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Testing of Efficiency of Wind Turbine Blade NACA2415 Aerofoil Type Using Recycled Carpet Waste Polymer Composite Material

Rakshapal Singh Rajawat[1, *], Rajneesh Kumar Singh[2]

Abstract

In 2020, over 50% of residential properties in the United States were outfitted with carpet flooring, boasting an average longevity ranging from 10 to 18 years. Carpets are crafted from various fibers, including woven nylon, polyester, polypropylene, or wool fibers. Historically, nearly 6 billion pounds of discarded carpets were directed to landfill sites, perpetually undergoing decomposition processes. My current project entails the fabrication of a wind turbine blade utilizing a NACA2415 aerofoil type (HAWT) constructed from polymer composite material derived from recycled carpet waste. The composite material integrates banana-hemp-glass fiber reinforcements, produced via hand lay-up technique. Rigorous assessments of tensile, flexural and impact strengths are conducted, yielding comprehensive insights. Based on outcomes, following conclusions are drawn regarding performance of HAWT employing the hybrid composite material blade featuring a modified aerofoil design incorporating lift-enhancing methodologies. Derived parameters reveal that elevating tower height and inlet velocity for the rough surface blade yield optimal actual power output and efficiency for the wind turbine.

Keywords: Composite material, Mechanical properties, Wind blade, RPM, Performance

INTRODUCTION

In 2020, over 50% of residential dwellings in the United States were equipped with carpet flooring, boasting an average lifespan ranging from 10 to 18 years. Carpets are manufactured from a variety of fibers, including woven nylon, polyester, polypropylene, or wool fibers. Historically, nearly 6 billion pounds of worn-out carpets were directed to landfill sites annually, where they underwent continuous decomposition processes. Upon reaching the end of their operational lifecycle, carpets are now diverted from landfills and directed towards recycling centers dispersed nationwide. The Carpet America Recovery Effort (CARE), a collaborative non-profit initiative between industry and governmental entities, is dedicated to devising strategies for the effective recycling of discarded carpets. Empirical data substantiates that carpet recycling presents a more environmentally friendly and sustainable alternative. The recycling process involves the disassembly of old carpets into their constituent raw materials, subsequently extracted and repurposed for various applications such as flooring, furniture, gardening products, and automotive interiors. Over time, carpet recycling emerges as not only a cost-effective but also a significantly safer solution for environmental preservation. Consequently, recycled carpeting has become the preferred choice

