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PERFORMANCE OF BAMBOO REINFORCED INTERLOCKING SOIL-CEMENT BLOCK WALL UNDER IMPACT LOADING

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Abstract

Pandemic Covid-19 has become a major factor that contributes to substantial increment of the recent construction cost during the economic recovery period which subsequently causes financial difficulties to people from low-income groups to own their desired home. To date, numerous researchers have been conducted to investigate the potential use of natural resources as an alternative construction material. In addressing the issue, the performance of bamboo as an alternative reinforcement for interlocking soil-cement block (ISCB) wall under given impact loading was investigated. *Gigantochloa Scortechinii*, a species of bamboo, was chosen as it is abundantly found in Peninsular Malaysia. The mechanical properties of the bamboo were investigated by performing the compression and tensile laboratory testing. Each of the testing consisted of 6 samples; 3 untreated bamboo (control) and the remaining bamboo were coated with epoxy as surface treatment. In impact load testing, the bamboo reinforcement was coated with epoxy and rolled with galvanized iron wire to increase the bonding strength between bamboo and mortar in the ISCB wall. Six ISCB walls with dimensions of 1500 mm × 1000 mm × 125 mm were prepared and tested under impact load test which consisted of 2 samples for each unreinforced, steel-reinforced, and bamboo-reinforced wall. Result denoted that the treated bamboo significantly stronger for both compressive and tensile strength with percentage improved to 7% and 46% respectively. It also observed that the bamboo-reinforced wall experienced much smaller initial (first crack), and maximum (after 15 blows) average crack width compared to unreinforced wall in the impact load testing. The bamboo-reinforced wall required 4 blows of impact load to start an initial crack pattern, which is similar to steel-reinforced wall. The study provides a significant finding that bamboo is a good and cheaper material to be used as an alternative reinforcement in the construction industry.

Keywords: Bamboo, Impact loading, Interlocking soil-cement block wall, Performance, Reinforcement.

1. Introduction

Pandemic Covid-19 has had a long-lasting impact to all Malaysians especially during the Movement Control Order (MCO) whereby they have been forced to work and spend more time at home. Due to that, based on the Consumer Sentiment Survey 2021 conducted by the PropertyGuru, it is found that 73% of Malaysians were keen to change their living situations through several choices such as renovation, purchasing their own house, or moving out to a better comfortable accommodation. Also, according to Moroz et al. [1], the housing demand in the regions is estimated to increase by 35 million units per year between 2000 and 2010, and by 39 million units per year between 2010 and 2020.

In particular, the conventional building materials such as concrete and steel has been used over decades in the construction industry. However, through years, the increment of market price for the cement and steel has become the major issue to the construction industry to build an affordable and comfortable housing especially for low to medium-income group. On the other hand, it has been reported that the production of steel reinforcement which provides tension strength to the reinforced concrete structure has harmful the environment. This occurs when about 1.83 tonne of carbon dioxide (CO2) is emitted during the production of steel [2]. The impact of this pollution not only cause dangerous phenomenon such as global warming and ozone depletion, but consequently affected the human health [2].

Many researchers have conducted some studies to investigate the potential natural resources which has quite similar properties to replace the steel reinforcement. Bamboo is one of the natural resources that widely available through the country especially in the Peninsular Malaysia. Besides having a high tensile strength, bamboo also demonstrated an ability as a sustainable element that offers a low construction cost, readily available and environmentally friendly during its lifetime [3]. For instances, bamboo was first used as concrete reinforcement for prefabricated structural elements by the United States Naval Civil Engineering Laboratory in year 1966 to 2000 [4].

Sevalia et al. [5] and Patel et al. [6] highlighted that bamboos are giant grasses that belongs to the family of the Bambusoideae which is estimated that about 1100–1500 species of Bambusoideae exits in the world. Bamboo is recorded as the fastest growing plant in the world where 45 genera of bamboo have been found to grow at up to 91cm (35 in) per day or at a rate of 0.00003km/h (0.00002mph) [7]. Bamboo is a natural composite fibre material which consists of cellulose fibres and lignin that act as reinforcement and matrix respectively [8]. The thickness of a bamboo culm reduces as it grows taller, while the density of the fibres rises from the inner to outer walls [9]. Meanwhile, the physical circular hollow shaped of bamboo culm which covered with the waxy surface serves as an eco-friendly material to prevent moisture from escaping.

