

Effect of Weathering on Salvaged Bamboo from Bamboocrete Panel

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Abstract. Bamboocrete panel has been introduced in the construction industry as a sustainable alternative building material. However, the impact of weathering on its strength remains a concern when designing bamboo structures and understanding their long-term performance. This study investigates the mechanical properties of weathered, treated salvaged bamboo from bamboocrete panels. The samples were prepared from bamboo salvaged from bamboocrete panels that had been exposed to weathering for one and three years. The tensile and compressive strengths of this weathered bamboo were compared to those of untreated and treated bamboo, both after exposure to weathering for one and three years. The findings show that the compressive strength of the weathered, treated salvaged bamboo is 49% higher than that of untreated bamboo, while its tensile strength is 17% lower than that of untreated bamboo after one year of weathering. These results suggest that untreated bamboo's strength may degrade over time due to environmental exposure, while treatment significantly enhances both compressive and tensile strength.

1 Introduction

Natural plant fibres are popularly used in the construction industry due to their low density and promising mechanical properties, such as flexural strength, durability, sustainability, and biodegradability [1]. Bamboo is one of the natural fibre building materials that can support sustainable development. It is particularly well-suited for this role because of its environmental, social, and economic benefits. As the price of steel is expected to rise due to the depletion of mineral resources, the steel demand will increase. Therefore, bamboo is seen as one of the best alternatives to conserve natural resources. Bamboo is also an excellent material for the construction industry due to its low cost, fast growth, and environmentally friendly nature. Its strength surpasses that of many timber products because of its strong fibres. Bamboo can replace up to 70% of the steel and wood used in construction, potentially reducing manufacturing costs by 40% [2], [3].

Studies have shown that bamboo can withstand pressures of up to 358.53 MPa, making it suitable for use as a horizontal member in structures up to 3–3.6 meters long without requiring middle support [3]. In Asia, bamboo has been a reliable construction material for bridges and houses for thousands of years due to its high tensile strength, versatility, and sustainability [4-6]. Bamboo also requires less energy to harvest and transport compared to other materials. As a renewable building material, bamboo can minimize energy

consumption, protect non-renewable natural resources, reduce pollution, and help maintain a healthy environment. Furthermore, bamboo can be utilized even in countries and regions without advanced manufacturing technology or construction techniques.

The most abundant bamboo species in Peninsular Malaysia and globally is *Gigantochloa scortechinii*, commonly known as *Semantan Bamboo*. This species grows naturally in many parts of the world, but some are also cultivated in countries such as Malaysia, Indonesia, Myanmar, Thailand, the Philippines, India, and Vietnam [7]. *Semantan Bamboo* is widely used in local industries in Malaysia due to its rapid growth. Moreover, previous studies have examined its anatomical, physical, and mechanical properties.

Bamboocrete panels are composite materials made by mixing bamboo with cement, which is then compressed and cured. These panels have been gaining attention as a sustainable alternative to traditional building materials, such as wood and steel. Bamboocrete panels offer several advantages, including high strength, low cost, and minimal environmental impact. Researchers have found that bamboocrete panels can have a design axial strength of up to 100 kN (10 tonnes) and an ultimate bending strength of at least 25 kN [8]. Studies suggest that bamboocrete can serve as an alternative to steel reinforcement, performing comparably to steel-reinforced concrete in terms of bending moment, compressive strength, and tensile strength [8]. Additionally, bamboocrete panels can be produced using locally sourced materials, which can reduce the environmental impact associated with transportation and provide economic benefits to local communities.

However, concerns remain about the durability of bamboocrete panels. A 40-year-old Assam-type house with bamboocrete walls was found to remain intact without any deterioration [9]. His finding was supported by a study highlighting the durability potential of bamboocrete [10]. Nonetheless, research has shown that bamboocrete panels are susceptible to moisture damage, which can lead to the growth of microorganisms and a decline in mechanical properties. Although bamboocrete is lighter than steel-reinforced concrete panels, its compressive strength is twice that of concrete. The density and moisture content of bamboo also significantly impact its compressive properties [11]. Studies have demonstrated that increasing the density and reducing the moisture content of bamboo can enhance its compressive strength. Furthermore, the compressive strength of bamboo is affected by the culm age, with younger bamboo culms exhibiting higher compressive strength than mature ones.

