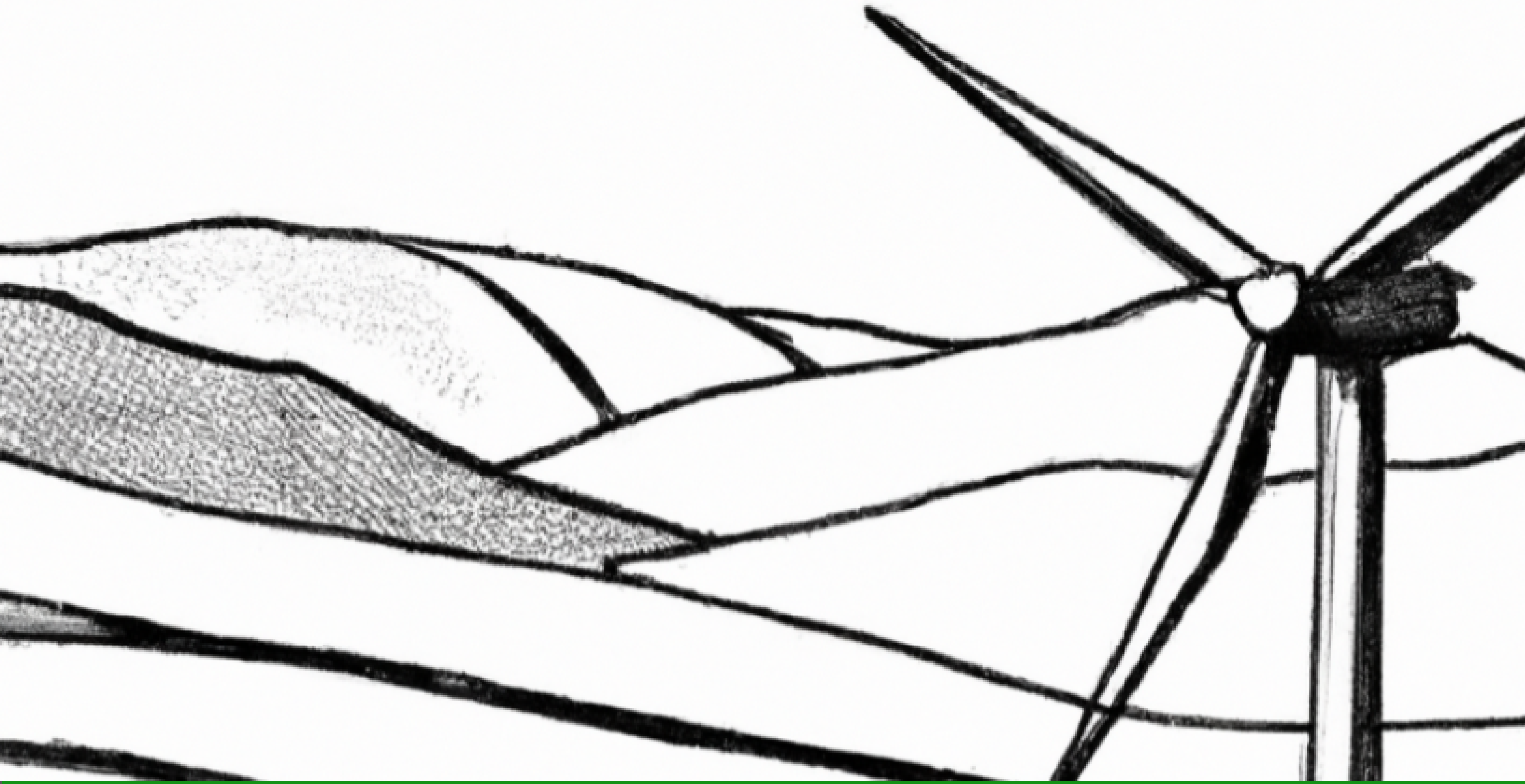

Green Roof Team
Sustainably Green Solutions

Enhancing Tensile Strength in Small Wind Turbine Blades: Materials and Testing Methods

