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Optimization of NFRP Turbine Blade Material on The Harper Malioboro Hetel Ballroom Ventilator Through Design Analysisof manuscript submitted to journal of applied mechanical engineering innovation (14 pt, Bold)

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ABSTRACT

This study aims to evaluate the performance of natural fiber-reinforced polymer (NFRP) composite material as an alternative to aluminum AA1100 for turbine ventilator blades, considering aluminum's limitations in sustainability. Numerical simulations were conducted using ANSYS Workbench 2025 R1, applying variations in fiber reinforcement combinations (Low, Mid, High) and fiber orientations (Bidirectional, Unidirectional, Random). The turbine blade design was visualized as a 3D model using Autodesk Inventor 2024. Analysis parameters included maximum stress (von Mises), total deformation, fatigue life, and equivalent alternating stress. Results showed that the Mid–Random configuration yielded the most optimal performance, with a maximum stress of 22.009 MPa, total deformation of 6.7009 mm, fatigue life reaching 5.3698×10^5 cycles, and an equivalent alternating stress of 9.0395×10^{31} Pa. This configuration also outperformed aluminum in terms of fatigue resistance. Based on these findings, the Mid–Random NFRP material is recommended as an environmentally friendly alternative for turbine ventilator blade applications.

1 Introduction

The demand for efficient and environmentally friendly ventilation systems has increased along with the growing emphasis on energy efficiency and sustainable building design. A turbine ventilator is one of the passive ventilation devices widely used in buildings because it can utilize natural airflow to improve indoor air circulation without consuming electrical energy. In this system, the turbine blade is a critical component because its material determines the structural reliability, durability, and operating performance of the ventilator.

Aluminum AA1100 is commonly used for turbine ventilator blades because of its low density, corrosion resistance, and ease of fabrication. However, aluminum production requires high energy input and may cause environmental burdens that are not fully aligned with sustainability principles. This condition creates a need for alternative materials that are lightweight, mechanically reliable, and more environmentally friendly for building ventilation applications.

Natural fiber-reinforced polymer (NFRP) composites are increasingly considered as promising alternatives because they combine polymer matrices with renewable natural fibers such as kenaf, jute, hemp, and flax. These materials offer low density, acceptable mechanical properties, biodegradability potential, and abundant availability [1]. Previous studies have also shown that high-performance polymer composites can be developed for structural applications when the reinforcement configuration is properly selected [2].

The mechanical performance of NFRP is strongly affected by the reinforcement fraction and fiber orientation. Low, medium, and high reinforcement levels may produce different stiffness and strength responses, while Bidirectional, Unidirectional, and Random fiber orientations affect stress distribution when the material is subjected to load. Fatigue behavior is particularly important because turbine ventilator blades experience repeated loading during continuous rotation; therefore, an evaluation of fatigue performance is necessary before these materials can be recommended for structural applications [3], [4].

This study aims to evaluate the mechanical and fatigue performance of NFRP composites as an alternative to aluminum AA1100 for turbine ventilator blades in the Harper Malioboro Hotel ballroom. The novelty of this work lies in comparing nine NFRP configurations based on reinforcement level and fiber orientation using numerical design analysis. The output of the study is a recommended NFRP configuration that provides a balance between stress resistance, deformation control, fatigue life, and environmental suitability.

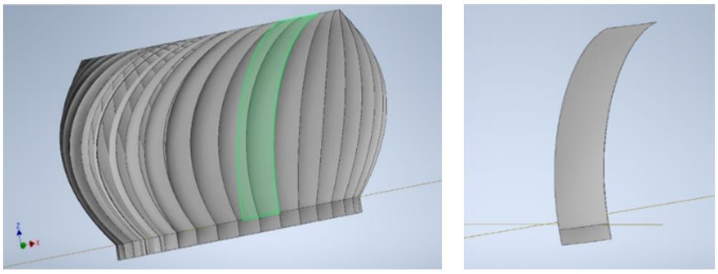

Figure 1. Turbine ventilator blade and cyclone blade configuration

2 Method

This research used a quantitative approach based on numerical simulation to evaluate the mechanical performance of NFRP composite materials as an alternative to aluminum for turbine ventilator blades. Numerical simulation was selected because it provides structural response visualization and allows the effect of cyclic loading to be examined efficiently before physical testing is conducted.

