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The Effect of Natural Weathering on Mechanical Properties of Silane Treated Bamboo Fibre Reinforced PLA/HDPE Composites for Electrical Insulation Application

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Abstract

Combination of bioplastics with petroleum-based plastics are widely used in various type of application due to the increased demand of sustainable products. Thus, this study investigated on the mechanical properties of bamboo fibre reinforced biodegradable PLA/HDPE with a specific focus on the potential as electrical insulation materials. The bamboo fibre was chemically treated with alkali and silane coupling agent for surface modification prior to produce composites via injection moulding at the bamboo fibre composition range from 3% to 7%. The untreated and silane treated bamboo fibre was characterized via Particle Size Analyzer (PSA) and Fourier Transform Infrared Spectrometry (FTIR). Further, the effect of natural weathering on tensile properties of bamboo fibre reinforced PLA/HDPE composites were assessed via Universal Tensile Machine (UTM), in terms of tensile strength, Young's Modulus and elongation at break. The results showed that 90% (D90) of the product was below than 65.8µm. The presence of C-O, CC-H, Si-O, Si-O-C, and Si-C bonding were successfully discovered from silane treated bamboo fibre using FTIR indicating improvement on hydrophobicity of the bamboo fibre. Natural weathering exposure lowers the tensile properties for both untreated and silane treated composites due to occurrence of photo-degradation of the composites. In conclusion, silane treatment and natural weathering greatly affects the tensile properties of bamboo fibre reinforced PLA/HDPE composites.

1. Introduction

In the modern era, the growing concerns regarding pollution and energy scarcity have sparked an increased interest among scientists and researchers in biomass composites, particularly those reinforced with natural fibers [1,2]. Additionally, natural fibre reinforced polymer composites/biocomposites have gained significant attention due to their natural availability, biodegradability, and environmental stability [3]. This global trend towards biocomposite research is continuously gaining momentum, as researchers worldwide are actively seeking alternative solutions to conventional materials that contribute to environmental harm. Moreover, polymer composites offer several advantages over traditional composites materials [4].

Natural fibers, such as coir, sisal, jute, lignin, and bamboo, have gained attention in textile industry, furniture and interior design, road construction, automotive, packaging including electrical insulation and biocomposites and bioplastics. This application natural fibre is due to their low cost and renewable nature [5,6,7]. These plant fibres exhibit excellent mechanical properties that can rival or even surpass those of synthetic fibres [8].

Bhasney and co-workers (2020) reported that the combination of PLA and HDPE as matrix materials in fibre reinforced composites offers numerous advantages, such as hydrophilicity, non-toxicity, cheap production and good as a replacement to the fossil fuel-based polymers. PLA contributes to environmental sustainability due to its biodegradability and renewable resources, while HDPE imparts high strength, stiffness, and impact resistance to the composites [9]. As a result, the composites exhibit excellent mechanical properties, including improved toughness and durability [10,11].

Bamboo is one of normal bamboo that has been appeared to have great mechanical properties and low cost. In any case, bamboo fiber strengthened polymer composites result in destitute interfacial attachment between the hydrophilic properties of normal fiber and the 4 hydrophobic networks which driven to ineffective stress transfer and low mechanical properties [12,13]

The objective of this research project is to investigate the impact of natural weathering on the mechanical properties of bamboo fibre reinforced PLA/HDPE composites used in electrical insulation. The effectiveness of silane treatment in enhancing durability and stability are evaluated. The results of this study provided valuable insights into the use of bamboo fibre reinforced composites for electrical insulation applications and contribute to the development of more sustainable materials.

2. Materials and methods

In this study, the bamboo fiber-reinforced PLA/HDPE composite was produced via a brabender internal mixer, crusher and compression molding machine. The particle size of the bamboo powder was measured via Particle Size Analyzer (PSA). While the characterization of untreated, alkali-treated, silane-treated bamboo fiber was examined via Fourier transform Infrared Spectroscopy (FTIR). Tensile properties of specimens are done by using Universal Tensile Machine (UTM)

2.1 Bamboo fibre and Poly(lactic) Acid and High-Density Polyethylene Resins

The bamboo fibre, *Gigantochloa Scortechinii* (local name: buluh semantan), that used in this experiment was purchased from Shopee with 1 meter long. The fiber was dried for a couple hours with temperature 100°C hours before grind using grinder. The bamboo fibre in powderform was sieved via laboratory siever to obtain 75µm particle size. The polylactic acid (PLA) and high-density polyethylene (HDPE) used will be in solid resin form.

2.2 Alkaline Treatment

During this process, the alkaline treatment was applied to bamboo fibre for 24 hours. The bamboo fibres were submerged in a sodium hydroxide solution (NaOH) with a fixed concentration of 6%. The bamboo fibres were rinsed entirely with distilled water eight times to eliminate the excessive NaOH on the fibre surface. Lastly, the fibres were dried in an oven at 80 °C for another 24 hours

2.3 Silane Treatment

During this process, the fibres were soaked in a silane solution with 1% concentration, in a mixture of distilled water and ethanol. The silane solution was made diluted 3-aminopropyltriethoxysilane in a 40:60 w/w (weight-to-weight) ratio of ethanol and water. Subsequently, the acetic acid was used to adjust and maintain the pH of the silane solution at 4–5. The fibres were soaked in the silane solution for 3 hours at room temperature with slow stirring. The fibres were dried in a drying oven at 80 °C for another 24 hours.

2.4 Composite Formulation

Composite compositions and designation of materials in this study is shown in Table 1, and Table 2. The addition of bamboo fibre is in the range of 3 - 7 wt% of PLA/HDPE with ratio 30:70 as a basis.

