



## Tensile and Flexural Analysis of a Hybrid Bamboo/Jute Fiber-reinforced Composite with Polyester Matrix as a Sustainable Green Material for Wind Turbine Blades

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### ABSTRACT

Recently, there has been a fast growth in research and investigation in the natural fibre composite due to the advantages of these materials, such as low environmental impact, low cost and good mechanical properties compared to synthetic fibre composites. Much effort has gone into increasing the mechanical performance and applications of natural fibres. This paper examines the mechanical properties of a novel hybrid bamboo/jute/polyester composite with five different combination ratios to achieve optimum properties. Fibre mats were prepared using manual mat making machine to reduce porosity in the composite. Samples were prepared and tested as per American Society for Testing and Materials (ASTM) standard. The result indicated that the hybrid composite with 10 % jute, 20 % bamboo and 70 % polyester shows highest tensile strength (yield strength of 72.03 MPa) compared to other combinations examined, and the hybrid composite with 0 % jute, 30 % bamboo and 70% polyester shows the highest flexural strength (133.9 MPa). The elongation of jute-reinforced composite was found to be the longest in the tensile test (2.98 mm).

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## 1. INTRODUCTION

The demand for energy is continuously increasing due to the increase in population, and by economic development. Different types of nonrenewable sources including coal, oil and natural gas have been excessively used to satisfy the energy needs. However, the risks of depletion of fossil energies and the impact of energy production from fossil fuels on the environment have led to a growing interest in using renewable and environmentally friendly energy sources [1]. The wind energy can be an alternative for electricity production. In Ethiopia, electricity is produced mainly from hydro, wind and geothermal sources. However, the majority of rural people have little access to grid electricity; thus, introducing small wind turbines as a cheap, safe and environmentally friendly alternative to the use of fossil energies is a vital engineering challenge

in a country like Ethiopia where the majority of people live dispersedly in rural areas. The blades of a wind turbine are critical and costly components of a wind turbine system. The selection of appropriate blade material plays a major role in the ultimate efficiency and overall cost of the wind turbine [2].

Wind turbine blades are manufactured mostly from carbon and glass fiber-reinforced composites. However, these synthetic fibers are costly and highly dependent on petroleum-based resources which are depleting rapidly and are not suitable for the environment [2]. Due to these and several other issues, the interest of the researchers has shifted on the use of natural biodegradable environmental friendly materials for wind turbine blades and other applications too. Natural fiber-reinforced composites can be used as a viable alternative due to its availability, renewability, recyclability, and low cost. Natural fibers such as sisal, bamboo, flax, hemp, jute, abaca and bagasse and others are cheap and easily available. However, natural fibers have common disadvantages such as a relatively low

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modulus of elasticity, high moisture absorption, and lower processing temperatures (fibers will begin to degrade when high processing temperature is used). In spite of these disadvantages, natural fiber-reinforced composites are promising candidate materials to fully or partially substitute the petroleum-based non-biodegradable polymer composites without sacrificing the basic criterion for the selection of materials for the wind turbine blades that is high strength and high stiffness, low density and adequate fatigue strength [3-6]. A comparison between natural plant fibers and E-glass is summarized in Table 1.

Many researches have been conducted over the previous and recent decades in the characterization and improvement of different natural fiber-reinforced composites for a wide variety of applications. Natural fibers generally exhibit considerable variation in mechanical properties from place to place; there are large deviations in values presented by different authors [3, 5, 7-19]. Kamrun N. Keya et al. [20] review the mechanical characterization of different natural fibers reinforced composites. The tensile strength of jute varies from 400 to 800 MPa and that of bamboo from

73 to 505 MPa. Mechanical test shows wide variation because of defects on the fiber, large amount of impurities attached to the surface and, some small empty holes. In this research, fibre mats were used to reduce this problem. Darshil U. Shah et al. [2] performed a novel comparative study by manufacturing a 3.5 m composite rotor blade from flax/polyester and E-glass/polyester. The test revealed that the blade fabricated from flax satisfies the structural requirements both under normal and worst case loading. Therefore, flax can be one of the suitable candidate materials for replacement of E-glass for small wind turbine blade applications. Holmes et al. [21] characterized a bamboo-poplar epoxy laminate for wind turbine blades application instead of common composites. This paper intends to examine the tensile and flexural behavior of a hybrid bamboo/jute/polyester composite with five different combination ratios to achieve optimum properties for small wind turbine blades application. Natural fibers can be improved by improving the fiber selection, extraction, treatment, and composite processing.