The initial stage consisted of creating the geometry of the turbine ventilator blade using Autodesk Inventor 2024. The model was then imported into ANSYS Workbench 2025 R1 for numerical analysis. The simulation used a static structural model combined with fatigue evaluation to represent the operating condition of the blade, which rotates continuously due to wind flow. The fatigue analysis followed the numerical evaluation procedure available in ANSYS Mechanical [5] and was supported by finite element modeling principles for fatigue-related problems [6].

The NFRP material was varied into three reinforcement levels: Low, Mid, and High. Each level represents a different ratio between natural fiber reinforcement and polymer matrix. Three fiber orientations were also evaluated: Bidirectional, Unidirectional, and Random. The combination of these variables produced nine NFRP configurations. Aluminum AA1100 was used as the comparison material because it is a conventional material for lightweight blade applications and its properties are widely available in engineering databases .

Each configuration was simulated under identical boundary conditions and mesh settings to maintain consistency between cases. The parameters evaluated were maximum von Mises stress, total deformation, fatigue life, and equivalent alternating stress. The simulation results were compared to identify the NFRP configuration with the most balanced performance in terms of strength, durability, and deformation efficiency.

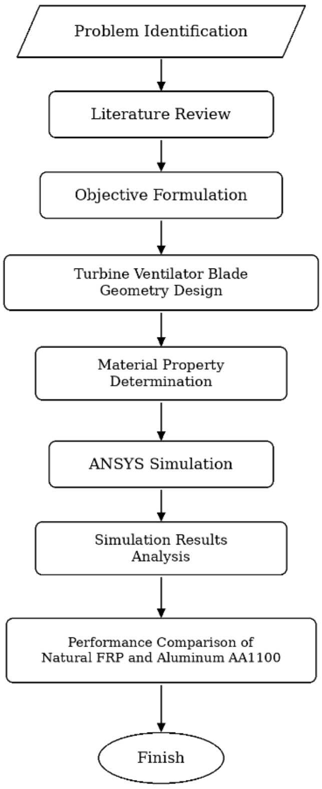

Figure 2. Research flowchart

3 Result and discussion

The simulation results show a clear difference in mechanical behavior among the tested NFRP configurations. In ANSYS Workbench 2025 R1, nine NFRP combinations were evaluated using four main parameters: maximum stress, total deformation, fatigue life, and equivalent alternating stress. The Mid-Random configuration produced the most balanced performance among the evaluated materials. Its maximum von Mises stress was 22.009 MPa, which remained below the material strength limit used in the simulation. The total deformation was 6.7009 mm, indicating stable structural behavior under the applied load.

The fatigue life of the Mid-Random configuration reached 5.3698×10^5 cycles, indicating that the material can withstand repeated loading for a relatively long service period. The equivalent alternating stress obtained from the simulation output was 9.0395×10^{31} Pa. The numerical results suggest that the selected NFRP configuration can reduce the mechanical response compared with aluminum AA1100 while maintaining fatigue resistance. This trend is consistent with studies reporting that natural fiber composites may provide competitive fatigue performance when reinforcement architecture and loading conditions are properly controlled [7], [8].