Table 1: Untreated Bamboo Fibre reinforced PLA/HDPE composites

Sample	Designation	PLA/HDPE (wt%)	Fibre (wt%)
PLA/HDPE/Bamboo Fibre 3	P/H/3%	97	3

Sample	Designation	PLA/HDPE (wt%)	Fibre (wt%)
PLA/HDPE/Bamboo Fibre 5	P/H/5%	95	5
PLA/HDPE/Bamboo Fibre 7	P/H/7%	93	7

Table 2: Silane treated Bamboo Fibre reinforced PLA/HDPE composites

Sample	Designation	PLA/HDPE (wt%)	Fibre (wt%)
PLA/HDPE/Bamboo Fibre 3	P/H/S3%	97	3
PLA/HDPE/Bamboo Fibre 5	P/H/S5%	95	5
PLA/HDPE/Bamboo Fibre 7	P/H/S7%	93	7

2.5 Preparation of Biocomposites

The bamboo fiber-reinforced PLA/HDPE composite was prepared by using three equipment, which is a brabender mixer, a crushing machine and an injection moulding. The bamboo fiber and PLA/HDPE were mixed manually before being fed into an internal mixer at 195°C for 6 minutes. The molten-like composite was crushed into a small size via a crushing machine. The granulated composite is inserted into the hopper are ready to inject via injection moulding at 210°C with holding for 10seconds to obtain a sample based on dogbone mold D638 type IV.

2.6 Characterization and Testing

2.6.1 Particle Size Analyzer (PSA)

A particle size analyzer, or PSA, determined the size and distribution of the particles that made up the after sieved bamboo fiber powder. The Mastersizer 3000 used laser diffraction to evaluate powder particle size distribution by measuring the intensity of light scattered when a laser beam traveled through a distributed particulate powder sample. After analyzing the data, the size of the particles responsible for the scattering pattern was established [14].

2.6.2 Fourier Transform Infrared Spectroscopy (FTIR)

In this research, Fourier transform infrared spectra were employed to analyze the changes in the chemical structures of pure bamboo fibers, silane-treated bamboo fiber, pure bamboo fiber with PLA/HDPE and silane treated bamboo fiber with PLA/HDPE. Fourier Transform Infrared Spectrometry (FTIR) was utilized to analyze the presence of peaks around 400 to 4000 cm^{-1} [15].

2.6.3 Natural Weathering Test

Natural weathering refers to the exposure of materials to the various environmental conditions they might encounter over time, such as sunlight, rain, temperature fluctuations, and atmospheric pollutants. Natural weathering test are held at UTHM Pagoh residential college. Test specimens are exposed to the natural weather for a week or 10 days.

2.6.3 Tensile Test

A tensile testing machine (UTM) that is used to perform the tensile test of the bamboo fibre reinforced PLA/HDPE composites according to ASTM D638 Standard Test Methods for Tensile Properties of Plastics with a 20kN load cell with speed 5mm/min.

3. Results and Discussion

This chapter discussed the results of testing described earlier in Chapter 3. The first part discusses on the size of bamboo powder. Second, characterization of untreated bamboo fibre, silane solution and silane treated bamboo fibre. The last part discussed on the effect of silane treated bamboo fibre content on mechanical properties of PLA/HDPE composite

3.1 Bamboo Fibre Characterization

3.1.1 Particle Size Analysis (PSA)

The particle size of the bamboo powder along with its polydispersity was identified using a particle size analyzer. Table X summarizes the median particle size of bamboo powder (D50), the size below 10 % (D10), and 90 % (D90) of the particle diameters lie, taken from the particle size distribution result as shown in Table 3.

Table 3: Particle size distribution

Fibre	Size Distribution	Particle Size (µm)		
		D_{10}	D_{50}	D_{90}
Bamboo Powder	Intensity	7.71	26.3	65.8

The median particle size of bamboo powder (D_{50}), the size below 10 % (D_{10}), and 90 % (D_{90}) of the particle diameters lie, taken from the particle size distribution result as shown in Figure 4.1. The median particle size of bamboo powder (D_{50}) is 52.3 µm, while the particle with size which low than 10% (D_{10}) are 7.71 µm. The results shows that 90% of the distribution was below than 65.8 µm.

The specific surface area of bamboo fibre based on the analysis was 37250 m^2/kg. Additionally, as shown in Figure 1, the polydispersity index of bamboo powder is 0.679 which is less than 1, which shows the uniformity size of bamboo powder.

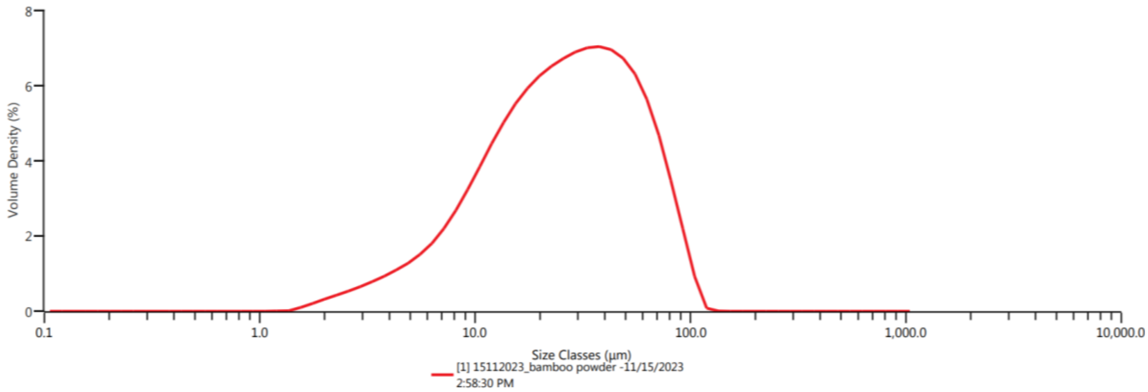

Figure 1: Particle size distribution of bamboo fibre

A study by Li et al., (2020) uncovered that the viewpoint proportion and estimate of common strands, including bamboo, apply a significant influence on the mechanical properties of composites. The consider highlighted that littler fiber sizes contribute to superior dispersion and upgraded mechanical performance, supporting the suggestion that a 75-micron measure can be profitable for dispersion. The use of a small filler size results in a good dispersion of particle within the matrix and adequate interaction between the filler and the matrix [12].

3.1.2 Fourier transform Infrared Spectroscopy (FTIR) Analysis

The FTIR spectra of untreated fibre, silane solution (3-APS) and silane treated bamboo fibre are shown in Figure 2. The changes of composition in bamboo fibre due to chemical treatment was investigated by FTIR spectroscopy. The sieved bamboo fibre in powder form was first undergone alkali treatment to remove lignin, surface hemicellulose and impurities.

