IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 11, Issue 4, April 2024

DOI: 10.17148/IARJSET.2024.11436

# DESIGN, ANALYSIS, AND EXPERIMENTAL INVESTIGATION OF WIND TURBINE BLADES WITH GLASS FIBER REINFORCED WITH ALUMINIUM

**S.P.CHRISTSON DANIEL**[1], **Dr. V.ANTONY VINCENT**[2]

PG Scholar, Department of Aeronautical Engineering, Noorul Islam Centre for Higher Education, Kumarakovil, Thuckalay, Kanyakumari District.[1]

Assistant Professor, Department of Aeronautical Engineering, Noorul Islam Centre for Higher Education, Kumarakovil, Thuckalay, Kanyakumari District.[2]

**Abstract:** This paper presents a thorough examination of wind turbine blade design, analysis, and material experimentation, focusing on the utilization of Glass Fiber Reinforced Polymer (GFRP) reinforced with aluminium powder. Through a combination of numerical simulations and experimental tests, the mechanical properties and performance of GFRP reinforced with aluminium powder are evaluated in comparison to conventional materials such as steel and non-reinforced GFRP. The findings highlight the superior suitability of GFRP reinforced with aluminium powder for wind blade applications, showcasing its mechanical strength, lightweight properties, corrosion resistance, and aerodynamic characteristics.

**Keywords:** Wind turbine blades, Glass Fiber Reinforced Polymer (GFRP), Aluminium powder reinforcement, Structural analysis, and Experimental validation.

## I. INTRODUCTION

The global pursuit of renewable energy sources has intensified in recent years, driven by concerns over climate change and the depletion of finite fossil fuel reserves. Among renewable energy technologies, wind power stands out as a promising and rapidly growing contributor to the global energy mix. Wind turbines, pivotal in converting wind energy into electricity, have witnessed substantial advancements in design and efficiency.

Central to the effectiveness of wind turbines are their blades, which play a critical role in capturing wind energy and converting it into rotational motion. The design and materials used in these blades are paramount, influencing factors such as efficiency, durability, and overall performance of the turbine system. Traditional materials like steel have historically dominated the industry due to their strength and familiarity. However, with the evolution of composite materials, new opportunities have arisen to enhance the capabilities of wind turbine blades.

Glass Fiber Reinforced Polymer (GFRP) has emerged as a notable contender in the quest for optimized blade materials. GFRP offers several advantages over traditional materials, including a high strength-to-weight ratio, corrosion resistance, and design flexibility. Despite these benefits, challenges such as delamination and impact resistance have prompted researchers to explore methods for improving the mechanical properties of GFRP.

One such approach involves the incorporation of reinforcing agents into the GFRP matrix. Aluminium powder, known for its strength and stiffness, presents an intriguing option for enhancing the mechanical characteristics of composite materials. By reinforcing GFRP with aluminium powder, researchers aim to address the limitations of conventional blade materials while leveraging the inherent advantages of composites.

This paper develops into the exploration of GFRP reinforced with aluminium powder as a potential superior material for wind turbine blades. Through a combination of design analysis, numerical simulations, and experimental investigations, the mechanical performance and suitability of this composite material are evaluated. The findings of this study aim to contribute to the advancement of renewable energy technology by providing insights into the optimal design and material selection for wind turbine blades.

## II. LITERATURE SURVEY

Wind turbine blades are commonly fabricated using composite materials, which offer improved property levels compared to traditional materials. These composites typically consist of fibers and polymers, with carbon and glass yarns being common choices for the fiber component due to their strength. Thermoset polymers are often used as the polymer matrix, although recycling these materials can be challenging [1].

To address the recycling challenge and achieve other benefits such as cost-effectiveness, lower weight, ease of fabrication, and reusability, the use of natural composites is recommended. Natural composites offer advantages such as lower environmental impact and biodegradability compared to thermoset polymers [2].

Hybrid composites, which involve the addition of multiple fiber types, are often employed to enhance the properties of composite materials. Hybrid composites typically exhibit superior physical characteristics compared to those made of single fibers [12]. Additionally, the incorporation of nano-materials into composite materials can further improve their properties, including increased strength and reduced weight, making them desirable for wind turbine blade manufacturing [16].

The responsibility for proper disposal of waste generated by wind turbine blades falls on the producers. Due to their significant organic content, wind turbine blades are not ideally suited for long-term storage, posing potential environmental hazards [4]. Recyclable materials are seen as a solution to this issue, with closed-loop recycling methods being employed to reproduce blades and address the financial challenges associated with recycling synthetic materials.
Studies have also explored alternative materials such as bamboo and wood veneer laminates, which exhibit comparable mechanical properties to glass-reinforced polymer laminates. Bamboo-reinforced polymer laminates, in particular, have shown promise, with a 30% bamboo content being sufficient to achieve desired mechanical characteristics [23]. Additionally, bamboo-reinforced polymer laminates with bamboo fillers have been found to have lower water consumption compared to empty bamboo-reinforced polymer laminates.

Experimental research conducted by Shen-xue et al. [22] suggests that bamboo-based materials are suitable for wind turbine blade applications. The mechanical properties of coir fiber composite materials have been found to be comparable to those of wood composite materials, with potential variations in mechanical characteristics under different environmental conditions.