**TABLE 1.** Comparison between plant fibers and E-glass [2, 22]

Criterion	Properties	Plant fiber	E-Glass fiber
Environmental	Renewable source	Yes	No
	Biodegradable	Yes	No
	Recyclable	Yes	Partially
	Toxic(during incineration)	No	Yes
Energy consumption	In MJ/kg	Low (4–15)	Moderate (30–50)
Economical	Cost of raw fiber	Low	Higher relatively
	Density	Low (~1.35–1.55 g cm-3)	High (2.66 g cm-3)
Mechanical	Tensile strength	Low (~0.4–1.5 GPa)	Moderate (2.0–3.5)
	Abrasive to machines	No	Yes

In Ethiopia, natural fibers such as bamboo, jute, and sisal are abundantly available to be used as reinforcement. However, there is not sufficient scientific evaluation proof for their strength, which makes it difficult for engineers to use them as a potential core material for the production of wind turbine rotor blades. In this article, the tensile and flexural analysis of a locally available bamboo and jute fiber-reinforced composite is discussed. The reinforcement of hybrid cellulose fibers (bamboo and jute fiber) into Polyester matrix is studied with different combination ratios, which is considered as partially biodegradable composites. Different studies have shown that the hybridization of natural fibers improved the composite properties [23]. Thus, the hybridization aims to achieve optimum properties.

The main loads on the turbine blades are produced due to the wind and gravity. The blades must be strong, stiff and must have good fatigue life to bear the extreme loads. The blade also needs to be light to generate the power easily and to avoid resonance [24-26].

## 2. MATERIALS AND METHODS

**2.1. Materials and Equipment** Jute and bamboo fibers, polyester resins, wax, release agent, gel coat were used in the production of the composite. The equipment used included weighing balance, glove, mouth cover, safety cloth and shoes, roller, knives, eyeglass, stirrers, measuring cylinder, mold, universal testing machine, and other miscellaneous items.

Jute fibre: Jute (*corchorus* species) fiber has a high strength to weight ratio, high aspect ratio, and good mechanical and thermal properties [27]. Jute fiber is used as packaging material, carpet backing, ropes, door, furniture, floor tiles, yarns, and other applications [18]. Jute is one of the cheapest natural fiber and abundantly available in Ethiopia. In this research, the Jute plant was collected from a place around Bahir Dar, Amhara region, and extracted manually.

Bamboo fibre: The bamboo fiber was prepared from species of Ethiopian hollow bamboo. There are around 1000 species of bamboo recognized worldwide. For this work, hallow bamboo (*Oxytenanthera Abyssinca*) was taken from a specific place called at Injibara, Amhara region. Bamboo fiber is used as building materials, manufacturing bathroom products, decorating items, hygiene products, etc. [19].

Resin: Polyester resins have many advantages such as, good adhesive and mechanical properties, better resistance to fatigue and micro cracking, reduced degradation from water ingress, increased resistance to osmosis (surface degradation due to water permeability) and good performance at elevated temperatures etc. The resin used for this study is polyester resin with brand name of GP-1003 (General Purpose Polyester) and catalyst used is methyl ethyl ketone peroxide with 6 grams catalyst to 1 Kg of polyester resin.

**2. 2. Methods**

Fiber Preparation: The raw jute fibers were cleaned and dried under direct sunlight, and then the resinous waste materials were eliminated using a knife by rasping until the needed fiber dimensions were obtained. The bamboo fibers were also extracted manually from the slices and dried pieces as recommended by ASTM D3379 (fiber length between 20 - 35 cm and diameter has a range of 0.09 mm to 0.25 mm [28]). Fibre mats were prepared using manual mat making machine to reduce porosity in the composite.

Matrix and Hardener Preparation: The matrix used to fabricate composite was general-purpose polyester resin with methyl ethyl ketone peroxide catalyst. The mixing ratio was 6 grams of methyl ethyl ketone peroxide for 1 Kg of polyester resin.

Composite Specimen Preparation: In this study, samples of laminates were made using the hand lay-up



**Figure 1.** Fibre mat preparing method

method due to its simplicity and availability of the items. The mold used for preparing composites was made from rectangular wood according to ASTM D-790 and D-3039 for bending and tensile samples respectively [29, 30]. The specimen for bending test were 170 mm in length-, -20mm wide and 4mm thick and for those for tensile test were 250 mm long, 25 mm wide and 4 mm thick. The specimen were prepared with five different combination ratios to achieve optimum properties.