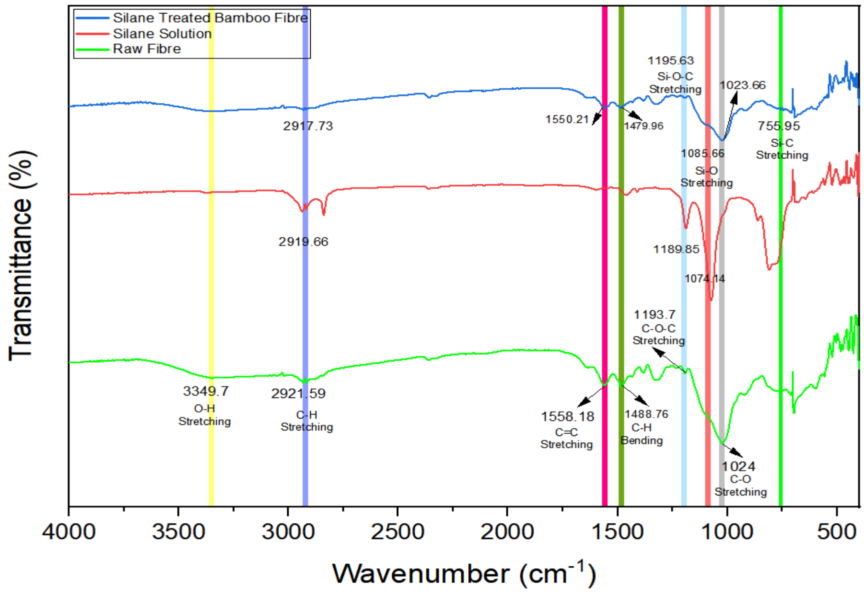

Figure 2: FTIR of untreated bamboo fibre, 3-aminopropyltriethoxysilane and silane treated bamboo fibre

Figure 2 shows the comparison on infrared spectra of untreated bamboo fibre, 3-aminopropylthoxysilane (3-APS) solution and silane treated bamboo fibre. In the spectrum of APS, the bands attributed by Si-O stretching were correspond at 1074.14 cm^{-1}. The band of 189.85 cm^{-1}, appeared from Si-O-C stretching while the peak of C-H stretching observed at 2919.66 cm^{-1}.

The spectrum of bamboo fibre (BF) was found at the peak 1558.18 cm^{-1} which is believed due to the C=C stretching vibration in the aromatic ring of lignin as agreed by Liew et al., (2015) and Rosa et al., (2012) [16,17]. Nevertheless, the C=C stretching was not observed in APS spectra. The peak of 3349.7 cm-1 shows the presence O-H stretching vibration (Liew et al., 2015). A similar trend found by Cai et al., (2018) with a peak number 1500-1600 cm^{-1} representing the lignin compound (aromatic C=C), the spectrum at absorption of 1735-1739 cm^{-1} represents the carbonyl (C=O) stretching the acetyl hemicellulose group [18]. The peak C-O stretch of about 1000-1100 cm^{-1} from the cellulose group and the C-O-C peak around 896 cm^{-1}

The effect of silane treatment in bamboo fibre show in reducing peak number of C=C stretching due to removal of some lignin. The peak of 1024 cm^{-1} and 1023.93 cm^{-1} shows the presence of C-O stretching of untreated BF and silane treated BF respectively. Furthermore, Si-C stretching was observed exist at peak 755.95 cm-1 and Si-O-Si stretching at peak 1074.14 cm^{-1}. A study from Haryati et al. (2021), discovered that the Si-C stretching bond exist at peak 813 cm^{-1} for 0.5% of silane solution [19]. Asyraf et al. (2021) stated that the upper band has established that the silane treatment forms the asymmetric stretching of either Si–O–C band on the bamboo surface in the peak around 1195.63 cm^{-1} [20]. Furthermore, the Si–C symmetric stretching bands can be found at 765 cm^{-1} [20]. Thus, the Si-C and Si-O-Si stretching bond revealed silane presence on the treated bamboo fibre surface. This was an indication of surface modification of bamboo fibre surface which successfully treated by APS. By removing O-H, that suggests that the silane treatment increase the hydrophobicity of the composites.

3.2 Unweathering Specimens

In this section the discussions were focused on the effect of silane treatment on tensile properties of bamboo fibre reinforced PLA/HDPE composites which are tensile strength, Young's Modulus and elongation at break at varied bamboo fibre content range 3% to 7%

3.2.1 Unweathering Specimens

Table 4 shows mechanical properties of unweathered specimen for both untreated and silane treated bamboo fibre respectively.

Table 4: Tensile properties of untreated and silane treated PLA/HDPE/Bamboo composites

Composites	Sample Designation	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at break (%)
Untreated PLA/HDPE/Bamboo	P/H/3%	2.45	1365.88	0.82
	P/H/5%	2.37	1474.02	0.47

Composites	Sample Designation	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at break (%)
Composites	P/H/7%	2.22	1651.34	0.35
Silane Treated PLA/HDPE/Bamboo composites	P/H/S3%	2.05	1097.71	0.32
	P/H/S5%	1.84	1106.71	0.29
	P/H/S7%	1.56	1376.72	0.21

Figure 3 shows the relationship between fibre content and tensile strength of PLA/HDPE composites for untreated and silane treated bamboo fibre. The importance of the treatment with a coupling agent can be assessed by comparing the results of treated and untreated composites. It is apparent that silane treatment of bamboo fibre has resulted in a lower tensile strength as compared to untreated composites. Tensile strength decreases steadily from 2.05MPa to 1.56MPa as the bamboo fibre content increases from 3 to 7%. The tensile strength for the silane treated composites was 16.3 to 29.7% lower compared to the untreated composites. The decrement was greater at 7% of fibre content, up to 29.7%.

