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# INVESTIGATION OF THE EFFECTS OF DIFFERENT NATURAL FIBERS ON THE STRENGTH OF COMPRESSED STABILIZED EARTH BLOCKS (CSEB)

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**ABSTRACT:** This study investigates the most effective combination of natural fibers (namely coconut coir, abaca, and maguey) used as reinforcement for Compressed Stabilized Earth Blocks (CSEB). Portland cement and 0.25% fibers by weight were used to stabilize and reinforce CSEB, respectively. The blocks were made primarily with Manila soil and were formed using hand-pressed machine. CSEB without fibers were first tested with varying cement contents of 6%, 8%, 10%, and 12% by weight. This was examined to determine the practical cement content (PCC). Three strength tests namely dry compressive strength, wet compressive strength, and flexural strength were conducted on CSEB at PCC with different fiber combinations of coir, abaca, and maguey fibers to determine the mix producing maximum strength. The highest dry compressive strength was obtained with 100% maguey fiber; the highest wet compressive strength was obtained with 100% abaca fiber; while the highest flexural strength was obtained with 17% coir fiber, 17% abaca fiber, and 67% maguey fiber. Using the Response Surface Methodology (RSM), the maximum strengths were predicted as follows: 100% maguey for dry compressive strength, 100% abaca for wet compressive strength, and 38.4% abaca and 61.6% maguey for flexural strength. However, the optimal mix of CSEB for three the strength tests consists of CSEB with 42.5% abaca and 57.5% maguey. The fibers were found to improve the performance of the block such as the strength and post-crack behavior. Furthermore, the performances of a wall made of fiber-reinforced and unreinforced CSEB were investigated. The test results showed a 33.79% increase in load carrying capacity of the fiber-reinforced wall compared to unreinforced wall.

*Keywords: Earth Blocks, Natural Fibers, Abaca, Coir, Maguey, Response Surface Methodology*

## 1. INTRODUCTION

Agricultural wastes are thrown away every day and if not properly managed, these wastes can have an impact on the general condition of the environment by degrading water quality and contributing to the amounts of pollution that is already present. By utilizing certain wastes such as coconut coir fiber, abaca fiber, and maguey fiber, will not only help protect the environment, but will also help provide alternative housing materials for construction. Given the abundance of these agricultural wastes in the Philippines, this drastically helps the environment through recycling waste materials and utilizing them for different applications such as in construction.

Housing problem exists in both rural and urban areas today; wherein both government and non-government agencies have undertaken measures to provide solutions for this problem, one of which is providing informal settlers with low-cost houses.

A building material that is often underestimated but has immense beneficial effects to society is the compressed stabilized earth block (CSEB). This is a type of construction block primarily made up of mechanically compressed soil stabilized by cement or lime. Cement stabilization is preferable for sandy soils to achieve immediate higher strength while lime stabilization is used for clayey soils. Soil as a building material has its own advantages such as cost efficiency, virtually soundproof, non-toxic, environmental friendly, durable, abundant, and thermal properties.

Compaction of moist soil, containing 4-20% optimum moisture content (OMC) and often combined with 3-8% cement stabilization by weight of soil, based on economic standard, can significantly improve compressive strength, water resistance, durability, dimensional stability, resistance, and tolerances, in comparison with traditional adobe blocks [1]. To further improve its mechanical properties and, at the same time, reduce waste, researchers are reinforcing it with natural fibers as they show a significant result in post-peak load deformation behavior. The use of fiber reinforcement into CSEB production creates a network of fibers that prevents cracking of the soil resulting from shrinkage and improves tensile and shearing strengths [2], [3]. The inclusion of fibers into CSEB results to resistance towards higher stresses by absorbing high amounts of energy, making them particularly important in earthquake prone regions [4].

The purpose of this study is to evaluate binding effects of coir, abaca, and maguey fiber; such as increasing strength and improving post-crack behavior. It is hypothesized that using these fibers increase the mechanical properties. The resulting strengths were also expected to vary depending on the fibers used and the characteristics of the chosen soil. Knowing these can increase the efficiency of CSEB usage. However, the long-term behavior and durability of the fibers are not included in this study.