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for homeowners seeking sustainable flooring options. Additionally, repurposing old carpets within the household remains a viable option, provided they are clean and intact. Following removal, old carpets can be redeployed in alternative rooms or areas with minimal foot traffic. The ethos of “reduce, reuse, recycle” underpins efforts to mitigate environmental impact and foster sustainable practices. Unlike previous practices of indiscriminate disposal, modern flooring companies collaborate with manufacturers to separate padding from discarded carpets, subsequently channeling the remaining material to recycling facilities. Here, carpets undergo further sorting to identify fiber composition, followed by shredding or cutting, washing, and reformatting for recycling with new backing materials. The majority of carpet fibers undergo reassembly, stitching, and thermal processing to manufacture new carpet backings for residential and commercial applications. In cases where carpet materials comprise plastics like polypropylene, they are subjected to melting processes to form pellets, subsequently utilized by other industries for manufacturing purposes such as plastic lumber and automotive components. Recycled carpets represent floor coverings crafted from repurposed or reclaimed materials, aligning with principles of sustainability and environmental stewardship. Their integration signifies a pivotal shift within the flooring industry towards conscientious and environmentally conscious practices, promoting waste reduction and the adoption of circular economy principles. Sotayo. A. et al. [1] investigated, Carpet Recycling: A Review of Recycled Carpets for Structural Composites, addressing the challenge posed by multilayered carpet compositions comprising various polymers and inorganic fillers, which present difficulties and high costs for reprocessing upon disposal. The UK alone generates approximately 400,000 tonnes of carpet waste annually, with landfill disposal becoming increasingly impractical due to escalating cost and limited available landfill sites. Muhammed. A. K et al. [2] conducted a study on the performance analysis of wind turbine blade materials using nanocomposites, focusing on the utilization of nanoparticle-reinforced composites (nanocomposites) in wind turbine blade construction. Nanocomposites are gaining popularity in both research and industrial sectors due to their exceptional properties, offering a wide array of applications across various domains. GFRE matrix composite are particularly favored for wind turbine blade consruction owing to their advantageous characteristics. Miraftab. M. et al. [3] focused on the utilization of carpet waste in reinforcement of substandard solids, addressing the challenge of managing the approximately 400 million tonnes of waste generated annualy in the UK, particularly the significant portion consisting of construction and demolition waste destined for landfills. Although textiles, including carpet waste, constitute only 2% of total waste by weight, their high volume-to-weight ratio results in significant landfill space occupation. Ucar. M. et al. [4] conducted research on utilization of recycled post-consumer carpet waste fibers as reinforcement in lightweight cementitious composites with the aim of investigating the feasibility of incorporating this waste material into a cost-effective, high-volume application. Given the substantial amount of post-consumer carpet waste disposed of in landfills there is a growing need to recycle such waste due to limited landfill capacity, environmental considerations, and resource conservation efforts. Wang. Y. et al. [5] conducted an analysis on “Fiber and Textile Waste Utilization” in response to the escalating global fiber consumption driven by population growth and enhanced living standards. This surge has led to a substantial increase in (Post-Industrial and Post-Consumer) fiber waste with carpets constituting a signification portion of textile waste. The paper presents a comprehensive overview of fiber and textile recycling methodologies, with a specific focus on carpet recycling. Meshram. P et al. [6] conducted a study on the mechanical properties of epoxy and (Nylon+epoxy) composites. This investigation involved the fabrication of Nylon Reinforced Composite (NRC) using the hand lay-up technique where nylon served as the reinforcing material and epoxy resin as the matrix. Comparative analysis was performed between NRC and pure epoxy polymer, focusing on parameters such as tensile strength and drilling thrust force. Vishwas C. Shetty et al. [7] analyzed the optimal combination of natural fiber and resin percentages through the preparation of various composites and subsequent mechanical testing. In this research, banana fiber served as the reinforcing element, while epoxy resin acted as the composite matrix. The fabrication process involved the utilization of a mild steel frame mold to achieve the desired distribution of fibers and resin in the composite. Gujjala et al. [8] investigated the mechanical properties of a novel hybrid composite

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comprising woven jute-glass reinforcements within an epoxy matrix. This study included an examination of layered matte composites, with an experimental investigation into the impact of stacking sequence on tensile, flexural and interlaminar shear properties. E. Deepak Naidu et al. [9] conducted an analysis focusing on the influence of fiber orientation on the mechanical properties of composite laminates composed of banana and basalt fibers embedded in an epoxy matrix. The study involved the fabrication of composite materials by integrating banana and basalt fibers with epoxy resin, followed by a comprehensive evaluation of the mechanical behavior of the resulting laminates. Ramnath et al. [10] focused on the evaluation of the mechanical properties of epoxy composites reinforced with a hybrid combination of abaca, jute, and glass fibers. This study involved fabrication and characterization of hybrid natural fiber composites, comparing them with conventional natural fiber composites utilizing abaca and jute separately as reinforcements. N. Venkateshwaran et al. N. [11] analyzed the impact of fiber length and fiber content on the mechanical properties of banana fiber/epoxy composites. Experimental procedures were conducted in accordance with ASTM standards to assess mechanical properties such as tensile strength, tensile modulus, flexural strength, flexural modulus and impact strength. Additionally, water absorption capacity of the composite was investigated. Furthermore, the fractured surfaces of specimens were subjected to morphological examination using scanning electron microscopy. Soumyalata. D et al. [12] conducted a study aimed at assessing the viability of employing CSP (Coconut Shell Power) and crop residue as potential alternatives to rice husks as reinforcing materials in polymer composites. The objective was to formulate composite materials incorporating these natural fillers and subject them to various mechanical tests to evaluate their performance. The investigation sought to analyze the mechanical behavior of the resultant composites based on different filler materials. Ramasubbu R, et al. [13] was work the mechanical properties of Areca catechu fiber-reinforced epoxy composites. In this method silicon carbide was used as filler material. In this studied water absorption, impact strength, Flexural strength, tensile and hardness test was analyzed. Padmanabhan R.G, et al. [14] was analysis the mechanical properties of and structural aspects of (Al+Hybrid) fibre metal laminates reinforced with fibres from including commercial-grade Al6061 alloy mesh (Al-DMEM). Palanisamy S, et al. [15] was work the current developments in raw materials, manufacturing processes, and application of natural fiber composite were reviewed. Natural fibes can signify a substitute for man-made (with glass, aramid, and natural carbon) in a variation of bio-composite submission. Mangalaraja RV, et al. [16] was work a sustainable energy transition to build a safer future. In this work the sustainability challenge of recent years is mainly related to greenhouse gases Emissions due to the use of fossil fuels, primarily coal, natural gas and oil Accounts for 61.3% of global electricity production. Such existing sources are used Due to their scarce supply and environmental impact.There is a need to transition to sustainable energy.