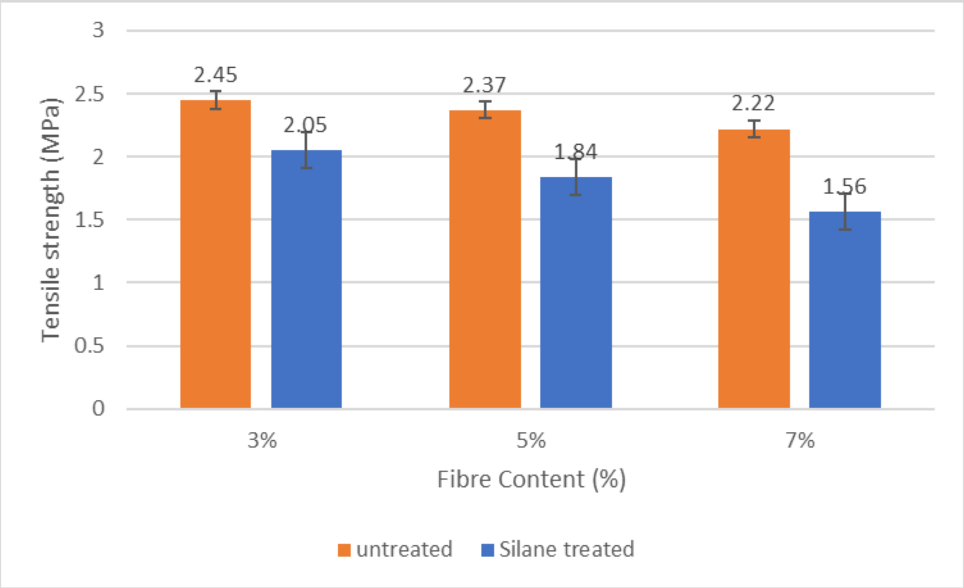

Figure 3: Comparison on untreated and silane treated of bamboo fibre reinforced PLA/HDPE composites in term of Tensile Strength

Mohd Ishak et al., (1998), reported that the incorporation of coupling agents did not produce any significant effect on the tensile strength of rice husk filled polymer composites [21]. In this study, rice husk was in a particulate form which had an irregular-shaped and had a strong tendency to bundles together. Thus, their capability to support stresses transmitted by the PVC matric was rather poop, even in the presence of coupling agent. Therefore, it is expected that agglomeration of the filler particles and dewetting of the polymer at the interphase would create stress concentration points thus led to the reduction in tensile strength of the bamboo fibre reinforced PLA/HDPE composites.

Figure 4 shows how fibre content affects Young's Modulus in PLA/HDPE composites with bamboo fibres. At 3% fibre content, both untreated and silane-treated fibres have similar Young's Modulus (around 1366 MPa). This modulus increases with fibre content, more notably for silane-treated fibres. For instance, at 7% fibre content, untreated fibres show a Young's Modulus of 1562.84 MPa, while silane-treated fibres reach 1651.34 MPa. Overalll silane treatment enhances stiffness, with up to 5.34% higher Young's Modulus in treated composites, especially evident at higher fibre contents.

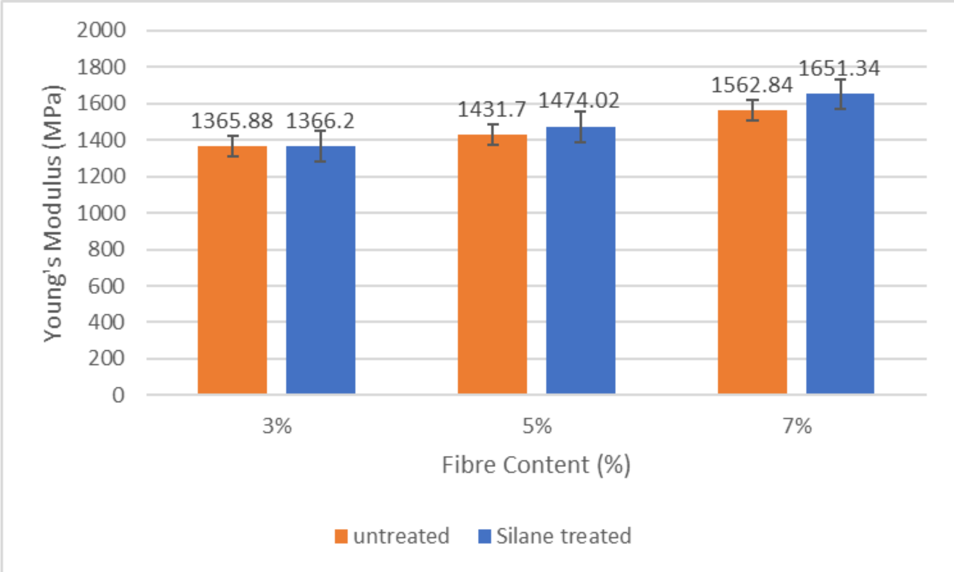

Figure 4: Comparison on untreated and silane treated of bamboo fibre reinforced PLA/HDPE composites in term of Young's Modulus

The silane treatment of bamboo fibre likely improves the interface bonding between the fibres and the matrix in the composite material. This improved bonding led to better stress transfer from the matrix to the fibre, hence increasing the stiffness of the composite material [21]. A similar trend was observed by Ridzuan and co-workers (2015) found the Young's Modulus of silane treated are higher than raw fibres, from 2.22GPa to 2.33GPa of *Raphia vinifera* fibres which increase up to 30.75% [22]. Colom *et al.* (2003) who also studied the effects of treatments on the interface of HDPE/ lignocellulosic fiber composites conclude that this mechanical property depends on the dispersion of the fillers in the polymer matrix, since the lignocellulosic fillers are responsible for the decrease of the deformation capacity within the elastic zone [23].

Figure 5 shows that silane-treated PLA/HDPE composites with bamboo fibres have lower elongation at break compared to untreated fibres across various fibre content levels. At 3% fibre content, silane-treated fibres show a significant reduction in ductility with only 0.32% elongation, compared to 0.82% for untreated fibres. This trend continues at 5% and 7% fibre content levels, with silane-treated fibres consistently demonstrating lower elongation rates than untreated fibres. The decrease in elongation for silane-treated composites ranges from 34.4% to 61.05%, with the largest drop at 3% fibre content.