## 2. METHODOLOGY

The soil used was obtained from a construction site in Recto, Manila. The soil sample used consists of 2.5% gravel, 69.7% sand, 27.8% fine. With this particle distribution, the soil used was classified as silty sand with shell fragments. The maximum dry density of the soil was 1,530 kg/m3 while the specific gravity was 2.67. Cement stabilization is recommended for soil with a plasticity index of 15% or less [5]. Since the soil was found to have negligible plasticity, cement was used. The OMC of the soil was determined to be 15.19%. Soil at OMC is the recommended condition to produce the blocks. For high strength blocks, additional quantity of water is needed. Therefore, a moisture content of 16% was used in the CSEB mixture.

The length of the fibers considered was based on the studies of [6], [7], where 50-mm fibers were used in the production of their CSEBs. The coir fibers were processed using dry mill while abaca fibers were extracted by hand. Consequently, maguey fibers were retted in the ocean.

Shown in Table 1 are the properties of the fibers used in this study. The coir fiber has the lowest tensile strength, though it is above the average tensile strength of 75.5 N/g.m. set by Philippine Fiber Industry Development Authority (PhilFIDA). Abaca and maguey fibers have almost the same tensile strength, which is relatively high compared to the coir. Although coir fiber has the lowest tensile strength, it has the highest capacity to elongate which is about twice of the standard of PhilFIDA of 10.62%. On the other hand, both abaca and maguey fiber exhibit low elongation.

Table 1 Physical properties of the fibers

| Fiber | Grade | Tensile Strength | Elongation |
|---|---|---|---|
| Coir | CH-3 | 112.6 N/g.m. | 20.43% |
| Abaca | S2 | 215.9 N/g.m. | 2.59% |
| Maguey | MR-1 | 232.3 N/g.m. | 2.59% |

Blocks with varying cement contents of 6%, 8%, 10% and 12% were tested for compressive strength to determine the practical cement content (PCC). The results of the test are shown in Table 2. The strengths obtained were compared to the classification of CSEB that is presented in Table 3. There are three categories to classify CSEB based on its strength and usage according to [8]. The strengths shown in Table 3 are dry compressive strength, wet compressive strength, and flexural strength.

Table 2 Compressive strength per cement content

| Cement Content (%) | Average Compressive Strength (MPa) |
|---|---|
| 6 | 3.27 |
| 8 | 3.79 |
| 10 | 4.83 |
| 12 | 5.06 |

Table 3 Classification based on strength [8]

| CSEB | Dry | Wet | Flexure |
|---|---|---|---|
| Category I | ≥ 2 MPa | ≥ 1 MPa | ≥ 0.345 MPa |
| Category II | ≥ 4 MPa | ≥ 2 MPa | |
| Category III | ≥ 6 MPa | ≥ 3 MPa | |

The average compressive strength for 6% and 8% cement content suggests that they are classified as Category I. On the other hand, cement contents of 10% and 12% are classified as Category II. Data produced by various researchers show strong, often linear, correlation between compressive strength and cement content [1]. However, handling of blocks with 6% cement content obtained cracks when transferred. This entails that the handling of the blocks need to be considered in choosing the practical cement content (PCC). Therefore, a cement content of 8% was used in this study. This complies with the suggested cement content of 3% to 8% based from an economic stand point [5].

### 2.1 Block Production

The Compressed Stabilized Earth Blocks were mixed at 16% moisture content, 8% PCC (Category I CSEB), and 0.25% fiber content as shown in the mixes in Table 4.

The CSEB used in this study measures 295 mm x 140 mm x 100 mm. The blocks were formed using a hand-pressed machine. The soil weight per block was 6kg, resulting to 15g of fiber that is to be mixed per block. Fifteen block specimens were prepared and tested for each mix shown in Table 4. Five specimens for each of the three strength test

Table 4 Design mix of reinforced CSEB by weight

| Mix Variations of Fibers | Coir, C (g) | Abaca, A (g) | Maguey, M (g) |
|---|---|---|---|
| (1) 100C | 15 | 0 | 0 |
| (2) 100A | 0 | 15 | 0 |
| (3) 100M | 0 | 0 | 15 |
| (4) 50C-50A | 7.5 | 7.5 | 0 |
| (5) 50A-50M | 0 | 7.5 | 7.5 |
| (6) 50C-50M | 7.5 | 0 | 7.5 |
| (7) 67C-17A-17M | 10 | 2.5 | 2.5 |
| (8) 17C-67A-17M | 5 | 10 | 2.5 |
| (9) 17C-17A-67M | 2.5 | 2.5 | 10 |
| (10) 33C-33A-33M | 5 | 5 | 5 |
| (11) Control Mix | 0 | 0 | 0 |