Bamboo has been referred as "strong-as-steel" reinforcement for concrete, which is frequently mentioned as a highly renewable and high-strength alternative to timber [10]. Moroz et al. [1] found that some species of bamboo have almost the same ultimate tensile strength of mild steel bar which is the maximum ultimate tensile strength of bamboo can rise up to 440 N/mm^2 and ultimate compressive strength can reach to 65 N/mm^2. Paulinmary and Tensing [11] highlighted that bamboo strength tensile can be very high in range of 120MPa to 250 MPa, which is similar to steel reinforcement, and it has very strong in compression up to 58 MPa. [12] revealed that bamboo has an excellent tensile strength because bamboo nodes help to avoid it from buckling, thus, it can be bent as far as reaching the ground without breaking.

On the other hand, the use of interlocking blocks also receives special attention from the construction's industry players. The blocks are typically 2½ times larger than regular burnt clay bricks or cement brick. Previous works proved that it could provide faster construction time due to its enormous size [13]. The blocks do not require cement to bond them together as the block will interlock each other, besides their ability is good in resisting shear for the building. Divya et al. [14] conducted study on soil cement bricks and revealed that after 21 days curing period, the compressive strength of bricks masonry wall had a greater stability effect compared conventional brick masonry wall (e.g., cement and clay bricks). The blocks become most favourable construction materials because it provides solution for more cost-effective walling material and construction techniques.

In addressing the issues, this study was conducted to investigate the performance of bamboo as an alternative reinforcement for interlocking soil-cement block (ISCB) wall. Towards sustainable and green technology, species type of *Gigantochloa Scortechinii* bamboo was chosen as it is abundantly found in Peninsular Malaysia [15] and has high tensile strength as reported by Paulinmary and Tensing [11]. Prior preparing the wall samples, the mechanical properties of bamboo was investigated through compression and tensile strength laboratory testing. The surface of bamboo reinforcement was coated with epoxy and rolled with galvanized iron wire to increase the bonding strength between bamboo and mortar in the ISCB wall. The impact load test was conducted to investigate the crack pattern of ISCB wall reinforced with bamboo compared with unreinforced and steel-reinforced wall. Throughout the study, the potential ability and performance of bamboo to be used as an alternative reinforcement was investigated from two main objectives i.e., to determine the mechanical properties of treated bamboo under compression and tensile load, and to investigate the performance of treated bamboo reinforcement in ISCB wall by considering the cracking initial and maximum cracking patterns under impact of load test.

2. Methods

The flowchart of research methodology presented in Fig. 1 is divided into seven stages i.e. (1) literature study which includes in-depth critical review on previous and recent related researches, guidelines and standard laboratory procedure, (2) determination of materials which consists of determination species and types bamboo, surface treatment, number of interlocking soil-cement block for construction of masonry wall, suitable mixing ratio of mortar (3) preparation of samples i.e., cylindrical and dog-bone shaped bamboo for both untreated and treated samples and ISCB wall (unreinforced, reinforced with bamboo strip, reinforced with steel rebar), (3) preparation of experimental setup for mechanical properties testing (compression and tensile load test) and impact load testing for ISCB Masonry wall, (4) result and analysis, and (5) conclusion.

3.Preparation of Bamboo Samples

Gigantochloa Scortechinii or *Bamboo Semantan* was chosen to act as the reinforcement in this research because of it is abundantly found in Peninsular Malaysia [15] and has high tensile strength as reported by previous researcher [11].

The age of bamboo was estimated more 5 years old after post-harvesting which is the resources from the authors' research teamwork i.e. Daud et al. [16]. The raw bamboo was soaked into boric acid about 15 days to kill fungi and termites or any insects that present in the bamboo. The sample were left to dried in temperature room for 24 hours to stabilize the humidity rate to less than 10% [17]. The average height of bamboo was approximately 3m and the diameter varied from 30 to 60 mm. The bamboo was selected according to the size, condition and specifications that meets with the requirements in required for specific experimental setup. Figure 2 shows the *Gigantochloa Scortechinii* which is available in the Laboratory Structure at National Defence University of Malaysia (NDUM).

