Jurnal Kejuruteraan (*Journal of Engineering*) Submission http://dx.doi.org/10.17576/jkukm-2019-31(1)
10 pages
ISSN: 0128-0198 e-ISSN: 2289-7526
Revision : 20190920

Performance Of Bamboo Reinforced Interlocking Soil-Cement Hollow Block Wall Under In-Plane Loading

(Prestasi Dinding Blok Tanah-Simen Berongga Kekunci Bertetulang Buluh Di Bebani Beban Dalam Satah)

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ABSTRACT

Steel has been widely used as a building material because of its strength. However, steel production can cause environmental issues such as global warming. This is because large -scale steel production will release a lot of carbon dioxide gas into the atmosphere. In addition, steel prices are also expensive due to high demand for construction projects. Therefore, there is need of replacing steel with more sustainable building material. Thus, the potential use of bamboo reinforced interlocking soil- cement hollow block wall under in-plane loading is investigated. Gigantochloa Scortechinii type of bamboo was used and; prepared in Dog-bone shaped and Cylinder-shaped for tensile and compression test respectively. Solid epoxy surface treatment of bamboo is adopted for this study and treated bamboo was then used as reinforcement in wall sample. Three types of walls 1.5m x 1m x 0.15m was constructed using soil-cement interlocking hollow block with different types of reinforcement. The result showed that the wall reinforced using bamboo can sustained up to 120kN maximum load. This indicates, bamboo may become a new alternative to better sustainable materials. The results of this study will be used for further study of new construction methods using cheaper new materials that contribute to promoting the national economy.

Keywords: Interlocking soil-cement hollow block; Bamboo Reinforcement; In-Plane Loading; Gigantochloa Scortechinii; Solid Epoxy

ABSTRAK

Keluli telah digunakan secara meluas sebagai bahan binaan kerana kekuatannya. Namun begitu, penghasilan keluli boleh menyebabkan isu alam sekitar iaitu pemanasan global. Ini kerana pengeluaran keluli berskala besar akan mengeluarkan banyak gas karbon dioksida ke atmosfera. Selain itu, harga keluli juga mahal kerana permintaan tinggi untuk projek pembinaan. Oleh itu, terdapat keperluan untuk menggantikan keluli dengan bahan binaan yang lebih lestari terutamanya, potensi penggunaan dinding blok berongga tanah-simen bertetulang buluh di bawah beban dalam satah disiasat. buluh jenis Gigantochloa Scortechini telah digunakan dan; disediakan dalam bentuk tulang anjing dan berbentuk Silinder masing-masing untuk ujian tegangan dan mampatan. Rawatan permukaan epoksi pepejal buluh diguna pakai untuk kajian ini dan buluh yang dirawat kemudiannya digunakan sebagai tetulang dalam sampel dinding. Tiga jenis dinding 1.5m x 1m x 0.15m telah dibina menggunakan bongkah berongga saling mengunci tanah-simen dengan jenis tetulang yang berbeza. Hasil kajian menunjukkan bahawa dinding yang diperkukuh menggunakan buluh boleh menahan beban maksimum sehingga 120kN. Hal ini menunjukkan, buluh boleh menjadi alternatif baharu untuk bahan lestari yang lebih baik. Hasil daripada kajian ini akan digunakan untuk kajian lanjut kaedah pembinaan baharu menggunakan bahan baharu yang lebih murah yang menyumbang kepada menggalakkan ekonomi negara.

Kata Kunci: Blok Tanah-Simen Berongga Kekunci; Tetulang Buluh; Beban Dalam Satah; Gigantochloa Scortechini; Epoksi Pepejal

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INTRODUCTION

Bamboo has been used for construction material as the reinforcement (Escamilla et al., 2018). It is one of the local materials which are cheap and available with a high strength. Bamboo strength tensile can be very high as 120MPa and it has very strong in compression up to 55 MPa that can act as steel bar for the reinforced concrete (Trujillo & López, 2019). Soil-Cement Bricks is cost effective content of soil cement bricks. The compressive strength of brick is also greatly depending on the soil-cement blocks making soil cement making wall great in strength (Divya et al., 2017).

