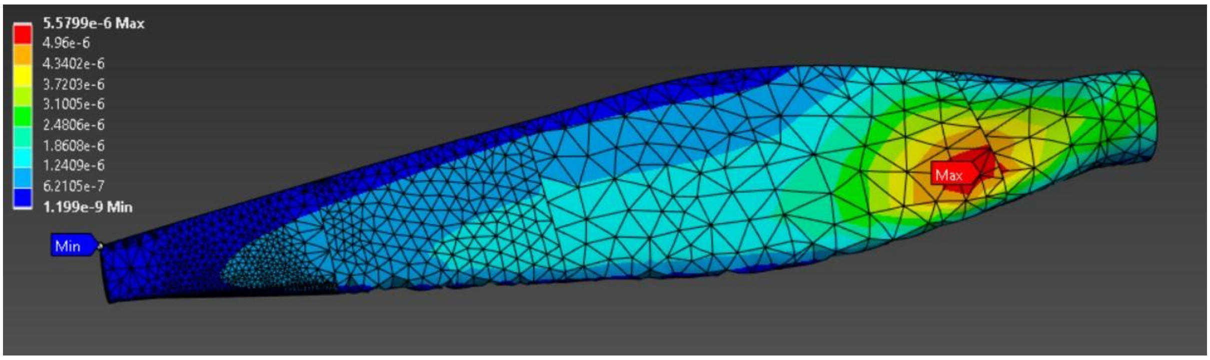

Figure 3. Equivalent elastic strain result for the E-Glass fibre

The equivalent elastic strain result for the E-Glass fibre blade is shown in figure 3.3, with strain values displayed in dimensionless form. The maximum equivalent elastic strain is 5.5799e-6, while the minimum strain is $1.199e^{-9}$. The contour distribution indicates that the strain is highest in the region where the blade experiences the greatest deformation and stress, which is visible in the yellow to red zone near the mid-to-tip section. The strain pattern follows a gradual increase from the root toward the region of maximum response, which is consistent with the behavior of a blade under bending load. The root area, shown in dark blue, experiences very low strain because it is constrained by the fixed support condition, while the larger strain values occur farther along the blade where flexibility increases. This variation demonstrates how the blade deforms under the applied load and how the material accommodates the resulting elastic response. The relatively small maximum strain value indicates that the E-Glass fibre blade remained within the elastic range during loading. This is an important observation because it suggests that the blade did not undergo permanent deformation and that the material retained its structural integrity under the applied conditions. The distribution of strain across the blade also shows smooth and continuous variation, which indicates stable structural behavior without abrupt strain concentration at isolated points. Equivalent elastic strain results confirms that the E-Glass fibre blade experienced limited elastic deformation under loading and maintained a favorable structural response.

3.2 Kevlar fibre

The total deformation result in figure 3.4 for the Kevlar fibre blade shows the displacement distribution along the blade under the applied load, with the unit expressed in meters. The maximum deformation is 3.9353e-5 m, and it occurs near the root-side region shown in red, where the blade experiences the greatest movement. The minimum deformation is observed toward the tip region, represented by dark blue, where the displacement approaches zero due to the fixed support effect and the way the load is transferred along the blade span. The contour pattern shows a smooth change in deformation from the maximum region to the minimum region, passing through yellow, green, cyan, and blue bands. This gradual variation indicates that the blade behaves in a stable and continuous manner under load, without sudden distortion or abrupt deformation zones. The higher deformation near the root-side region is typical of a cantilever-like structural response, where the flexible section deflects more under loading while the restrained end resists motion. Compared with a stiffer response, this deformation value suggests that the Kevlar fibre blade experiences a moderate elastic displacement under the same loading condition. Kevlar is known for its high strength-to-weight ratio and good toughness, and the result reflects its ability to deform while still maintaining structural integrity. The deformation remains small in absolute magnitude, which indicates that the blade does not undergo excessive deflection that could negatively affect aerodynamic performance. Overall, the figure 4.4 demonstrates that the Kevlar fibre blade has a controlled deformation pattern with the maximum response concentrated near the loaded side and the least response near the constrained end.