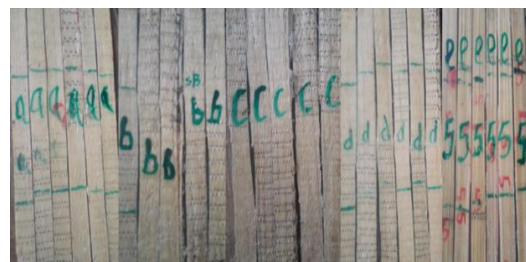
Mechanical testing: Five different sample specimens were tested a minimum of five times repeatedly for each combination ratio in universal tensile tester of a capacity 100 KN and set to 5 mm/min.

**3. RESULT AND DISCUSSION**

The tensile tests were carried out according to ASTM D-3039 and the three-point bending tests were carried out according to ASTM D-790 in a universal tester. Samples were tested five times repeatedly for every five different combinations consist of bamboo/jute as a reinforcing agent and polyester as a polymer matrix.

**TABLE 2.** Sample combination ratios for tensile test

Different samples	Weight percentage (Jute/Bamboo/Polyester)	Density, kg/m <sup>3</sup> (Average)
Sample A	15/15/70%	917
Sample B	20/10/70%	1056
Sample C	10/20/70%	1047
Sample D	30/0/70%	1087
Sample E	0/30/70%	1142

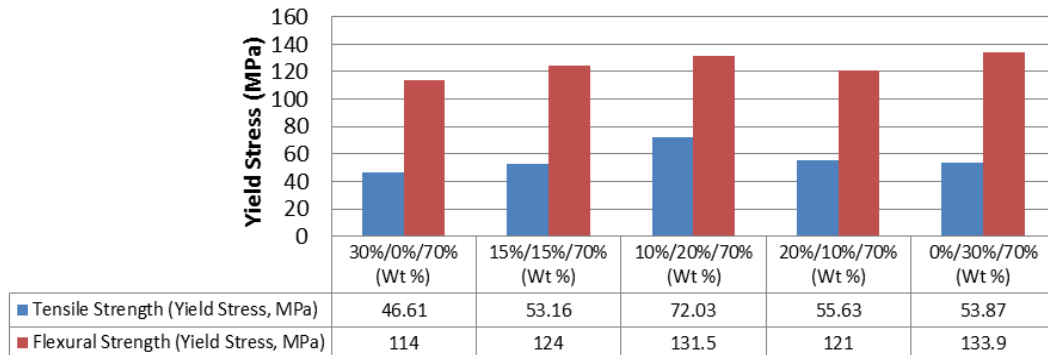


**Figure 2.** Five different sample specimens for test



**Figure 3.** Universal Tester Machine (Bending Test)

**Comparison of Tensile & Flexural Strength of Hybrid Jute/Bamboo/Polyester Composite**



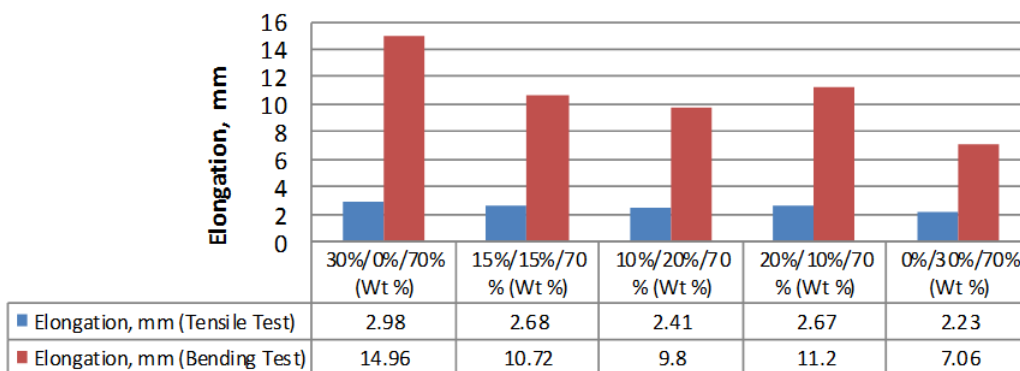
**Figure 4.** shows the result of the average tensile and flexural strength properties of the five different samples

The result indicated that the hybridization of the constituent with 10 % of jute, 20 % of bamboo and 70 % of polyester shows the highest tensile strength (yield strength of 72.03MPa) compared to other combinations examined. Figure 4 shows the result of the average flexural properties of the five different samples. Flexural strength is the stress in the composite material just before it yields in a flexural test. The result indicated that the constituent with 0 % of jute, 30% of bamboo and 70% of polyester shows the highest flexural strength (133.9 Mpa) compared to other hybrid combinations examined which contain no jute fibers.