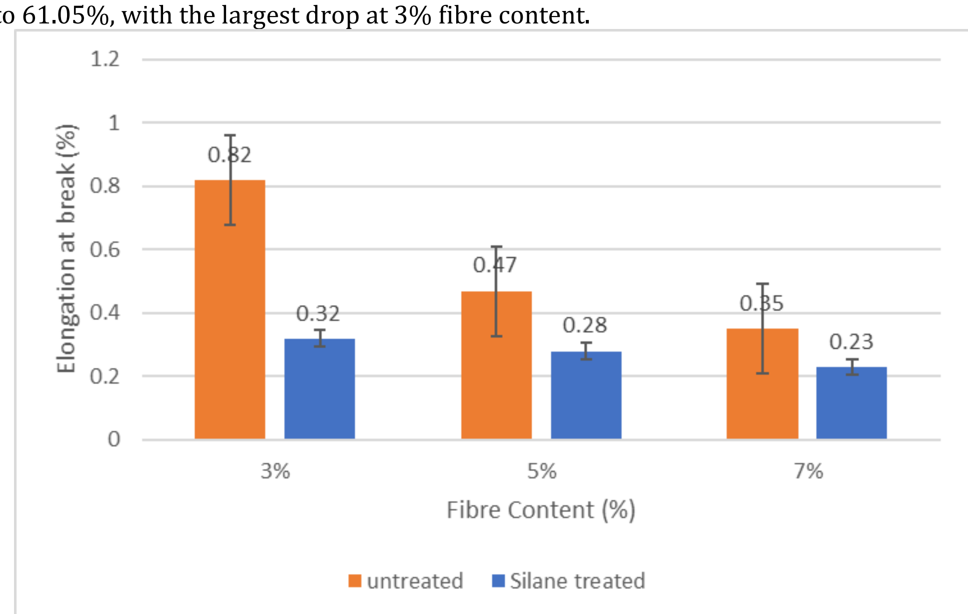

Figure 5: Comparison on untreated and silane treated of bamboo fibre reinforced PLA/HDPE composites in term of elongation at break

The overarching trend underscores that silane treatment diminishes the elongation at break of bamboo fibres across all tested concentrations. This reduction in ductility likely arises from the treatment's capacity to enhance bonding between the fibres and matrix, thereby restricting the fibbers' ability to elongate [22]. It suggests that silane treatment renders the composite more rigid, reducing its propensity to stretch, aligning with the observed increase in Young's Modulus for silane-treated fibres.

3.2.2 Weathered Specimens

In this section the discussions were focused on the effect of natural weathering on tensile properties of untreated and silane treated bamboo fiber reinforced PLA/HDPE composites which are tensile strength, Young's Modulus, and elongation at break. Table 5, describe interpret data of tensile properties of specimens after 10 days after natural weathering.

Table 5: Tensile properties of untreated and silane treated PLA/HDPE/Bamboo composites upon natural weathering effects

Conditions	Composites	Designation	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at break (%)
Unweathered	Untreated PLA/HDPE/Bamboo Composites	P/H/ 3%	2.45	1365.88	0.82
		P/H/ 5%	2.37	1431.70	0.47
		P/H/ 7%	2.22	1562.84	0.35
	Silane Treated PLA/HDPE/Bamboo Composites	P/H/ S3%	2.05	1097.71	0.32
		P/H/ S5%	1.84	1106.77	0.29
		P/H/ S7%	1.56	1376.72	0.21
Weathered	Untreated PLA/HDPE/Bamboo Composites	P/H/ 3%	2.05	1366.20	0.32
		P/H/ 5%	1.76	1474.02	0.28
		P/H/ 7%	1.43	1651.34	0.23
	Silane Treated PLA/HDPE/Bamboo Composites	P/H/ S3%	1.55	1142.4	0.22
		P/H/ S5%	1.31	1314.9	0.20
		P/H/ S7%	1.22	1510.2	0.16

3.2.2.1 Untreated Bamboo Fibre Reinforced PLA/HDPE composites

Figure 6 illustrates that the tensile strength of untreated bamboo fibre reinforced PLA/HDPE composites decreases after natural weathering. Initially, the strength is 2.45 MPa at 3% fibre content, dropping to 2.05 MPa post-weathering. At 5% fibre, it reduces further from 2.37 to 1.76 MPa. The most significant decline is observed at 7% fibre, where it falls from 2.22 to 1.43 MPa. Silane treated composites show a 16.3-35.9% lower strength than untreated ones, with the largest drop (35.6%) at 7% fibre content.

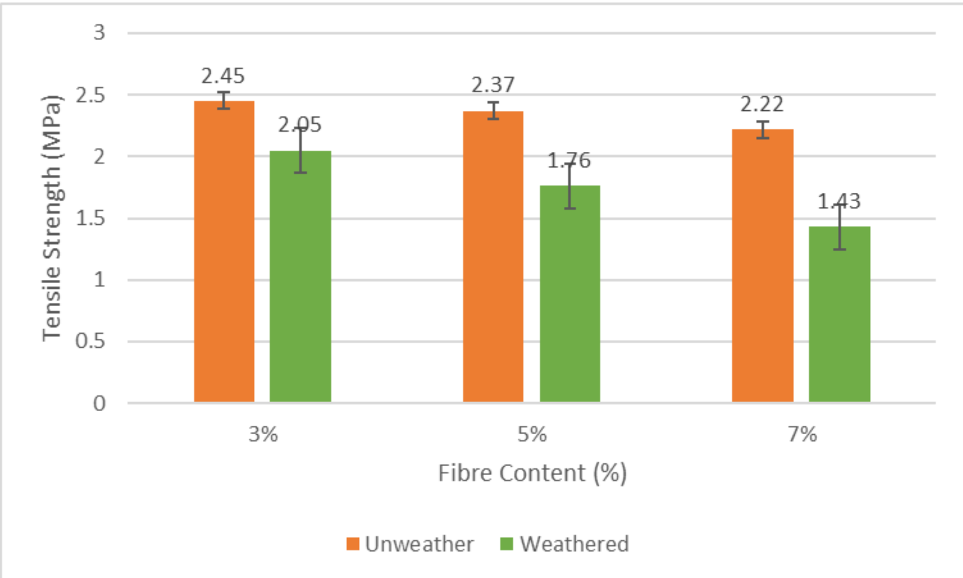

Figure 6: Tensile strength of untreated bamboo fibre reinforced PLA/HDPE composites before and after natural weathering.

Overall, these findings indicate that composites exposed to natural weathering has a detrimental impact on tensile strength. Dayo and co-workers (2020) found that after the weathering exposure, the tensile strengths of the bio-composites were further reduced, as the removal of the moisture from fibre surfaces increased the void spaces between fibres and matrix formed, and reduced the fibre/matrix interfacial adhesion [24]. A similar trend was observed by Rashdi and co-workers (2010) who investigated on kenaf unsaturated polyester composites (KFUPC) found natural weathering reduce tensile strength of KFUPC due to UV radiation which degrades the polymer matrix, reducing strength and stiffness and subsequently weakening the bond [25].

