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Compressive Properties of Hawaiian Gold Timber Bamboo under Different Conditions

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Abstract – *With the current emphasis on environmental-friendliness and sustainability, natural fibre composites are starting to gain attentions from various industries to serve as alternative materials. However, not many elementary studies have been done on the mechanical properties of natural fibre composites. Therefore, this project will study on the compressive properties of bamboo, a type of natural fibre composite. The bamboo species used for this project is the Hawaiian Gold Timber Bamboo and this project will focus on three conditions of this bamboo species, which are dry bamboo, wet bamboo that have been immersed in distilled water at room temperature until it reaches enough saturation and boiled bamboo that have been immersed in boiled distilled water for 2 hours. The compressive properties of these three bamboo conditions will be compared to study the effects due to different conditions. Immersing the bamboo in distilled water allows water absorption while boiling it will accelerate the aging process of bamboo. From the tests, it is found that boiling the bamboo specimens has drastic effects on their compressive properties compared to dry bamboo specimens. But, the effects are not as drastic on the compressive properties of wet bamboo specimens. Nevertheless, the compressive strength of this Hawaiian Gold Timber bamboo is considered tough as it is comparable with other conventional materials such as granite and concrete at its maximum and minimum ultimate compressive stress respectively and could be enhanced by hybridized it with other conventional composite materials.*

Keywords: Natural fibre, Bamboo, Eco composite, Compressive, Elementary test

1.0 INTRODUCTION

Composites are being widely used in many industries nowadays such as in aeronautics, automotive, constructions and furnishing. The usage of composites has increased drastically in the recent years due to their lightweight and durable properties. For example, more and more components of the aircraft are made up of composite material. Around 53% of the weight of the Airbus A350 are contributed to composite materials [1]. However, the usage of composite materials has given rise to pollution problem since most conventional composite are non-recyclable. With the current emphasis on environmental-friendliness and sustainability, natural fibre composites have gained the attention of many industries as alternative materials. Natural fibre composites are composed of natural fibres embedded in matrix. Natural fibre composites have many advantages such as it is sustainable, biodegradable, abundant, environmental-friendly and low cost. The standout advantage of natural fibre composite is their low density, which ultimately, gives them high specific strength [2]. It is said that natural fibre composite has high potential to substitute synthetic fibre reinforced plastics at lower cost and better sustainability [3]. Bamboo is a type of natural fibre composites that can be found abundantly in tropical and subtropical countries. In China, bamboo has been widely used in the construction industries such as building bridges and as scaffolding [4-5].

The failure of bamboo to support these applications is possible if no proper studies and tests have been conducted to determine the compressive properties of bamboo as from the open literature it is known to have good properties in tensile but not in compression [6-7]. This makes the studies on compressive properties of bamboo even more crucial. Since most bamboo structures, such as bridges and scaffoldings, are constantly exposed to water (rain or river), it is also important to study the effect of water on the mechanical properties of bamboo. To date, there are not many studies have been done on the compressive properties of bamboo and the effect of moisture content on their compressive behaviour. In addition, the properties of bamboo are different for different species and the studies that have been done are on some bamboo species only [8]. For example, the compressive properties of several bamboo species that have been previously carried out by researchers are Kao Jue *(Bambusa pervariabilis)* [9], Mao Jue (*Phyllostachys pubescens*) [9-10], *Bambusa balcooa*, *Bambusa bambos, Bambusa nutans, Bambusa tulda, Dendrocalamus giganteus*, *Dendrocalamus strictus*, *Melocanna bambusoides* [11] and so on.

By far, the study on the compressive properties of the Hawaiian Gold Timber Bamboo that abundantly can be found in Malaysia has not extensively been carried out. The availability of this bamboo species maybe can be applied in vehicles, constructions or furnishing structure design such as cart for oil and gas industry [12]. Thus, there is a need to carry out study on the compressive properties of this species.