Nowadays, the application of soil–cement as raw material in the manufacture of building components comes to meet this requirement due to be a low cost material with great durability; in addition, it is adaptable to stable configurations so has multiple possibilities for its use as building material (Fay et al., 2014). According to the Food and Agriculture Organisation of the United Nations, it is estimated that over one billion people worldwide live in traditional bamboo housing, and 2.5 billion people depend economically on bamboo (Xu et al., 2022). It has also been demonstrated that bamboo is a more sustainable material than steel, concrete, and timber (Trujillo & López, 2019).

Numbers of study conducted by previous research that focusing on partially or fully replace the material of the hollow block instead of replacing the reinforcement. Then, is to take advantage of National Bamboo Industry Development Action Plan (2021-2030) that was initiated to sustain the bamboo resources, to plant bamboo, to empower the human capital, to promote research and development and to lead in marketing and promotion of bamboo products taken lead by the Malaysia Timber Industry Board (MTIB). High cost of raw material is one of the issues that slowing down the Malaysia development. Large scale of construction material production can also contribute to carbon dioxide gas release to environment that causing global warming issue. Many laboratory tests were carried out by many researchers to analyse the effect bamboo as construction material. This study will investigate further the strength of soil-cement hollow block wall with bamboo reinforcement under the flexural load before the wall failure.

The aim of this research studies is to investigate the strength of soil-cement hollow block wall reinforced with treated bamboo under in-plane loading. Data and result of this study can be used as references of the future research that involves in interlocking hollow block wall and bamboo as reinforcement material.

Nowadays, our government are focusing on using the natural resources as product and material for country economic growth. Therefore, the research can be helpful to increase the information about bamboo as the natural resources for construction material. This study can also be a guidance for people that have an interest in using interlocking wall with bamboo as reinforcement.

METHODOLOGY

Several experiments were carried out to determine and analyse load, cracking, and ultimate load. The experimental programme was divided into two parts. The first stage was test to determine the characteristics of the bamboo when it is subjected to compressive and tensile loads. The axial compression test under static load was the second stage. For the axial compression test, the wall sample will be arranged on the magnus frame, then the ultimate load of the wall when the failure or crack occur will be recorded. A flowchart for this investigation is shown in Figure 3.1.

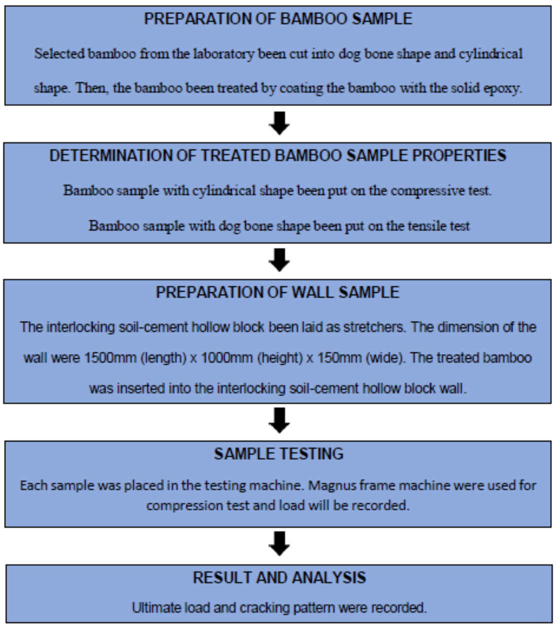

FIGURE 1. Flow chart of research

Experimental Approaches and Methodologies

For the bamboo properties test, the test that involved were the compressive and tensile test. Each sample bamboo has different shape of cut according to each test. For tensile test, the shape that been used was the dog bone shape. As for the compressive test, the shape that been used was the cylindrical shape. There were six sample for each test and from the six sample there three treated

Jurnal Kejuruteraan (*Journal of Engineering*) Online First DOI XXX 9 pages
ISSN:0128-0198 E-ISSN:2289-7526

bamboo and other three were not treated. The treatment that been used were solid epoxy coating. By using the paint brush and plastic scraper. The sample will be swept smoothly and evenly, to guarantee that the epoxy filled every corner, it was applied over the aligned samples. The treated bamboo then shall be left for 24 hours until its completely dry before it can be applied to test.

