Mechanical Properties of Bamboo Coated with Surface Treatment Under Static Loading

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Abstract. Literature proved that bamboo can be used as an alternative reinforcement because it has high tensile strength, which is almost similar to steel reinforcement. Besides, bamboo is lightweight and cheap that suitable for low-cost construction industry. Therefore, in this study, the mechanical properties of bamboo coated with different surface treatment is investigated under static loading. Bamboo type '*Gigantochloa Scortechinii*' or also known as '*Buluh Semantan'* in Malaysia is chosen as it is largely found in Peninsular Malaysia and has high tensile strength as reported by previous researchers. The bamboo samples were prepared into two different shapes, i.e. cylinder and dog-bone. Prior to laboratory testing, the bamboo samples were coated with solid epoxy and water-based epoxy. These epoxy coatings were chosen because it may provide the best surface treatment as reported by numerous researchers. A total of 18 samples were prepared and tested under static loading. The laboratory tests were performed using the Compression Testing Machine and Universal Testing Machine for compression and tensile tests respectively. Results denoted that the highest compressive strength of bamboo was observed when the bamboo is coated with solid epoxy. The compressive strength of bamboo coated solid epoxy is 6.2% and 23.77% higher than the bamboo coated with water-based epoxy and untreated surface bamboo respectively. Similarly, the ultimate tensile strength of bamboo improved up to 45% coated with solid epoxy compared to other samples of bamboo. The study concluded that the bamboo coated with solid epoxy is the best surface treatment for bamboo reinforcement compared to water-based epoxy and untreated bamboo. The outcome of this study provides essential information on the utilization or application of bamboo as an alternative reinforcement of construction material especially in low-cost construction industry.

INTRODUCTION

Many buildings and skyscrapers require safe and robust construction work to function well and withstand the imposed loading during its design lifetime. In most construction industry, concrete and steel are two dominant materials that massively being used compared to others materials, i.e. wood, bamboo, stone, brick, masonry, etc. Both materials usually work as concrete-steel composite structural elements whereby the concrete material provides compressive strength alongside steel reinforcement which strengthen the tensile properties of the structural component against imposed loading. Concrete is a composite material made with a combination of cement, aggregates and water [1]. Concrete becomes popular because it provides low construction cost, ease accessibility and imperviousness to fire, although it has low elasticity. It has high compressive strength and good heat resistance but essentially lowers tensile strength. Most commonly, steel reinforcement is embedded in concrete to provide a tensile strength in concrete structural components, and widely known as reinforced concrete structures.

However, due to escalating of price of the steel material in the market especially due to the Pandemic Covid-19, development of a new alternative material of reinforcement to be used in construction industry has received special attention from many engineering field. Previous researchers (e.g. [2,3]) proved that bamboo is a potential alternative material to be used as reinforcement in concrete, which subsequently reduce the usage of steel reinforcement and provides new idea in establishing sustainable construction development.

Bamboo is green building material is natural, cheap, widely available material. Bamboo strength tensile can be very high in range of 120MPa to 250MPa, which is similar to steel reinforcement, and it has very strong in compression up to 58 MPa [4]. Bamboo is a natural habitat that has the most appeal of availability and easy handle in rural and farming communities in the construction world (i.e. [5,6]). Besides, the use of bamboo reinforcement promises advantage of its lightweight and cost-effective [7].

In addressing the advantages of natural resources, in this study, the mechanical properties of bamboo coated with different surface treatment is investigated under static loading. Throughout this research, the best surface treatment to be used in preparing the bamboo reinforcement was determined. The outcome of this study provides essential information on the utilization of bamboo an alternative reinforcement in construction material. It offers a solution to convert abundant of bamboo wastes into valuable products. In this project, several scopes are presented in order to achieve the stated objectives.