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### 2.2 Strength Test

The blocks were subjected to three strength tests, namely dry compressive strength, wet compressive strength, and flexural strength, after 28 days of curing, to evaluate the effects of natural fibers on CSEBs. The blocks for dry and wet compressive strength had the same production and testing process. The main difference was that the blocks for wet compressive strength test underwent full submersion in water bath for 24 hours before testing, while the blocks for dry compressive strength test are directly tested after 28 days of curing. A uniform loading rate of 0.0575 MPa/s must be applied for the three strength tests [8].

Drop test was performed to qualitatively test the block’s impact strength. The blocks were subjected to fall freely at a height of 3.5 meters. This was done to further highlight the effect of fiber reinforcement and post-crack behavior difference between fiber-reinforced and unreinforced CSEB.

### 2.3 Wall Test

A wall test was conducted on walls made unreinforced CSEB and fiber-reinforced CSEB. It has seven staggered rows with 3 blocks each. As shown in Fig. 1, a proving ring was placed on top of the wall to measure the load applied by the two hydraulic jacks to the wall panel. The hydraulic jacks were situated below the constructed wall. The two dial gauges were placed on opposite sides of the wall to measure the displacement.

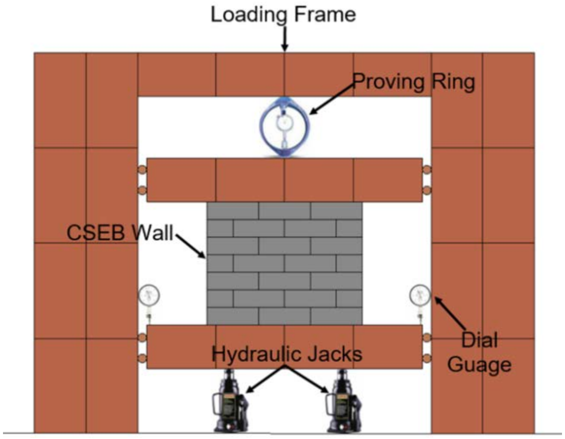

Fig. 1 Wall test set-up

Prior to the wall test, fiber-reinforced CSEBs and unreinforced CSEBs were tested again for their dry compressive strength to be used in the computation of the expected maximum load that can be applied on the wall.

## 3. RESULTS AND DISCUSSIONS

The results of the tests of the blocks and the test of the walls will be presented in this section.

### 3.1 Testing of Blocks

The results of testing of blocks are presented in terms of how the fibers influenced the following: strength test, failure mode, drop test, and optimal mix.

#### *3.1.1 Influence of Fiber on Strength Tests*

The summary of the strength tests are tabulated in Table 5. The values are the average strength of the test results of 5 CSEB specimens.

Table 5 Experimental strength test results

| Mix | Dry (MPa) | Wet (MPa) | Flexure (MPa) |
|---|---|---|---|
| 100C | 2.83 | 2.05 | 0.377 |
| 100A | 2.99 | 3.13 | 0.297 |
| 100M | 4.27 | 2.53 | 0.407 |
| 50C-50A | 2.71 | 2.20 | 0.459 |
| 50A-50M | 3.16 | 2.49 | 0.466 |
| 50C-50M | 2.84 | 1.86 | 0.351 |
| 67C-17A-17M | 2.08 | 1.76 | 0.409 |
| 17C-67A-17M | 2.15 | 1.80 | 0.449 |
| 17C-17A-67M | 2.13 | 1.80 | 0.495 |
| 33C-33A-33M | 2.93 | 1.80 | 0.380 |
| Control Mix | 3.00 | 1.99 | 0.424 |

The dry compressive strength test was performed to determine the strength of the blocks that were cured for 28 days. The compressive strength is mainly influenced by the type of soil, compacting procedure, and binding materials used [9]. The control (unreinforced) CSEBs have an average dry compressive strength of 3.00 MPa. This value satisfied Category I CSEB, which has a minimum dry compressive strength of 2 MPa. On the other hand, the highest dry compressive strength for the fiber-reinforced CSEB was obtained from samples with 100% maguey fiber (100M), which is 4.42 MPa or additional 42.33% strength compared to the control.

