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COMPRESSED EARTH BLOCKS WITH POWDERED GREEN MUSSEL SHELL AS PARTIAL BINDER AND PIG HAIR AS FIBER REINFORCEMENT

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ABSTRACT: Compressed Earth Blocks (CEB) made from soil and compacted using a mechanical molder can be stabilized using cement. Moreover, CEB can perform as well as concrete hollow blocks (CHB) when properly strengthened with ordinary Portland cement. Due to the low tensile strength of CEB, pig hair fibers (PHF) which is waste material, can be utilized as fiber reinforcement to improve the performance of CEB against cracking. Due to the high cost of cement, green mussel shells (GMS), which is another waste material, can be used as partial cement substitute in compressed earth blocks. In this study, CEBs with PHF and GMS were subjected to compressive, flexural, and drip erosion tests. By using 4 variations of fiber content of PHF (0, 0.5%, 0.75%, and 1%) and 3 variations of percentages of cement replacement with GMS (0, 5%, and 10%) resulted to 12 PHF-GMS mix combinations. The compressive strength at 7, 14 and 28 days were evaluated for each mix combination. A total of 276 specimens were prepared in this study. Statistical analysis using the software Stata was conducted to filter the test results. ANOVA and T-Test were also used to determine the significance of the increase in strength with reference to the control specimen. Using the validated test results, the best performing mix was determined. The results showed that CEB with 0.75% PHF and 10%GMS is the best mix among those tested. It yielded 67% increase in compressive strength and 626% increase in flexural strength. Lastly, the same specimens, 0.75%PHF-10% GMS, also performed well in the drip erosion test.

Keywords: Earth Blocks, Fiber Reinforcement, Cement Replacement, Pig Hair, Green Mussel Shells

1. INTRODUCTION

Compressed earth blocks (CEB) are construction materials made from soil that is compacted using a molder, turning it into a block. CEB is considered to be a good alternative material because it is relatively cheap compared to other materials and is readily available, it requires low technical skills to work efficiently, and it has good natural thermal and sound-proofing capability.

However, it also has weaknesses that are not present in other construction materials. Some of these weaknesses include low strength, low resistance to water penetration which results in crumbling failure, low abrasion resistance which results to the need for more maintenance requirement, etc. Thus, the stabilization of CEBs is needed. The addition of cement will help strengthen the blocks, resulting in a more stabilized compressed earth blocks. The amount of cement affects the strength of the CEB. The more cement added, the stronger the CEB [1].

Some studies have researched incorporating fibers as reinforcement for earth blocks which improves the performance of the blocks [2]-[4]. Originally, fibers had been used in concrete as fiber reinforcement. It has been widely used in the construction industry due to its ability to improve the concrete's strength and other parameters [5].

In this study, pig hair which is a waste product from slaughterhouses is utilized as fiber reinforcement. Pig hairs are non-biodegradable waste materials which usually end up in landfills. It is a cheaper alternative to other fiber reinforcement like glass fibers, steel fibers, synthetic fibers, and plant-based fibrous materials.

Another alternative material that is used in this study is powdered green mussel shells. Green mussel shells or commonly known as "tahong" in the Philippines are grown and harvested in bays to be used as food. However, their shells are non-biodegradable and are considered wastes [6]. Based on chemical and microstructure analysis, green mussel shells were found to be mostly made of calcium carbonate (CaCO3) and other impurities in small amounts [7]. When green mussel shells are exposed to heat, it turns brittle and can be turned into a powder by grinding. By turning green mussel shells into powder, it is possible to use green mussel shells as cement replacement.

A previous study had already shown the possibility of use of both pig hair fibers and green mussel shells in enhancing concrete [8]. The combination yielded positive results which mean that the combination could be further explored for use in other construction materials, such as CEB.

The main objective of this study is to determine the effects of incorporating pig hair fibers and powdered green mussel shells to compressed earth blocks. The following are the specific objectives: a) to investigate the effects of different percentage of pig hair fibers (PHF) to the strength of CEB, b) to investigate the effects of different amounts of powdered green mussel shell (GMS) as partial substitute to cement, and c) to investigate the effects of fiber reinforcement and cement substitution in the durability of CEB through drip erosion test.

2. METHODOLOGY

The study investigated the combination of GMS and PHF at varying amounts in the mixture of conventional CEB. However, the following parameters were made constant: the amount of cement/binder which is set at 5% by weight of the mixture; the length of the pig hair was maintained from 20mm to 40mm, and the GMS powdered particles have a diameter of less than 1mm.

The study incorporated 3 independent variables in the mixture of CEB. These are the following; 1) the percent of GMS powder as a partial cement substitute, 2) the percent of PHF as fiber reinforcement, and 3) the specimen curing age. The amount of GMS powder was varied from 0%, 5%, and 10% by weight of the amount of cement. Meanwhile, the percentages of PHF fiber reinforcement were 0%, 0.5%, 0.75%, and 1% of the total weight of the mix. This resulted in 12 mix combinations. To identify the specimens, the mixed code used was based on the percentage GMS and percentage PHF. For example, 10%GMS-7.5%PHF means 10% GMS cement replacement and 0.75% pig hair fiber reinforcement.