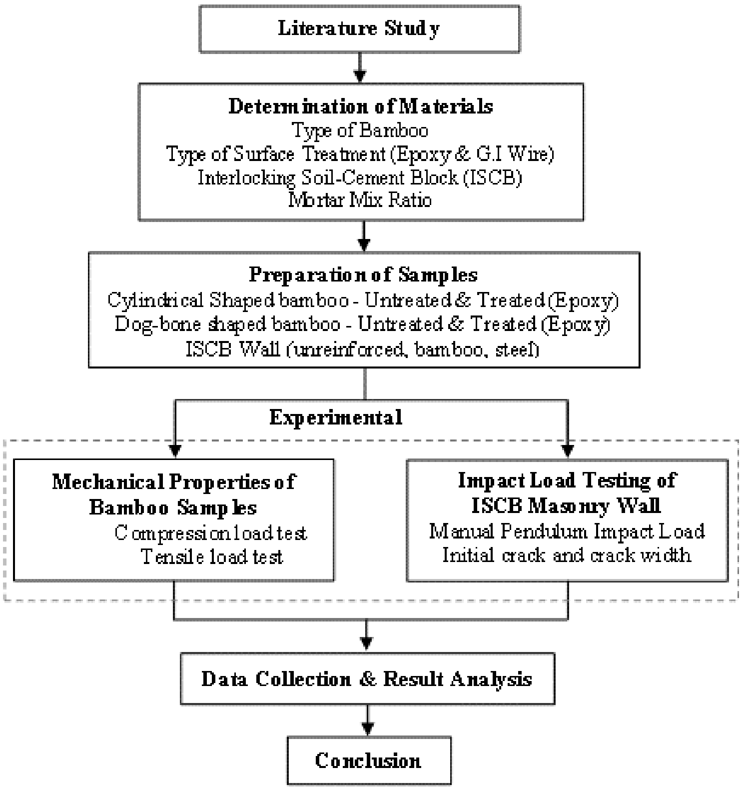


Fig. 1. Research flowchart.

Fig. 2. Bamboo *Gigantochloa Scortechinii.*

Total of 6 bamboo samples for each shape were prepared which consists of 3 samples for each untreated bamboo and epoxy coated bamboo. The Epoxy Pioneer was used as it provides better bonding strength and good waterproofing as reported by Osmi et al. 18]. Dey and Chetia [19] reported that surface treatment is necessary to avoid water penetration due to micro or macro cracks in concrete.

For compression test, the bamboo was cut into 100 mm length with diameter ranging from 40 mm to 50 mm as shown in Fig. 3. However, the bamboo was cut into dog-bone shaped samples with length of 165 mm as illustrates in the Figs. 4 and 5 for tensile test. The procedure for both laboratory testing was carried according to standard guidelines explained in the ISO 22517-1:2004 [20] and ASTM D143-94 [21]. Similar procedure and detail measurement (Fig. 5) also has been adopted by previous study performed by [22, 23].

Meanwhile, for preparation of reinforcement, the bamboo culms were cut into strip shape because this shape are generally more suitable to be used as reinforcement in concrete or composite structure compared to the whole culms [24]. The bamboo reinforcements were cut into 1000 mm length and 20 mm width to fix the holes of the interlocking wall size. Total of 12 bamboo reinforcements were coated with solid epoxy and rolled with galvanized iron wire as reported by [18] shown in Fig. 6.

(a) Untreated bamboo

(b) Treated bamboo

Fig. 3. Cylindrical shape of bamboo samples for compression test.

(a) Untreated bamboo.

(b) Treated bamboo.

Fig. 4. Dog-bone shape of bamboo samples for tensile test.

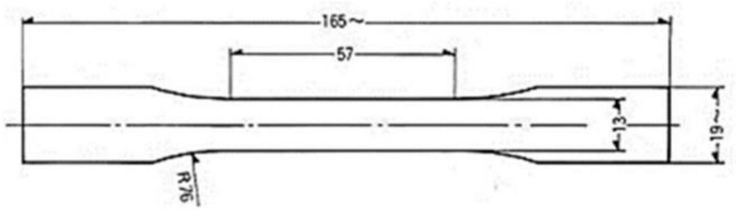


Fig. 5. Detail measurement (unit in mm) of dog-bone sample [20-23].

(a) Untreated bamboo

(b) Treated bamboo

Fig. 6. Bamboo strip for reinforcement in ISCB wall.