Figure 7 compares the tensile strength of untreated bamboo fiber-reinforced PLA/HDPE composites, before and after weathering. The Young's Modulus of unweathered composites starts at 1365.88 MPa with 3% fiber, slightly increasing with fiber content, reaching 1651.34 MPa at 7%. Weathered composites show a similar pattern up to 5% fiber (1431.7 MPa), but decrease to 1562.84 MPa at 7%. Silane-treated composites show a 0.1% to 5.4% higher Young's Modulus, more pronounced at 7% fiber content.

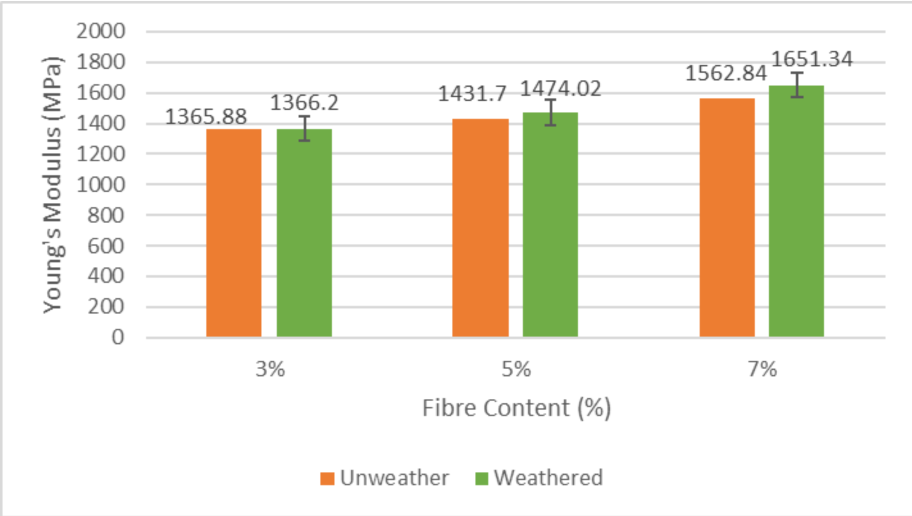

Figure 7: Young's Modulus of untreated bamboo fibre reinforced PLA/HDPE composites before and after natural weathering

Weathering consistently reduces stiffness, with a decreasing impact as fiber content rises. There may be an optimal fiber content to maintain stiffness post-weathering, as seen in the decline from 5% to 7% fiber content in weathered composites [24].

Figure 8 reveals that untreated bamboo fiber-reinforced PLA/HDPE composites have different elongation at break before and after natural weathering. With 3% fiber, non-weathered composites elongate more (0.82%) than weathered ones (0.28%). At 5% fiber, both see reduced elongation (0.47% for non-weathered, 0.32% for weathered). At 7% fiber, this reduction continues (0.35% for non-weathered, 0.23% for weathered). Silane treated composites show 34.3% to 61.0% lower tensile strength than untreated ones, with the greatest decrease (61.0%) at 3% fiber content.

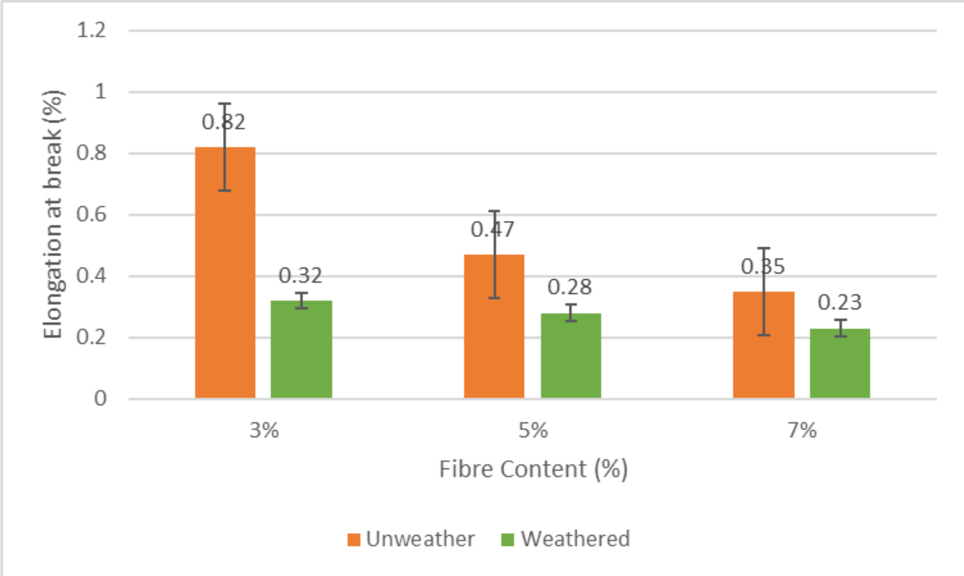

Figure 8: Elongation at break of untreated bamboo fibre reinforced PLA/HDPE composites before and after natural weathering

The consistent reduction in ductility due to weathering, a distinguished interaction between fibre content and the impact of weathering on ductility, and a tendency for composites with lower fibre contents to retain a higher percentage of their original elongation at break following weathering [26].

3.2.2.2 Silane Treated Bamboo Fibre Reinforced PLA/HDPE Composites

Figure 9 indicates that silane treated bamboo fibre reinforced PLA/HDPE composites' tensile strength decreases after weathering. For 3%, 5%, and 7% fibre contents, strength drops from 2.05 to 1.55 MPa, 1.84 to 1.31 MPa, and 1.56 to 1.22 MPa, respectively. The decrease in strength ranges from 14.7% to 25.6%, with the most significant drop at 5% fibre content.

