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Effect of Glass Fillers on Mechanical Properties of Jute/Polyester Composites for Wind Turbine Blades

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Abstract

One of the biggest obstacles to use natural fibers for industrial applications is their poor mechanical and water-absorbing qualities. The study aims to improve the jute/polyester composite's void fraction, rate of water absorption, strength of impact, tensile strength and composite degradation by using glass fillers and apply in making small wind turbine blades. Jute fiber of 20, 30 weight percentages and fillers of 2.5%, 5%, 7.5% and 10% weight percentages were utilized to make the composites. The experiments were conducted in compliance with ASTM guidelines. Glass fillers improved the jute/polyester composite's void fraction, rate of water absorption, strength of impact, tensile strength and composite degradation. For dry 20/80 jute/polyester composites, glass fillers demonstrated a maximum increase of 61.9% strength of impact and a tensile strength of 21.5% while 30/70 composites of dry form showed an increment in strength of impact and tensile strength by 46.9%,12.2% respectively. Additionally, 20/80 composite's water absorption was decreased by 50% and by 44.1%. for 30/70 composites. The 5-weight percent glass filled 30/70 composite had the highest tensile (14.17%) and impact strength values (14%), while the 10-weight percent glass filled 20/80 composite had the lowest water absorption. Addition of glass fillers resulted in improvement of void fraction by 21.3% for 20/80 composites and 26.7% for 30/70 composites.

Keywords: jute fiber; glass filler; void fraction; rate of water absorption; strength of impact; tensile strength and composite degradation

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1. Introduction

Renewable energy has emerged as a more viable choice for exploitation and consumption in recent years, with regard to the global energy revolution. Of these renewable energy sources, wind energy is particularly noteworthy [1,2]. According to Saeed et al., (2020) the only potential barrier to wind energy's utilization has been its exponential growth in recent years, which has allowed it to realize its full potential [3].

Wind turbines are expected to last for 20 years and at the end a sizable structure will eventually need to be disposed of in the environment when the service ends. Wind turbines are still made of materials that are not biodegradable. Because of this, engineers and scientists are always working to replace the current wind turbine material system with biodegradable materials. Natural fiber reinforced composites, which are biodegradable and possess superior mechanical properties, comprise one such class of materials.

The use of composite materials has tremendously aided the development of wind turbines because of its good mechanical properties and low weight [4]. Fiber-reinforced polymer composites are one type of composite material utilized in wind turbine blade development. Recent research demonstrated that natural fibers can potentially replace synthetic fibers, despite the fact that synthetic

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fibers are not ecofriendly despite their mechanical advantages, such as their elevated ratio of strength-to-weight. Compared to synthetic fibers, natural fibers have lower densities and are primarily derived from plants.

The most crucial component of a wind turbine is its blades [5], which are subject to a variety of load circumstances, including gravitational, cyclic, and dynamic-wind forces [6,7]. When developing the blade's structural design, efforts must be made to demonstrate a high strength-to-weight ratio of materials [8,9]. However, a number of other parameters, like the kind of airfoils [10], turbine geometry, material type, etc., further influence the blade weight. Therefore, to achieve stronger blade surface quality, careful material selection along with advanced production techniques is required [11].

Most wind turbine blades are made of polymer composite materials reinforced mostly with glass fibers, while some also contain carbon fibers or carbon fibers in hybrid combinations with glass fibers [12]. The process's ultimate goal is to create a material with hybrid features or better desirable attributes than base materials. The two major components of a composite are the reinforcement and the matrix. Matrix is a uniform polymer substance, helps to distribute stress, provide form, toughness and protect the fibers from structural stresses and unfavourable chemical reactions. In situations involving compressive loading, the matrix also stabilizes the composite to prevent buckling [13].

The thermoset polymers that make up the majority of matrix resins include vinylester, polyester, and epoxy. Nearly 80% of commercially utilized composites use polyester-based matrix. In many applications, epoxy resin has now taken the place of polyester resin. Numerous positive attributes of jute fiber include its large source, affordability, quick degradability, renewable nature, and environmental friendliness [14].

Fillers are among the most effective hybrid materials for enhancing the properties of fiber-reinforced composites and reducing the cost of the finished product [15]. Many researchers have tried to use a range of natural and synthetic fillers, such as graphene powders, wood dust flour, wood charcoal and carbon nanotube fillers to enhance the performance of fiber-reinforced polymeric composite materials [16]. The most widely utilized reinforcements are glass and carbon fillers due to their unique properties and versatility. Glass fiber-reinforced polymers (GRP) are the most widely utilized composite materials in the wind turbine industry as it offers the required qualities at a reasonable price [17]. These materials enhanced the ratio of strength-to-weight allowed for the production of larger capacity blades that could endure a variety of wind conditions [18]

In the present study, glass fillers was used to strengthen jute polyester composite and provides a brief description of the physical and mechanical characteristics of materials that may find use in the development of wind turbine blades.