METHODOLOGY

The flowchart of research methodology presented in Fig. 1 is divided into five stage i.e. (1) determination of materials, (2) preparation of sample, (3) preparation of experimental setup, (4) result and analysis, and (5) discussion and conclusion. In this study, bamboo type '*Gigantochloa Scortechinii*' is chosen as it is most abundantly and naturally found in Peninsular Malaysia [8] and has high tensile strength as reported by previous researcher [4].

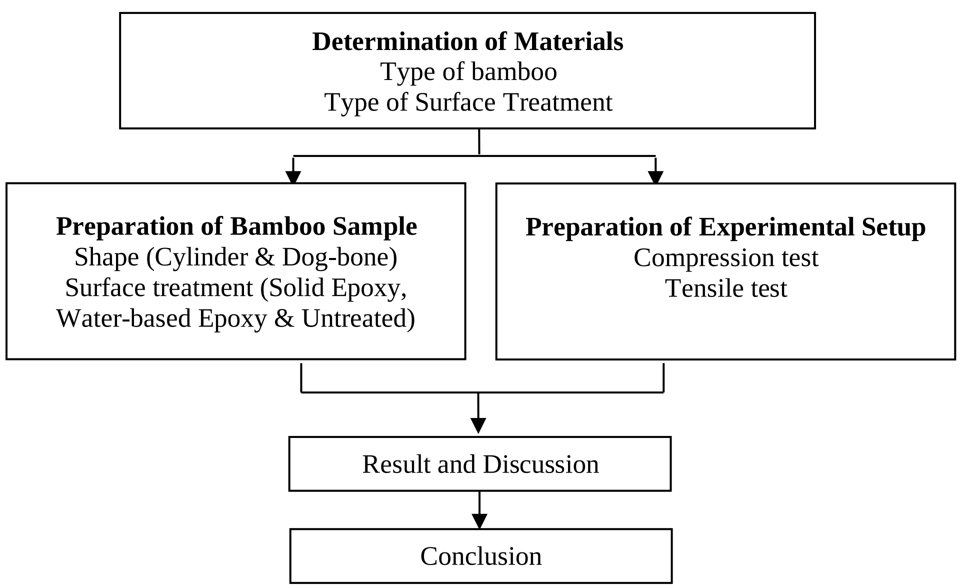


FIGURE 1. Research Flowchart

Background of *Gigantochloa Scortechinii*

Gigantochloa Scortechinii also known as *Buluh Semantan* in Malaysia is the most abundant species of bamboo found in Peninsular Malaysia and globally [8]. The bamboo is one of the most easily available resources to supplement local wood and usually matured around 3 to 4 years [9]. Physical properties of the bamboo describe by the characteristic stems of the bamboo which usually bent, difficult to separate, free bunches, no thistles and thick-walled.

The steam can reach a height of 10 to 20 m and a thickness of 4 to 10 cm [10]. The bamboo normally grows naturally on stream banks, side of the road, bad land and open ground, at low elevations [5]. Each plant delivers various new stems every year and develop to their greatest stature in their first year of development [11]. The new stem could be as much as 30 meters tall, with everyday increments in stature of 30 cm or more during their pinnacle development time [10]. This makes them the absolute quickest developing species on the planet.

FIGURE 2. *Gigantochloa Scortechinii*

Preparation of Samples

The bamboo samples were prepared into two different shapes, i.e. cylinder and dog-bone. Prior to laboratory testing, three types of bamboo samples were prepared, i.e. (1) untreated bamboo, (2) bamboo coated with solid epoxy, and (3) bamboo coated water-based epoxy. These epoxy coatings were chosen based on previous study conducted by the main authors [12] which reviewed the best surface treatment of bamboo using the systematic literature review.

Meanwhile, the species of the *Gigantochloa Scortechinii* bamboo is selected due to abundant production of bamboo yearly as reported by the Forest Research Institute Malaysia (FRIM) especially in the Peninsular Malaysia [8]. Besides, according to the best author's knowledge, none of the previous study about mechanical properties of *Gigantochloa Scortechinii* bamboo coated with surface treatment is reported in literature.