Numerous studies have been conducted to evaluate the compressive properties of bamboo, showing that the compressive strength varies depending on the species, location, age of the bamboo culm, and its density and moisture content [12-15].

While bamboo is widely accepted as a construction material, weathering effects on its strength remain a concern when designing bamboo buildings. One study [16] found a decrease in compressive strength in bamboo exposed to natural environmental conditions, while another study [17] observed a reduction in mass and impact strength in bamboo-reinforced composites after weather exposure. Weathering has also been found to deteriorate the flexural properties of alkali-treated bamboo strips [18]. However, salvaged bamboo has shown the potential to retain its strength and flexibility when used in load-bearing panels [19]. Therefore, further investigation is needed into the specific effects of weathering on the strength of salvaged bamboocrete panels.

Research has demonstrated that bamboo can have significantly higher tensile strength when treated with borax and boric acid compared to untreated bamboo. A study found that the tensile and compressive strengths of bamboo treated with borax and boric acid were significantly improved [20]. Similarly, treatment with a borax solution as a preservative can significantly increase bamboo's compressive, tensile, and bending strength, with the optimal borax concentration being 30-50% [21]. Another study [22] showed that bamboo treated with boric acid had improved wettability, dimensional stability, and mechanical strength, making

it more suitable for lamination. Treating bamboo is essential to enhance its properties and durability [23]. Other preservative treatments, such as Copper Chrome Boron (CCB) and Boron, have also been used in previous studies, resulting in greater modulus of rupture and compression strength properties in treated bamboo [24].

Most previous studies agree that treated bamboo meets the minimum requirements to be used as a construction material. However, there is a lack of data on the strength of treated salvaged bamboo from bamboocrete panels after three years of weather exposure. This paper aims to examine the mechanical properties of salvaged bamboo from bamboocrete panels to analyse its vulnerability to weathering. To determine the mechanical properties of weathered, treated salvaged bamboo from bamboocrete panels, compressive strength and tensile strength tests were carried out in this study.

2 Methodology

In this study, the salvaged bamboo species *Gigantochloa scortechinii* (*Buluh Semantan*) was sourced as abandoned raw bamboo from Hulu Langat, Malaysia, with diameters ranging from 45 mm to 60 mm. Before being dried under a shed for four weeks, the bamboo was treated by immersion in a solution of borax and boric acid for two weeks. The treated bamboo was then cut into lengths of 1.45 meters. Four bamboo pieces were grouped, securely tied, and wrapped in wire mesh to ensure proper bonding with the concrete. Concrete panels with dimensions of 1500 mm × 300 mm × 125 mm were cast using the treated bamboo as reinforcement. After a 28-day curing period, the panels were subjected to loading and subsequently exposed to weathering conditions for three years in a sheltered environment. The treated salvaged bamboo was then extracted from the bamboocrete panels, and samples were prepared for a series of mechanical property tests to evaluate the effects of weathering.

A ball sander machine was used to shape the bamboo into dog bone specimens for tensile strength testing and cylindrical specimens for compressive strength testing. The procedures and tests used in this study adhered to the International Standards ISO 22157:2019 [25]. Compressive strength and tensile strength samples were tested using a Universal Testing Machine (UTM) under test conditions of 27 ± 2 °C and $70 \pm 5\%$ relative humidity, which better reflect the service environments in countries where bamboo grows.

For compressive strength testing, the weathered treated salvaged bamboo from the bamboocrete panel was divided into three sections: the top, middle, and bottom parts of each culm, as shown in Fig. 1(a). The height of each specimen was cut to twice its external diameter, so the exact height varied depending on the respective external diameter. Since the external diameters and thicknesses of the samples differed, an Analysis of Variance (ANOVA) test was conducted to determine the significance of the relationship between these variables. The compression testing setup is illustrated in Fig. 1(b). The ultimate compressive strength, σ_{ult} and the cross-sectional area, A were calculated by using Equation 1 and Equation 2 respectively.