In summary, the exploration of various composite materials and their combinations, as well as natural alternatives like bamboo, holds promise for enhancing the performance and sustainability of wind turbine blades. These materials offer opportunities for improved mechanical properties, reduced environmental impact, and effective recycling solutions, contributing to the advancement of renewable energy technology.

### 2.1 Aim

The aim of this study is to investigate the suitability of different materials for wind turbine blades and to identify the optimal material through design and structural analysis. Specifically, the study aims to assess the performance of steel, Glass Fiber Reinforced Polymer (GFRP), and GFRP reinforced with aluminium powder using CATIA for design and ANSYS for structural analysis.

### 2.2 Objectives

**Material Properties:** Evaluate the mechanical properties of steel, GFRP, and GFRP reinforced with aluminium powder to understand their suitability for wind turbine blade applications for doing analysis.

**Design Optimization:** Utilize CATIA software to optimize the design parameters of wind turbine blades, including length, chord distribution, twist angle, and airfoil shape, to maximize aerodynamic efficiency.

**Structural Analysis:** Employ ANSYS for structural analysis to assess the performance of wind turbine blades made from different materials under various loading conditions, including wind forces and rotational forces.

**Comparative Study:** Conduct a comparative analysis of the performance of steel, GFRP, and GFRP reinforced with aluminium powder based on factors such as deformation, equivalent stress, and strain energy.

**Experimental work:** The mechanical strength of the identified optimal material, GFRP reinforced with aluminium powder, through experimental tests such as tensile, compression, and impact tests on laminate samples.

DOI: 10.17148/IARJSET.2024.11436

**Assessment of Additional Benefits:** Evaluate additional benefits of the optimal material, including lightweight properties, corrosion resistance, and aerodynamic characteristics, to provide a comprehensive understanding of its suitability for wind turbine blade applications.

By achieving these objectives, the study aims to contribute to the advancement of wind turbine technology by identifying the most suitable material for wind blade applications.

## III. METHODOLOGY

The methodology for this study involves several sequential steps to achieve the aim and objectives effectively:

**Literature Review:**
Conduct a comprehensive review of existing literature on wind turbine blade materials, design methodologies, and structural analysis techniques.

Identify key parameters and criteria for evaluating material suitability and performance.

**Material Characterization:**
Evaluate the mechanical properties of steel, GFRP, and GFRP reinforced with aluminium powder through experimental testing or literature data.

Analyze factors such as tensile strength, modulus of elasticity, density, and fatigue behavior to understand material behavior under operational conditions.

**CATIA Design:**
Utilize CATIA software to create detailed 3D models of wind turbine blades for each material option.

Optimize design parameters such as length, chord distribution, twist angle, and airfoil shape to maximize aerodynamic efficiency while adhering to design constraints.

**ANSYS Structural Analysis:**
Import the CATIA models into ANSYS for finite element analysis (FEA) to simulate the structural behavior of wind turbine blades under various loading conditions.

Define boundary conditions, apply loads (including wind loads and rotational forces), and assess factors such as deformation, stress distribution, and strain energy.

**Comparative Analysis:**
Compare the results obtained from structural analysis for each material option.

Evaluate performance metrics such as deformation, equivalent stress, strain energy, and any other relevant parameters to determine the optimal material.

**Experimental Work:**
Prepare laminate samples of GFRP reinforced with aluminium powder according to predetermined specifications.

Conduct experimental tests, including tensile, compression, and impact tests, to validate the mechanical strength of the optimal material identified through numerical analysis.

**Assessment of Additional Benefits:**
Evaluate additional benefits of the optimal material, such as lightweight properties, corrosion resistance, and aerodynamic characteristics.

Consider these factors alongside mechanical performance to provide a comprehensive assessment of material suitability for wind turbine blade applications.