During the preparation of samples, the bamboo culm is first boiled and soaked in water after cut to the appropriate smaller size (Fig. 3). This process helps to remove the natural essence, sugar and keep away insects. This is a friendlier safe method that also softens lignin and loosens the bond between lignin and cellulose fibers [13]. After boiling, the bamboo is cut into two different shapes i.e. circular shape and a dog-bone shape for compression and tensile test respectively according to standard guidelines explained in the ISO 22517-1:2004 [14] and ASTM D143-94 [15]. Similar procedure also has been adopted by previous study performed by [16]. As depicted in Fig. 4, the samples are cut into cylindrical shape with the length range between 100 mm to 110 mm and diameter range between 30 mm to 40 mm [14,16]. Meanwhile, the detail measurement proposed by [14, 17] is adopted in this study for preparation of dog-bone shape samples shown in Figs. 5 and 6. Then, the samples were dried in the temperature room for 24 hours to stabilize the humidity rate to less than 10% [16].

FIGURE 3. Bamboo culm soaked in water

FIGURE 4. Cylindrical shape of bamboo sample for compression test

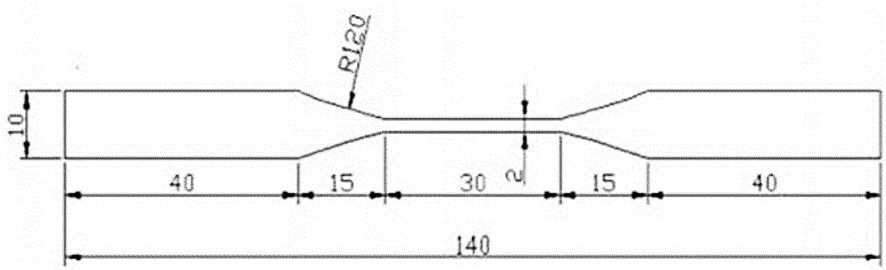


FIGURE 5. Detail measurement (unit in mm) of dog-bone shape bamboo sample modified after [14,17].

FIGURE 6. Dog-bone shape of bamboo sample for tensile test

Surface Treatment

To minimize water absorption and enhance bonding strength between concrete and bamboo, several impermeability treatment chemicals are used [18]. In this project, Epoxy Pioneer (Fig. 7(a)) and Heavy-Duty Epoxy Polyurethane (Fig. 7(b)) are used as solid epoxy coating and water-based epoxy coating respectively. The samples are swept evenly and smoothly. Using a plastic scraper and paint brush, the epoxy was applied over the aligned samples to ensure that it filled every corner [17,19]. As summarized in Table 1, a total of 18 samples were prepared and tested under static loading. The laboratory tests were performed using the and Compression Testing Machine and Universal Testing Machine for compression test and tensile test respectively.

(a) Bamboo coated with solid epoxy

(b) Bamboo coated with water-based epoxy

FIGURE 7. Preparation of bamboo samples coated with surface treatment

TABLE 1. Total number of sample for each test

Samples	**Compression Test** (Cylinder shape)	**Tensile Test** (Dog-bone shape)	**Total Samples** (for each surface treatment)
Untreated (Control)	3	3	6
Solid Epoxy	3	3	6
Water-based Epoxy	3	3	6
Total Samples (for each test)	9	9	18

All samples were divided into 3 parts and contains of 6 bamboo samples for each surface treatment i.e. solid epoxy coating, water-based epoxy coating and untreated samples which left without surface treatment. To minimize water absorption and enhance bonding strength between concrete and bamboo, several permeability treatment chemicals were used [18]. In this project, as suggested by previous researchers [12], two brand of epoxy that available in market i.e. Epoxy Pioneer and Heavy Duty Epoxy Polyurethane were used as solid epoxy coating and water based epoxy coating respectively.