2. Materials and Methods

Materials: We bought 0.1 mm Fasco glass fillers from A P Polymers in New Delhi. Jute, butanox hardener, un-saturated polyester resin and all other ingredients were purchased from a nearby producer of composite materials.

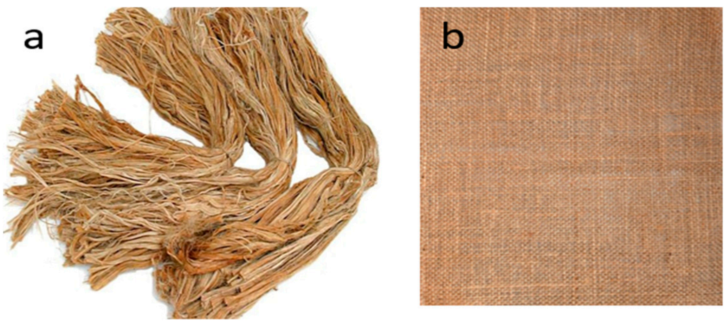

Figure 1. a: Brown jute fiber; b: Composite.

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Treatment of fiber: Gum is an undesirable substance present on the surface of jute fibers which interfere with its performance and function. Chemical degumming is the method to remove impurities. The 10-inch samples were first cut, combed, oven-dried and utilized for subsequent procedures. In accordance with a procedure described previously by Sever et al the fibers were treated in three steps [19]. In step one samples were treated in one bath with 1% H_2SO_4, and in step two in another bath with hydrogen peroxide (H_2O_2), sodium silicate (Na_2SiO_3) and trisodium phosphate (Na_3PO_4). The two steps were performed with a 1:20 fiber-to-liquor ratio in a bath for 30 minutes at 50 °C. The breakdown of hydrogen bonds in the cellulose is caused by the alkaline treatment. Consequently, it makes the surface rougher, which helps the fibers and matrix interact more successfully. With the same liquid ratio as in the earlier steps, the fibers were treated with NaOH, Na_2SiO_3, Na_2SO_3 and $MgSO_4$ for 90 minutes under 80°C in stage three. They were then washed three times with distilled water. Prior to the composite preparation, samples were oven dried at 70 °C for 3hrs.

Preparation of matrix: Polyester resin was combined with butanox M-60 hardener to create the matrix. Additionally glass fillers of 2.5, 5, 7.5 and 10 at weight percentages are added to create a modified matrix. Since maximum outcomes are recorded at filler loading less than 10% the glass fillers were manufactured below 10 weight % [20,21]. For even dispersion of the fillers in the modified matrix, a mechanical stirrer running at 200 rpm for 15 minutes was employed to mix a predetermined quantity of fillers and resins in a container. After adding the proper amount of hardener, the matrix was agitated for two more minutes.

Preparation of Composite: An SK-160B twin roll mixer was used to mix the polyster resin with jute fiber (JF). The roller spacing was between 0.2 and 0.5 mm, and resin was fed from the top of the roller at 140 °C [22]. Jute fibers were added for 8–10 minutes of mixing after the resin had been processed for 10minutes. When the material was formed into a film, it was scraped off, leaving a smooth surface. For hot pressing, a QLB plate vulcanizing press machine was employed. After mixing, the premixed film was poured into the mold. According to Lee et al., [23] the composites were made using 10 weight percent and 30 weight percent jute fibers increases the composites flexural strength by 4% and 8.6 % whereas Shah etal; and Charlet et al. reported that although fiber contents are restricted to 55–65% of weight, larger fiber amounts increase stiffness [24,25]. When it had completely cooled, the mold was removed and demolded. When graphite fillers were added to 20% fiber-reinforced composites, strength of impact improved by 146% and their tensile strength by 28% at 15% granite filler content as opposed to 0% granite filler [26]. Glass fillers are added to both 20 and 30 weight percent fiber-loaded composites to compare the results and use the best ones. Filler-free matrix with jute fibers were used to create two laminates (L1 and L2). The modified matrix and jute fibres were used to create eight (L3–L10) composites.

Water absorption: ASTM D 570–98 (1998) guidelines were used to prepare specimens with the dimensions of 74.6 x 23.5 x 3mm^3 which are pre weighed and immersed in water at room temperature. At 24-hour intervals, the specimens were taken out of the water and weighed. Any remaining water was removed from the specimen's surface using clean cotton. The specimens were weighed after 20 days of immersion and then re-submerged in the water at predetermined intervals until saturation had been reached. A digital balance was used to measure the weight with a precision of 0.01 g. Following equation is used to assess the specimen's water absorption behaviour

$$Ma = \frac{Mw - Mo}{Mo} X\ 100\% \qquad (1)$$

Ma=The specimen's percentage of water absorption, Mw= weight of wet specimen, Mo= dry specimen weight.