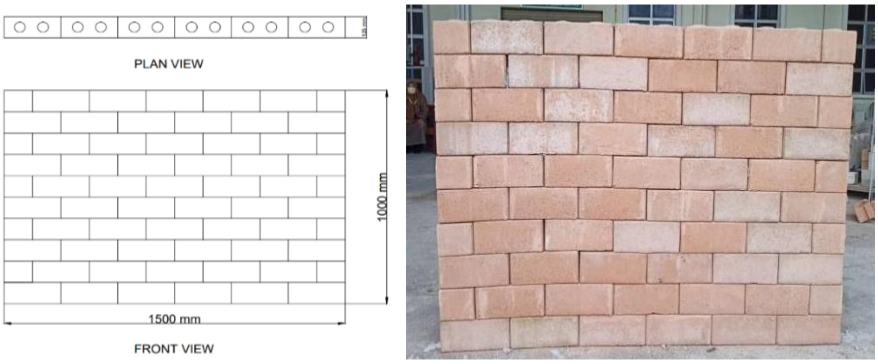
4. Preparation of ISCB Masonry Wall

The blocks were arranged for the first three layer of at the platform of the wall before the bamboo was inserted to reinforce the wall and the grout was filled in the hollow to provide bonding between bamboo and block. The ISCB with a dimension of 250 mm length, 100 mm height and 125 mm width were supplied by local industrial company, Stong Hills Sdn. Bhd. which a main collaborator for this research works. In this study, the interlocking wall is designed with 1000 mm × 1500 mm × 125 mm dimension, whereby the bamboo reinforcement was inserted in the hollow blocks at one-hole interval. Mortar was prepared to create a bond between bamboo and interlocking wall. The mixture design of mortar used is 3:1 for sand to cement ratio by volume. Figure 7 shows the arrangement of bamboo and steel reinforced ISCB masonry wall. Total of 6 samples of ISCB wall were casted consists of 2 samples for each unreinforced, steel-reinforced, and bamboo-reinforced wall. Figure 8 shows the full dimension of ISCB wall.

(a)

(b)

Fig. 7. Arrangement of reinforcement in interlocking wall (a) bamboo reinforcement (b) steel reinforcement.



(a) **(b)**

Fig. 8. **Detail dimensions of (a) proposed design and (b) laboratory samples of ISCB wall.**

5. Experimental Setup

The experimental setup is divided into two stages of laboratory testing i.e., mechanical properties of bamboo samples and impact load test of ISCB masonry wall. The first stage of laboratory testing is conducted to investigate the behaviour of untreated and treated bamboo samples under compressive and tensile applied load. Meanwhile, the latter stage of laboratory testing was performed to examine the performance of ISCB wall reinforced with bamboo to withstand the impact of lateral load. Further description of laboratory testing is explained in next sub-sections.

5.1. Compression test

The procedure was referred to the standard method accordance to ISO 22157-1(2004) [20]. The ultimate compressive strength was evaluated by adopting Eq. (1) and Eq. (2).

$$\sigma_{ult_{comp}} = \frac{F_{ult_{comp}}}{A_{comp}} \sigma_{ult_{comp}} = \frac{F_{ult_{comp}}}{A_{comp}} \sigma_{ult_{comp}} = \frac{F_{ult_{comp}}}{A_{comp}} \quad (1)$$

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

where is the $\sigma_{ult_{comp}}$ is the compressive stress (MPa), $F_{ult_{comp}}$ $F_{ult_{comp}}$ is the maximum load (N) during compression test, $A_{comp} A_{comp}$ is the cylindrical bamboo cross-sectional area (mm²), D is the bamboo outer diameter (mm) and t is the bamboo thickness (mm). Vernier Callipers was used to determine the outer and inner diameter of samples. The compression test was conducted using Shimadzu Universal Testing Machine (UTM) with capacity of 600 kN, under a constant rate of 1 kN/min until the samples failure. The maximum load for each specimen was recorded. Figure 9 shows the Shimadzu Universal Testing Machine (UTM) which is located at Structural Laboratory, NDUM and the bamboo tested under compression test using the UTM.