My current project involves the fabrication of wind turbine blades using a NACA2415 aerofoil type manufactured from polymer composite material derived from recycled carpet waste. In this experimental work, naca 2415 aerofoil type blade was tested in HAWT.

MATERIAL FABRICATION PROCESS.

Banana fiber: Banana silk rugs and carpets utilize fibers derived from the harvesting and processing of banana plant stems. This unique material yields soft, lustrous, and environmentally friendly rugs suitable for areas with moderate foot traffic. While conventional wisdom often categorizes carpet fibers into natural (e.g., wool, cotton, silk) and entirely synthetic (e.g., polyester, nylon), banana silk rugs represent an innovative and sustainable alternative. Figure 1 shows banana fiber carpet. Hemp: Hemp, a variant of the Cannabis Sativa plant, boasts a rich history spanning over 10,000 years and is renowned as one of the earliest cultivated plants. Recognized for its rapid growth rate, hemp stands as a dependable and renewable resource on a global scale. Figure 2 shows hemp fiber carpet. Fiberglass: Fiberglass, also referred to as glass-reinforced plastic (GRP) and glass fiber reinforced plastic (GFRP), comprises a composite material crafted from exceptionally fine glass fibers. These fibers are typically woven into a fabric – like mat or utilized as reinforcement within a plastic resin matrix. The resultant composite marries the strength and durability of glass with the flexibility and mold ability inherent to plastic. Figure 3 shown glass fiber.

In this experimental investigation, hybrid composite was fabricated using a combination of banana fiber, hemp fiber and glass fiber. Subsequently, surface rust was removed by abrasively rubbing the base plate with abrasive paper, followed by drying. Thinning agents were applied for further cleaning, and once dry, a silicone gel coating was administered to the surface to facilitate mold lay-up. After allowing a brief setting period, epoxy resin and hardener were meticulously mixed at a ratio of 10:1. The pot life, indicating the time available for application, typically recorded on laboratory charts, was 20 minutes. Special precautions were taken to prevent premature curing within the mixing vessel. Continuous monitoring of the mixture was conducted using a stopwatch. Prior to incorporation into the composite, natural fibers underwent sun-drying for 5 to 7 hours. The initial laminate was constructed utilizing a hand-laying process, combining banana and GF with epoxy resin on the base plate. This laminate comprised three layers of GF and two layers of BF. The laminate dimensions were constrained to (300 mm×300 mm×4 mm), with distinct top, middle and bottom layers. Glass fiber was incorporated in the top and bottom layers, while natural fibers filled the second and fourth layers. Similar hybrid laminates, incorporating hemp and glass fibers, as well as banana, hemp and glass fiber combinations with epoxy resin, were prepared using the same hand-laying technique. Subsequently, three sets of hybrid laminates were cured under load for 12 hours using a wet press. The raw banana and hemp fibers utilized in composite laminate fabrication are depicted in Figure 4, and Figure 5.