Experimental Setup

The testing procedure for compression strength test follow the standard methods accordance with ISO 22517-1 (2004) [14]. The maximum compressive stress was calculated by the adopting Eq. 1 and Eq. 2.

$$\sigma_{ult_{comp}} = \frac{F_{ult_{comp}}}{A_{comp}} \tag{1}$$

$$A_{comp} = \frac{\pi \times \left[D^2 - (D-2t)^2\right]}{4} \tag{2}$$

Where $\sigma_{ult_{comp}}$ is the compressive stress (MPa), $F_{ult_{comp}}$ is the maximum load (N) during compression test, A_{comp} is the cylindrical bamboo cross-sectional area (mm²), D is the bamboo outer diameter (mm) and t is the bamboo thickness (mm). To set the sample, a loading of no more than 1 kN and loading on the samples at the constant rate of 0.01 mm/s was applied. The maximum loading at which the sample fails was recorded as the final reading. The example of samples under compression was tested using the Compression Testing Machine as shown in Fig. 8(a). Similarly, in ISO 22517-1 (2004) [14] the tensile strength is tested accordance to standard methods in the ASTM D 143-94 [15] as proposed by [20]. The displacement rate of 1 mm/min is applied. The test automatically stops when the sample failed or break off. The ultimate tensile strength was determined by using Eq. 3.

$$\sigma_{ult_{tensile}} = \frac{F_{ult_{tensile}}}{A_{tensile}} \tag{3}$$

Where $\sigma_{ult_{tensile}}$ is the ultimate shear strength (MPa), $F_{ult_{tensile}}$ is the maximum load at the test piece fails (N) during compression test, $A_{tensile}$ is the mean cross-sectional area of the gauge portion (mm²). For tensile testing, the dog-bone bamboo sample were set up and clamp between the grips of the Universal Testing Machine. The displacement rate of 1 mm/min was applied. The test automatically stops when the sample failed or break off. Then, the data of the tensile test result was recorded, and the stress-strain curves is plotted. Fig. 8(b) illustrated the tension test arrangement, which was parallel to the bamboo grain.

(a) Compression Test (b) Tensile Test

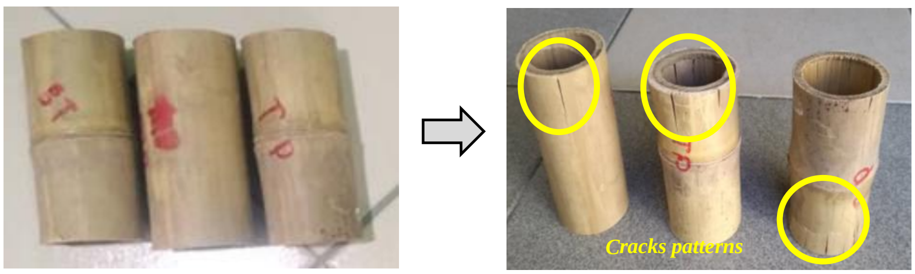
FIGURE 8. Experimental setup of bamboo samples for compression and tensile test

RESULTS AND DISCUSSION

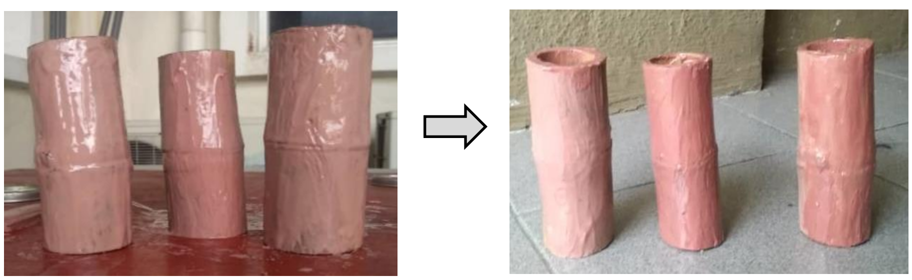
The results obtained for both compression and tensile tests presented herein highlight the mechanical properties of the bamboo samples prepared in this study. The results were analyzed for three different surface treatment of bamboo i.e. untreated bamboo (i.e. control sample), solid epoxy and water-based epoxy.