Treated bamboo were used as the reinforcement for interlocking soil-cement hollow block wall. Firstly, the bamboo was cut as height of the wall which was 1m length. The bamboo section than will be cut parallelly until the wide of the bamboo were 3cm which was fit enough to enter the hollow block wall's hole. The bamboo then was treated by coting it with solid epoxy. The treated bamboo then was left for a day until the epoxy dry. After the epoxy dry, the galvanized steel was wrapped around the treated bamboo as shown in figure 2. There were 12 treated bamboos were prepared as the reinforcement. For each wall required six reinforcement and there were two walls of treated bamboo.

FIGURE 2. Treated Bamboo Reinforcement

The experiment was firstly set up by testing the properties of the bamboo. Before the project were taken in place, it is important to check the bamboo properties. It was to confirm the strength of the bamboo before it can be used as reinforcement. Even though, there's already data about the bamboo properties from previous research. We still need to test the material to see it recent strength that may already worn out because of the age, humidity, and weather issue. The test was taken in measuring the bamboo strength are the tensile test and compressive test. The type of the bamboo that been used was Gigantochloa Scortechinii that was taken at the Structure Laboratory, National Defense University of Malaysia. Before being used, the bamboo that been cut were boiled in the water to remove the natural essence and sugar to keep away insects. This is one of the safest methods that also softens the lignin and loosens the bond between lignin and cellulose fibers.

For compressive test, the result of the test which was the compressive test was calculated by Equation 3.2 and Equation 3.3

$$A = (\pi \times [D^2 - (D-2t)^2]) / 4 \qquad \text{(Eqn 3.2)}$$

$$\sigma ult = Fult / A \qquad \text{(Eqn 3.3)}$$

Where;

σult is the compressive stress (N/mm²).
Fult is the maximum loading (N).
A is the bamboo cross-sectional area (mm²).
D is the bamboo outer diameter (mm).
t is the bamboo thickness (mm).

By using the Compression Testing Machine as shown in figure 3, the load was applied to the sample with no more than 1kN at increase by the constant rate of 0.01 mm/s applied. For the final reading, maximum loading was recorded which was the load before samples failed.

FIGURE 3. Compressive test set up in Compression Testing machine

For tensile test, the bamboo culm that been boiled were cut into a dog bone shape as a sample shown at Figure 3.2 (Awalluddin et al., 2017) with the measured of cross section given. The sample then were left dried by the room temperature for 24 hours to stabilise till the rate humidity less than 10%. Three samples of dog bone shape bamboo were prepared for the tensile test. The tensile strength was measured by calculating the ultimate tensile strength by using the Equation 3.1

$$\sigma ult = Fult / A \qquad \text{(Eqn 3.1)}$$

Where,

σult is the ultimate shear strength (MPa).
Fult is the maximum loading at the test piece fails (N). A is the mean cross-sectional area of the gauge portion (mm²).

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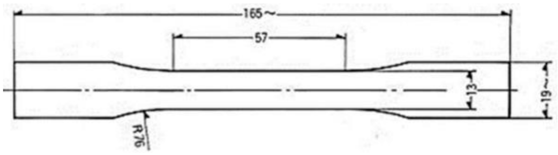

FIGURE 4. Cross section measure of dog bone

FIGURE 5. Tensile test set up in Universal Testing machine

The dog bone sample will be set up into the Universal Testing Machine as shown in figure 5 by clamping the sample from both sides. 1mm/min rate of displacement were applied. When the sample breaks or failed, test will be automatically stops. Data of tensile result will be recorded. Figure 3.3 shown the arrangement of the tensile test.

Before the wall erected, the grout shall be prepared for the bonding of the hollow block wall and reinforcement in it. For the grout preparation, the required sand to cement ratio of 2:1 by volume was used to reduce amount of expensive cement. A water cement ratio of 1:2 was also important for the workability and consolidation, and to make it easier to mix and poured the grout into the cores. If the void were occurred inside the wall, the data were not going to be the best result of the wall capability.