Test for tensile strengths: Experiments were performed in compliance with ASTM D3039 guidelines with 100 KN load cell of MTS universal testing machine, at 1 mm/min cross speed under room temperature (Model 810-Microcomputer Controlled Electro-hydraulic Servo Universal Testing Machine). Each composite had cut into five specimens, measuring 240 x 10 x 4 mm^3 each. To determine the effects of water absorption and hybridization on the deterioration of composites tensile strength, the test was conducted using specimens that were submerged in water for 20 days. Three different temperatures were used for water immersion: room temperature, 50 °C, and 70 °C.

Composites Void Fraction: The following formula was used to get the composites' void fraction (Vfr)

$$Vfr = \frac{\rho t - \rho exp}{\rho t} \qquad (2)$$

ϱt = theoretical, ϱexp =experimental densities of the composite.

Test for impact: ISO 179-1 (2010) guidelines was followed for conducting the charpy impact test. Five unnotched specimens, each measuring 85 x 15 x 6 mm^3, were made for each test. Wet specimens were created by immersing in a water bath for 20 days in order to examine the impact of rate of absorption of water on the deterioration of the impact strength of composite. Pendulum Impact Testing Machine, Model: DI-Impact 300 with impact energy 300J was used to perform the impact test. The specimens were pounded in both normal and flat direction. The experiments were conducted at room temperature.

3. Results and Discussion

Two laminates (L1 and L2) were made using the jute fibers with polyester and filler-free matrix. Eight (L3–L10) laminates were made using polyester resin with glass fillers, a modified matrix and jute fibers (Table 1)

Table 1. Content of composite and its classification.

Laminate	Classification	Composition
L1	Composite 20/80	20 wt% jute fiber + 80 wt% polyester
L2	Composite 30/70	30 wt% jute fiber +70 wt% polyester
L3	G 2.5, Composite 20/80	Glass filler (2.5% of the 20/80 composite) + 20/80 composite
L4	G 5, Composite 20/80	Glass filler (5wt% of the 20/80 composite) + 20/80 composite
L5	G 7.5, Composite 20/80	Glass filler (7.5wt% of the 20/80 composite) + 20/80 composite
L6	G10, Composite 20/80	Glass filler (10wt% of the 20/80 composite) + 20/80 composite
L7	G2.5, Composite 30/70	Glass filler (2.5wt% of the 30/70 composite) + 30/70 composite
L8	G 5, Composite 30/70	Glass filler (5wt% of the 30/70 composite) + 30/70 composite
L9	G 7.5, Composite 30/70	Glass filler (7.5wt% of the 30/70 composite) + 30/70 composite
L10	G 10, Composite 30/70	Glass filler (10wt% of the 30/70 composite) + 30/70 composite

Water absorption: Table 2 depicts the water absorption of all composites. The 20/80 and 30/70 composites of pure jute and polyester resin showed the highest water absorption (L1 and L2). Since jute fibers are hydrophilic, the proportion of water absorption increases as the amount of jute fibers in the composites increased.

Table 2. Water absorption percentage at composite's saturation.

Laminate	% of water absorption (Average % ± SD)
L1	6.4 ± 0.16
L2	6.8 ± 0.23
L3	5.6 ± 0.04
L4	4.7 ± 0.07

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L5	3.8 ± 0.11
L6	3.2 ± 0.05
L7	5.8 ± 0.16
L8	5.1 ± 0.12
L9	4.2 ± 0.05
L10	3.8 ± 0.16

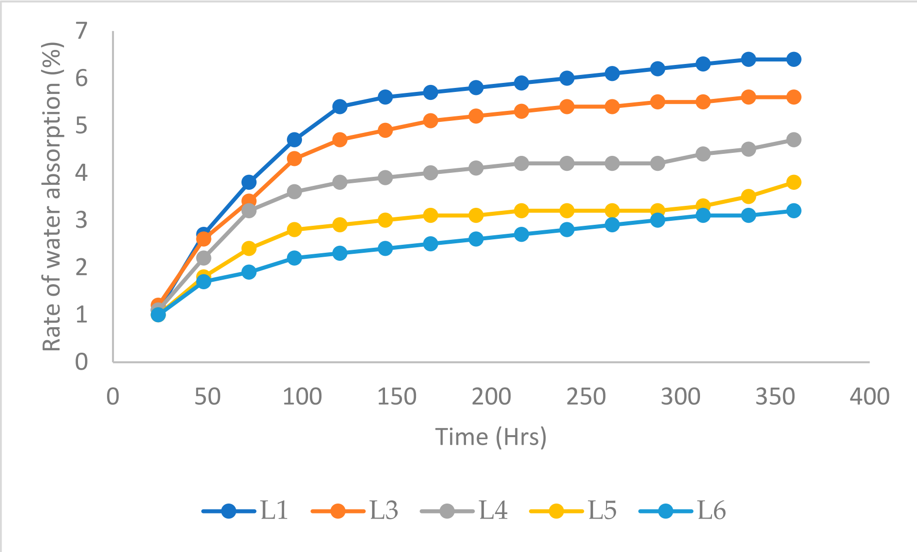

Figure 1. Impact of glass fillers on 20/80 composites water absorption rate.