Compression Strength

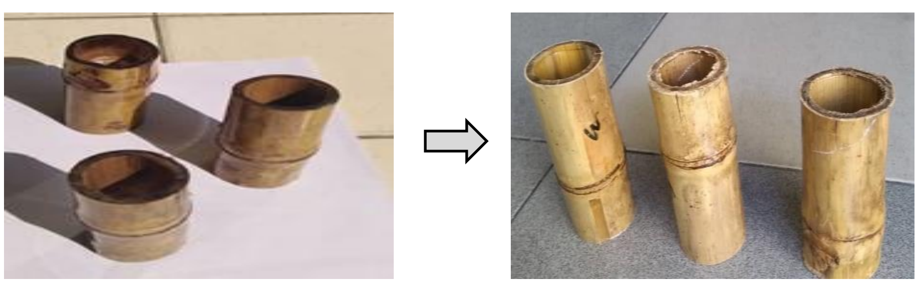
The physical failure and cracks pattern of the untreated, solid epoxy and water-based epoxy of samples under applied static load are compared in Fig. 9, whereby the pictures were taken before and after test have been conducted. It shows that the sample revealed several cracks, which eventually led to splits as specimens' sections buckled. Untreated bamboo shows the clear part of cracks compared to the solid epoxy and water-based epoxy. The results provide similar agreement with previous study conducted by [9] which proved that bamboos with air-dried culms or not treated experienced brittle failure.



(a) Untreated bamboo samples



(b) Bamboo samples coated with solid epoxy



(c) Bamboo samples coated with water-based epoxy

FIGURE 9. Pre- and post- bamboo samples under applied load during compression test

The compressive strength of sample recorded for each surface treatment is summarized in Table 2 and Fig. 10. It is noted that the average compressive strength of the bamboo was found to be rather high using solid epoxy is 67.27 N/mm^2, which is 6.2% higher than that of water-based epoxy and 23.77% greatly higher than untreated surface bamboo. Although the solid epoxy is similar to the water-based epoxy, but it provides much better frictional properties to the bamboo compares to the untreated surface.

TABLE 2. Compressive strength for bamboo coated with different surface treatment

Surface treatment	Sample	Outer Diameter (mm)	Thickness (mm)	Cross sectional Area (mm^2)	Maximum loading (kN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
Untreated bamboo	1	55.00	6.00	923.75	46.60	50.45	54.35
	2	54.50	5.80	760.30	42.90	56.43	
	3	55.20	5.50	801.30	45.00	56.16	
Solid Epoxy	1	54.80	5.05	789.29	55.35	70.13	67.27
	2	55.00	5.10	799.50	54.90	68.67	
	3	55.10	4.80	758.51	47.80	63.01	
Water-based Epoxy	1	55.20	5.20	816.81	49.50	60.60	63.35
	2	55.10	5.50	857.03	56.60	66.04	
	3	55.40	5.30	834.19	52.90	63.42	