Many papers report the results of tensile strength which describes the maximum stress that the composite can withstand before failing; whereas in this paper, the results yield strength are presented which is the minimum yield stress under which the composite deforms permanently. Figure 5 shows the results of the average elongation in tensile test (the ratio of the length of the stretched sample to that of the original length at the

break) of the five different reinforced composites. The elongation of jute fiber-reinforced composite at break was found to be the largest (2.98 mm); while bamboo reinforced composite had the smallest elongation of 2.23 mm, and a hybrid composite of 10 % jute and 20 % bamboo had 2.41 mm elongation. Figure 5 also presents the results of the average elongation at bending break and the jute fiber-reinforced composite found to have the largest value (14.96 mm); while bamboo reinforced composite had the smallest elongation of 7.06 mm, and a hybrid composite of with 10 % jute and 20% bamboo had 9.8 mm elongation. Honey Banga et al. [31] studied the effect of bamboo fibres at different weight percentages (20, 30 and 40) to modify epoxy resin, and found that 30 wt% of bamboo fibre mixed epoxy gives optimum mechanical properties. Commonly natural fibers are non-uniform with irregular cross sections that make their structures quite unique and much different with synthetic fibers such as glass fibers, carbon fibers, etc. [32].

**Comparison of Elongation of Hybrid Jute/Bamboo/Polyester Composite**



**Figure 5.** Comparison of Elongation at break for five different samples

#### 4. CONCLUSION

This study aimed at developing low cost and environmentally friendly composite material for wind turbine blade applications; the tensile and flexural behaviors of a bamboo-jute laminate with five different combination ratios were characterized. The experimental analysis has shown that the hybridization has improved the tensile properties of the composite laminates. The hybridization with 10 % jute, 20 % bamboo and 70 % polyester shows the highest tensile strength compared to other combinations examined. However, those with no jute, 30 % bamboo and 70% polyester show the highest flexural strength (yield strength of 133.9 MPa). This study reveals that both jute and bamboo fibers were successfully used as reinforcement fibers in hybrid composites. It is suggested that this composite be used in the small wind turbine blades application. Checking its structural integrity both under normal and worst case loading is recommended for future study.

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اخیراً، به دلیل مزیت مواد مرکب طبیعی در مقایسه با کامپوزیت‌های الیاف مصنوعی، از جمله اثرات زیست‌محیطی کم، هزینه‌ی پایین و خواص مکانیکی خوب نسبت، رشد سریع در تحقیقات وجود داشته است. تلاش زیادی برای افزایش عملکرد مکانیکی و کاربردهای الیاف طبیعی انجام شده است. در این مقاله به بررسی خصوصیات مکانیکی کامپوزیت بابو/جوت/ پلی‌استر هیبریدی با پنج نسبت ترکیبی مختلف برای رسیدن به خواص بهینه می‌پردازیم. برای کاهش تخلخل موجود در کامپوزیت، ورقه‌های الیاف با استفاده از دستگاه ساخت ورقه‌ساز دستی تهیه شدند. آزمون‌ها طبق استاندارد انجمن آزمایش و مواد آمریکا (ASTM) تهیه و آزمایش شدند. نتایج نشان داد که کامپوزیت ترکیبی حاوی ۱۰٪ جوت، ۲۰٪ بامبو و ۷۰٪ پلی‌استر بالاترین استحکام کششی (استحکام تسلیم ۷۲/۰۳ MPa) را نسبت به سایر ترکیبات مورد بررسی نشان می‌دهد و کامپوزیت ترکیبی با ۱۰٪ جوت، ۳۰٪ بامبو و ۷۰٪ پلی‌استر بالاترین مقاومت خمشی (۱۳۳/۹ MPa) را نشان می‌دهد. ازدیاد طول کامپوزیت تقویت شده با جوت در آزمون کشش (۲/۹۸ میلی متر) از همه نمونه‌ها بالاتر بود.

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