## IV. MODELS

### 4.1 Wind Blade Design

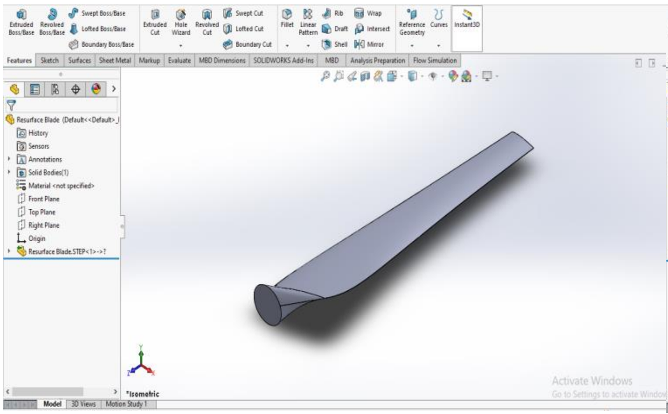


Fig (4.1) Isometric View

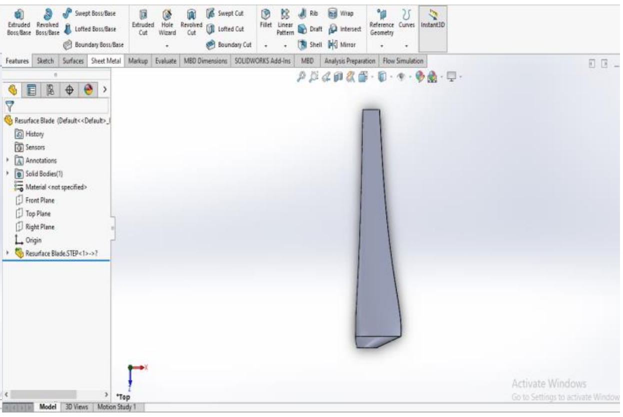
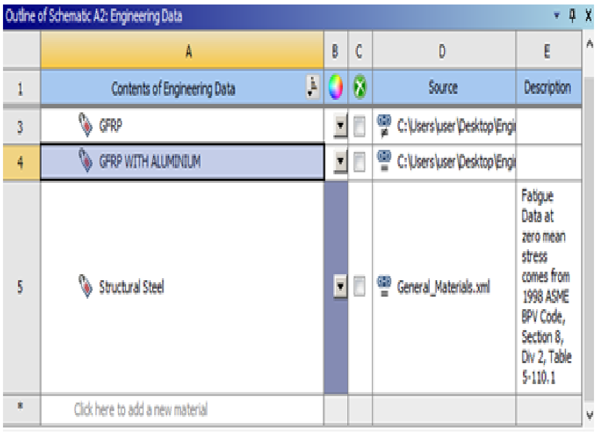


Fig (4.2) Top View

### 4.2 Analysis of Wind Blade



Outline of Schematic A2: Engineering Data

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Contents of Engineering Data | | | Source | Description |
| 3 | GFRP | | ☐ | C:\Users\user\Desktop\Engi | |
| 4 | GFRP WITH ALUMINIUM | | ☐ | C:\Users\user\Desktop\Engi | |
| 5 | Structural Steel | | ☐ | General_Materials.xml | Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1 |
| * | Click here to add a new material | | | | |