The RSM was used to plot a 3D surface model for dry compressive strength and the result is shown in Fig. 2. This model was chosen to analyze the data because of its ability to show the relationship between any fiber combination and its corresponding dry compressive strength. Using this model, the highest value of dry compressive strength was predicted to be 4.19 MPa at 100% maguey fiber (100M).

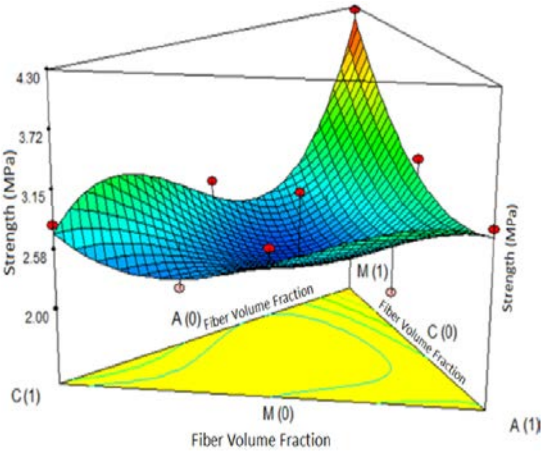

Fig. 2 Dry compressive strength model using RSM

The wet compressive strength test was performed to determine the strength of the blocks that were cured for 28 days and then submerged in water for 24hrs. Unreinforced CSEB has an average wet compressive strength of 1.99 MPa, which satisfy the requirement for Category I CSEB. On the other hand, the highest average wet compressive strength for reinforced CSEB, was found to be 3.13 MPa at 100% abaca fiber (100A). Thus, resulting to an additional 57.59% in strength compared to the control mix.

Similar to dry compressive strength, the RSM was used to plot a 3D surface model for wet compressive strength and is shown in Fig. 3. Using this model, the highest value of wet compressive strength was predicted to be 3.11 MPa and at 100% abaca fiber.

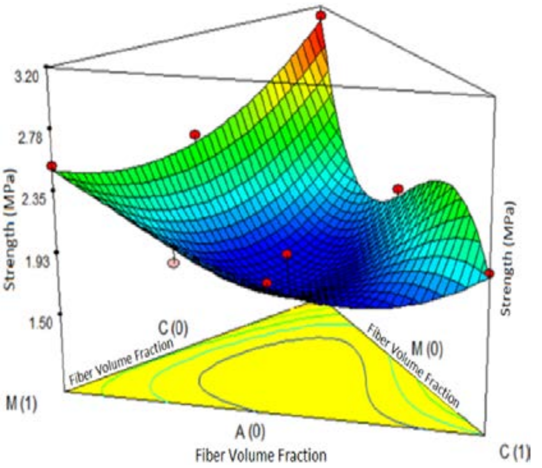

Fig. 3 Wet compressive strength model using RSM

The flexural strength test was performed to determine the 3-point bending strength and the post-crack behavior of the blocks that were cured for 28 days. It was obtained that unreinforced CSEB has an average flexural strength of 0.424 MPa, which satisfies the strength for Category I CSEB. However, the block failed immediately after the peak strength, breaking it in two and discontinues further testing on said block. On the other hand, the highest average flexural strength of 0.495 MPa was obtained by specimens with 17% coir, 17% abaca and 67% maguey (17C-17A-67M) and this resulted to an additional 16.89% strength compared to the control.

Similar to dry and wet compressive strength, RSM was used to plot a 3D surface model for flexural strength as shown in Fig. 4. Using this model, the highest value of flexural strength was predicted to be 0.483 MPa and at 38.4% abaca and 61.6% maguey (38.4A-61.6M).