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I. Introduction

Small wind turbines have gained increasing popularity in recent years as a viable source of renewable energy for individual households and small-scale applications. While the focus of wind power generation has predominantly been on large industrial turbines, the emergence of small wind turbines has opened up new opportunities for decentralized energy production. These compact turbines offer several advantages, including lower installation costs, greater flexibility, and reduced environmental impact. [2]

Tensile strength plays a critical role in the performance and structural integrity of small wind turbine blades. As the blades capture wind energy and convert it into rotational motion, they are subjected to significant forces, including aerodynamic loads and turbulence. The ability of turbine blades to withstand these forces and maintain their shape and stability is directly influenced by their tensile strength.

Tensile strength is a key determinant of the overall durability and reliability of small wind turbine blades. Higher tensile strength allows blades to resist bending, flexing, and deformation under various loads, including gusts and turbulent wind conditions. It ensures that the blades maintain their structural integrity, preventing premature failure and reducing the risk of catastrophic damage.

Moreover, tensile strength also affects the overall efficiency and power output of small wind turbines. Blades with higher tensile strength can withstand greater stresses without significant deflection, leading to improved aerodynamic performance and increased energy capture. This translates into enhanced power generation and higher energy yields, making tensile strength a critical factor for maximizing the economic viability of small wind turbines.

To enhance tensile strength in small wind turbine blades, careful selection of materials is of utmost importance. Traditional materials such as aluminum and steel, while commonly used, may have limitations in terms of their tensile strength, weight, and resistance to environmental factors. Therefore, exploring alternative materials, such as composite materials (e.g., fiberglass, carbon fiber), nanostructured materials, and biodegradable materials, becomes crucial to optimize tensile strength and overcome existing limitations.

However, the mere selection of appropriate materials is not sufficient. Comprehensive testing methods are essential to evaluate the tensile strength and performance of these materials under real-world operating conditions. Rigorous testing ensures that the chosen materials exhibit the required durability, fatigue resistance, and long-term reliability needed for small wind turbine blades.

By investigating the significance of tensile strength in small wind turbine blades and emphasizing the importance of selecting suitable materials and testing methods, this white paper aims to provide insights into enhancing the tensile strength of small wind turbine blades. Through a comprehensive examination of materials and testing techniques, this paper intends to contribute to the advancement of small wind energy technology and the overall sustainability of the renewable energy sector.

II. Material Selection for Tensile Strength

Small wind turbine blades are typically constructed using a variety of materials, each with its own advantages and limitations. Understanding the characteristics of these materials is crucial in selecting the most suitable ones for enhancing tensile strength. Some commonly used materials in small wind turbine blades include the following [1]:

- Fiberglass: Fiberglass is widely utilized due to its excellent combination of strength, flexibility, and cost-effectiveness. It consists of glass fibers embedded in a resin matrix, providing high tensile strength and resistance to fatigue. Fiberglass offers good structural stability and can be easily molded into complex blade shapes.
- Carbon Fiber: Carbon fiber is renowned for its exceptional strength-to-weight ratio. It is composed of carbon atoms bonded together in a crystalline structure, resulting in lightweight yet incredibly strong material. Carbon fiber-reinforced composites offer superior tensile strength, stiffness, and fatigue resistance, making them ideal for high-performance small wind turbine blades.
- Aluminum: Aluminum alloys are known for their high strength-to-weight ratio and corrosion resistance. They are commonly employed in small wind turbine blades, particularly for lighter and smaller-scale designs. While aluminum may not match the tensile strength of carbon fiber or fiberglass, it provides cost advantages and ease of manufacturing.

To verify whether these common materials are the best ones, a material selection graph in Granta is shown below. The y-axis is chosen to be tensile strength because that is the property to be maximized. The x-axis contains density as the turbine blade should be as light as possible and price is included for cost purposes. **Figure 1** shows the groups of materials that will help achieve a low-cost, lightweight, and strong turbine blade.