The use of glass fillers significantly reduced the percentage of water absorption of the 20/80 and 30/70 jute/polyester composites. This is because glass and jute fibers hybridize and lowers the maximum absorption. Hybridization is anticipated to enhance the mechanical and physical properties of the polymer composites in addition to reducing moisture absorption [27]. By filling the gaps and lowering the content in the composites, glass fillers can prevent water particles from penetrating the materials. The hybrid 30/70 jute/polyester composites exhibited higher water absorption than the hybrid 20/80 jute/polyester composites with the same quantity of glass fillers (Figures 2 and 3). In comparison to the laminate L1, L6 has the lowest water absorption of all the glass-filled composites (3.4%) with a reduction of 50% compared to L1. Of the glass-filled composites, laminates L10 (G 10, Composite 30/70) and L5 (G 7.5, Composite 20/80) exhibited the second-lowest water absorption (3.8%). Compared to the glass-filled 30/70 composites with the lowest water absorption (L10), the glass-filled 20/80 composites with the lowest water absorption (L6) were 5.8% less absorbent.

Tensile Strength: Figure 3 and 4 illustrates the increase of composites tensile strength with glass fillers. Among 20/80 composites, the composite with 7.5 weight percent glass fillers (L5) had a higher recorded tensile strength and among 30/70 composites, composite with 5 weight percent glass fillers (L8) had the highest value. This is because the 20/80 composites have a larger volume of polyester than the 30/70 composites, which allows glass fillers to be added up to 7.5 weight percent before the tensile strength starts to decrease due to poor bonding. Results also show that, as the glass content surpassed 5 weight percent, tensile strength of 30/70 composite decreased. Tensile strength decreases as glass fillers are added because of the aggregation of glass fillers in the polyester material and the poor connection between the reinforcement and matrix [28]. Addition of glass fillers increase tensile strength by a maximum of 12.2% for dry 30/70 composites and 21.5% for dry composites 20/80. The dry G5 30/70 composite (L8) had the highest tensile strength, which was 14.17% greater than the G 7.5 20/80 composites with maximum tensile strength (L5). For improved tensile strength, glass fillers are preferred in 30/70 composites over 20/80 composites. It was observed that the dry samples tensile strength was higher than the corresponding wet samples. Tesfay et al. claim that water absorption can quickly debond, delaminate and lose structural integrity, plasticizing the system and reducing its tensile strength [29].

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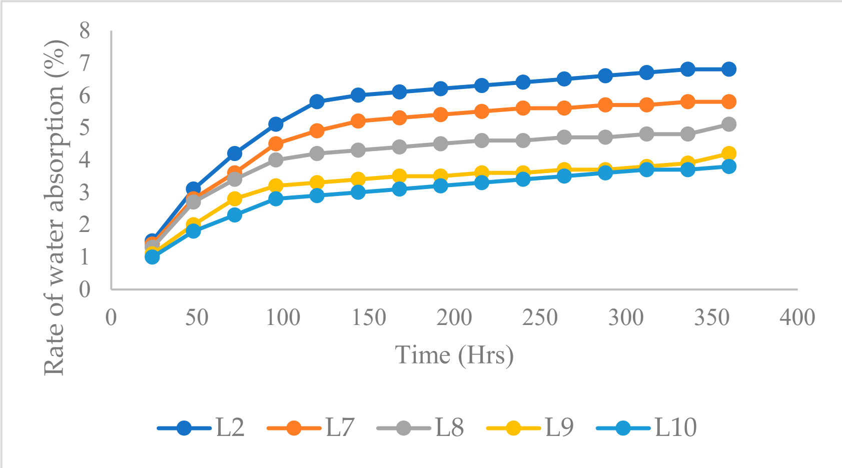

Figure 2. Impact of glass fillers on 30/70 composites water absorption rate.