Fig (4.3) Material Property

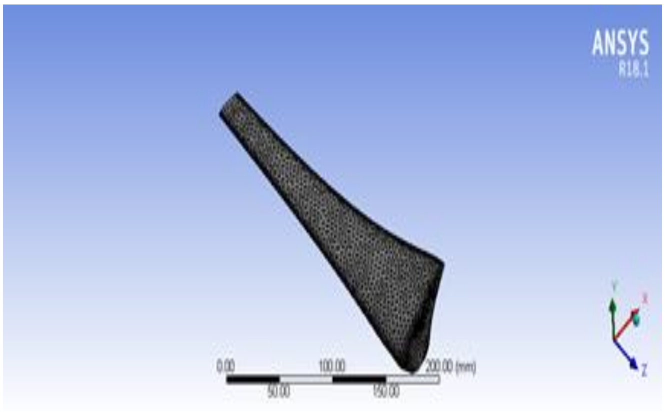


Fig (4.4) Meshing

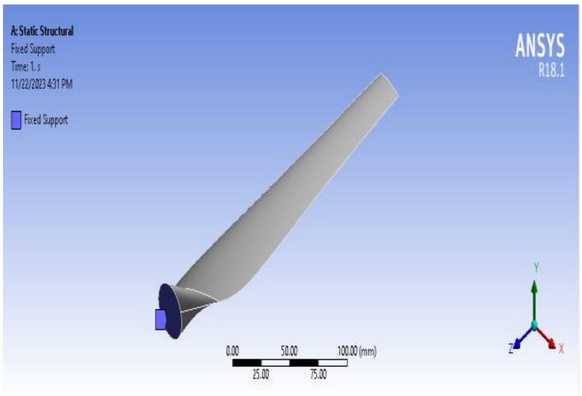


Fig (4.5) Fixed support

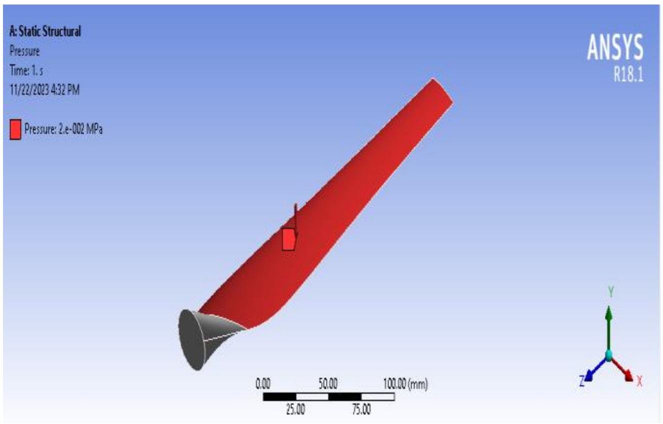


Fig (4.6) Pressure applied

## V. RESULTS & DISCUSSION

### 5.1 Structural Steel Results

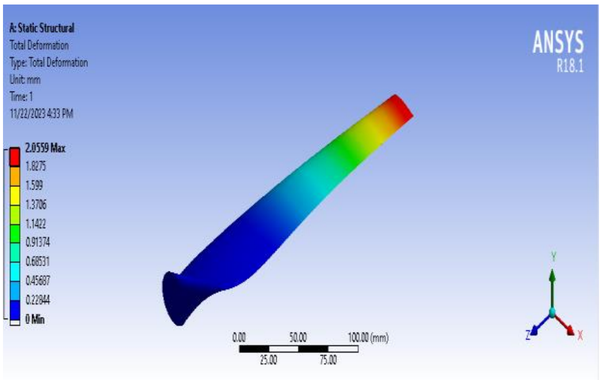


Fig (5.1) Total deformation

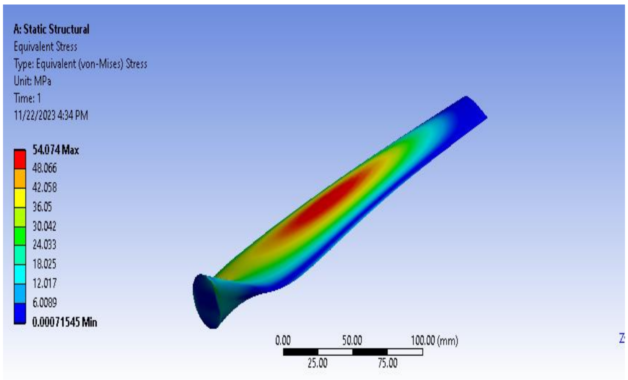


Fig (5.2) Equivalent stress

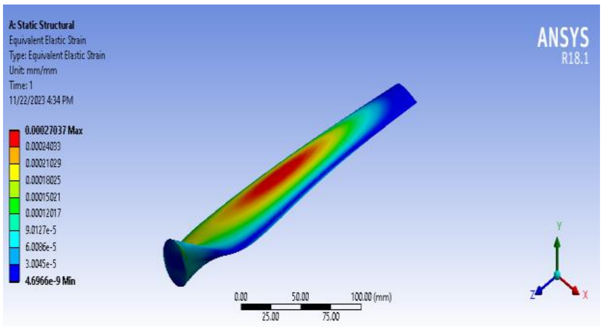


Fig (5.3) Equivalent elastic strain

### 5.2 GFRP Results

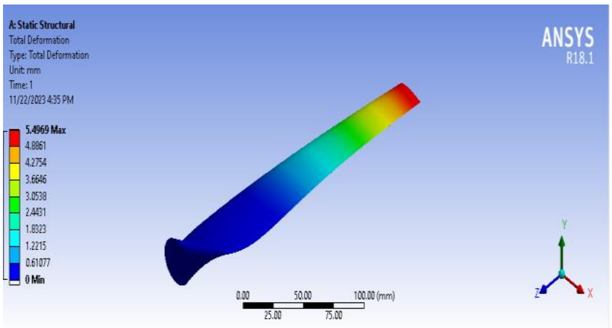


Fig (5.4) Total deformation

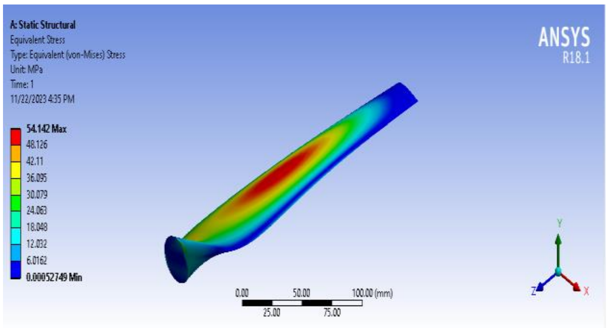


Fig (5.5) Equivalent stress

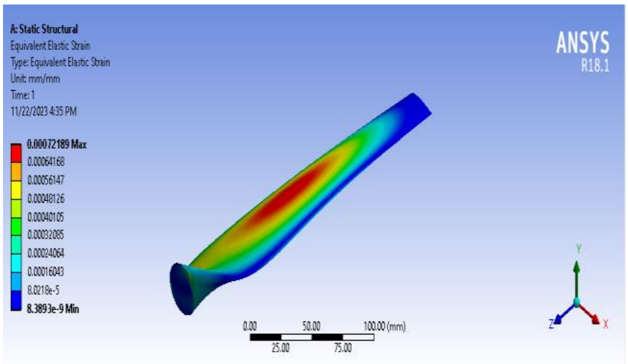


Fig (5.6) Equivalent elastic strain

### 5.2 GFRP with Aluminium Results

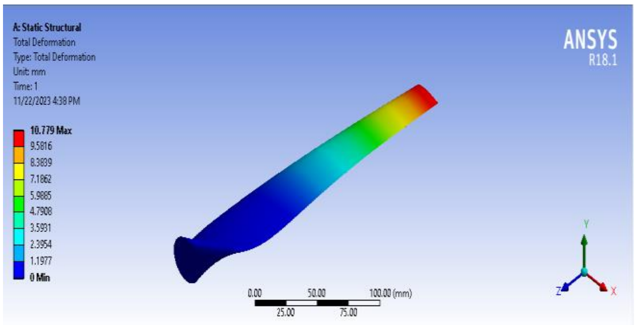


Fig (5.7) Total deformation

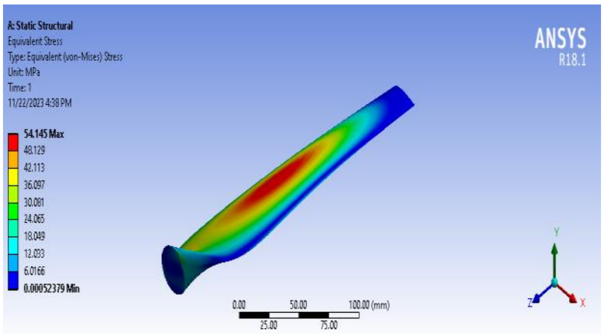