Not surprisingly, the best materials belong to the fibers class. However, natural fibers, for example, jute, kenaf, and coir fibers shown in the graph, also qualify in the selection criteria. The pursuit of sustainable and environmentally friendly solutions has led to the exploration of natural fibers as potential materials for small wind turbine blades. These natural fibers offer distinct advantages over traditional materials like carbon fiber, but they also come with unique challenges and considerations.

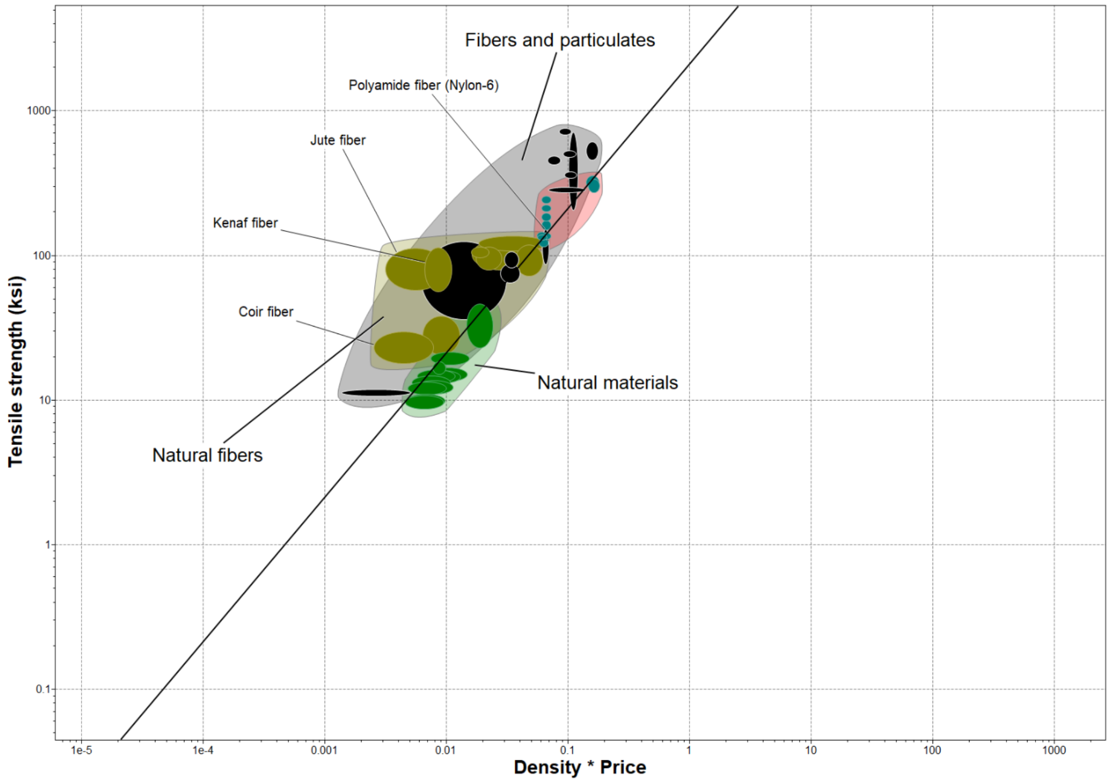

Figure 1. Density*price vs tensile strength of level 3 materials in Granta software.

The characteristics and use of the natural fibers identified in the graph above are summarized below:

- Jute: Jute fibers are derived from the jute plant's stem and are known for their affordability, low density, and biodegradability. They possess reasonable tensile strength and are often used in applications where cost-effectiveness and moderate mechanical properties are desired.
- Kenaf: Kenaf fibers, obtained from the Kenaf plant's bast, exhibit good tensile strength, lightweight properties, and biodegradability. Kenaf composites are used in various industries, including automotive and construction, for non-structural and semi-structural components.
- Coir: Coir fibers are extracted from coconut husks and offer good tensile strength, moisture resistance, and biodegradability. They are commonly used in geotextiles, mats, and erosion control products due to their natural resistance to decay and rot.