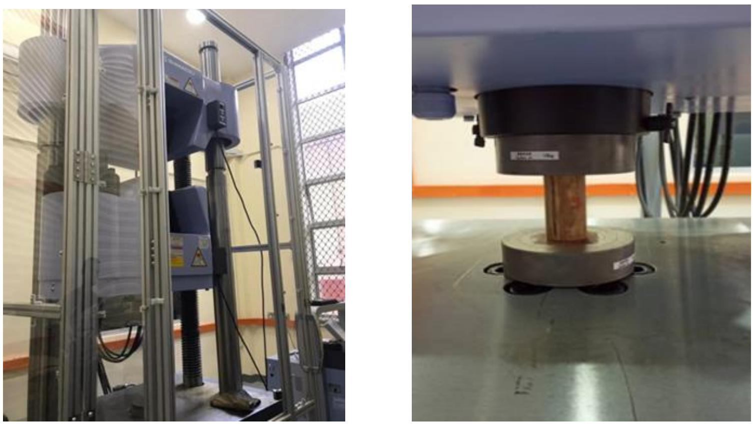


Fig. 9. Compression test of bamboo using Shimadzu UTM.

5.2. Tensile test

The tensile strength is tested accordance to standard methods in the ASTM D143-94 [21]. The tensile test of bamboo samples was conducted by using Instron Universal Testing Machine (UTM) with capacity of 100kN which located at the automotive laboratory, NDUM. The dog-bone shaped of bamboo samples were clamped on the grips and 1 mm/min load was applied gradually. The bamboo samples were placed parallel to bamboo's grain as shown in Fig. 10. The test was automatically stop when the samples is failed or break off. The ultimate tensile strength was determined by using Eq. (3).

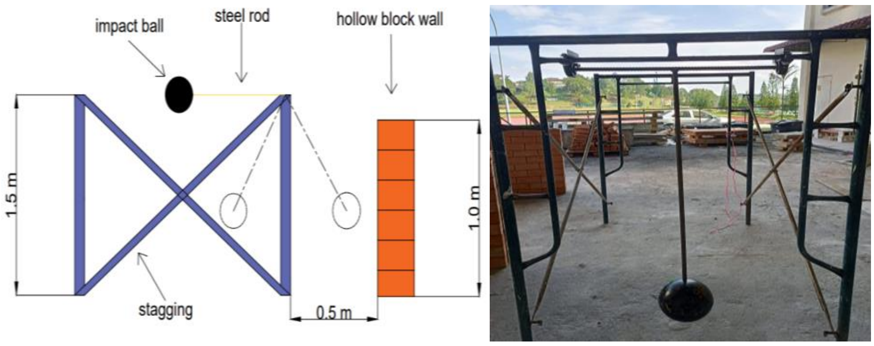
$$\sigma_{ult_{tensile}} = \frac{F_{ult_{tensile}}}{A_{tensile}} \tag{3}$$

where $\sigma_{ult_{tensile}}$ $\sigma_{ult\,tensile}$ is the ultimate shear strength (MPa), $F_{ult_{tensile}}$ $F_{ult\,tensile}$ is the maximum load at the test piece fails (N) during compression test, $A_{tensile} A_{tensile}$ is the mean cross-sectional area of the gauge portion (mm²). For tensile testing, the dog-bone bamboo sample was arranged parallel to bamboo grain and was clamped between the grips of UTM (Fig. 10). The displacement rate of 1 mm/min was applied. The test automatically stops when the sample failed or break off.

Fig. 10. Tensile strength test of bamboo using Instron UTM.

5.3. Compressive strength test

Impact load tests were conducted where the impact ball was hit 6 samples of ISCB walls with different reinforcement method i.e., unreinforced (control), steel rebar and bamboo rebar. The manual pendulum testing machine was designed and fabricated as illustrated in Fig. 11. The 7 kg impact ball load was used to give an impact to the ISCB walls with size 1500 mm × 1000 mm × 125 mm. The impact ball was pull to 90° height and released to hit the centre of the wall. The number of drops were recorded until the first visible crack appeared on the surface of wall. The wall was hit with 15 blows of impact and the crack appeared on the wall will be measured.



(a) **(b)**

Fig. 11. Impact load instrument. (a) Proposed design of impact load test and (b) Fabricated manual pendulum impact load test machine.