Fig (5.8) Equivalent stress

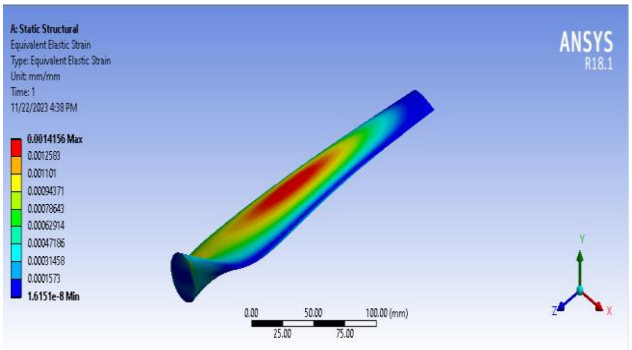


Fig (5.9) Equivalent elastic strain

### 5.3 Comparison with Results

**Table 5.1 TOTAL DEFORMATIONS (mm)**

| TYPE | STRUCTURAL STEEL | GFRP | GFRP WITH ALUMINIUM RESULTS |
|---|---|---|---|
| TOTAL DEFORMATION (mm) | 2.0559 | 5.4969 | 10.779 |

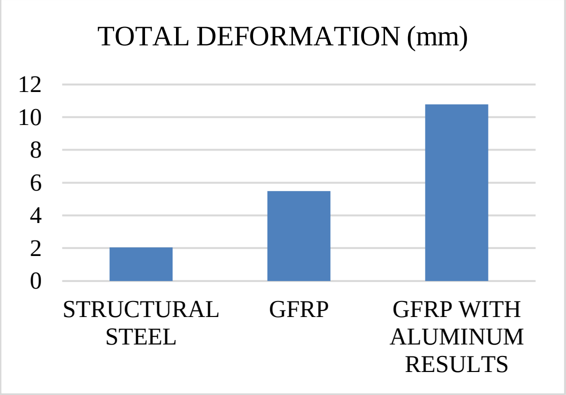


Fig. (5.10) Comparison of Total Deformation

TABLE 5.2 Equivalent Stress (MPa)

| TYPE | STRUCTURAL STEEL | GFRP | GFRP WITH ALUMINIUM RESULTS |
|---|---|---|---|
| EQUIVALENT STRESS (MPa) | 54.074 | 54.142 | 54.145 |

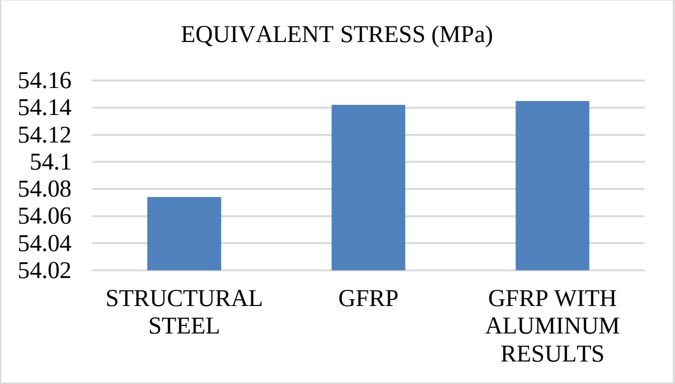


Fig. (5.11) Comparison of Equivalent Stress

TABLE 5.3 Equivalent Elastic Strain (mm/mm)

| TYPE | STRUCTURAL STEEL | GFRP | GFRP WITH ALUMINIUM RESULTS |
|---|---|---|---|
| EQUIVALENT ELASTIC STRAIN (mm/mm) | 0.00027037 | 0.00072189 | 0.0012583 |