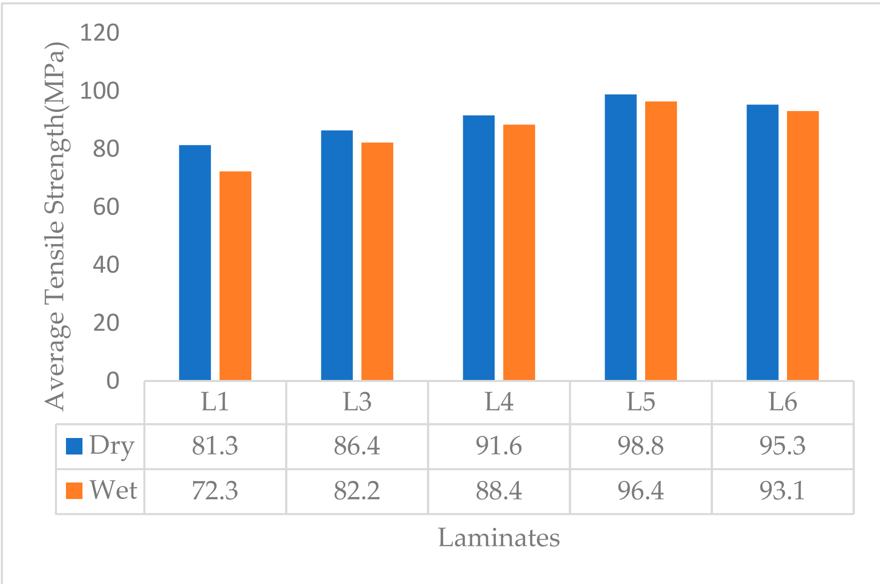

Figure 3. Impact of glass fillers on 20/80 composites tensile strength.

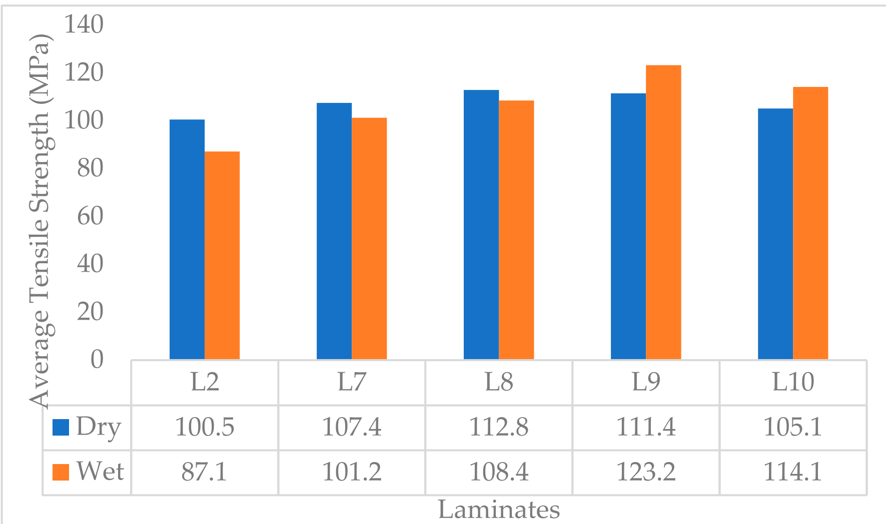

Figure 4. Impact of glass fillers on30/70 composites tensile strength.

Void fraction: Table 3 shows that, on comparing the laminates (L1 and L2) without glass fillers the void fraction of L2 is 18% lower than that of L1. Addition of glass fillers resulted in improvement of void fraction by 21.3% for composites 20/80 and 26.7% for composites 30/70. The highest strength of impact is observed in G 10 30/70 composite (L10) with 16.73% more than the value among the glass-filled 10 G 20/80 compo-sites (L6). According to Mishra et al., the void content reduces as the fiber content increases. The presence of voids significantly influences the mechanical properties and overall efficiency of composites [30]. An increased amount of voids usually suggests reduced fatigue resistance and greater vulnerability to penetration and weathering due to moisture exposure. It is evident that all filled composites have densities that are higher than those of unfilled composites. This includes the fact that adding fused silica, glass powder and mineral silica has increased the density of composites and void fraction [31].

Table 3. Different composites void fraction.

Laminate	Composition	Theoretical Density (ρt g/cm³)	Experimental Density (ρ *exp* g/cm³)	Void Fraction (%)
L1	20 wt% jute fiber + 80 wt% polyester	1.166 ± 0.018	1.109±0.020	4.89±0.002
L2	30 wt% jute fiber +70 wt% polyester	1.148 ± 0.016	1.102±0.018	4.01±0.003
L3	2.5% Glass filler of the composite 20/80 + composite 20/80	1.175 ± 0.028	1.108±0.031	5.70±0.003
L4	5% Glass filler of the composite 20/80 + composite 20/80	1.178 ± 0.022	1.110±0.023	5.77±0.001
L5	7.5% Glass filler of the composite 20/80 + composite 20/80	1.182±0.019	1.112±0.024	5.92±0.005
L6	10% Glass filler of the composite 20/80 + composite 20/80	1.184±0.025	1.114±0.025	5.93±0.001
L7	2.5% Glass filler of the 30/70 composite) + 30/70 composite	1.168 ± 0.026	1.116±0.027	4.45±0.001
L8	5% Glass filler of the composite 30/70 + composite 30/70	1.172 ± 0.028	1.117±0.029	4.69±0.001
L9	7.5% Glass filler of the composite 30/70+ composite 30/70	1.174 ± 0.024	1.118±0.029	4.77±0.005
L10	10% Glass filler of the composite 30/70 + composite 30/70	1.180 ± 0.029	1.120±0.031	5.08±0.002