Besides species, the compressive properties of bamboo also depends on the site/soil and climatic condition, harvesting technique, diameter, density, age, moisture content, height, nodes or internodes and position in the culm [13]. Beside these factors, it is also noted that bamboo is an orthotropic material, meaning that it has different mechanical properties in the longitudinal, radial and tangential direction of the bamboo [14]. The compressive properties of the bamboo depends on its fibre density and the above factors will affect the fibre distribution. The higher the fibre density, the stronger the bamboo will be. Naik reported the compressive properties of bamboo of different species is in the range of 53-100 MPa [11]. According to Godbole and Lakkad the compressive properties of bamboo are reduced after water absorption [15]. The objective of this paper is to study the compressive properties of bamboo, specifically Hawaiian Gold Timber Bamboo, under different conditions which are dry bamboo, wet bamboo and boiled bamboo. The findings of this study will provide the compressive properties data of the bamboo species used and these data can be used as reference for hybridization works with other composite materials. Besides that, the effects of water absorption and ageing on the compressive properties of tested bamboo also can be determined.

2.0 MATERIAL AND METHOD

The bamboo species used for this study is the Hawaiian Gold Timber Bamboo (*Bambusa vulgaris vittata*) which can be found abundantly in Universiti Teknologi Malaysia that located in south peninsular of Malaysia. Compression test will then be carried out on the dry bamboo, wet bamboo and boiled bamboo specimens.

2.1 Bamboo Specimens Preparation

A long section of the Hawaiian Gold Timber Bamboo which has been pre-cut and dried for 6 months is cut into culms using a jigsaw machine. These culms are then cut into smaller blocks with its skin removed. Using the same jigsaw machine, sand paper and sanding machine, the

Penerbit Akademia Baru
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bamboo blocks are trimmed and sanded into the required dimensions. The dimensions of the specimens are around 110 mm (L) X 10 mm (W) X 3 mm (T) as shown in Figure 1. This dimension is in accordance to ASTM D3410/D3410M-03 (Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading) [16] with some modifications upon suggestions by the laboratory technician. Three specimens are prepared for each configurations.

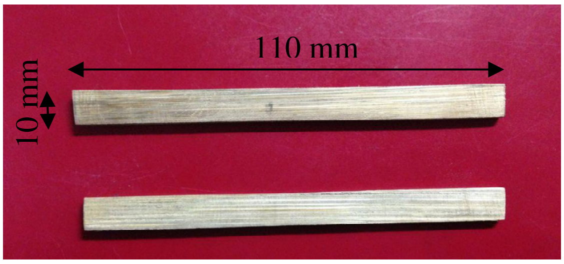

Figure 1: The dimension of the specimens

2.1.1 Wet Bamboo Specimens

The wet bamboo specimens refer to specimens that have been immersed in the distilled water. Before immersion, the initial mass of the bamboo specimens are first measured and recorded. The mass of the wet bamboo specimens are measured from time to time to measure its mass increment. All the wet bamboo are taken out after it reaches enough saturation (more > 680 hours). The final mass of wet bamboo, the percentage of mass increment and the water absorption rate are recorded as shown in Table 1.

2.1.2 Boiled Bamboo Specimens

The boiled bamboo specimens refer to specimens that have been immersed in hot distilled water using water bath machine. This is done to increase the water absorption rate in order to accelerate the ageing process of the bamboo as implemented in [15, 17]. The initial mass of the boiled bamboo specimens are first measured before immersed into hot distilled water. When the water bath reaches maximum temperature of 95 ℃, the boiled bamboo specimens are put into the water bath to boil for 2 hours as implemented in [15]. When two hours are up, the final mass of the boiled bamboo specimens are measured again before conducting the compression test as recorded in Table 1.

Table 1: Specimens label and configurations

Condition	Specimen	Initial Mass (g)	Final mass (g)	Mass Increment (%)	Water absorption rate (g/hr)
Dry	C-D-1	2.73	-	-	-
	C-D-2	2.66	-	-	-
	C-D-3	2.76	-	-	-
Wet	C-W-1	2.76	4.86	76.11	0.003270
	C-W-2	2.72	4.96	82.35	0.003284
	C-W-3	2.55	4.85	90.07	0.003236
Boiled	C-B-1	2.66	4.98	87.07	0.89
	C-B-2	2.61	4.96	89.92	0.94
	C-B-3	2.46	5.42	120.36	0.98

Note: The designation of specimens was based on the code [T-C-n] where T: Type of test, C: Condition and n: Specimen number.