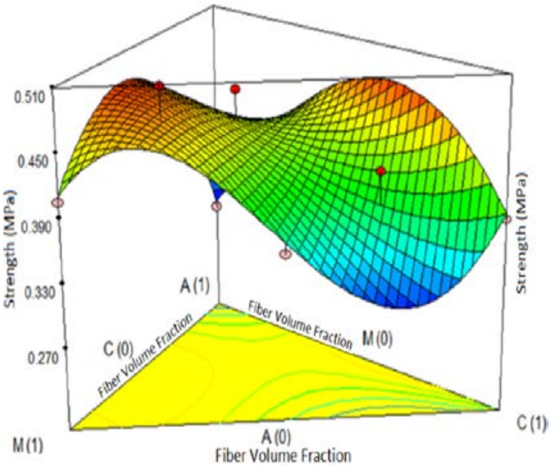

Fig. 4 Flexural strength model using RSM

*Influence of Fiber on Failure Mode*

The results obtained suggest that the higher the tensile strength of the fiber, the stronger the block is. For dry and wet compressive strength test, it was evident that the fibers provided sufficient resistance towards breakage, holding the block more intact compared to the unreinforced CSEB. This supports the theory where reinforcing fibers in the soil matrices prevent cracking through their adhesion or bonding [6]. Meanwhile, unreinforced CSEB presents noticeable breakage since there is no added fibers that holds the block together. Said breakage occurs roughly 15% of the block population.

For flexural strength, unreinforced CSEBs underwent sudden failure resulting in a total separation of the block in two halves during its 3-point loading test. This sudden failure was present at roughly 1 second of the test, immediately ending the experiment. Meanwhile, fiber-reinforced CSEBs were tested until the fiber reinforcement can no longer sufficiently hold the block for further testing. The presence of the fibers prevented sudden failure or total separation of the block and allowed continuous testing. Upon the removal of the reinforced CSEB from the testing machine, it became apparent that the blocks were split in two but were still held together by the fibers. The observed failure mode was consistent with the findings reported by [1], [10].

### 3.1.2 Drop Test

A drop test is the simplest way to qualitatively emphasize the advantage of reinforced CSEB against unreinforced CSEB in terms of the post-crack behavior. The drop test was performed by releasing the block at a height of 3.5 meters above ground. Dropped unreinforced CSEBs disintegrated into many pieces upon impact, which shows a zero-possible recovery. On the contrary, dropped fiber-reinforced CSEBs obtained damages but it did not disintegrate fully. This clearly suggests that fiber inclusion improves post-crack behavior.

### 3.1.3 Optimal Mix

Using RSM, the optimal mix or most desirable fiber combination based on the 3 strength tests was obtained. The desirability of the fiber mixtures is shown in Fig. 5 using a contour model. The best desirability has a value of 1.0. Based on the figure, it can be deduced that any mixture combining the three fibers results to low desirability. The optimal mix is the combination of 42.5% abaca fiber and 57.5% maguey fiber (42.5A-57.5M), with a desirability value of 0.703. Using this model, the predicted dry compressive strength, wet compressive strength, and flexural strength for the abaca-maguey values were found to be 4.42 MPa, 2.40 MPa, and 0.482 MPa, respectively.

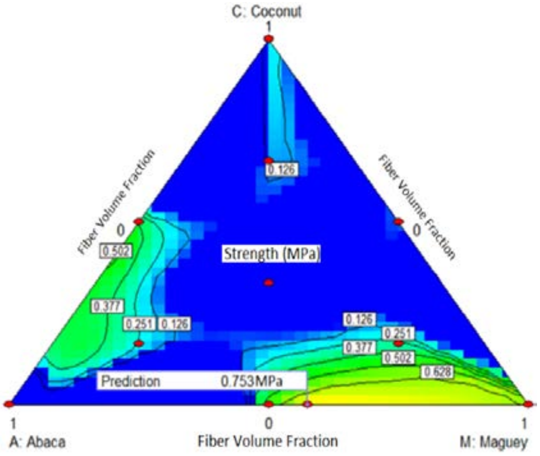

Fig. 5 Optimum mix based on desirability contour

A verification test was performed for the optimal mix (42.5A-57.5M) to compare the resulting data achieved through the RSM with the actual results. The predicted value for the dry compressive strength is 4.42 MPa and the actual value from testing is 4.19 MPa resulting to a 5.48% difference. The predicted value for the wet compressive strength is 2.40 MPa and the actual value from testing is 2.46 MPa resulting to 2.44% difference. Lastly, the predicted value for the flexural strength is 0.482 MPa and the actual value from testing is 0.525 MPa resulting to a 8.19% difference. Thus, the predictions made by RSM are highly reliable.