Test for impact: Glass fillers have improved the impact strength of the 20/80 and 30/70 composites, as seen in Figures 5 and 6. The composite of 20/80 composition with a weight of 7.5% filler composition (L5) and with a weight of 5 percent filler composition of 30/70 composites (L8) had the highest impact strength, which was comparable to the tensile strength. Biswas et al. (2019) claim that adding more glass fillers reduced the composites' impact strength because filler agglomeration in the polyester causes poor fiber-matrix interaction and reduced debonding resistance [32]. Laminates (L1 and L2) without glass fillers are less impact-resistant than the matching composite. Addition of glass fillers resulted in improvement of impact strength of dry composites 20/80 by 61.9% and 46.9% for dry composites 30/70. Dry composite of 5 G 30/70 (L8) exhibited the greatest impact

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strength when compared to the glass-filled composites, showing an increase of 14% over the highest value recorded for the glass-filled 20/80 composites (L5). Compared to their dry counterparts, wet composites have a comparable trend in impact strength.

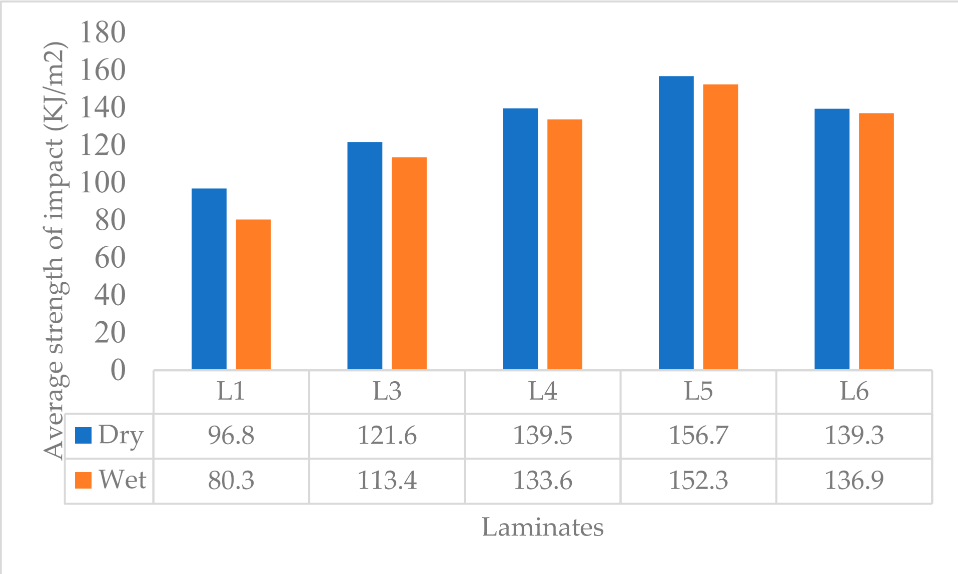

Figure 5. Impact of glass fillers on strength of impact of 20/80 composites.

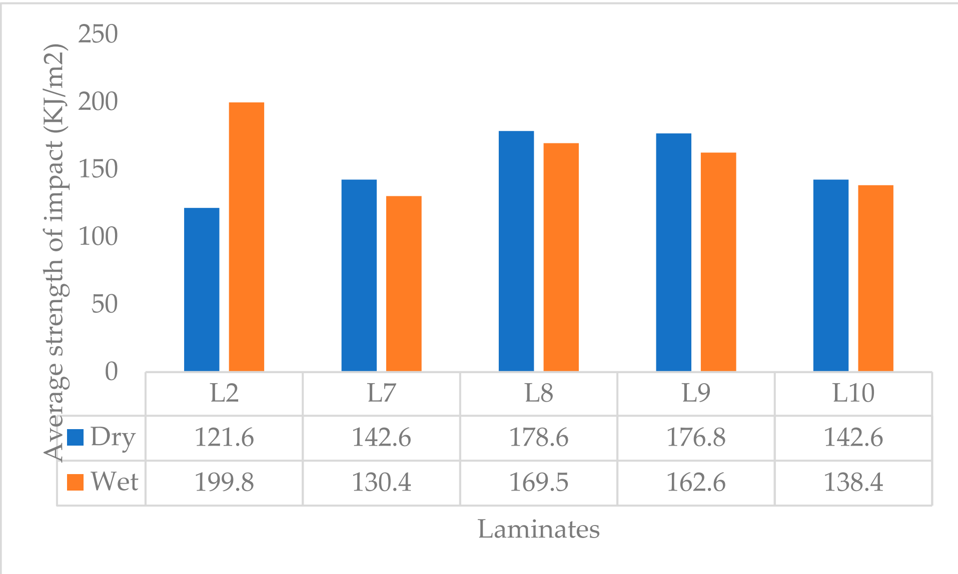

Figure 6. Impact of glass fillers on strength of impact of 30/70 composites.