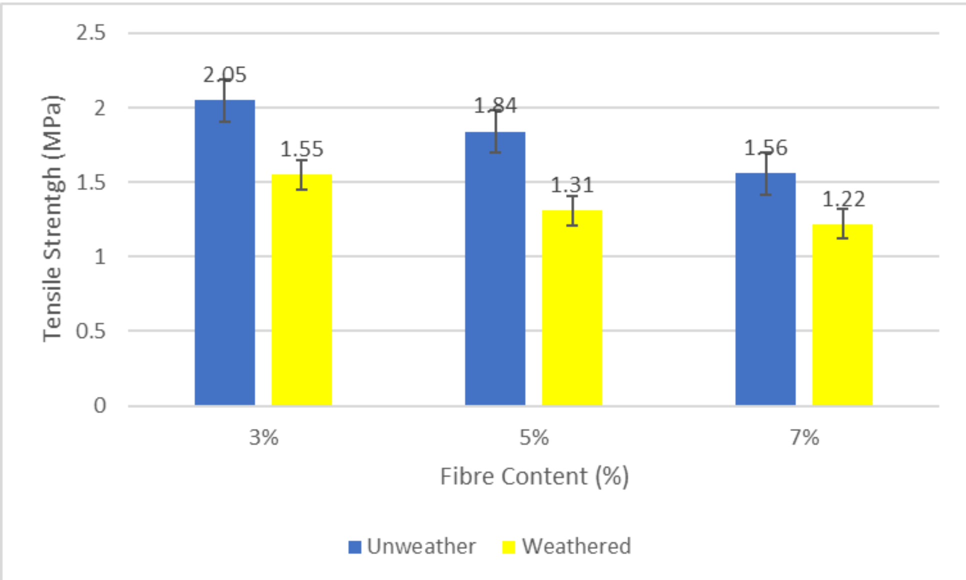

Figure 9: Tensile strength of silane treated bamboo fibre reinforced PLA/HDPE composites before and after natural weathering

The exposure to the humid conditions reduced the tensile strength of the composite in the range of 6.1-9.7% as compared to the unconditioned sample while silane treated hemp fibre recorded high in tensile strength [24].

Figure 10 presents Young's Modulus of silane-treated bamboo fibre reinforced PLA/HDPE composites, comparing before and after weathering effects. Initially, at 3% fibre, the unweathered composite's Modulus is 1097.71 MPa, slightly less than its weathered counterpart at 1142.42 MPa. Increasing the fibre to 5% results in the unweathered composite's Modulus rising to 1314.9 MPa, but it drops in the weathered composite to 1106.77 MPa. At 7% fibre, the unweathered composite reaches a Modulus of 1510.2 MPa, compared to a lower 1376.72 MPa in the weathered one. Key observations include that higher fibre content improves stiffness, weathering's varying impact on stiffness, and silane treatment's reduced effectiveness in maintaining stiffness under weathered conditions as fibre content increases. The bar graph also illustrates the elongation at break percentage for these composites under both unweathered and weathered conditions.

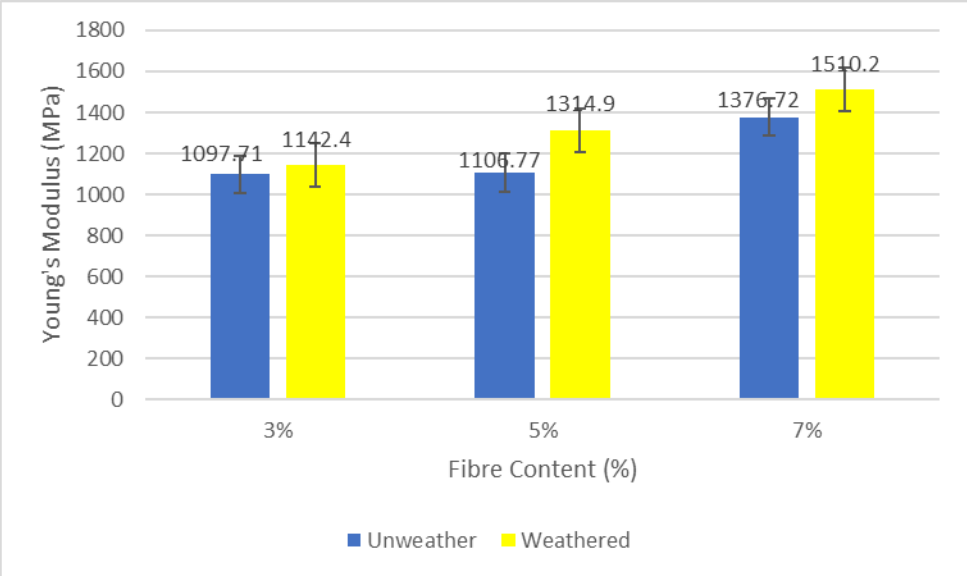

Figure 10: Young's Modulus of silane treated bamboo fibre reinforced PLA/HDPE composites before and after natural weathering

The similar trend was observed for Young's modulus values, the lowest values were recorded for the WHF composites. After the natural weathering exposure, the highest decline (0.71 GPa) in the modulus value was recorded for washed hemp fibres composites [24].

Figure 11 shows that natural weathering reduces the elongation at break of silane-treated bamboo fibre reinforced PLA/HDPE composites. For 3%, 5%, and 7% fibre content, the elongation decreases in both weathered and unweathered composites, with the largest drop at 3% fibre content. The silane treatment does not prevent this reduction. Weathering consistently lowers elongation at break, regardless of fibre content.

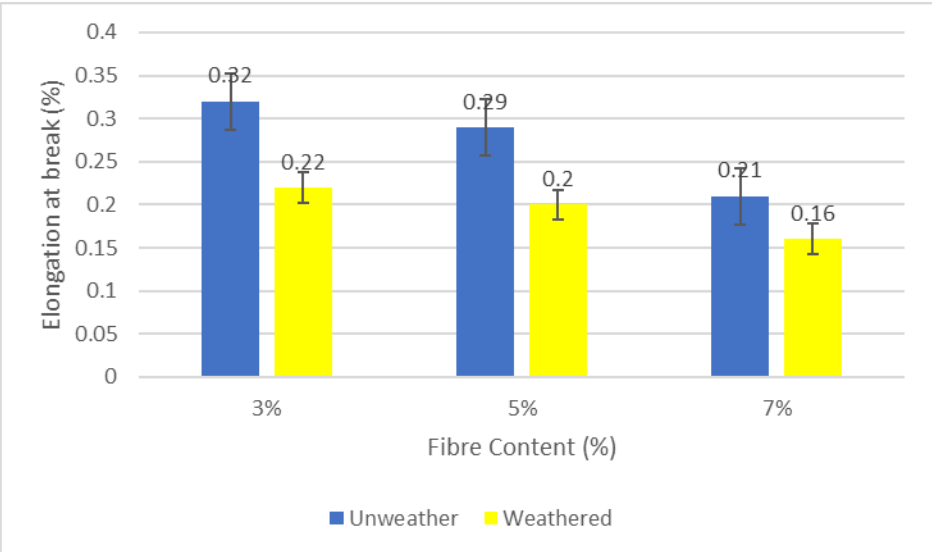

Figure 11: Elongation at break of silane treated bamboo fibre reinforced PLA/HDPE composites before and after natural weathering