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2.2 Compression Test

The compression test is carried out using the Instron 8801 Universal Testing Machine as shown in Figure 2. The test is carried out according to the guidelines from the standards ASTM D3410/D3410M-03 [16]. The bamboo specimen is first clamped to the machine with suitable clamping pressure as shown in Figure 3. It is made sure that the fibre direction of the specimens are parallel to the force direction. The specimen is compressed at a rate of 1.5 mm/minute. The compression test is stopped once there is a major breakage of the fibers that can be indicated by the sharp drop in the stress-strain graph.

Figure 2: Instron 8801 Universal Testing Machine

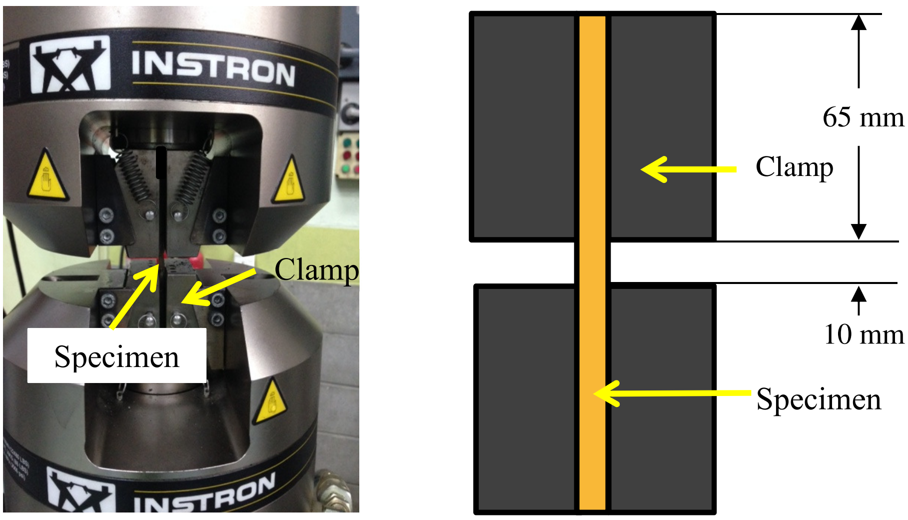

Figure 3: Compressive test setup configuration

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3.0 RESULTS AND DISCUSSION

Three different conditions (dry, wet and boiled) of Hawaiian Gold Timber bamboo specimens have been applied with compression loads. Therefore, the behavior of the compressive properties (maximum and minimum) of this bamboo can be examined in order to consider the risky cases when it being exposed to the water and when the internal lignin structure has damage due to the ageing process.

Figure 4 shows the damage specimens of different conditions after the compression test. All bamboo specimens failed in their mid-sections as highlighted by the red circles. Figure 5 shows the graph of compressive stress versus strain of bamboo specimens of all conditions while Table 2 compares their important compressive properties. Dry bamboo specimens have better mechanical properties when compared to the wet and boiled specimens. Boiling the bamboo specimens have drastically decreased its compressive properties. However, the effect is not that drastic for the wet bamboo specimens. In terms of compressive modulus of elasticity, the wet bamboo specimens showed an average decrease of 25.44% when compared to the dry bamboo specimens. The compressive modulus of elasticity of boiled bamboo specimens is 61.03% lower than the dry bamboo specimens. In terms of yield stress, the wet and boiled bamboo specimens showed a massive decrease of 70.11% and 84.12%, respectively when compared to the dry bamboo specimens. Last but not least, the ultimate compressive stress of the wet and boiled bamboo are 46.02% and 83.73% lower than that of the dry bamboo specimens.