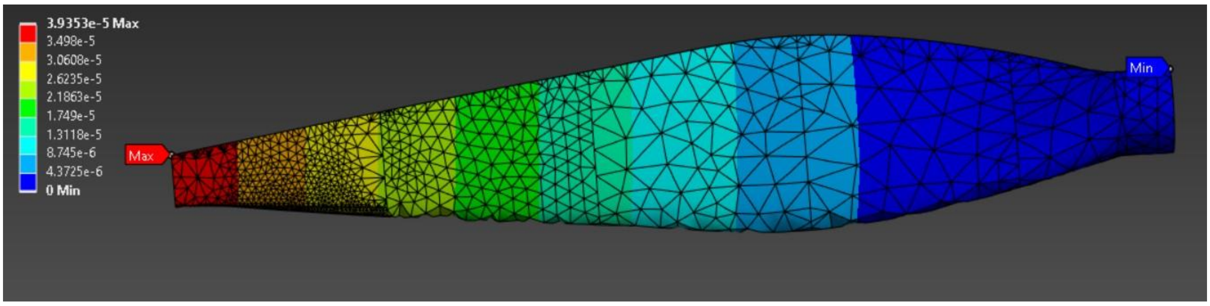

Figure 4. Total deformation result for the Kevlar fibre

The equivalent stress result for the Kevlar fibre blade is shown in the figure 3.5, with the stress values expressed in Pa. The maximum equivalent stress is 3.9429e5 Pa, while the minimum stress is 74.331 Pa. The highest stress appears in the mid-to-tip region of the blade, where the red zone is visible around the marked maximum location. This region is subjected to greater structural demand because of bending effects and the transfer of load along the blade length. The stress contour shows a progressive change from blue near the lower-stress region to green, yellow, and red in the more highly stressed region. This gradual distribution indicates that the blade was loaded in a way that produced a smooth stress field without sudden discontinuities. The lower stress near the root-side region and the higher stress toward the middle section are consistent with a cantilever-type structural response under external pressure loading. The result suggests that the Kevlar fibre blade can resist the applied load effectively, with the maximum stress remaining within a moderate range. Kevlar is known for its excellent toughness and impact resistance, and the stress response shown here reflects its suitability for structures that must tolerate cyclic and dynamic loading. The visible spread of stress across a large portion of the blade also indicates that the load was distributed rather than concentrated at a single point. The equivalent stress plot demonstrates that the Kevlar fibre blade experienced a controlled structural response under the applied load.