Carbon fiber generally offers higher tensile strength compared to natural fibers, making it suitable for demanding applications with significant mechanical stresses. Carbon fibers are reported to have around 4000 MPa while natural fibers normally have up to 1000 MPa. However, natural fibers are lighter in weight and have lower density compared to carbon fiber. This can be advantageous for reducing the overall weight of wind turbine blades. Additionally, carbon fiber is notably more expensive than natural fibers. Natural fibers like jute, kenaf, and coir are more cost-effective options, making them attractive for small wind turbine applications with budget constraints. **Table 1** summarizes the costs of common types of fibers.

Table 1. Cost comparison of different fibers

Material	**Cost ($/pound)**
Carbon fiber	Standard Grade: $10 - $20 per pound High-Performance Grade: $20 - $40+ per pound
Fiberglass	E-Glass: $1.5 - $4 per pound S-Glass: $4 - $8 per pound
Jute	$0.5 - $1.5 per pound
Kenaf	$1 - $2 per pound
Coir	$0.5 - $1.5 per pound

III. Utilization of Natural Fibers in Lamination for Wind Turbines

Incorporating natural fibers into the lamination of wind turbine blades is an area of active research and development. Raw natural fibers often have high moisture content which may damage the structure in the long run. Thus, they are often used as reinforcements in composite materials to enhance their mechanical properties and reduce environmental impact.

Natural fibers can be combined with traditional materials, such as glass fiber or carbon fiber, to create hybrid composites. These composites capitalize on the strengths of both materials while reducing costs and environmental footprints. Natural fibers can also be woven, aligned, or stacked in specific orientations during the lamination process to optimize their mechanical properties. This technique ensures that the resulting composite material is tailored to meet the required tensile strength and stiffness.

The choice of matrix material, such as epoxy or bio-based resins, is crucial for binding the natural fibers together and ensuring cohesive composite structures. The matrix also influences the overall mechanical performance, durability, and environmental impact of the blade.

In 2009, Holmes et al. developed a bamboo-based composite as a sustainable green material for wind turbine blades and found that the material showed high strength and stiffness. [3] The schematic of making this material is shown below in **Figure 2**.

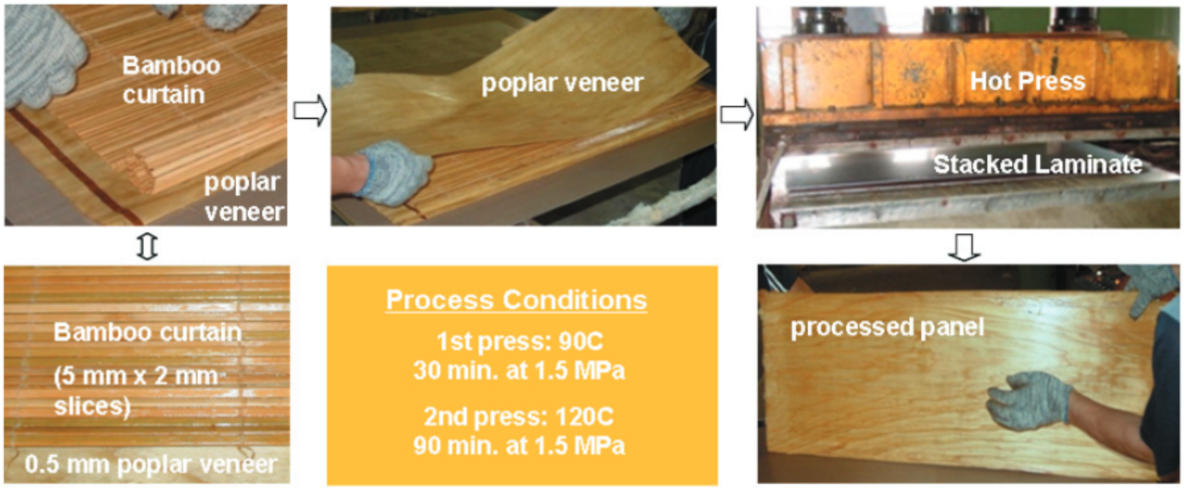

Figure 2. Schematic of creating bamboo fiber composite material.