Figure 1. Raw Banana fiber carpet [17].

Figure 2. Raw Hemp fiber carpet [17].

Figure 3. Glass fiber carpet [17].

Figure 4. Fabricated banana-glass fiber composite laminate [17].

Figure 5. Fabricated hemp-glass fiber composite laminate [17].

EXPERIMENT MODEL

In this method, a die of the NACA-2415 airfoil type is prepared. Table 1 displays the coordinates of the NACA-2415 airfoil, which were generated using the Airfoil Tool Generator shown in Figure 6. To create the top and bottom layers, three layers of woven roving are stacked on top of each other. After curing for 14 to 16 hours, the top and bottom structures become quite strong. Following this, the GFRP laminates are removed from the mold. The main components of the experimental setup are the rotor blade, shaft, support block, and flap.

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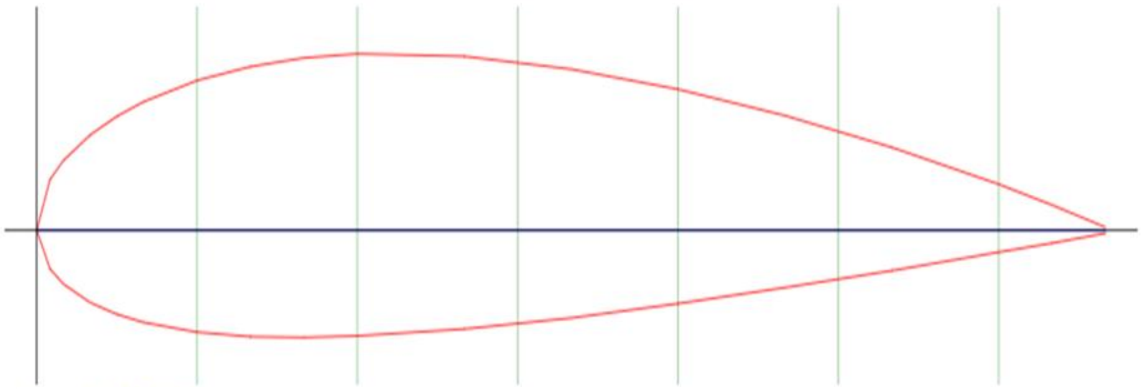
Table 1. (NACA airofoil).

Airofoil naca2415-il – NACA 2415	
Chord (mm)	100
Radius (mm)	0
Thickness (%)	120
Origin (%)	0
Pitch (degrees)	0
Halo (mm)	0
Halo (mm)	0
Line thickness (%)	100
X grid (mm)	15
Y grid (mm)	15
Paper width (mm)	280
Paper height (mm)	200



Name = NACA2415
Chord = 100 mm Radius = 0 mm Thickness = 120% Origin = 0% Pitch = 0°

Figure 6. NACA 2415 airofoil [18].

SPECIFICATION OF BLADE

Length of blade = 0.3
Cord length = 5.2 cm
Camber position 2.2 cm from Leading Edge
Blade twisting 11 Degree
Blade nomenclature = NACA Aerofoil type
Twist angle = 10 deg.
Camber area = 2.4 cm
Blade thickness = 0.7 cm
Number of blades = 3

METHOD

In accordance with Betz's Limit theory, the maximum power generated is theoretically limited to 59% of the total kinetic energy possessed by the incoming wind flow before its interaction with the rotor blades of the wind turbine. This parameter is commonly referred to as the Betz coefficient (Cp). Thus, the equation can be expressed as follows

P (theoretical maximum power) = Cp $(1/2 \rho A V i^2)$

= Cp K.E. (Available in the wind stream)