This reduction in ductility likely arises from the treatment's capacity to enhance bonding between the fibres and matrix, thereby restricting the fibbers' ability to elongate [22]. Due to exposure of high UV radiation decrease the mechanical properties of specime [24]. The literature reports on the carbonyl group as the main cause for the polymer' degradation reactions when are under UV light, when polyethylene (PE) are exposed under ultraviolet light carbonyls, vinyl, carboxilic acid, ketone groups are forming [27]. Peng et al., (2014) studied UV ageing of PP, lignin, cellulose and wood based composites and they noticed a decrease of modulus, flexural strength alongside delamination of polypropylene layers [28].

3.3 Effect of Temperature and Moisture Content on Tensile Properties

Natural weathering is generally done to examine durability of materials in natural conditions and to determine the extent of biodegradability possessed by composites when exposed to natural weather. Temperature and humidity mainly affect the mechanical properties of the composites. Table 6 shows the recorded conditions of natural weather within 10 days exposure to the composites.

Table 6: Conditions of natural weather during natural weathering testing

Days	Day / Night	Temperature (C°)	Humidity (%)	Remarks
Day 1	Day	31	65	Sunny
	Night	23	97	Cloudy
Day 2	Day	31	68	Sunny
	Night	24	97	Cloudy
Day 3	Day	32	65	Sunny
	Night	24	95	Cloudy
Day 4	Day	29	75	Rainy
	Night	24	95	Cloudy
Day 5	Day	32	65	Cloudy
	Night	25	94	Rainy
Day 6	Day	31	70	Rainy
	Night	24	94	Rainy
Day 7	Day	31	75	Cloudy
	Night	24	98	Rainy
Day 8	Day	31	65	Cloudy
	Night	25	94	Cloudy
Day 9	Day	27	95	Rainy
	Night	26	94	Cloudy
Day 10	Day	27	65	Rainy
	Night	24	95	Cloudy

The data acquired from website *Jabatan Meteorologi Malaysia (Laman Web Rasmi Jabatan Meteorologi Malaysia, 2023)* [28]. This tabulation of data is crucial for understanding the environmental stresses that materials, specifically fibre-reinforced polymer composites, undergo during such tests. For instance, the daily temperature fluctuations, ranging from highs of 31°C to nighttime lows of 23°C, subject the composites to thermal expansion and contraction. These cycles can stress the bond between the fiber and the matrix, potentially leading to micro-cracking and eventual material failure. A study from Rashdi and co-workers (2010), they found that exposure to natural conditions for four months resulted in a decrease in tensile properties and an increase in moisture uptake, especially in samples with higher fibre content [25]. Degradation processes caused by the polymer material ageing through photo-irradiation, thermal degradation photo-oxidation, as well as through hydrolysis processes lead to series of changes in the physical, chemical and mechanical properties of the polymer and polymer composite materials [28,29].

Table 7 show the mass of the polymer composites after 10 days exposed to natural weathering. It is interesting to observe that the mass of specimen increased significantly with increasing bamboo fibre content, up to 6.3% for untreated composites. It can be observed that the mass increment for untreated specimen is higher as compared to the silane treated specimen. This suggests that the silane treatment increase the hydrophobicity of the composites which led to the reduction in the moisture [25,30].

Table 7: Specimen mass after exposed to natural weathering

Conditions	Designation	Mass after weathering (g)
Untreated	P/H/ 3%	+0.091
	P/H/ 5%	+0.148

Conditions	Designation	Mass after weathering (g)
	P/H/ 7%	+0.233
Treated	P/H/S3%	+0.022
	P/H/S5%	+0.038
	P/H/S7%	+0.047

From the data in the table, we can observe that the untreated samples have a higher mass increase after weathering compared to the treated samples. This suggests that the surface treatment (potentially silane treatment) on the bamboo fibres effectively reduces the moisture absorption, which is known to adversely affect the mechanical properties of natural fibre reinforced composites. However, there are no physical changes appears on the specimen as shows in Figure 12.

In the context of materials science and engineering, moisture absorption can lead to swelling, increased weight, and degradation of mechanical properties such as tensile strength, flexibility, and durability [24]. Therefore, the silane treatment of bamboo fibres in the polymer composite likely acts as a protective layer, reducing the fibre's hygroscopicity, which is its tendency to absorb moisture from the environment [30]

Figure 12: Specimens after exposure to natural weather

4. Conclusion

In this chapter, the outcome of this study was summarized based on the overall findings obtained. The results obtained in this study prove that the objectives of this study were successfully achieved. The objectives of the study were accomplished. The bamboo powder was successfully prepared from bamboo fiber with a siever. Next, the median particle size of the bamboo powder was 26.3μm (D_{50}), 7.71μm was less than 10% (D_{10}), and 90% of the product was below 65.8μm. Thus, the target to get the size of bamboo powder at approximately 75 microns was successfully met and surpassed the intended target size. The objectives of the study is to characterize the effect of silane treatment of bamboo fibre, based on the FTIR, the results reveals distinctive peaks corresponding to C-H stretching, Si-O stretching, Si-O-C stretching and Si-C stretching observed at 2917.13 cm^{-1}, 1085.66 cm^{-1}, 1095.63 cm^{-1}, 936.02 cm^{-1}, and 755.95 cm^{-1} respectively. Additionally, peaks indicative of C-O stretching and C=C stretching was observed at 1024.00 cm^{-1} and 1550.21 cm^{-1}, respectively. This confirms the successful application of alkali and silane treatments for the surface modification of bamboo fiber. The objectives of two and three were successfully identified on the mechanical properties of tensile strength, elongation at break and Young's Modulus of the composite's silane treated show decrement in terms tensile strength and elongation at break for both composites unweathered and weathered as compared to untreated bamboo fibre due to unstable composition between polymer matrix of silane treated bamboo fibre.

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