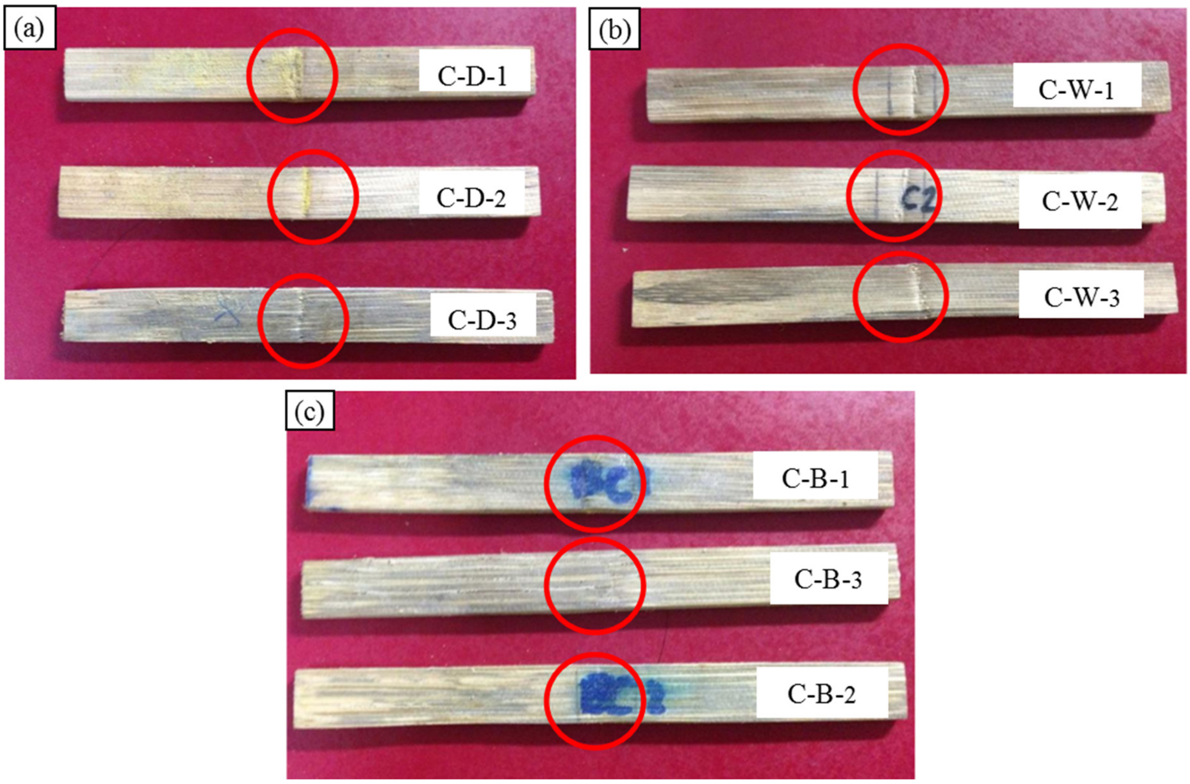

Figure 4: Failed bamboo specimens. (a) Dry bamboo. (b) Wet bamboo. (c) Boiled bamboo.

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Table 2: Comparison of compressive properties of bamboo specimens of different configurations

Compressive Properties	Dry	Wet	Boil
Compressive Modulus of Elasticity (GPa)	6.21	4.63	2.42
Yield Stress (MPa)	50.31	15.04	7.99
Ultimate Compressive Stress (MPa)	124.04	66.96	20.18

The drastic decrease in the compressive properties of the boiled bamboo specimens can be explained by the effect of high temperature on lignin. Lignin is the matrix in bamboo that holds the bamboo cellulose fibres together as shown in Figure 6. Lignin is responsible for the compressive properties of bamboo and it is damaged when exposed to high temperature [15].

When the bamboo specimens are boiled, most of the lignin is damaged and this explains why boiled bamboo specimens have the lowest compressive properties. On the other hand, lignin is also water resistant in nature. The dispersion of data of the boiled bamboo specimens are due to different level of lignin damage. When more lignin is damaged, the specimen will absorb more water and this ultimately give it lower compressive properties. In this study, in can be concluded that C-B-3 has the highest lignin damage as it has the highest percentage of mass increment (120.36%) and the lowest ultimate compressive strength (16.19 MPa), followed by C-B-2 (89.92% and 19.22 MPa, respectively) and C-B-1 (87.07% and 25.14 MPa, respectively). Wet bamboo specimens do not experience lignin damage, hence, their compressive properties are higher than that of the boiled bamboo specimens. The reduction in compressive properties of the wet bamboo specimens is due to water absorption only.