Theoretical power of wind turbine is,

Power air $= 1/2\ \rho A v i 3$

Actual power, Power actual = $1/2\ \rho\ AVa\ (vi^2-ve^2)$

Where, ρ = Density of the air =1.2 kg/m^3

vi = Inlet velocity at the blade in m/s

ve = Exit velocity at the blade in m/s

A = Swept area of rotor blade in m2

Va =Average Velocity in m/s

Coefficient of Power,cp = Actual power/Theoreticl power

Putting the value of b in the original equation of power coefficient,

We get, cp = Actual power/Theoretical power

$cp = va/vi(1-b^2)$

$cp= (vi+ve)(1-b^2)/2vi$

$cp = 1/2\ (1-b^2)(1+b)$

EXPERIMENTATION CASES

To conduct a power analysis of a wind turbine, a working model was developed. Experiments were carried out on the model at different wind speeds and tower heights. During the experiments, we used the blade at various times, locations, and wind speeds.

Date of experiment	***Place of experiment***
24/05/2023	Dewas (M.P)
28/05/2023	Dewas (M.P)
30/06/2023	Dewas (M.P)

- Wind turbine rotor blade featuring a textured surface
- Wind turbine blades with diverse heights

RESULT

Natural and artificial fiber-reinforced hybrid composite materials are becoming increasingly popular due to their eco-friendly, recyclable, biodegradable, and user-friendly properties. Many researchers are working in this field to develop hybrid composites that can replace metals and alloys in engineering and technology without compromising weight, resonant capabilities, or cost. In the current work, banana and hemp fibers are hybridized with glass fiber to create hybrid composite laminates. Examination samples are then prepared from the composite laminates in accordance with ASTM standards, and the materials are tested under tensile, flexural, and impact loading conditions using a UTM and an impact testing machine, as shown in Figures (7–10). Table 2 displays the findings of the examination into the mechanical properties of the tested composite samples. In this section, a detailed parametric study is carried out based on different types of samples. The material properties of different samples are listed in Table 2, which shows the mechanical properties discovered using ASTM standards.

Table 2. (Mechanical Properties) [17].

Sample	Banana-glass fiber composites	Hemp-glass fiber composites	Banana-hemp-glass fiber composites
Tensile strength (MPa)	39.2	37.3	28
Flexural strength (KN)	0.51	0.28	0.52
Impact strength (Joules)	0.532	5.33	8.67

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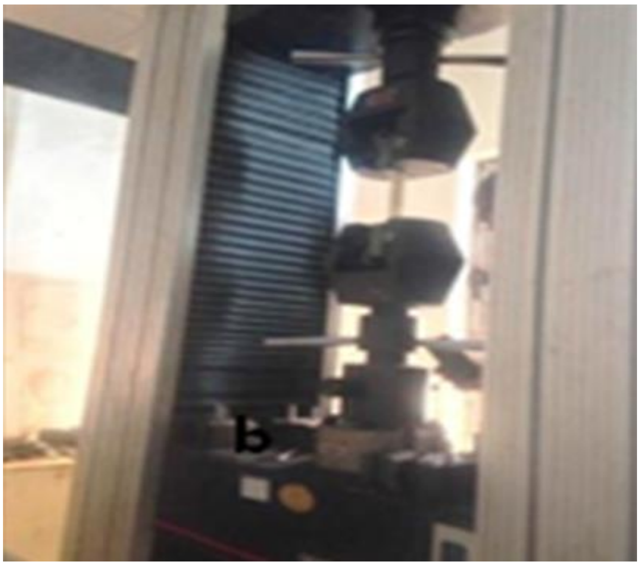

Figure 7. (UTM tensile test machine with ASTM-D638 standars) [19].

Figure 8. (UTM flexural strength test machine with ASTM-D790 standards) [20].

Figure 9. (Impact test machine with ASTM-A370 standards) [21].