For the soil-cement hollow block, the material consists of 60% of clay, 20% of sand, 18% of cement and 2% of water by volume. The dimension of each of the soil-cement hollow block is 300mm length x 150mm wide x 100mm height. The soil-cement hollow block also provides two holes with diameter of 40mm that been used to insert the treated bamboo and the grout for the bonding of the reinforcement.

The interlocking soil-cement hollow block can only be laid as stretchers where both hole facing upwards or else it was not function as it supposed to. The dimension of a wall sample was 1500mm x 1000mm x 150mm which needed 60 interlocking soil-cement hollow block for each wall. Figure 6 shown the dimension of the wall sample. Figure 7 shown the layout of the reinforcement inside the soil-cement interlocking hollow block wall.

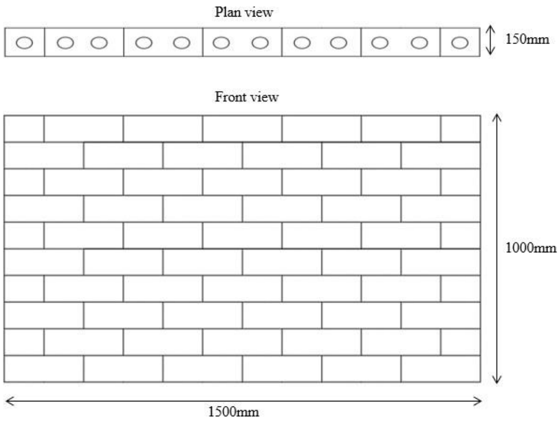

FIGURE 6. Interlocking soil-cement hollow block wall dimension.

There 3 different types of samples been used in this wall axial compression test. First wall was a control wall (WC) that doesn't have any reinforcement in it. The holes been filled with only grout as reinforcement. For second wall (WS), the wall sample been consisting of steel bar as reinforcement. For the last wall (WB), the wall was inserted with treated bamboo as reinforcement. The grout still was used for the bonding of the reinforcement and the interlocking soil-cement hollow block.

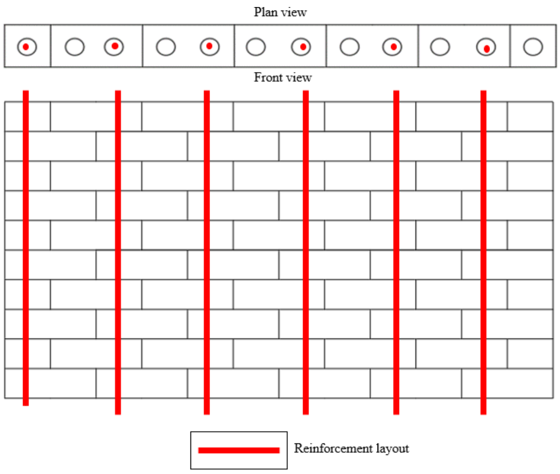

FIGURE 7. Layout of wall sample reinforcement

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ISSN:0128-0198 E-ISSN:2289-7526

After the grout mixture has been done, the interlocking soil-cement hollow were arranged on the magnus frame as in Figure 8. When the wall reaches three layers of block, the reinforcement was inserted into the reinforcement wall. The grout that had been prepared been poured into each of the hollow block hole. After the wall reach a meter height, the wall sample were left for a day before it been put into a test. This was to give times for the grout to gain it strength and hardening. During the test, a timber with length of 162cm and were put on the wall sample.

Then an I beam with a length of 101cm been put on the top of the timber as shown in Figure 9. Lastly, two steel plate with a length of 25cm been placed on the top before the wall sample having a load on it. These materials were place on the top of the wall sample in order to distribute the load on to the wall sample. Load cell censor were used to measure the load that been given to the wall. Hydraulic jack that installed with load censor been putting load on to the sample for the compression test. Each pump of the hydraulic ram increases the load on the wall sample. Figure 10 shows the load were measured and recorded by the LVDT. The test then been repeated with different types of reinforcement.