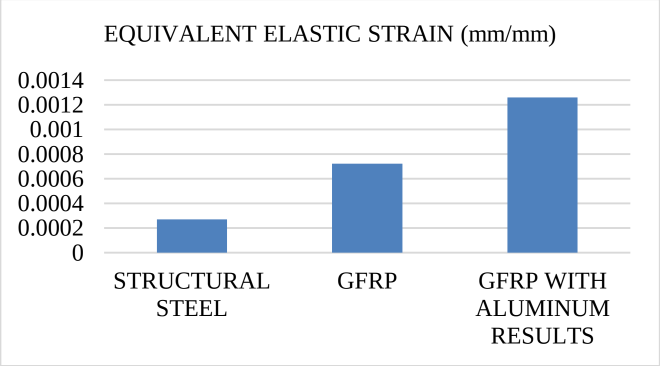


Fig. (5.12) Comparison of Equivalent Elastic Strain

### 5.4 Experimental works

### 5.4.1 Lamination Process of GFRP with ALUMINIUM

Fig (5.13) Marking

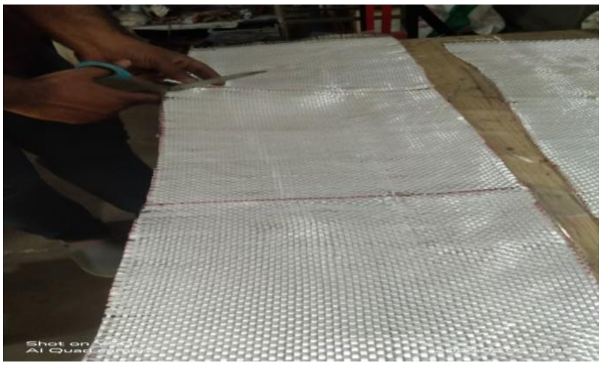


Fig (5.14) Cutting as per Marking

Fig (5.15) Measurement of GFRP Matt with 345.5 g

Fig (5.16) Hardener & Resin

Fig (5.17) Measurement of Aluminium Powder

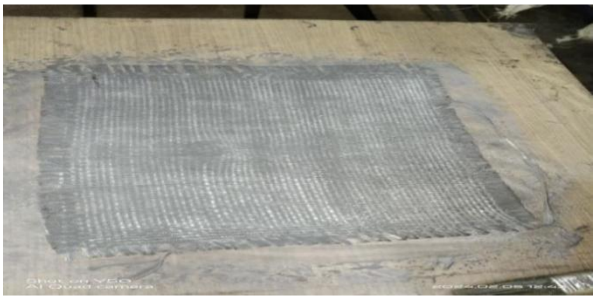


Fig (5.18) GFRP with Aluminium Laminated Plate

### 5.5 Mechanical Testing

Fig (5.19) Tensile Test Setup

Fig (5.20) Compression Test Setup

Fig (5.21) Impact Test Setup

### 5.5.1 Comparison Results for Mechanical Testing

TABLE 5.4 Ultimate Tensile Strength (MPa)

| ULTIMATE TENSILE STRENGTH (MPa) | |
|---|---|
| **GFRP REINFORCED WITH ALUMINIUM** | **GFRP** |
| 263 | 206 |

DOI: 10.17148/IARJSET.2024.11436

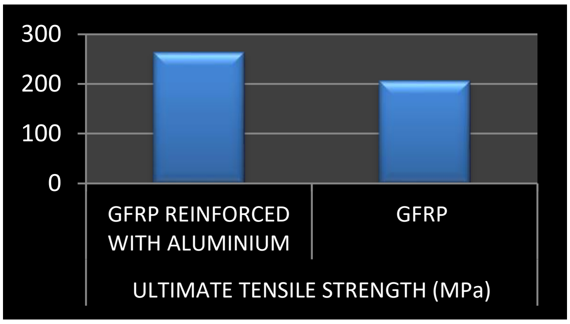


Fig. (5.22) Ultimate Tensile Strength (MPa)

TABLE 5.5 Ultimate Tensile Load (kN)

| ULTIMATE TENSILE LOAD (kN) | |
|---|---|
| **GFRP REINFORCED WITH ALUMINIUM** | **GFRP** |
| 23.08 | 21.381 |

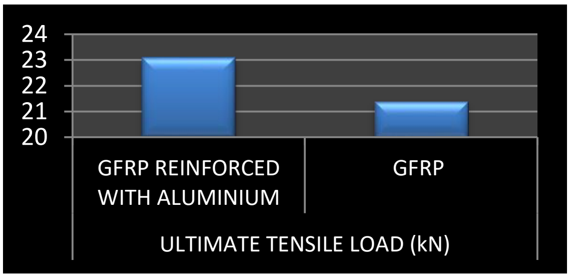


Fig. (5.23) Ultimate Tensile Load (kN)

TABLE 5.6 Ultimate Compression Strength (MPa)

| ULTIMATE COMPRESSION STRENGTH (MPa) | |
|---|---|
| **GFRP REINFORCED WITH ALUMINIUM** | **GFRP** |
| 16 | 15 |

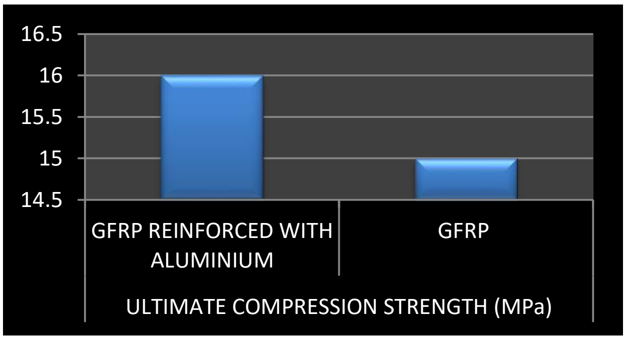


Fig. (5.24) ULTIMATE COMPRESSION STRENGTH (MPa)

TABLE 5.7 Ultimate Compression Load (kN)

| ULTIMATE COMPRESSION LOAD (kN) | |
|---|---|
| **GFRP REINFORCED WITH ALUMINIUM** | **GFRP** |
| 1.43 | 1.21 |

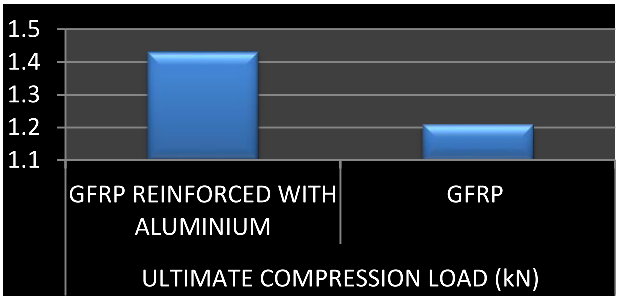


Fig. (5.25) Ultimate Compression Load (kN)