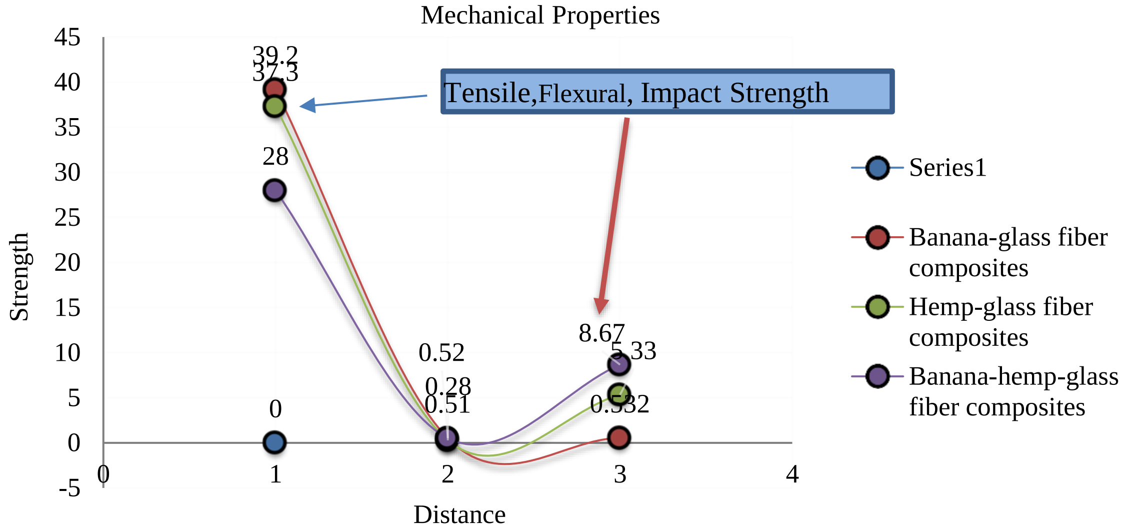

Figure 10. (Mechanical properties).

Table 3 illustrates the power and efficiency analysis of a wind turbine that was built with hybrid polymer composite materials at various tower heights. The findings are supported by observations for a range of rotor blade scenarios with uneven surfaces. The wind speed fluctuates between 4.8 and 6.6 meters per second as the tower height rises from ground level to 8.8 meters. This results in a change in rotational speed (RPM) from 35 to 52 shown in Figure 11 and a change in real power production from 0.0798 to 0.5428 watts. Rough surface blades were discovered to have the best performance and actual power of the wind turbine. Figure [12, 13] shows the changes in power, and efficiency at various tower heights and inlet velocities. Table 3 performance evaluation of a wind turbine employing a hybrid polymer composite under different tower elevations.

Table 3. (Power analysis)

Tower height	Inlet Velocity (m/s)	Outlet Velocity (m/s)	R.P.M	Actual Power (Watt)	Efficiency (%)
6.4	4.8	4.6	35	0.0798	0.00425
6.8	5.4	4.5	40	0.2800	0.01051
7.4	5.6	4.2	45	0.3828	0.01285
8.2	6.2	3.8	48	0.50351	0.0124
8.8	6.6	3.6	52	0.5428	0.01113

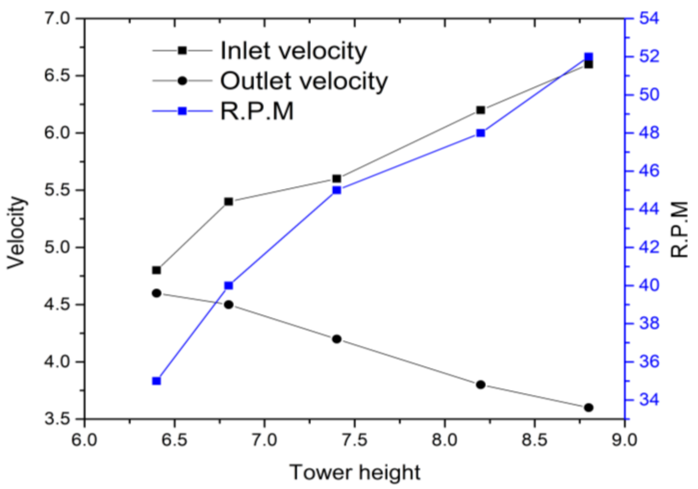

Figure 11. (R.P.M with respect to tower height and inlet velocity).