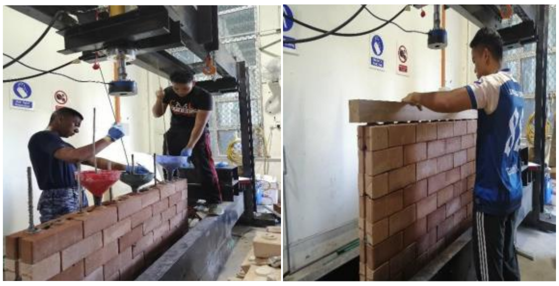


FIGURE 8. Wall sample preparation and testing

FIGURE 9. Compression test experimental layout

FIGURE 10. Hydraulic ram and LVDT

formulated to guide the review process, such as identifying the factors influencing sediment transport capacity such as slope gradient, flow discharge, soil properties, hydraulic parameters, and root parameters. Also, methods used either theoretical models, numerical or empirical experiment for measurement or modelling. Next, inclusion and exclusion criteria are established to select relevant studies, which may include peer-reviewed articles, conference papers, and technical reports published in English within a specified timeframe, 2017 until 2024. A comprehensive search strategy is then developed, utilizing appropriate keywords and database search techniques to identify relevant literature from databases such as Science Direct, Scopus, and Google Scholar. Following the search, retrieved studies undergo screening based on titles, abstracts, and full texts to determine eligibility for inclusion in the review. Data extraction is then conducted systematically using a predefined data extraction form to gather pertinent information from selected studies, including study objectives, methodologies, key findings, and factors influencing sediment transport capacity in the form of tabulation and charts. Quality assessment is performed to evaluate the methodological rigor and reliability of included studies, considering factors such as study design, sample size, and potential biases.

RESULTS AND DISCUSSION

The compressive strength of untreated bamboo and solid epoxy coating bamboo has been done. Table 1 shown the comparison before and after the sample were tested. The result from the compression test were shown on Table 2 and Table 3. Each sample shown several cracks that in the were led to split of the specimen. It shows that the treated bamboo shown less cracking than the untreated bamboo. Its prove that air-dried culm bamboo which is untreated bamboo were face brittle failure (Awalluddin et al., 2017).

TABLE 1. Bamboo sample before and after test

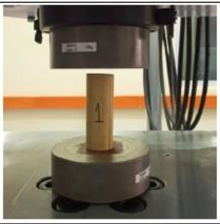
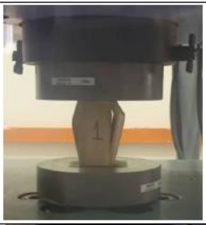
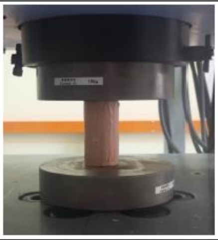
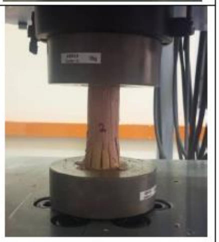
Surface Treatment	Before test	After test
Untreated Bamboo		
Solid Epoxy		

TABLE 2. Compressive strength of untreated bamboo

Sample	Thickness (mm)	Outer Diameter (mm)	Max Loading (kN)	Cross Sectional Area (mm²)	Compression Strength (N/mm²)	Average Compression Strength (N/mm²)
1	5.0	43.4	32.9	603.19	52.9	57.10
2	4.5	46.0	37.2	586.69	63.4	
3	4.5	49.1	34.7	630.52	55.0	

TABLE 3. Compressive strength of treated bamboo

Sample	Thickness (mm)	Outer Diameter (mm)	Max Loading (kN)	Cross Sectional Area (mm²)	Compression Strength (N/mm²)	Average Compression Strength (N/mm²)
1	5.0	44.6	44.1	622.04	70.9	61.11
2	4.5	45.9	33.9	585.28	56.7	
3	6.0	45.6	41.5	746.44	55.6	