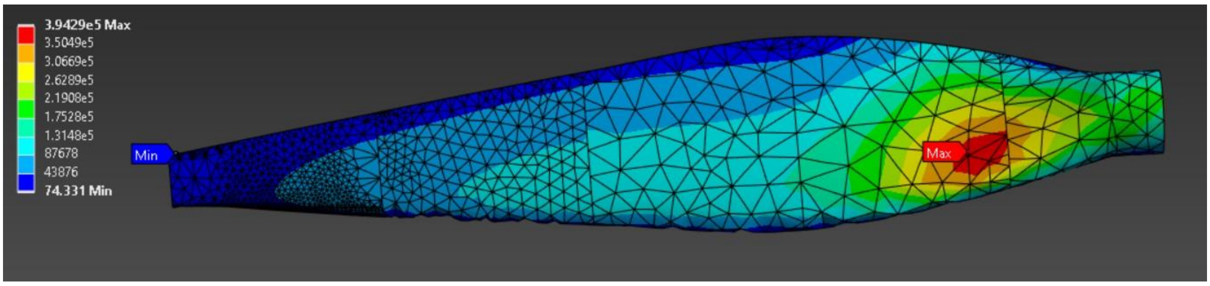

Figure 5. Equivalent stress result for the Kevlar fibre

The equivalent elastic strain result for the Kevlar fibre blade is shown in the figure 3.6, with strain values expressed in dimensionless form. The maximum equivalent elastic strain is 3.5208e-6, while the minimum strain is 8.8396e-10. The highest strain is observed in the mid-to-tip region of the blade, where the red zone appears near the marked maximum location. This indicates that the blade undergoes the greatest elastic response in the region where bending effects are most pronounced. The strain contour shows a smooth transition from low strain near the left side of the blade to higher strain in the central and upper loaded regions. The blue zone near the lower strain region represents areas with minimal elastic response, while the green, yellow, and red regions indicate increasing strain as the structural load is transferred along the blade span. This pattern is typical of a blade under bending load, where the deformation becomes more significant away from the restrained side. The relatively low maximum strain value suggests that the Kevlar fibre blade remained well within the elastic range under the applied load. This means that the blade did not experience permanent deformation and retained its structural integrity during the analysis. Kevlar is known for its toughness and resistance to mechanical loading, and the strain distribution shown in the figure reflects those characteristics. The result demonstrates that the Kevlar fibre blade experienced controlled and stable elastic deformation under the applied loading condition.