Composite's degradation: The composite’s tensile and impact strengths deteriorated as a result of water absorption (Figures 7–10). The laminates without fillers (L1 and L2) had the highest percentage of deterioration. The decline in tensile strength and impact strength was noted to be 13.5% and 18.9%, respectively, for the 30/70 composites (L2). More hydrophilic jute fibers in L2, increased the water absorption rate and made to deteriorate the strength of impact and tensile strength more quickly than in laminates L1. The deterioration of the composites was reduced through the incorporation of glass fillers. The composites 20/80 and 30/70 showed a continuous decline in tensile and impact strength until 10 weight percent glass fillers were added. When compared to L1 laminates, glass-filled composites 20/80 of 10 weight percent (L6) show a least degradation (2.2%), equivalent to an 80.71% reduction. Compared to the similar 30/70 hybrid composites, the 20/80 hybrid composites have demonstrated less deterioration.

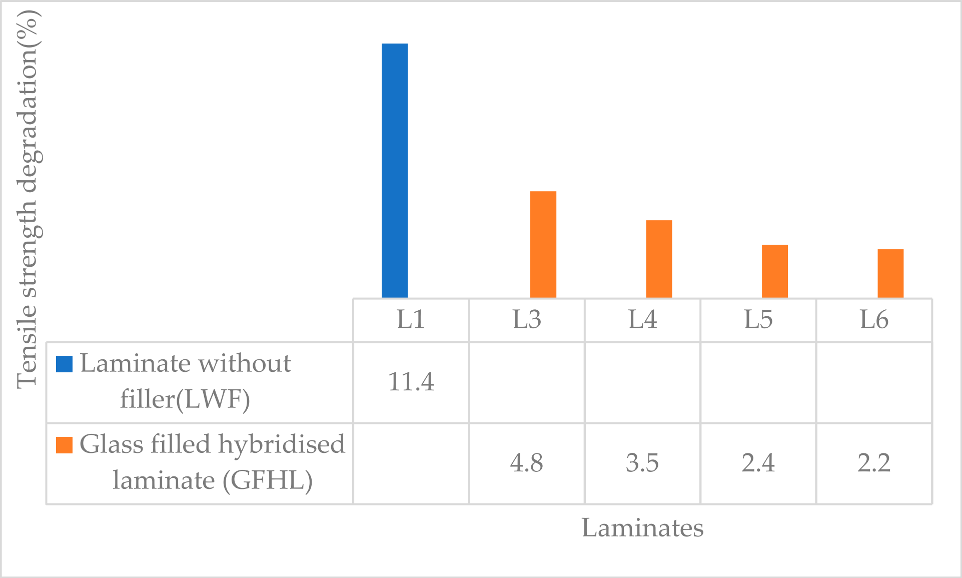

Figure 7. Degradation of tensile strength of 20/80 composites with glass fillers.

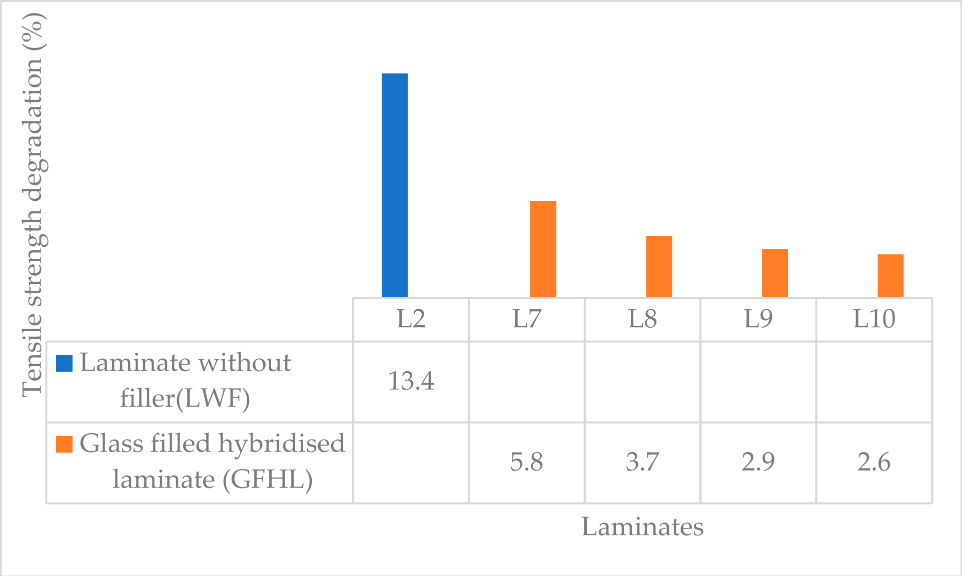

Figure 8. Degradation of tensile strength of 30/70 composites with glass fillers.