TABLE 5.8 Impact Strength (Joules)

| IMPACT STRENGTH (JOULES) | |
|---|---|
| **GFRP REINFORCED WITH ALUMINIUM** | **GFRP** |
| 13.3 | 11 |

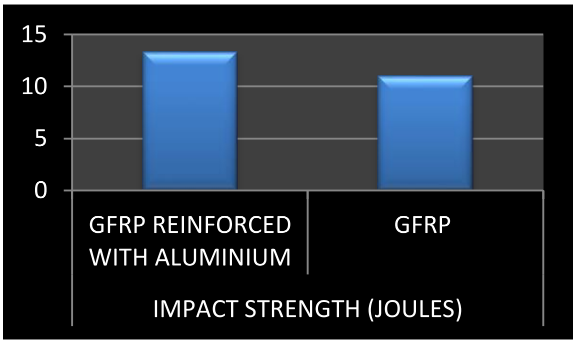


Fig. (5.26) Impact Strength (Joules)

TABLE 5.9 Hardness Results

| Shore D Hardness | |
|---|---|
| **GFRP-EPOXY COMPOSITE** | **GFRP EPOXY REINFORCED WITH ALUMINIUM COMPOSITE** |
| 14 | 21 |

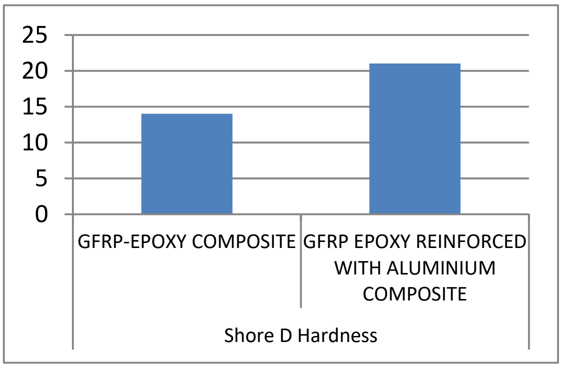


Fig. (5.27) Shore-D Hardness

DOI: 10.17148/IARJSET.2024.11436

### 5.5.2 Corrosion Test Results
### NEUTRAL SALT SPRAY

TABLE 5.10 Sample of GFRP-Epoxy Reinforced With Aluminium (ASTM-B-117-2019)

| **Test Parameter** | **Observation** |
|---|---|
| Test Duration (Hours) | 24 Hours |
| Tower Temperature (*C) | 47.5-48.5 |
| Air Pressure (PSI) | 14-18 |
| Chamber Temperature (*C) | 35-45 |
| Components Loading in Chamber Position (Degree Angle) | 15-30 Degree from vertical |
| Concentration of Solution (%) | 4.80-5.30% of Nacl |
| pH value | 6.65-6.85 |
| Volume of Salt Solution Collected (ml/hr) | 1.00-1.50 |
| Test Observation | **No Rust Formation Noticed up to 24 Hrs** |

### 5.5.3 Macro Images for GFRP-Epoxy Reinforced and GFRP-Epoxy Reinforced With Aluminium

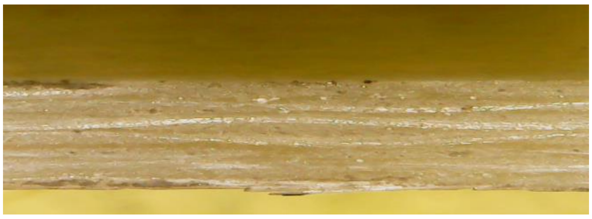


Fig. (5.28) Macro for GFRP-Epoxy Reinforced

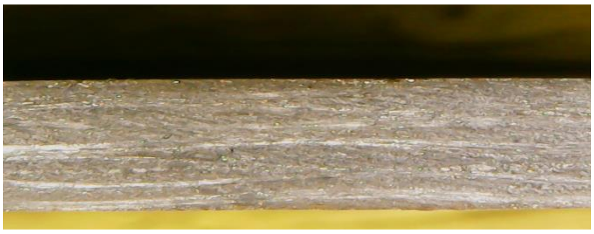


Fig. (5.29) Macro for GFRP-Epoxy Reinforced With Aluminium

## VI. CONCLUSION

The experimental investigation demonstrated that GFRP reinforced with aluminium powder offers superior mechanical properties compared to structural steel and GFRP alone. The addition of aluminium powder enhances the flexibility, stress absorption, and impact resistance of GFRP, making it an optimal material for wind turbine blades. These findings contribute to the advancement of renewable energy technology by providing insights into the design and material selection for more efficient and durable wind turbine blades. Further research and development in this area are warranted to optimize the manufacturing process and scale up production for practical applications.