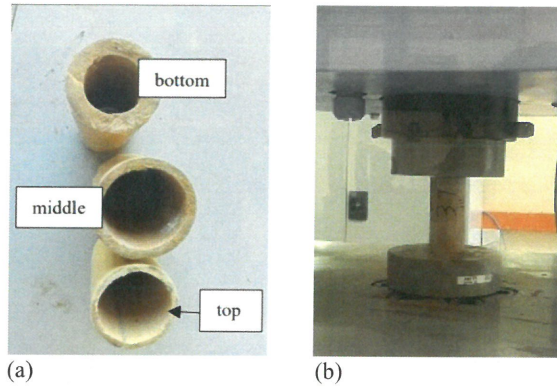


Fig. 1. Test Setup (a) Top, middle and bottom samples of bamboo (a) Compression loading setup on UTM machine

$$\sigma_{ult} = F_{ult} / A \quad (1)$$

$$A = \frac{\pi \times [D^2 - (D - 2t)^2]}{4} \quad (2)$$

where, σ_{ult} is compressive stress (MPa), F_{ult} is maximum load (N), A is bamboo wall cross-sectional area (mm^2) and D is external diameter (mm) and t is the thickness of bamboo wall (mm).

For the tensile strength samples, material was obtained from each of the three sections (top, middle, and bottom) and trimmed into strips, with the gauge length ranging between 50 and 100 mm. The dimensions of the bamboo strip samples are illustrated in Fig. 2. The maximum tensile strength of the bamboo strips and the cross-sectional area at the gauge length were calculated using Equations 3 and 4, respectively.

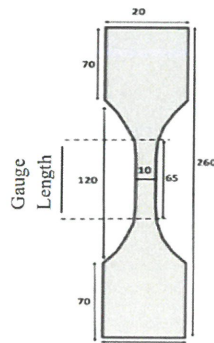


Fig. 2. Illustration of bamboo strip

$$\sigma_{t,ult} = F_{t,ult} / A \quad (3)$$

$$A = w \times t \text{ (at gauge length)} \quad (4)$$

where, $\sigma_{t,ult}$ is ultimate tensile strength (MPa), $F_{t,ult}$ is maximum tensile load (N), A is bamboo strip cross-sectional area (mm^2), w is width at gauge length (mm) and t is the thickness at gauge length (mm).

3 Results and Discussions

The compressive samples and tensile samples of the weathered treated salvaged bamboo from the bamboocrete panel were tested under direct loading using UTM machines until total failure. Fig. 3 shows the specimen of the weathered treated salvaged bamboo under loading and the failure of the specimen.

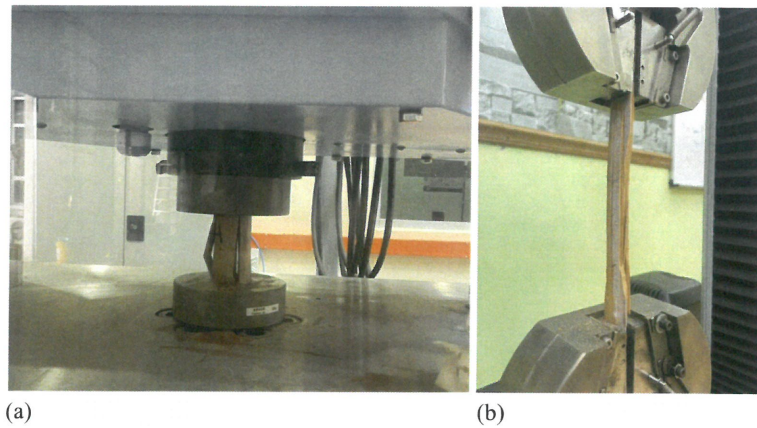


Fig. 3. The failure of the bamboo samples under (a) compressive and (b) tensile loading

The ANOVA test was performed to assess whether there are significant differences in compressive strength among three sections of bamboo samples: top, middle, and bottom. The summary of the input data of the compressive sample is shown in Table 1. Table 2 presented the ANOVA test of the compressive sample. According to Table 2, the p-value is 0.1014747, which is greater than the standard significance level of 0.05, and the F-value is 2.742327, which is less than the F critical value of 3.80556. These results indicate that the variation in compressive strength between the top, middle, and bottom sections is not statistically significant. Hence, although the bottom section was expected to have the highest strength due to its thickness (which was controlled between 4 to 5 mm across all sections), the differences observed in compressive strength among the three sections are not significant enough to draw a conclusive result.