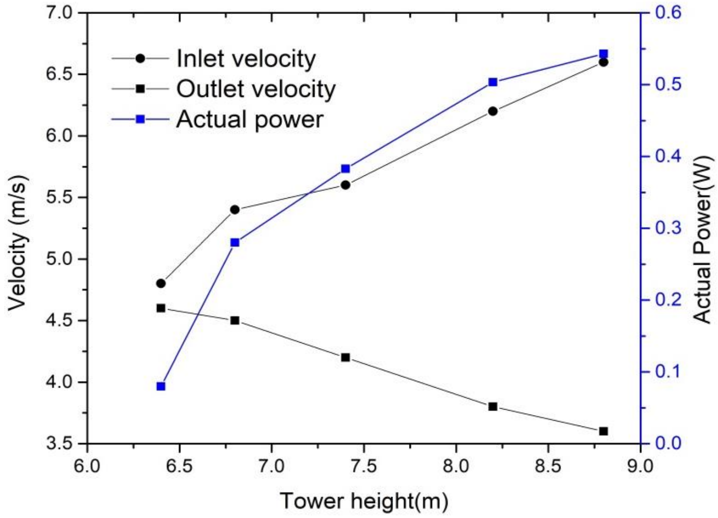

Figure 12. (Power analysis with respect to tower height and inlet velocity).

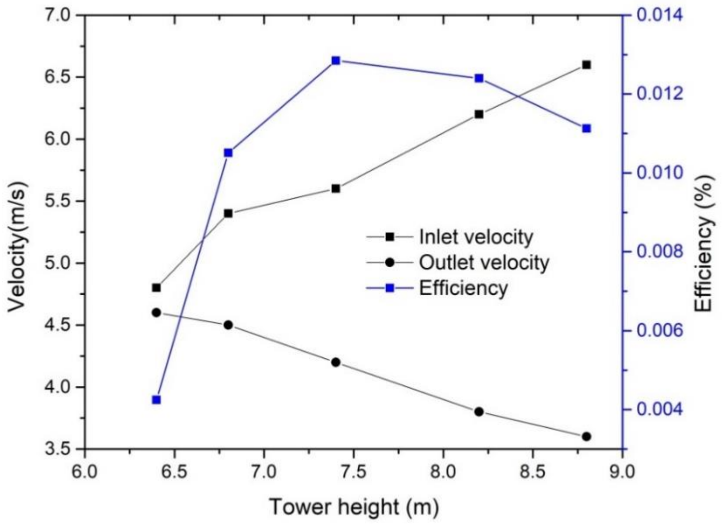

Figure 13. (Efficiency analysis with respect to tower height and inlet velocity).

CONCLUSION

Environmental Sustainability: Recycled carpeting, devoid of chemical additives and synthetic constituents, exemplifies eco-friendliness by mitigating environmental impact. Its recycling process diminishes landfill accumulation and conserves resources, contributing to a sustainable cycle. At the end of its service life, recycled carpeting can undergo further recycling for new carpeting or alternative recycled applications.

- *Mechanical Strength Comparison:* Hybrid composites combining banana and glass fibers exhibit superior tensile strength (39.2 MPa) compared to standard hemp-glass fiber reinforced counterparts (37.3 MPa). Moreover, composites reinforced with banana-hemp-glass fibers demonstrate enhanced flexural strength, achieving a maximum of 0.52 KN surpassing the 0.51 KN exhibited by banana + glass fiber composite.
- *Impact Resistance:* The impact strength of hybrid composites ranges from 5.33 to 8.67 Joules, underscoring their resilience and durability. Wind Turbine Performance: Findings stem from analyses conducted on horizontal axis wind turbines (HAWT) outfitted with aerofoil blades and advanced lift augmentation techniques. Optimal values for tower height and inlet velocity correspond to heightened turbine power output and efficiency. Notably, an increase in tower height and inlet velocity correlates positively with wind turbine power generation. Economic

Viability: Hybrid composite blades present a cost-effective solution with a lifespan of ten to fifteen years, offering long-term economic benefits.

Declaration of Interest

No potential conflict of interest was reported by the author(s).

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