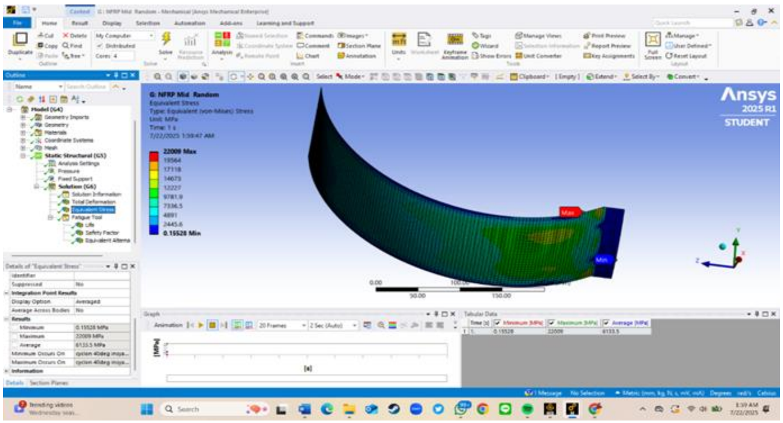

Figure 3. Stress distribution of NFRP Mid-Random

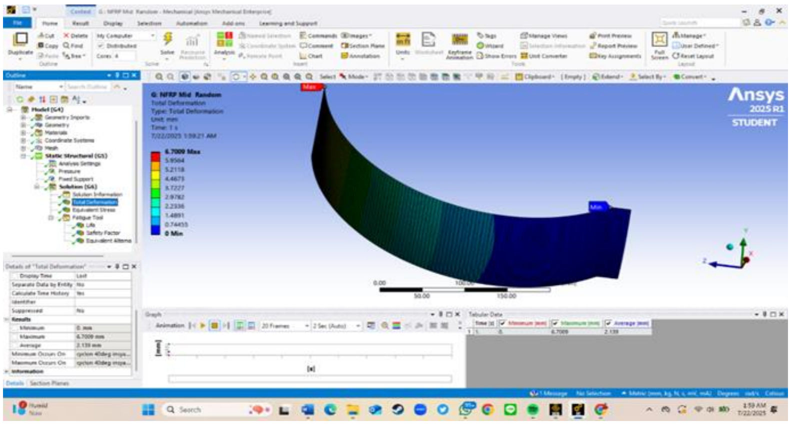

Figure 4. Deformation distribution of NFRP Mid-Random

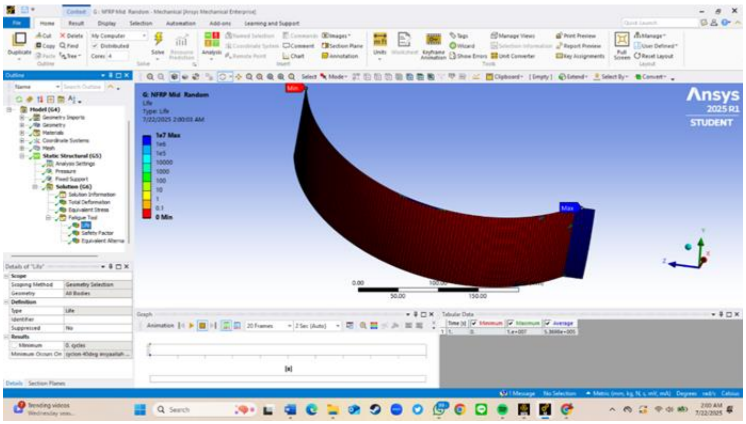

Figure 5. Fatigue life distribution of NFRP Mid-Random

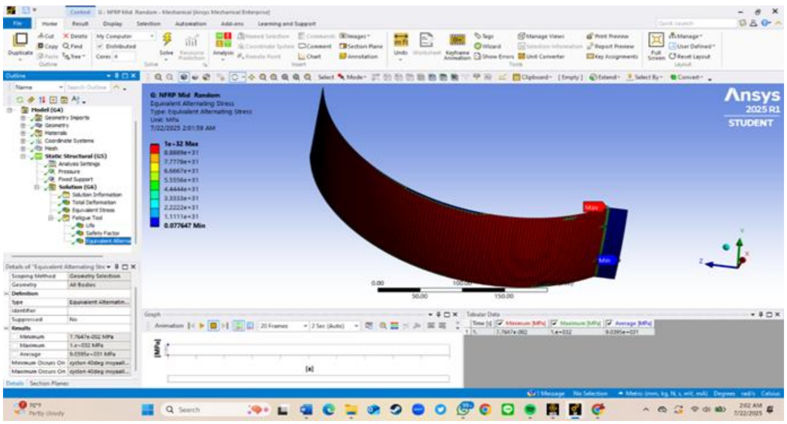

Figure 6. Equivalent alternating stress distribution of NFRP Mid-Random

Configurations with a high reinforcement level did not always produce better overall performance. Although increasing the reinforcement fraction can improve stiffness, the results indicate that high fiber content may reduce the uniformity of load transfer between fiber and matrix. As a result, the stress and deformation responses were not substantially better than those obtained from the Mid reinforcement level. The Unidirectional orientation also showed a more limited response because it is less effective when the load direction varies across the blade surface.