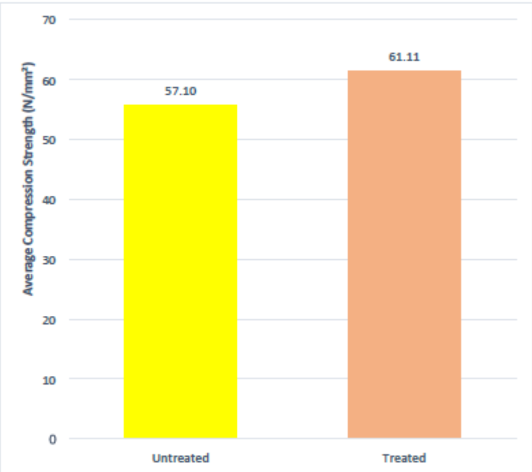


FIGURE 11. Compressive strength of treated and untreated bamboo comparison

Based on Figure 4.1, average compressive strength of treated bamboo which is coated with solid epoxy is greater which is 61.11 N/mm², which is 9.2% higher than untreated bamboo. Therefore, it proven that surface treatment influences the strength of bamboo.

In the same manner as the compressive strength test, a tensile strength test parallel to the grain of the bamboo was conducted. The results of the average ultimate tensile strength of six samples of untreated and solid epoxy coated bamboo are shown in Tables 5 and Table 6, which also include the bamboo's thickness, width, ultimate tensile strength, and maximum loading.

TABLE 4. Tensile comparison sample before and after test

Surface treatment	Before test	After test
Untreated bamboo		
Solid epoxy		

According to past research findings, bamboos perform better than other materials like wood and steel in terms of strength characteristic (Trujillo & López, 2019). Table 4 shown the before and after test of samples from the tensile test. For many samples, a similar failure was brought on by stress and shear parallel to the grain. From the observations it demonstrates that solid epoxy failure was less severe than failure in untreated bamboo.

TABLE 5. Tensile strength of untreated bamboo

Sample	Thickness (mm)	Width (mm)	Max Loading (kN)	Ultimate Tensile Strength (MPa)	Average Tensile Strength (MPa)
1	5.5	15	10429.8	126.42	152.49
2	6.0	15	14358.6	159.54	
3	5.5	15	14149.5	171.51	

TABLE 6. Tensile strength of treated bamboo

Sample	Thickness (mm)	Width (mm)	Max Loading (kN)	Ultimate Tensile Strength (MPa)	Average Tensile Strength (MPa)
1	6.0	15	20069.2	222.99	244.11
2	6.0	15	22675.5	251.95	
3	6.0	15	23166.2	257.40	

ISSN:0128-0198 E-ISSN:2289-7526

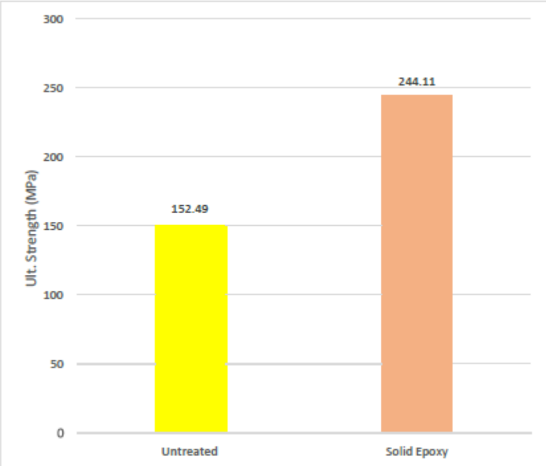


FIGURE 12. Tensile strength of treated and untreated bamboo

Figure 12 shows the comparison of the ultimate tensile strength between untreated bamboo sample and treated bamboo sample. It is shown from the data in that treated bamboo by coating the bamboo with epoxy does increase the tensile strength of the bamboo. The tensile strength for treated bamboo has recorded to be the highest than the untreated bamboo which is 244.11MPa, while the ultimate tensile strength of the untreated bamboo is 152.49MPa. There are 37.5% differences of ultimate tensile strength between the treated and untreated bamboo sample.