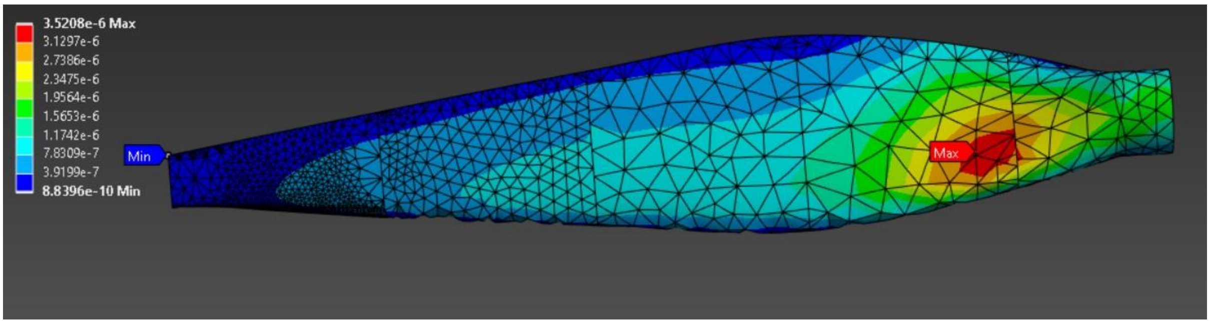

Figure 1. The equivalent elastic strain result for the Kevlar fibre

3.3 Epoxy Carbon

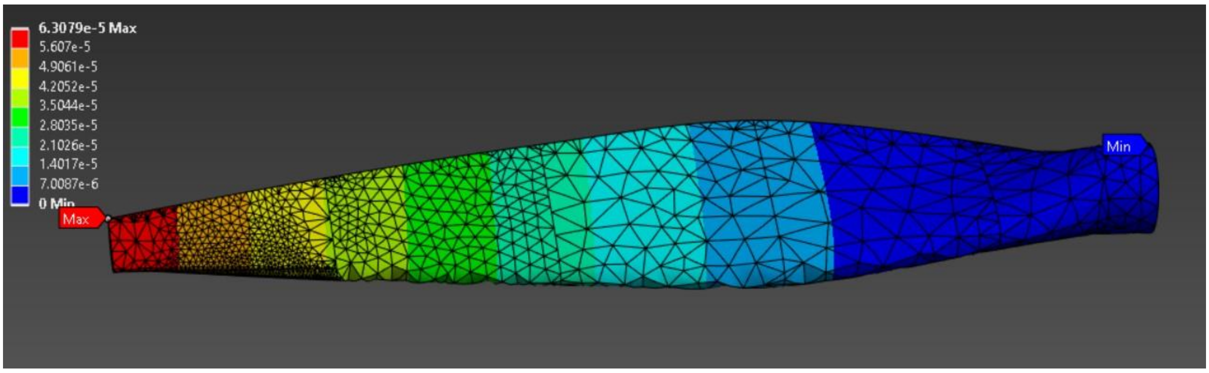

Figure 2. The total deformation result for the Epoxy Carbon

The total deformation result for the Epoxy Carbon blade is shown in the figure 3.7, with the unit measured in meters. The maximum deformation is 6.3079e-5 m, and it is observed near the root-side region marked in red. The minimum deformation is seen at the tip region, represented by dark blue, where the displacement approaches zero due to the boundary condition and the way the load is transferred along the blade span. The deformation contour shows a smooth progression from high deformation near the left side to low deformation toward the right side of the blade. The colour variation from red and yellow to green, cyan, and blue indicates that the blade undergoes gradually decreasing displacement along its length. This is consistent with the behaviour of a cantilever-like structure under external loading, where the flexible region experiences the largest movement and the restrained region resists it. The maximum deformation value suggests that the Epoxy Carbon blade experienced a noticeable elastic response under the applied load. Since the deformation remains small in absolute terms, the blade still retained its structural stability during analysis. However, compared with a stiffer composite, this deformation level indicates that the Epoxy Carbon configuration is more flexible under the same load condition, which can influence aerodynamic shape retention during operation. The mesh pattern in the figure shows that the deformation field was captured across the entire surface of the blade, including the root, mid-span, and tip regions. The gradual deformation distribution suggests that there were no abrupt shape changes or localized numerical irregularities.