The existence of these case studies points to the possibility of utilizing natural fibers instead of carbon fiber in wind turbine lamination. However, there remain several disadvantages to natural fibers. Firstly, out of most literature, the combination of natural fibers into a composite material is a complicated process that requires specific machines. For Green Roof Team, this will incur additional production costs. Furthermore, natural fibers often come in their raw fiber forms, thus, customers buying the wind turbine educational pack will find it much harder to assemble compared to the carbon fiber sheets.

For the above reasons, carbon fiber remains the best material choice for the company at present.

IV. Factors Influencing Tensile Strength

Several factors influence the tensile strength of materials used in small wind turbine blades. These factors should be carefully considered during material selection to optimize blade performance and durability.

The type, orientation, and volume fraction of fiber reinforcements significantly impact tensile strength. Fiberglass blades typically incorporate continuous strands of glass fibers, whereas carbon fiber blades utilize carbon fiber laminates. The arrangement and alignment of these fibers play a vital role in determining the overall tensile strength of the blade.

Secondly, the choice of resin system is crucial as it binds the fiber reinforcements together, providing cohesion and structural integrity. Different resins exhibit varying properties, such as flexibility, adhesion, and resistance to environmental factors. Epoxy resins are commonly used due to their excellent adhesion and mechanical properties.

Finally, the manufacturing process employed for blade fabrication influences the final tensile strength. Factors such as curing temperature, pressure, and post-processing methods can affect the bonding between fibers and resins, leading to variations in tensile strength.

V. Testing Methods for Tensile Strength Evaluation

To evaluate the tensile strength and performance of materials used in small wind turbine blades, various testing techniques are employed. These techniques provide valuable data for assessing the structural integrity and reliability of the blades. Some commonly used testing techniques include:

- Static Testing: Static tensile testing involves applying a constant load to a test specimen until it reaches failure. This method determines the ultimate tensile strength, elongation at break, and Young's modulus of the material.
- Dynamic Testing: Dynamic testing, also known as fatigue testing, subjects the material to cyclic loading that simulates real-world operating conditions. This testing method evaluates the material's resistance to fatigue failure and provides insights into its durability and longevity.
- Non-Destructive Testing: Non-destructive testing techniques, such as ultrasonic testing and thermography, are utilized to assess the internal structure and detect potential defects without damaging the material. These methods allow for the detection of hidden flaws and the monitoring of material degradation over time.

VI. Relevant Testing Standards and Protocols

To ensure standardized and reliable testing procedures, various international organizations and standardization bodies have developed testing standards and protocols for assessing the tensile properties of materials. Some commonly referenced standards include:

- ASTM D3039: This standard provides guidelines for performing tensile testing of polymer matrix composite materials. It outlines the test specimen dimensions, loading rates, and calculation methods for determining tensile properties.
- ISO 527: The ISO 527 standard specifies the general principles for determining the tensile properties of plastics, including test conditions, specimen preparation, and data analysis.
- IEC 61400-23: This International Electrotechnical Commission (IEC) standard focuses specifically on the testing and evaluation of small wind turbine blades. It provides guidelines for mechanical tests, including tensile strength evaluation, to ensure the blades meet the required performance and safety criteria.

VIII. Future Trends and Developments

As the field of wind energy evolves, so do the possibilities for enhancing the tensile strength of small wind turbine blades. Looking ahead, several trends and developments are poised to shape the landscape of blade design and performance optimization.

Continued research into composite materials is expected to yield innovative combinations and formulations that provide exceptional tensile strength, along with enhanced durability and sustainability. This may include the integration of bio-based resins, self-healing materials, and functionalized reinforcements.

The incorporation of nanomaterials, especially carbon nanotubes for carbon fiber composites, holds the promise of further enhancing the mechanical properties of composite materials. These materials can contribute to increased tensile strength, toughness, and fatigue resistance.

Additionally, researchers are exploring biomimicry to develop materials that mimic natural structures, optimizing their mechanical properties. Bio-inspired designs, such as those inspired by natural composites found in bones or shells, could revolutionize the way we approach tensile strength optimization.