When compared with aluminum AA1100, the NFRP configurations demonstrated better performance in fatigue and deformation indicators. Aluminum AA1100 produced higher maximum stress and much larger deformation than the evaluated NFRP configurations. This indicates that NFRP can be considered not only as a sustainable material alternative, but also as a structurally efficient candidate for dynamic components such as turbine ventilator blades. In addition, natural fiber composites have been reported to offer potential advantages in vibration and acoustic response, which may support their use in rotating blade applications [9].

Overall, the use of numerical simulation allowed a broad comparison of material configurations without direct physical testing at the preliminary design stage. However, experimental validation remains necessary to confirm the simulation results, particularly for fatigue behavior, fiber-matrix bonding quality, environmental exposure, and long-term performance under actual operating conditions.

Table 1. Maximum stress results

Material	Maximum stress (MPa)
Aluminum AA1100	54.326
NFRP Low-Bidirectional	25.677
NFRP Low-Unidirectional	22.009
NFRP Low-Random	18.341
NFRP Mid-Bidirectional	29.346
NFRP Mid-Unidirectional	25.677
NFRP Mid-Random	22.009
NFRP High-Bidirectional	33.014
NFRP High-Unidirectional	29.346
NFRP High-Random	25.677

Table 2. Average fatigue life results

Material	Average fatigue life (cycles)
Aluminum AA1100	2.7586×10^5
NFRP Low-Bidirectional	5.1593×10^5
NFRP Low-Unidirectional	5.266×10^5
NFRP Low-Random	5.1036×10^5
NFRP Mid-Bidirectional	5.1764×10^5
NFRP Mid-Unidirectional	5.2684×10^5
NFRP Mid-Random	5.3698×10^5
NFRP High-Bidirectional	5.1956×10^5
NFRP High-Unidirectional	5.2823×10^5
NFRP High-Random	5.3707×10^5

Table 3. Total deformation results

Material	Total deformation (mm)
Aluminum AA1100	197.16
NFRP Low-Bidirectional	7.4268
NFRP Low-Unidirectional	5.7008
NFRP Low-Random	6.2411
NFRP Mid-Bidirectional	7.9573
NFRP Mid-Unidirectional	6.3659
NFRP Mid-Random	6.7009
NFRP High-Bidirectional	7.1616

Material	Total deformation (mm)
NFRP High-Unidirectional	6.1358
NFRP High-Random	6.6509

Table 4. Average equivalent alternating stress results

Material	Average equivalent alternating stress (MPa)
Aluminum AA1100	9.6438×10^{31}
NFRP Low-Bidirectional	9.1875×10^{31}
NFRP Low-Unidirectional	9.0395×10^{31}
NFRP Low-Random	9.4581×10^{31}
NFRP Mid-Bidirectional	8.8426×10^{31}
NFRP Mid-Unidirectional	9.0633×10^{31}
NFRP Mid-Random	9.0395×10^{31}
NFRP High-Bidirectional	9.1875×10^{31}
NFRP High-Unidirectional	9.0849×10^{31}
NFRP High-Random	9.0633×10^{31}

The tabulated results confirm that natural fiber composite materials have competitive mechanical behavior compared with the conventional metal material used as the baseline. The Mid-Random configuration was selected as the recommended material because it provided a balanced combination of low maximum stress, controlled deformation, high fatigue life, and suitability for sustainable structural design.

4 Conclusion

Based on the numerical analysis of several reinforcement levels and fiber orientations, NFRP composites show strong potential as alternative materials for turbine ventilator blades. Compared with aluminum AA1100, the NFRP configurations produced lower maximum stress and lower total deformation while maintaining better fatigue performance under cyclic loading. Among the evaluated configurations, NFRP Mid-Random provided the most balanced result, with a maximum stress of 22.009 MPa, fatigue life of 5.3698×10^5 cycles, total deformation of 6.7009 mm, and equivalent alternating stress of 9.0395×10^{31} Pa. These results indicate that NFRP Mid-Random is feasible for turbine ventilator blade applications in passive ventilation systems such as the Harper Malioboro Hotel ballroom. Further experimental testing is recommended to validate the simulation results, especially under real wind loading, humidity exposure, and long-term cyclic operation.

Acknowledgements

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Conflicts of Interest

The authors declare no conflict of interest.

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