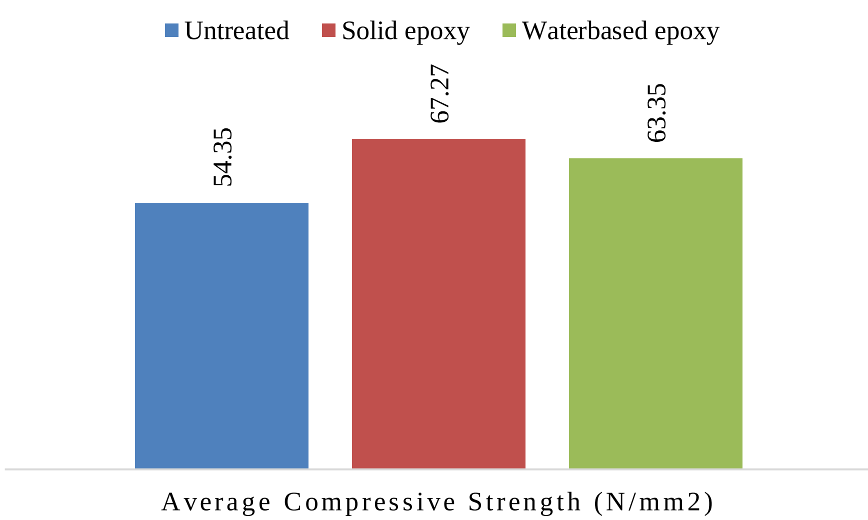
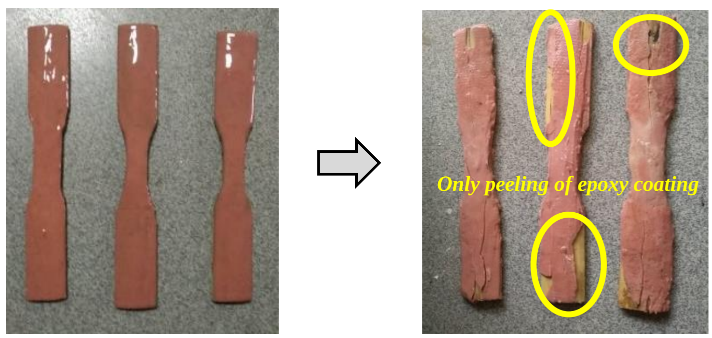


FIGURE 10. Average compression strength of sample with different surface treatment

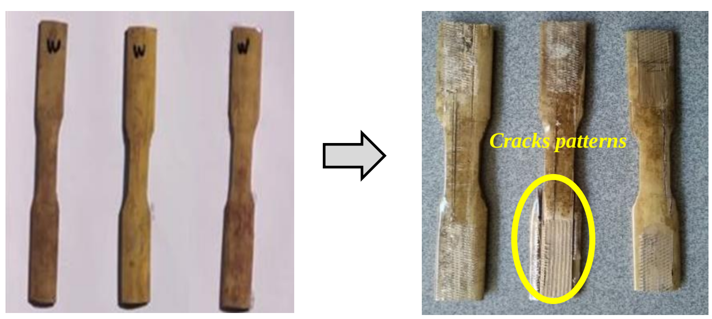
Tensile Strength

The tensile strength test is set-up parallel to the grain of bamboo and were performed under the same conditions as compressive strength tests. The physical failure and cracks pattern of the untreated, solid epoxy and water-based epoxy bamboo samples under applied static load are compared in Fig. 11, whereby the pictures were taken before test and after test have conducted.

(a) Untreated bamboo samples



(b) Bamboo samples coated with solid epoxy



(c) Bamboo samples coated with water-based epoxy

FIGURE 11. Pre- and post- bamboo samples under applied load during tensile test

Bamboos outperform other materials such as wood in terms of strength characteristics, according to previous research findings by [7]. As illustrated in Table 3, the untested and post-tested samples conducted for tensile test shows a combination of stress and shear parallel to the grain caused a comparable failure in a significant number of samples. The results show that the untreated bamboo experienced extensive damages compared to the bamboo coated with solid or water-based epoxy with less critical failure.

The tensile strength of sample recorded for each surface treatment is summarized in Table 3, Fig. 12 and Table 4. Refer to the results, for the tensile modulus, untreated bamboo has low result compared to bamboo coated with solid and water-based epoxy. It also shown that the tensile modulus of bamboo coated with solid epoxy is 7835.72 MPa, which is 8.13% higher than that of water-based epoxy, and 53.29% higher than the untreated surface. The tensile strain at break for bamboo coated with solid epoxy also provide highest percentage of strain value compared to other samples.