Advanced simulation tools like finite element analysis (FEA) are expected to become even more sophisticated, allowing for more accurate predictions of how different designs and material choices affect tensile strength and overall performance. The field of non-destructive testing is also evolving, with technologies such as terahertz imaging and acoustic emission becoming more prevalent. These techniques offer real-time monitoring of structural health, helping identify potential weaknesses before they lead to failure.

The future of enhancing tensile strength in small wind turbine blades is marked by a blend of innovation, technology, and sustainability. As new materials, testing methods, and technologies emerge, the potential for further advancements in blade performance becomes increasingly promising. These future trends have the potential to revolutionize the field, creating blades that are not only stronger and more durable but also more adaptable to the changing demands of renewable energy generation.

IX. Conclusion

Enhancing the tensile strength in small wind turbine blades is a pivotal aspect of improving their performance, reliability, and overall efficiency. Throughout this paper, key findings underscore the significance of optimizing tensile strength and its impact on the wind energy industry.

Tensile strength plays a critical role in ensuring the structural integrity and durability of small wind turbine blades. Higher tensile strength translates to enhanced resistance against mechanical stresses, leading to reduced risks of failure and improved performance.

The choice of materials, whether traditional or innovative, directly influences the tensile strength of blades. Selecting suitable materials with high tensile strength and favorable mechanical properties is a fundamental step in blade design. Successful enhancement of tensile strength results from a combination of material selection, design considerations, and manufacturing processes. Synergizing these elements leads to the creation of blades with superior structural properties.

The paper concludes that while natural fibers have many benefits, carbon fiber remains the best choice considering its strength and ease of use. Nevertheless, it is important to note that other design factors like geometric considerations also impact the tensile properties of the final blade. Thus, it is important to consider all factors, not just materials, when designing the final product.

X. References

[1] Mishnaevsky, L., Branner, K., Petersen, H. N., Beauson, J., McGugan, M., & Sørensen, B. F. (2017, November 9). *Materials for Wind Turbine Blades: An Overview*. MDPI. https://doi.org/10.3390/ma10111285

[2] Veers, P. S., Ashwill, T. D., Sutherland, H. J., Laird, D. L., Lobitz, D. W., Griffin, D. A., Mandell, J. F., Musial, W. D., Jackson, K., Zuteck, M., Miravete, A., Tsai, S. W., & Richmond, J. L. (2003). Trends in the Design, Manufacture and Evaluation of Wind Turbine Blades. *Wind Energy*, *6*(3), 245–259. https://doi.org/10.1002/we.90

[3] Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011, June). A review on the tensile properties of natural fiber reinforced polymer composites. *Composites Part B: Engineering*, *42*(4), 856–873. https://doi.org/10.1016/j.compositesb.2011.01.010

[4] Venkateshwaran, N., Elayaperumal, A., & Sathiya, G. (2012, March). Prediction of tensile properties of hybrid-natural fiber composites. *Composites Part B: Engineering*, *43*(2), 793–796. https://doi.org/10.1016/j.compositesb.2011.08.023

[5] Holmes, J. W., Brøndsted, P., Sørensen, B. F., Jiang, Z., Sun, Z., & Chen, X. (2009, March). Development of a Bamboo-Based Composite as a Sustainable Green Material for Wind Turbine Blades. Wind Engineering, 33(2), 197–210. https://doi.org/10.1260/030952409789141053

[6] Sager, R., Klein, P., Lagoudas, D., Zhang, Q., Liu, J., Dai, L., & Baur, J. (2009, June). Effect of carbon nanotubes on the interfacial shear strength of T650 carbon fiber in an epoxy matrix. Composites Science and Technology, 69(7–8), 898–904. https://doi.org/10.1016/j.compscitech.2008.12.021

[7] Zhou, Y., Wang, Y., Xia, Y., & Jeelani, S. (2010, February). Tensile behavior of carbon fiber bundles at different strain rates. *Materials Letters*, *64*(3), 246–248. https://doi.org/10.1016/j.matlet.2009.10.045