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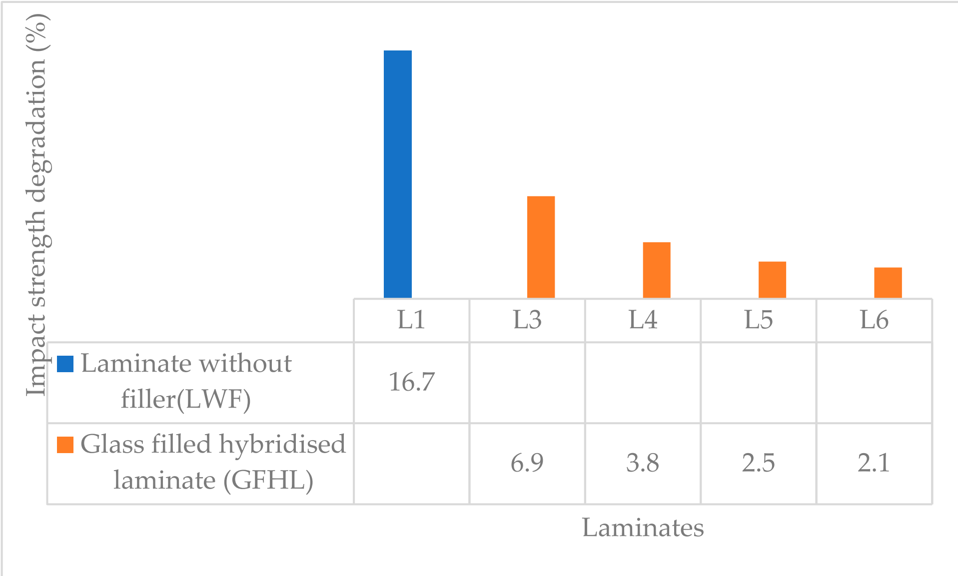

Figure 9. Degradation of impact strength of 20/80 composites with glass fillers.

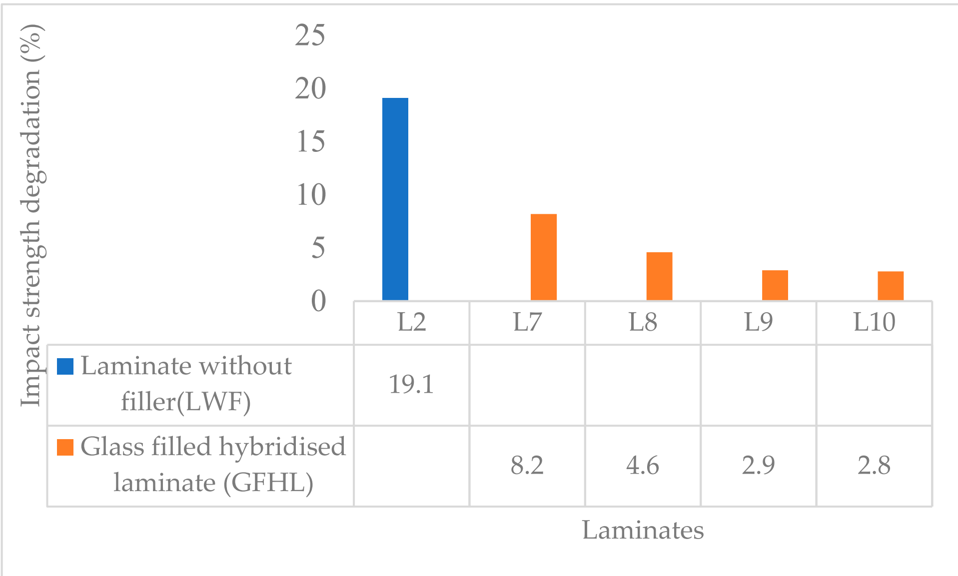

Figure 10. Degradation of impact strength of 30/70 composites with glass fillers.

4. Conclusion

Composites reinforced with natural fibers is a viable alternative to the traditional material systems used in the wind industry. Hybridized jute/polyester composites with glass fillers at the proper mass fraction shown enhanced water and mechanical absorption which can be utilized to make wind turbine blades. The fillers had a significant impact on the degrading characteristics, water absorption, void fraction and impact strength with a moderate impact on the tensile strength. Better tensile and impact strengths are achieved by adding fillers to the 30/70 composites but decreased water absorption and degradation qualities make the 20/80 composites better.

Author contributions: Conceptualization, B.N.R.; methodology, B.N.R., and S.K.; validation, C.S.R., B.N.R., A.G.T., and S.K.; formal analysis, C.S.R., B.N.R., A.G.T., and S.K.; investigation, C.S.R., and B.N.R.; writing—original draft preparation, C.S.R.; writing—review and editing, B.N.R., S.K., and A.G.T.; visualization, C.S.R., B.N.R., and S.K.; supervision, B.N.R and S.K. All authors have read and agreed to the published version of the manuscript.

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Competing interests: The authors have no competing interests.

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