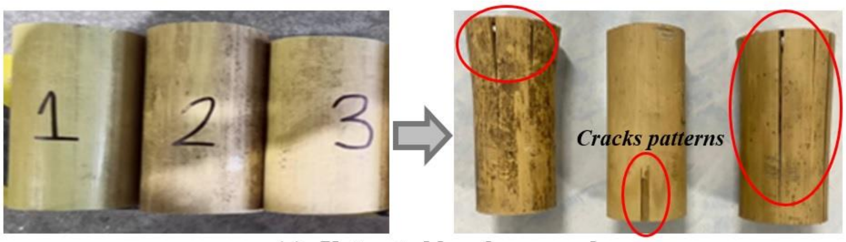
6. Results and Discussion

The results on mechanical properties of bamboo and impact load test of ISCB masonry wall is presented and discussed in next sub section.

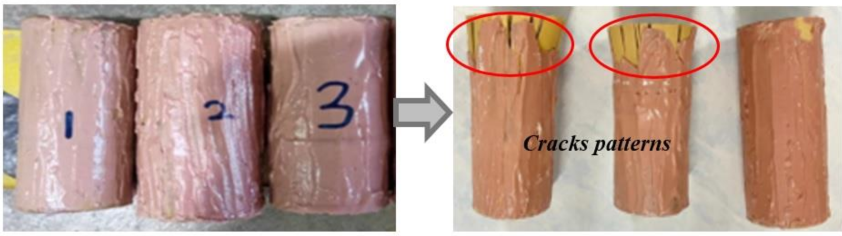
6.1. Compressive strength

The physical failure and cracks pattern of the untreated and treated bamboo samples under applied compression load are compared in Fig. 12 for pre-and post-laboratory test performed using the Shimadzu UTM. The sample shows several cracks and buckling of the samples. It is found that the untreated bamboo shows the clear part of cracks compared to the solid epoxy. It is also observed that the treated bamboo experienced cracking at one part of the bamboo at the same location of peeling-off epoxy coating occurred. The third sample of the treated bamboo have not experienced any significant failure after compression test. Similar agreement was provided by previous study conducted by [9, 18] which proved that untreated bamboo has experienced brittle failure compared to treated bamboo.

Table 1 shows the result of maximum loading and the average compressive strength for untreated and treated bamboo respectively. It is found that the average compressive strength of treated bamboo shows the higher value of 61.11 N/mm² compared to bamboo without surface treatment with only 57.10 N/mm². The percentage increased approximately about 7 % of compressive strength, which making the hypothesis that the surface treatment on bamboo can increase the mechanical properties of bamboo is accepted. The results proved that the surface treatment can increase or modified the compressive strength of the bamboo.



(a) Untreated bamboo samples



(b) Bamboo samples treated with epoxy coating

Fig. 12. Pre- and post- bamboo samples under compression test.

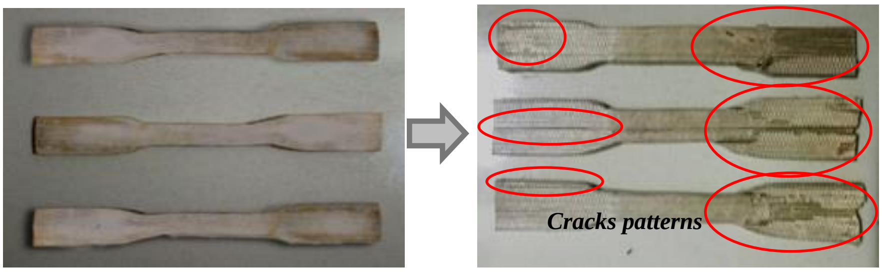
Table 1. Average compressive strength for untreated and treated bamboo.

Surface Treatment	Outer Diameter (mm)	Thickness (mm)	Maximum loading (kN)	Compression Strength (N/mm^2)	Average Compression Strength (N/mm^2)
Untreated	43.4	5.0	32.9	52.9	
	46.0	4.5	37.2	63.4	57.1
	49.1	4.5	34.7	55.0	
Treated with epoxy	44.6	5.0	44.1	70.9	
	45.9	4.5	33.9	56.7	61.11
	45.6	6.0	41.5	55.6	