## 3.2 Wall Test

The blocks in the CSEB wall were arranged in staggered manner. The wall has a dimension of width, height, and thickness of W= 900 mm, H=700 mm, and T= 140 mm, respectively. The test was done by gradually applying compressive force on the wall. The failure load was measured and was also predicted by calculating the maximum compressive load (Pc), bucking load (Pe), and shear load (Pv). The formulas used are as follows:

$$\boldsymbol{Pc = f_{dry}\,(W\,T)} \tag{1}$$

$$\boldsymbol{Pe = \pi^2\,EI/H^2} \tag{2}$$

$$\boldsymbol{Pv = A_{sheared}\tfrac{1}{6}\sqrt{f_{dry}}} \tag{3}$$

Where $f_{dry}$ = dry compressive strength of the block at the day of wall testing, E = modulus of elasticity of the wall, and $A_{sheared}$ = area sheared calculated by multiplying the wall width by the product of the block height x the number of rows sheared.

### *3.2.1 Unreinforced Wall Test*

The peak strength was measured to be 142.61 kN. Shown in Fig. 6 is the observed failure pattern of the wall. It can be noticed that the diagonal crack indicates shear failure. The crack passed through 4.5 rows of blocks. The dry compressive strength of these unreinforced blocks is $f_{dry}$=3.66 MPa.

Fig. 6 Complete failure of unreinforced wall

### *Reinforced Wall Test*

The peak load was measured to be 190.79 kN, Almost the same pattern of failure was observed, indicating that the failure mode is also shear. The crack passed through 5 rows of CSEB blocks. The dry compressive strength of these fiber-reinforced blocks is $f_{dry}$=4.56 MPa.

### *3.2.2 Comparison of Wall Panels*

It was clearly observed that the fiber-reinforced CSEB wall was able to carry higher load than the unreinforced CSEB wall. This corroborate with the previously finding that fiber-reinforced CSEB is stronger than unreinforced CSEB. Shown in Fig. 7 are the plots of the load-displacement curves of the two walls. The wall test show that the fiber-reinforced wall exhibits 33.79% increase in load carrying capacity than the unreinforced wall. The lower stiffness of the fiber-reinforced CSEB wall may be attributed to the elongation of fibers causing larger displacement but with an increased strength.

Based from the calculation of strength at failure, both wall panels failed in shear as indicated in Table 6 since the calculated shear load is closest to the actual load. The calculations were done using Eq.(1) to Eq.(3).

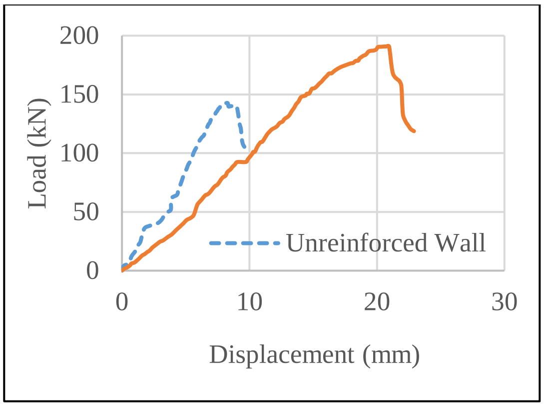

Fig. 7 Load-displacement diagram of CSEB walls

Table 6 Calculated load compared to actual load

| Wall type | Pc (kN) | Pe(kN) | Pv(kN) | Actual |
|---|---|---|---|---|
| U-CSEB | 457.3 | 8120.4 | 129.1 | 142.6 |
| FR-CSEB | 572.5 | 4634.7 | 160.1 | 190.8 |

Note: U=unreinforced, FR=fiber reinforced

## 4. CONCLUSION

The effects of adding coconut coir, abaca, and maguey fibers in CSEB were investigated. The results showed significant strength improvement of CSEB at certain fiber combination may be obtained for all strength tests conducted. RSM was used to model how the strength may be predicted for s given fiber combination or vice-versa. Furthermore, using RSM, a mix of 42.5% Abaca and 57.5% Maguey was predicted and verified to be the optimum mix. The increase in strength may be explained by the bonding effect of the fibers.

The wall test of reinforced CSEB walls shows a 33.79% increase in compressive strength compared to unreinforced CSEB wall, where both walls failed through shear. Due to the establishment of shear failure as the governing mode of failure of the wall, it is recommended that the blocks are best suited for pavements because of their high compressive strength when used individually. It is also recommended to have interlocking blocks for walls instead of plain blocks to enable further reinforcements such as steel, which minimizes shear failure and enables it to be used as load bearing wall. Lastly, changes in the dimensions of blocks are also recommended to further reduce the shear failure.

## 5. ACKNOWLEDGEMENTS

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