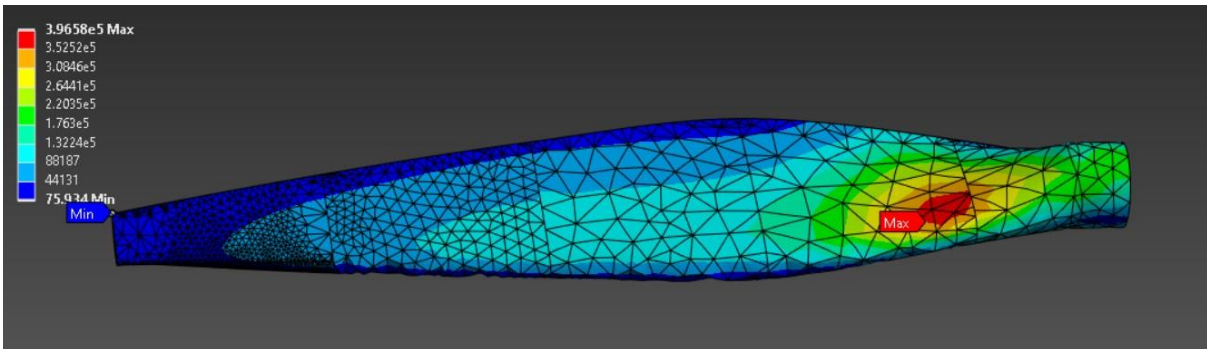

Figure 3. Equivalent stress results for Epoxy Carbon blade

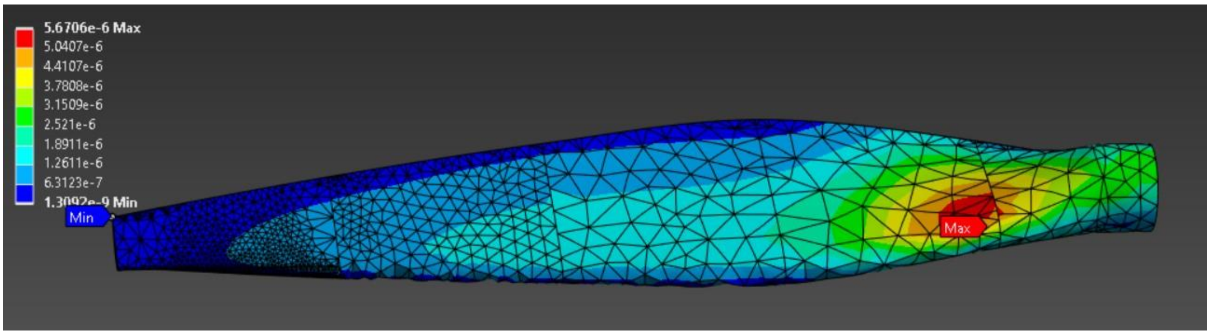

Figure 4. The equivalent elastic strain result for the Epoxy carbon blade

The equivalent stress result for the Epoxy Carbon blade is shown in the figure 3.8, with stress values expressed in Pa. The maximum equivalent stress is 3.9658e5 Pa, while the minimum stress is 75.934 Pa. The highest stress occurs in the mid-to-tip region of the blade, where the red zone appears around the marked maximum location. This region is more highly stressed because of the bending effect and the distribution of load across the blade span. The stress contour shows a gradual transition from blue near the lower-stress region to green, yellow, and red in the higher-stress region. This pattern indicates that the blade experienced a smooth stress distribution without any sharp discontinuities. The lower stress near the root-side region and the higher stress toward the central and upper portion of the blade are consistent with the structural response of a tapered blade subjected to external pressure loading. The result suggests that the Epoxy Carbon blade can withstand the applied load with a moderate stress level. Although the material is comparatively more flexible in terms of deformation response, the stress distribution remains stable and well spread along the blade surface. This indicates that the blade design maintained its structural integrity under the imposed loading condition. The visible mesh and contour field show that the stress was captured effectively across the entire blade surface.

The equivalent elastic strain result for the Epoxy Carbon blade is shown in the figure 3.9, with strain values represented in dimensionless form. The maximum equivalent elastic strain is 5.6706e-6, while the minimum strain is 1.3092e-9. The highest strain appears in the mid-to-tip region of the blade, where the red zone is visible around the marked maximum location. This indicates that the blade undergoes the greatest elastic response in the region where bending effects are more pronounced. The strain contour shows a smooth progression from the low-strain region near the left side of the blade to the higher-strain region toward the centre and upper loaded area. The blue area represents minimal elastic response, while the green, yellow, and red zones indicate increasing strain as the load is transferred along the blade span. This pattern is typical of a blade under bending load, where the structure experiences increasing strain away from the restrained side. The maximum strain value suggests that the Epoxy Carbon blade remained within the elastic range during loading. This means the material did not undergo permanent deformation and retained its structural integrity under the applied condition. The strain distribution is continuous and stable, showing that the deformation response was spread smoothly across the blade rather than concentrated in a very small area. This result shows that the Epoxy Carbon blade experienced moderate elastic deformation and maintained a consistent structural response under the applied load.

Table 1. Material Results comparison table

	Total Deformation (m) (x 10^{-5})	Equivalent Stress (Pa) (x 10^{5})	Equivalent Elastic Strain (x 10^{-6})
E-Glass fibre	6.1433	4.0062	5.5799
Kevlar fibre	3.9353	3.9429	3.5208
Epoxy Carbon	6.3079	3.9658	5.6706