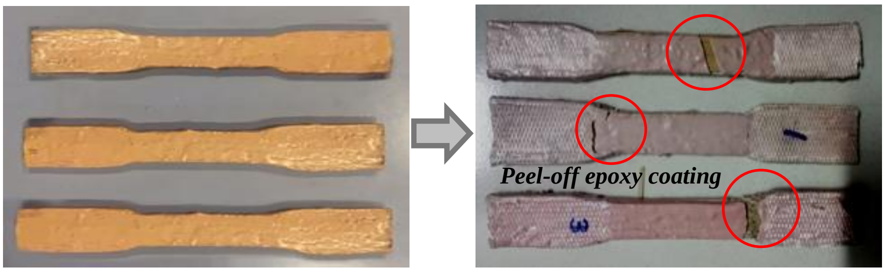
6.2. Tensile strength

Tensile test of bamboo was conducted using Instron UTM. Total of 3 samples for each of untreated bamboo and treated bamboo coated by epoxy. The thickness and width of the dog-bone shape was measured before the laboratory testing. Figure 13 shows the pre- and post- of the untreated and treated bamboo samples. Significant number of physical failure and cracks patterns can be seen on untreated bamboo compared to the bamboo coated with epoxy. It is observed that there is no clear crack pattern on appeared on treated bamboo, but more on peeling-off the layer of epoxy coating.

Table 2 shows the maximum load and the average ultimate tensile strength for untreated and treated bamboo. The effectiveness of surface treatment is measured on the average tensile strength whereby the strength of the bamboo improved approximately about 46 % after treated (244.11 N/mm^2) with epoxy compared to the untreated bamboo (152.49 N/mm^2). This shows that the application of surface treatment on the bamboo may increase the ultimate tensile strength.



(a) Untreated bamboo samples.



(b) Bamboo samples treated with epoxy coating

Fig. 13. Pre- and post- bamboo samples bamboo under tensile test.

Table 2. Average ultimate tensile strength for untreated and treated bamboo.

Surface Treatment	Thickness (mm)	Width (mm)	Maximum loading (kN)	Ultimate Tensile Strength (N/mm^2)	Average Tensile Strength (N/mm^2)
Untreated	5.5	15	10.43	126.42	
	6.0	15	14.36	159.54	152.49
	5.5	15	14.15	171.51	
Treated with epoxy	6.0	15	20.07	222.99	
	6.0	15	22.68	251.95	244.11
	6.0	15	23.17	257.40	

Crack width and crack patterns

The impact load test was carried out on the 6 samples of ISCB walls which consisted of 2 samples for each unreinforced, steel-reinforced, and bamboo-reinforced wall. Figure 14 shows the number of blows required to produce the initial crack on different types of interlocking wall and the average initial crack width measured for each wall.

Using the manual pendulum impact load test with 7 kg load ball, the crack width pattern on the surface of the wall was recorded at initial stage (first crack occurred) and at final stage after 15 blows of impact load (maximum crack width). The average reading of crack width is calculated based on two number of wall samples for each type of reinforcement method.

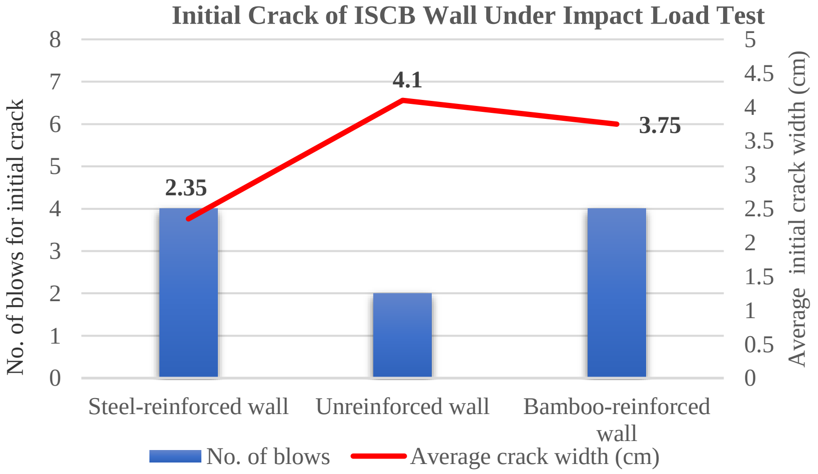


Fig. 14. Average initial crack width and average number of blows for different sample of wall.