## REFERENCES

[1] M.R. Piggott, P.S. Chua, D. Andison, The interface between glass and carbon fibers and thermosetting polymers, Polym. Compos. 6 (4) (1985) 242–248.

[2] Yongxiang Yang et al., Recycling of composite materials, Chem. Eng. Process. Process Intensif. 51 (2012) 53–68.

[3] Furqan Ahmad, Heung Soap Choi, Myung Kyun Park, A review: natural fiber composites selection in view of mechanical, light weight, and economic properties, Macromol. Mater. Eng. 300 (1) (2015) 10–24.

[4] Lennart Y. Ljungberg, Materials selection and design for development of sustainable products, Mater. Design 28 (2) (2007) 466–479.

[5] Yue Liu et al., Cost-effective reduced graphene oxide-coated polyurethane sponge as a highly efficient and reusable oil-absorbent, ACS Appl. Mater. Interfaces 5 (20) (2013) 10018–10026.

[6] Dieter Klemm et al., Nanocelluloses: a new family of nature-based materials, Angew. Chem. Int. Ed. 50 (24) (2011) 5438–5466.

DOI: 10.17148/IARJSET.2024.11436

[7] Vijay Kumar Thakur, Manju Kumari Thakur, Processing and characterization of natural cellulose fibers/thermoset polymer composites, Carbohydr. Polym. 109 (2014) 102–117.

[8] David B. Dittenber, Hota V.S. Ganga Rao, Critical review of recent publications on use of natural composites in infrastructure, Compos. Part A: Appl. Sci. Manuf. 43 (8) (2012) 1419–1429.

[9] Lijin Thomas, M. Rramachandra, Advanced materials for wind turbine blade-a review, Mater. Today: Proc. 5 (2018) 2635–2640.

[10] Luca Di Landro, Gerardus Janszen, Composites with hemp reinforcement and bio-based epoxy matrix, Compos. B Eng. 67 (2014) 220–226.

[11] N. Saba, M.T. Paridah, M. Jawaid, Mechanical properties of kenaf fibre reinforced polymer composite: a review, Constr. Build. Mater. 76 (2015) 87– 96.

[12] A.K. Bledzki, Jochen Gassan, Composites reinforced with cellulose based fibres, Prog. Polym. Sci. 24 (2) (1999) 221–274.

[13] Yan Li, Yiu-Wing Mai, Lin Ye, Sisal fibre and its composites: a review of recent developments, Compos. Sci. Technol. 60 (11) (2000) 2037–2055.

[14] S. Mishra et al., Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites, Compos. Sci. Technol. 63 (10) (2003) 1377–1385.

[15] A. Arbelaiz et al., Mechanical properties of flax fibre/polypropylene composites. Influence of fibre/matrix modification and glass fibre hybridization, Compos. A Appl. Sci. Manuf. 36 (12) (2005) 1637–1644.

[16] Jian Chen, Ramasubramaniam Rajagopal, Nanocomposites and methods thereto. U.S. Patent No. 7,479,516. 20 Jan. 2009.

[17] Leon Mishnaevsky et al., Materials for wind turbine blades: an overview, Materials 10 (11) (2017) 1285.

[18] Kai-Wern Ng, Wei-Haur Lam, Saravanan Pichiah, A review on potential applications of carbon nanotubes in marine current turbines, Renew. Sustain. Energy Rev. 28 (2013) 331–339. [19] L.C. Hollaway, A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties, Constr. Build. Mater. 24 (12) (2010) 2419–2445.

[20] Ian G. Wright, T.B. Gibbons, Recent developments in gas turbine materials and technology and their implications for syngas firing, Int. J. Hydrogen Energy 32 (16) (2007) 3610–3621.

[21] Naresworo Nugroho, Naoto Ando, Development of structural composite products made from bamboo II: fundamental properties of laminated bamboo lumber, J. Wood Sci. 47 (3) (2001) 237–242.

[22] Jiang Shen-xue, Zhang Qi-sheng, Jiang Shu-hai, On Structure, production, and market of bamboo-based panels in China, J. Forest. Res. 13 (2) (2002) 151–156.

[23] Fuming Chen et al., Impact properties of bamboo bundle laminated veneer lumber by preprocessing densification technology, J. Wood Sci. 60 (6) (2014) 421–427.

[24] www.Flax composites.com.

[25] James Francis Pratte, Scott A. Rogers, Dominique Ponsolle, Thermoplastic composites and methods of making and using same. U.S. Patent No. 8,158,245. 17 Apr. 2012.

[26] K. Van Rijswijk et al., Optimisation of anionic polyamide-6 for vacuum infusion of thermoplastic composites: choice of activator and initiator, Compos. A Appl. Sci. Manuf. 37 (6) (2006) 949–956.

[27] Daniel R. Bortz, Erika Garcia Heras, Ignacio Martin-Gullon, Impressive fatigue life and fracture toughness improvements in graphene Bortz, Daniel R., oxide/ epoxy composites, Macromolecules 45 (1) (2011) 238–245.

[28] Jolie Frketic, Tarik Dickens, Subramanian Ramakrishnan, Automated manufacturing and processing of fiber-reinforced polymer (FRP) composites: an additive review of contemporary and modern techniques for advanced materials manufacturing, Addit. Manuf. 14 (2017) 69–86.