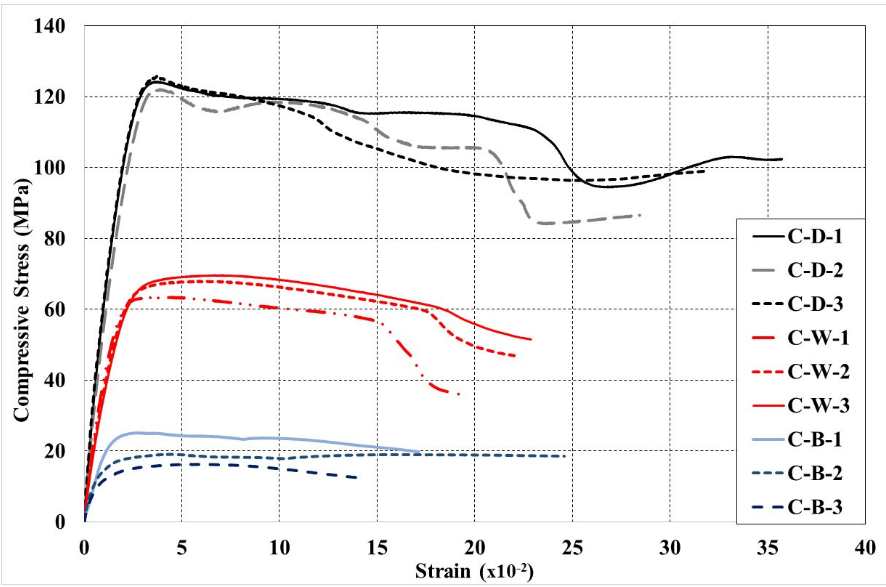

Figure 5: Compressive stress-strain graphs of bamboo specimens of all configurations

Table 3 shows the comparison of the compressive properties of bamboo to other material. In its strongest state (dry), bamboo has an ultimate compressive stress that is comparable to granite. After being immersed in distilled water for more than 680 hours, the ultimate compressive stress of the bamboo is close to that of sandstone. In its weakest state (boiled in

Journal of Advanced Research in Applied Mechanics
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distilled water for 2 hours), the ultimate compressive stress of bamboo is still comparable to concrete.

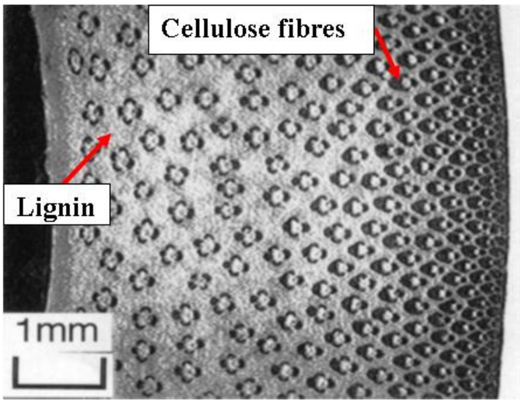

Figure 6: Cross-section of bamboo culm [18]

Table 3: Comparison of the ultimate compressive stress of bamboo with other material

Condition	Bamboo	Other Material
Dry	124.04 MPa	Granite (130 MPa) [19]
Wet	66.96 MPa	Sandstone (60 MPa) [20]
Boiled	20.18 MPa	Concrete (20 – 40 MPa) [21]

4.0 CONCLUSION

In conclusion, the results obtained from the experiment are satisfying when compared to the results that are commonly reported in the literature review. In this project, the compressive properties of Hawaiian Gold Timber bamboo of different conditions have been successfully obtained. Therefore, the maximum compressive properties of this bamboo can be determined from the result analysis of dry bamboo specimen. From the analysis, it is noted that boiling the bamboo has drastically accelerate the ageing process and decreased its compressive properties to the minimum (i.e. compressive modulus elasticity 61%, yield stress 84% and ultimate compressive stress 83%) due to lignin damage and water absorption. The reduction in the compressive properties of wet bamboo is also significant (i.e. compressive modulus elasticity 25%, yield stress 70% and ultimate compressive stress 46%) compared to the dry bamboo specimen although it is due to water absorption only.

Nevertheless, it can be concluded that this bamboo has good compressive properties as at its strongest (dry) and weakest (boiled) states are comparable to compressive properties of granite and concrete respectively. Moreover, it is believed that this properties could be improved by performing hybridization process with other composite materials such as fibre-glass type materials that would be the future works of this study.

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