It is shown that the bamboo-reinforced wall required 4 no. of blows to experience the initial crack which similar to the steel-reinforced wall. Although the average initial crack of bamboo-reinforced wall is slightly higher than steel-reinforced wall, but still lower than unreinforced wall, i.e., 3.75 cm, 2.35 cm, and 4.10 cm respectively. Figure 15 shows the crack patterns appeared after 15 blows of impact load for three types of ISCB masonry walls. It is observed that all types experienced clear surface cracking after 15 blows being hit with 7 kg impact load.

Cracks patterns on the surface of walls

(a) Unreinforced wall. (b) Steel-reinforced wall. (c) Bamboo-reinforced wall.

Fig. 15. Crack patterns on three ISCB walls after 15 blows of impact load.

Detail measurement of crack width occurred on the surface of three ISCB masonry walls (i.e., unreinforced, steel-reinforced, and bamboo-reinforced wall) is summarised in Table 3 for both vertical and horizontal direction. Based on the results, the steel-reinforced wall produced the lowest average crack width at vertical direction followed by bamboo-reinforced and unreinforced wall with recorded value of 16.6 cm, 23.8 cm and 31.9 cm respectively. Similar cracking pattern occurred at the horizontal direction, whereby the steel-reinforced wall experienced the lowest average crack width followed by bamboo-reinforced and unreinforced wall with recorded value of 11.5 cm, 14 cm and 16.3 cm respectively.

However, the bamboo reinforcement provides better performance in reinforcing masonry wall compared to unreinforced wall with percentage difference of 29.1% and 15.2% for vertical and horizontal direction, respectively. This is proved that the use of bamboo as alternative reinforcement in the interlocking wall may reduce the crack width on the surface wall and simultaneously avoid the risk of water penetration through the cracking which eventually will weaken the structures.

Table 3. Average maximum crack width for different types of walls.

Wall Samples	Crack Width		Average Crack Width	
	Vertical (cm)	Horizontal (cm)	Vertical (cm)	Horizontal (cm)
Unreinforced	20 43.8	13 19.6	31.9	16.3
Steel-reinforced	13.5 19.7	6.5 16.5	16.6	11.5
Bamboo-reinforced	26.5 21	10.4 17.5	23.8	14

7. Conclusion

The performance of bamboo as an alternative reinforcement for interlocking soil-cement block (ISCB) wall under 7kg impact loading was investigated. *Gigantochloa Scortechinii*, species type of bamboo was chosen as it is abundantly found in Peninsular Malaysia. The mechanical properties of the bamboo were investigated by performing the compression and tensile test. Each of the testing consisted of 3 untreated and 3 treated bamboos coated with epoxy as surface treatment. For the impact load testing, the bamboo reinforcement was coated with epoxy and rolled with galvanized iron wire to increase the bonding strength between bamboo and mortar in the ISCB wall. Total of 6 samples of ISCB wall with dimension of 1500 mm × 1000 mm × 125 mm were prepared and tested under impact load test which consisted of 2 samples for each unreinforced, steel-reinforced, and bamboo-reinforced wall. For the first objective which focus on the mechanical properties of the bamboo, result denoted that the treated bamboo significantly stronger for both compressive and tensile strength with percentage improved to 7% and 46% respectively compared to untreated bamboo. The average compressive strength of treated bamboo is 61.11 N/mm², much higher compared to untreated bamboo with only 57.10 N/mm². Similarly, in the tensile test, the treated bamboo shows the good potential in increasing the average ultimate tensile strength from 152.49 N/mm² up to 244.11 N/mm².

Meanwhile, it also observed that the bamboo-reinforced wall experienced much smaller initial (first crack), and maximum (after 15 blows) average crack width compared to unreinforced wall in the impact load testing. The bamboo-reinforced wall required 4 blows of impact load to start an initial crack pattern, which is similar to steel-reinforced wall. The bamboo reinforcement provides better performance in reinforcing the ISCB masonry wall compared to unreinforced wall with percentage difference of 29.1% and 15.2% for vertical and horizontal direction respectively, thus achieved the second objective of the study. This is proved that the use of bamboo as alternative reinforcement in the interlocking wall may reduce the crack width on the wall surface and simultaneously avoid the risk of water penetration through the cracking which eventually will weaken the structures. The study provides a significant finding that the bamboo is a good alternative reinforcement in the construction industry that promising much cheaper construction cost and provides solution to reduce environmental pollution globally.

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