TABLE 3. Tensile strength for bamboo coated with different surface treatment

Surface treatment	Sample	Thickness (mm)	Width (mm)	Maximum Loading (N)	Ultimate Tensile Strength (MPa)	Average Ultimate Tensile Strength (MPa)
Untreated bamboo	1	4.95	10	7940.08	160.41	154.3
	2	5.12	10	7645.83	149.33	
	3	5.05	10	7734.25	153.15	
Solid Epoxy	1	5.00	10	13582.87	271.66	280.23
	2	5.11	10	14013.63	274.24	
	3	5.03	10	14827.55	294.78	
Water-based Epoxy	1	5.10	10	11042.35	216.52	248.73
	2	5.14	10	28386.13	261.24	
	3	5.05	10	3556.17	268.44	

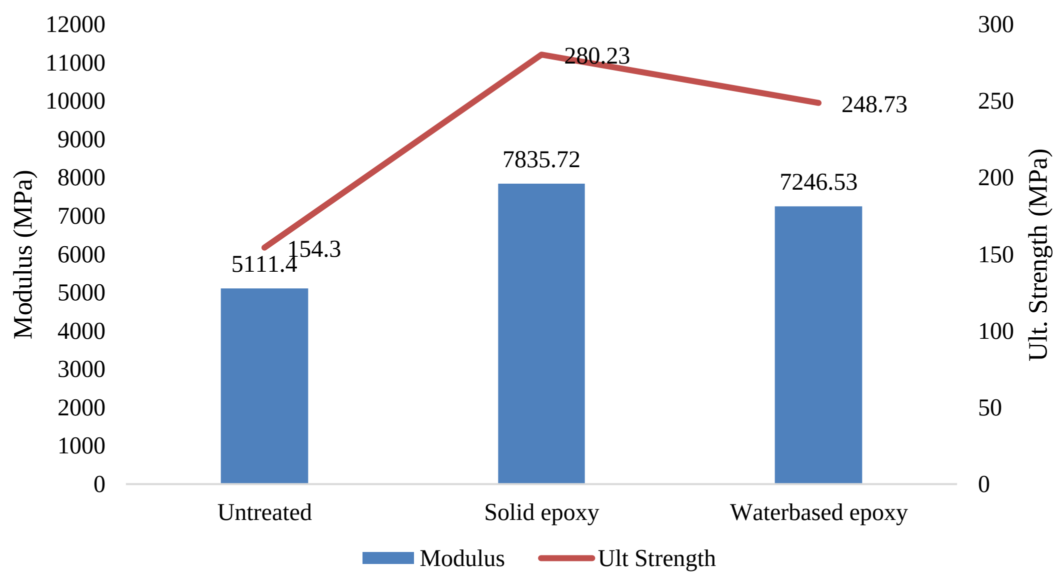


FIGURE 12. Modulus and ultimate tensile strength of the bamboo samples

TABLE 4. Average modulus and ultimate strength of bamboo treatment

Surface Treatment	Average Modulus (MPa)	Tensile stress (MPa)	Tensile strain at break (%)
Untreated	5111.4	154.3	14.66
Solid epoxy	7835.72	280.23	36.61
Water-based epoxy	7246.53	248.73	32.34

For the ultimate tensile strength, bamboo coated with solid epoxy shows the highest strength compared to the other surface treatment. According to the Fig. 13, the ultimate tensile strength of bamboo coated with solid epoxy is 280.23 MPa, which is in range of 11% to 45% higher than the water-based epoxy and untreated bamboo respectively. In overall, solid epoxy gives highest result for the tensile strength among the others. The results show that the application of surface treatment significantly modified and increased the mechanical properties of the bamboo compared to untreated bamboo.