Table 1. Summary of the compressive sample

Groups	Count	Sum	Average	Variance	Standard variation
Top	6	306.440	51.073	26.2800	5.12640444
Middle	6	336.681	56.113	39.1261	6.255086965
Bottom	4	240.364	60.091	51.2742	7.160603266

Table 2. ANOVA test of the compressive sample

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	202.8704	2	101.4352	2.742327	0.1014747	3.80556
Within Groups	480.8534	13	36.98872			
Total	683.7238	15				

*Notes: SS - Sum of Squares; df - Degrees of Freedom; MS - Mean Square; F - F-statistic; P-value - Probability Value

The variation of both compressive and tensile strengths across different bamboo samples at various stages of treatment and weathering are presented in Table 3 and Fig. 4. The results show the pattern of increment for both compressive and tensile samples after treatment and retain much of their initial strength nevertheless have minimal degradation after being exposed to one year and three years of weathering. This suggests that environmental exposure may reduce bamboo's strength over time if left untreated and proves that treatment significantly improves both compressive and tensile strength. The compressive strength increases by approximately 60%, while the tensile strength rises by around 33%. It is also noticeable that the tensile strength of the samples is much higher than the compressive strength same as previous studies on bamboo and timber [19][[26]. However, tensile strength declines more noticeably after three years, implying that while treatment offers protection, the material's ability to resist tensile forces may still degrade over long periods of exposure. These findings underscore the importance of treating bamboo to improve its mechanical performance and extend its lifespan, particularly in construction applications where durability is crucial.

Table 3. Compressive strength and tensile strength of the bamboo samples

Samples	Compressive Strength (MPa)	Tensile Strength (MPa)
Untreated bamboo (Immediate Test)	36.89	N/A
Untreated bamboo (1 year)	36.08	263.47
Treated bamboo (Immediate Test)	58.96	N/A
Treated bamboo (1 year)	56.41	351.19
Weathered of Treated Salvaged Bamboo from Bamboocrete Panel, E (3 years)	55.15	225.36

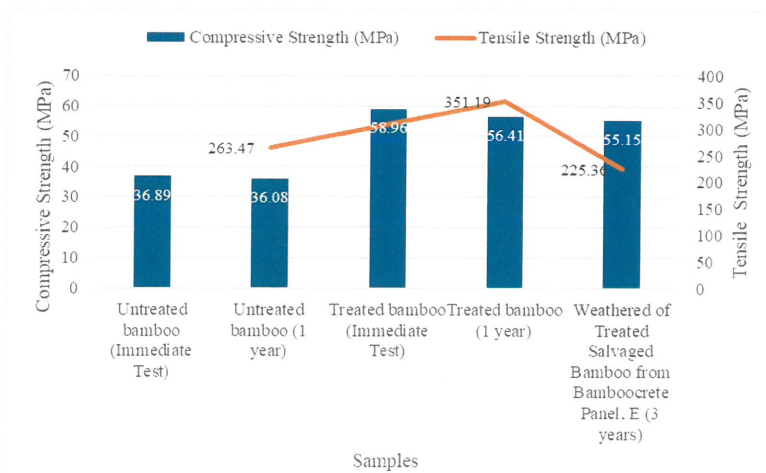


Fig. 4. Compressive strength and tensile strength of the bamboo samples

4 Conclusions

The mechanical properties of weathered, treated salvaged bamboo from bamboocrete panels in this study were determined by conducting two tests: the compressive strength test and the tensile strength test. In the compressive test, the highest average compressive strength among the three sections was achieved in the middle section, with a value of 56.69 MPa. The overall average compressive strength of the weathered, treated salvaged bamboo from all three sections was 55.51 MPa, which was neither the highest nor the lowest observed value. For the Tensile Strength Test, the highest tensile strength recorded for the weathered, treated salvaged bamboo sample was 367.5 MPa. However, the average tensile strength across all bamboo samples was 225.36 MPa, the lowest value in the study.

In addition, the mechanical strength achieved by this sample in the study exceeded that of the control samples, leading to the conclusion that treated bamboo can be considered a good construction material. Future research should examine the long-term effects of weathering on treated salvaged bamboo, explore improved treatment methods, and compare its performance with other sustainable materials. Furthermore, studying its application in composites like bamboocrete, along with developing treatment standards and weatherproofing techniques, will promote its broader adoption in sustainable construction.

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