The comparison of the analysis results shows clear differences in the structural response of the three selected materials under the same loading condition. In terms of total deformation, Kevlar fibre exhibited the lowest value at 3.9353×10^{-5} m, indicating that it provided the greatest resistance to deflection and therefore the highest stiffness among the three materials in this study. E-Glass fibre showed a higher deformation of 6.1433×10^{-5} m, while Epoxy Carbon recorded the highest deformation at 6.3079×10^{-5} m. This suggests that, under the applied load, Kevlar fibre was more effective in limiting blade displacement, whereas Epoxy Carbon showed comparatively greater flexibility. Since excessive deformation in wind turbine blades can affect aerodynamic performance and operational efficiency, a lower deformation value is generally preferred for maintaining blade shape during service. The equivalent stress results also reveal an interesting comparison among the materials. E-Glass fibre produced the highest equivalent stress value of 4.0062×10^5 Pa, followed closely by Kevlar fibre at 3.9429×10^5 Pa, while Epoxy Carbon showed the lowest stress at 3.9658×10^5 Pa. Although the difference in stress values is not very large, the trend indicates that the E-Glass blade section experienced slightly higher internal resistance under loading, whereas Epoxy Carbon carried the load with comparatively lower stress concentration. This reflects how the different material properties influence the stress distribution in the blade structure. A lower stress value is generally desirable because it reduces the likelihood of material failure, crack initiation, and long-term damage under cyclic loading. The equivalent elastic strain values further support the deformation trend observed in the analysis. Kevlar fibre again demonstrated the best performance, with the lowest strain value of 3.5208×10^{-6}, showing that it underwent the least elastic stretching under the applied load. E-Glass fibre recorded a strain of 5.5799×10^{-6}, while Epoxy Carbon showed the highest strain of 5.6706×10^{-6}. This indicates that Epoxy Carbon experienced the greatest elastic response, while Kevlar remained comparatively more stable and resistant to strain development. Since elastic strain is directly related to the ability of the blade to maintain its structural integrity without excessive distortion, the lower strain shown by Kevlar fibre suggests a more favorable response for blade applications. From the comparative evaluation, Kevlar fibre appears to offer the most balanced structural performance because it produced the lowest deformation and strain values while also maintaining a stress level comparable to the other materials. E-Glass fibre showed moderate behavior, with slightly higher deformation and strain than Kevlar, but still within an acceptable range for blade use. Epoxy Carbon, on the other hand, showed the highest deformation and strain, which indicates greater flexibility, although its stress value remained close to the others. Based on these results, Kevlar fibre appears to be the most suitable material among the three for reducing structural deflection and elastic response in the wind turbine blade, while E-Glass and Epoxy Carbon may still be useful depending on the design requirement, cost consideration, and desired balance between stiffness and flexibility.

The study successfully evaluated the structural behaviour of a wind turbine blade using three different materials, namely E-Glass fibre, Kevlar fibre, and Epoxy Carbon, through a systematic methodology that included design evaluation, CAD modelling, boundary condition application, meshing, and finite element analysis. The results obtained from deformation, equivalent stress, and equivalent elastic strain showed that the blade response varied with material selection, confirming that material properties play a significant role in determining blade performance. Among the selected materials, Kevlar fibre demonstrated the lowest deformation and strain values, indicating better stiffness and improved resistance to elastic response under the applied loading condition. E-Glass fibre showed moderate performance, while Epoxy Carbon exhibited comparatively higher deformation and strain. These findings indicate that the selection of blade material has a direct influence on the structural stability and operational suitability of wind turbine blades.

The study also showed that the stress distribution remained within a comparable range for all three materials, with only slight variation in maximum equivalent stress. This suggests that the chosen blade geometry and loading condition produced a consistent structural response across the materials, while the differences in deformation and strain were mainly governed by the individual material characteristics. The analysis therefore confirms that Kevlar fibre is the most favourable option among the three for minimizing deflection and maintaining structural stability. At the same time, E-Glass fibre and Epoxy Carbon may still be considered depending on the design priorities, such as cost, weight, and manufacturability. The results obtained in this work provide a useful basis for material comparison and blade optimization in wind turbine applications.

So, following are the conclusions derived from this study.

- The wind turbine blade was successfully analysed using a systematic methodology that included design evaluation, CAD modelling, boundary condition application, meshing, and structural analysis.
- The selection of material had a significant influence on the structural response of the blade, confirming that material properties directly affect deformation, stress, and strain behaviour.
- Among the three materials studied, Kevlar fibre showed the lowest total deformation and equivalent elastic strain, indicating better stiffness and improved resistance to elastic response under the applied load.
- E-Glass fibre and Epoxy Carbon also produced acceptable results, but their deformation and strain values were comparatively higher than Kevlar fibre, showing a greater tendency toward flexibility.
- The equivalent stress results for all three materials remained within a similar range, which suggests that the blade geometry and loading condition produced a stable structural response across the selected materials.

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