The axial compression test of the treated bamboo wall (WB), steel wall (WS), and control wall (WC) are done conducted. Table 7 shown the comparison sample before and after the test shows the different sample between before and after the test. The result of the compression test as shown in Table 8. From table 9, wall reinforced with treated bamboo revealed to have several cracks along the center of the wall sample. Control wall sample shown the least cracking on the wall sample which slightly occurred on the top area of the wall. While the steel reinforced wall doesn't show any sight of cracking.

TABLE 7. Wall comparison after and before

Wall Reinforcement	Before test	After test
Treated Bamboo (WB)		
Control (WC)		
Steel (WS)		

TABLE 8. Compression test for control wall

Sample	Ultimate load (kN)	Wall after the test
WC1	130	
WC2	130	

ISSN:0128-0198 E-ISSN:2289-7526

TABLE 9. Compression test for steel wall

Sample	Ultimate load (kN)	Wall after the test
WS1	140	
WS2	36	

TABLE 10. Compression test for treated bamboo wall

Sample	Ultimate load (kN)	Wall after the test
WB1	38	
WB2	120	

By referring Table 9, WS1 sample doesn't show any sign of crack even though the objective of this research is to find out the load before the crack occur. This happens because of the condition of the magnus frame itself that started to lift up when the load exceed more than 140kN. Therefore, the ultimate load of the WS1 should be more than 140kN. And as for the WS2 sample, there's an error happens on the load measurement device. The loading measurement doesn't increase after it reach 36kN even the load had been applied to the wall. This is because the hanging problem that been disturbing the device. The load must have exceeded the capability of the magnus frame during the hanging period, making the WS2 sample collapse. The WS2 sample is still intact after the collapse.

From table 10, its shown that WB1 sample were collapse when it reaches load of 38kN. This happen because of the wall position isn't accurately center from the hydraulic jack. The position of the hydraulic jack was slightly in front of the wall sample center.

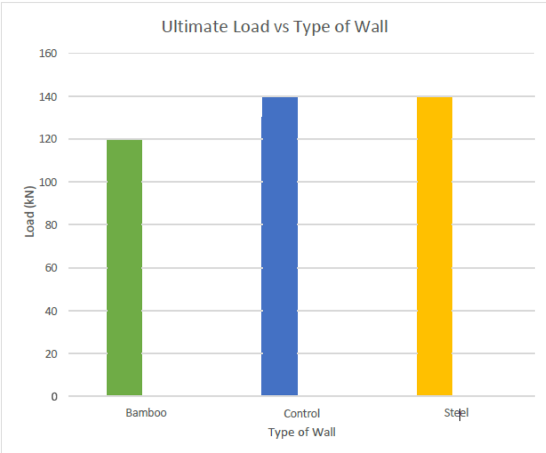


FIGURE 12. Each type of wall sample ultimate load comparison

Based on Figure 12, steel reinforced wall recorded to have the highest ultimate load which was 140 kN that is 7.1% higher than control wall with ultimate load of 130kN. For the treated bamboo reinforced wall was observed to be lowest with 120kN ultimate load which was 14.3% lower than the steel reinforced wall.

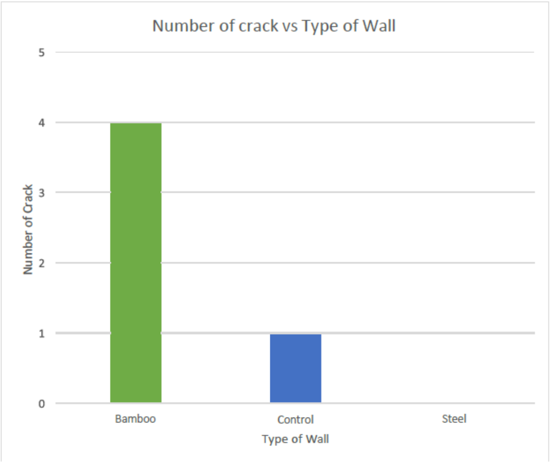


FIGURE 13. Each type of wall sample cracking number comparison

Based on the Figure 13, the number of cracking treated bamboo reinforced wall was at the highest which is 4 cracking hollow block. Then goes to the cracking number of the control wall which only have one crack at the hollow block. While the steel reinforced wall doesn't show any cracking along the wall sample.