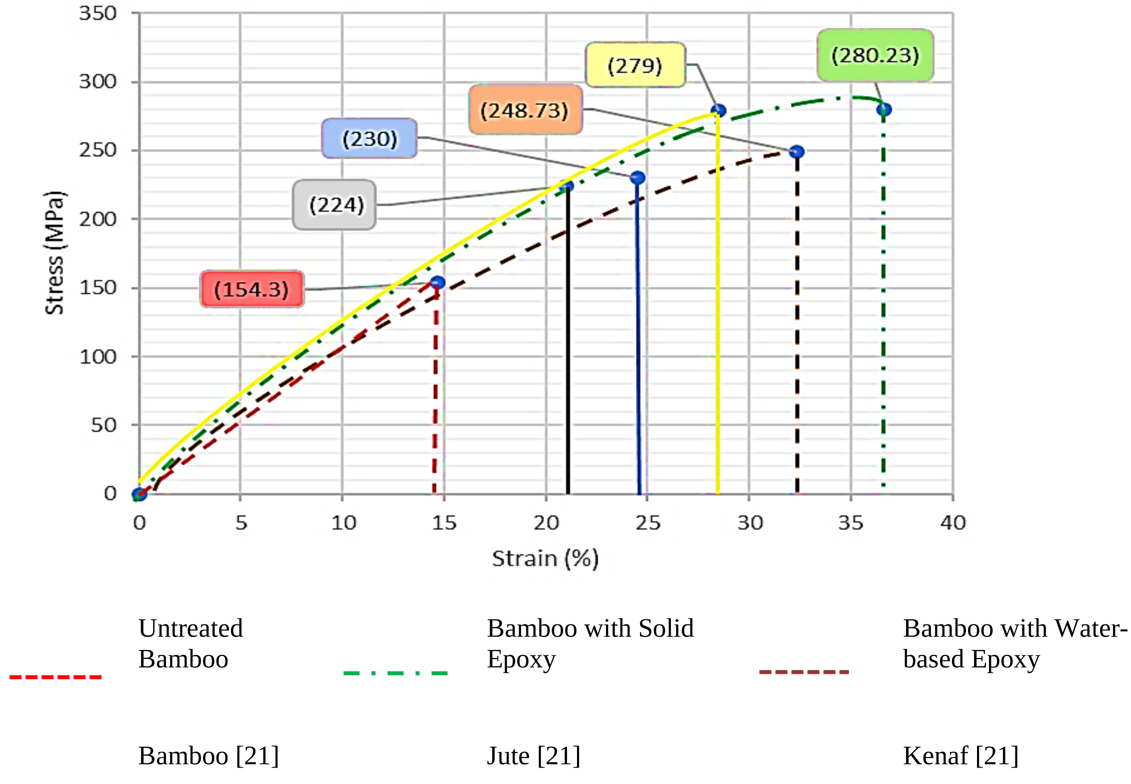


FIGURE 13. Typical stress-strain curves between surface treatment

Fig. 13 shows typical tensile stress-strain curves for the bamboo. The tensile strength of bamboo samples coated with different was compared with the previous study performed by [21]. The result highlighted that the bamboo coated with solid epoxy improved the tensile strength of the bamboo compared to others. All tensile stress rose linearly with strain until the maximum value was reached, followed by a rapid load reduction, resulting in the ultimate fracture [22,23].

CONCLUSION

In this study, compression and tensile tests were conducted to test surface treatment ability and capability of bamboo. Three types samples were prepared i.e. untreated bamboo, bamboo coated with solid epoxy and bamboo coated with water-based epoxy. Total of 18 samples were tested under static loading to investigate the mechanical properties and physical deformation of bamboo. It is noted different surfaces treatment of the bamboo showed significant influence on the mechanical properties of the bamboo. In terms of surfaces treatment, solid epoxy exhibited better properties compared to water-based epoxy and untreated bamboo. However, the epoxy coated showed the best results with significant improvement in mechanical properties thereby considered to be the optimum compared to the untreated bamboo. As conclusion, the application of solid epoxy on the surface of bamboo resulted to highest increment of compression and tensile strength on bamboo, followed by water-based epoxy, and untreated bamboo.

ACKNOWLEDGEMENT

The authors gratefully acknowledged the National Defence University of Malaysia, Sungai Besi Camp, 57000 Kuala Lumpur, Malaysia for the opportunity to conduct this research.

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