Based on Table 11, the cracking pattern of each wall can be observed. For the treated bamboo reinforced wall, it seems that the cracks were likely to occur at the centre of the wall sample. The crack goes from the top of the wall and down to the bottom part of the sample.

TABLE 11. Comparison of number of cracking on the walls

Wall sample	Sample cracking pattern after compression test	Number of cracking
Treated Bamboo Reinforced Wall		4
Control		1
Steel Reinforced Wall		0

Based on the bamboo properties result, the treated bamboo does surpassed the strength of the untreated bamboo through the bamboo properties test which was the compressive and tensile strength. The increasing strength does occur because of the fibre degradation. Epoxy coated bamboo involved in the failure behavior in vertical orientation of fiber breakage. This because the epoxy coating does protect the fiber structure from being damage (Ismail et al., 2020).

As for the axial compression test, the cracking are much more obvious with treated bamboo reinforced wall. The cracking of using bamboo in concrete have been mention before because of it low modulus of elasticity. Its conclude that when its subjected to ultimate load, the cracking of the concrete cannot be prevented (Kathiravan et al., 2021). The strength of the bamboo also depends on its culm. The culm thickness and shape whether the whole bamboo or half of the bamboo been used will affect the strength of the bamboo (Chaowana et al., 2021). If the whole bamboo been used it called bar bamboo while the bamboo that been split up to half or quarter been called splint bamboo. Therefore, the properties bamboo test that been conducted may not truly indicate the strength of the reinforcement in wall. Cylindrical shape that been use in the compressive test was bar bamboo, while the reinforcement was splint bamboo that been cut.

CONCLUSIONS AND RECOMMENDATIONS

For the bamboo properties test, the treatment that been used for the bamboo does give additional strength to the bamboo. The result shows an increase from both test, which was the tensile test and compressive test. This proves that by adding a coating material on the surface of the bamboo does increase the strength of the bamboo, whether in tensile strength or the compressive test.

Different types of reinforcement on wall does affect the ultimate load of the soil-cement interlocking hollow block wall. The cracking of the wall does significate the strength of the wall. It can be seen when the wall wanted to be carried out the magnus frame, after the test has been done by using the forklift. The steel reinforced wall still in one piece after been carried out, while treated bamboo reinforced wall collapse when the sample is on the forklift. The control wall can't be carried by the forklift because without the reinforcement, there's nothing to hold the soil-cement hollow block together.

In addition, the number of cracks on treated bamboo reinforced wall was greater than the control wall by having 4 cracking on the wall, while the control wall having one crack before it reaches the ultimate load. The steel reinforced wall

recorded to have the least number of cracks by having none of it. It's because the steel reinforced wall doesn't reach the ultimate load yet, because of the magnus frame conditions.

The ultimate load of each soil-cement hollow block wall sample was observed to be the highest by applying the steel as the reinforcement which is 7.1% higher than the control wall. The ultimate load steel reinforcement wall should exceed the recoded data which was above 140kN. The treated reinforced bamboo wall ultimate load

recorded as the lowest from all wall sample which is in comparison with steel reinforced wall is 14.1% difference.

As conclusion, bamboo reinforced wall withstood the most in number of cracking while become the least in strength by having lower ultimate load then control wall sample. From the experimental findings, treated bamboo reinforcement wall isn't an excellence performance in terms of bearing a heavy load.

As the recommendation, for further study on the research was by using different kind bamboo culm such as bamboo bar instead of using just the splint bamboo as for the comparison. This was in order to find a greater material replacement for steel to become the wall reinforcement. It also because of the fact that the bamboo strength

was various upon the culm characteristic. In addition, the research uses only one layer of coating of solid epoxy. For further study, was recommended to use different kind of surface treatment and increase the number of layers that been used.

Last not least, was to add data about the lateral deflection of the wall sample. It was to follow the standard of the experiment that conducted for the compression test of the wall. The lateral deflection in this research isn't recorded because of the lack of equipment and the soil-cement interlocking hollow block wall can also act as load bearing wall that doesn't show significant different in lateral deflection.

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