2.1 Materials Used

To make CEBs suitable building material, the soil properties have to be determined. The strength of CEB depends on the character of the soil it uses. The soil used in the research is the typical soil found in Quezon City, Metro Manila. The soil was first sieved using a #10 sieve to ensure that large particles of soil will not be included in the mixture. Soil properties that were determined in the laboratory were; a) grading, b) specific gravity, c) optimum moisture content (OMC), and d) Atterberg limits.

The cement used was a Type I Portland Cement. According to New Mexico Earth Block Building Code of the New Mexico Adobe Code (NMAC) [9], which complies with ASTM D1633 [10], blocks must contain a minimum of 6 percent Portland cement by weight. The amount of cement adopted in this study was 5%. It was made a little bit lower on the idea that the additional alternative materials may help in improving the strength of the CEB.

Shown in Fig. 1 are the pictures of the GMS and PHF for reference.

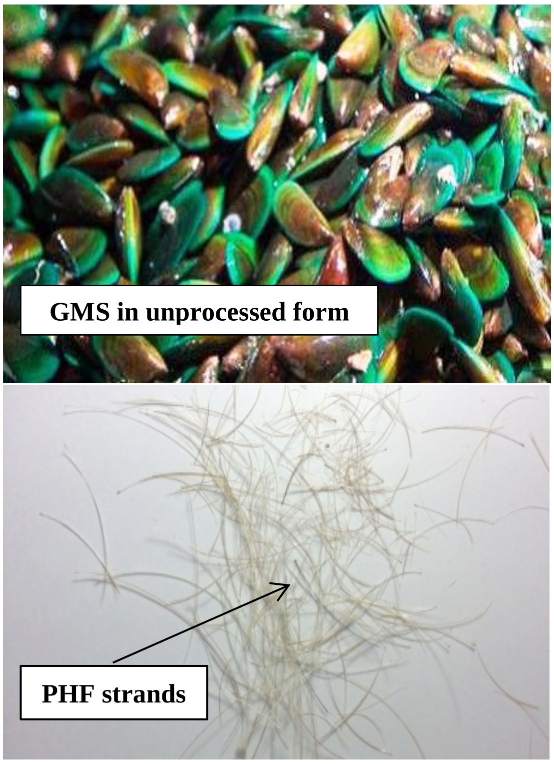

Fig.1 Photo of GMS (top) and PHF (bottom)

The shells were obtained from a tahong chip factory in Bacoor, Cavite. The shells were heated until they were brittle enough to be crushed into powder so that particle size would be less than 1mm. The specific gravity of GMS was found to be 2.62.

The pig hair fibers were obtained from two different slaughterhouses. One was from Dasmariñas, Cavite and the other from Quezon City, Metro Manila. However, the investigation showed that the properties of the pig hair from the two sources are the same. The pig hair fibers were found to have a density of 1300 kg/m3.

2.2 Production of CEB

The materials used for the CEB were weighed according to their proportion. The powdered GMS were mixed first with cement. Then the soil, cement, and PHF were dry-mixed for 10 to 15 minutes until uniformly distributed. Water was gradually added for the mixture to reach the OMC of the soil. After which, the mixture was placed in the mechanical molder which compacted the specimen to a block size of 30cm x 15cm x 10cm as shown in Fig. 2.

The CEBs were cured in a dry place and keeping them covered with plastic sheets so that water in the CEB would not evaporate. This condition has been maintained until the testing of the specimens.

Fig.2 Photograph of the production of CEB using a mechanical molder.

2.3 Experimental tests

The experimental tests were the compressive strength test, flexural strength test and drip erosion test. The compressive strength tests were done for 3 different curing ages: 7, 14, and 28 days. The flexural strength was obtained by measuring the modulus of rupture of the CEB using center-point loading with the supports placed 50mm from each end of the CEB. Flexural strength was evaluated for 28-day curing age. Five specimens were prepared for each strength test. For the drip erosion test, three specimens were prepared for each mix combination and tested at 28-day. This resulted in a total of 276 specimens, 240 specimens for the strength tests and 36 specimens for the drip erosion test.

Strength tests were conducted in a universal testing machine. These tests were performed in accordance with NMAC [9]. The load was applied at a rate of 500 psi/ min or 0.0575 MPa/s.

The drip erosion test or also known as Swinburne accelerated erosion test was developed by the University of Technology of Swinburne, Australia to determine the quality of the block after a simulated rainfall. Drip Erosion tests were done to test the water resistivity of CEBs. This testing method is done by subjecting a specimen to a constant water fall for a certain amount of time [11]. Three specimens for each mix combination were tested. The specimens were qualitatively evaluated by subjecting the specimens with drip test using 2250 mL water bottle that lasts for about 30 minutes.

3. RESULTS AND DISCUSSION

The properties of soil were evaluated because they affect the quality of CEB that will be produced. The properties of the soil used in this study are tabulated in Table 1.

Table 1 Properties of soil used in making CEB

Property	Value	Property	Value
OMC	11.7 %	% Gravel	0%
MDD	17.25 kN/m^3	% Sand	92%
Liquid limit	60	% Fines	8%

Note: OMC = optimum moisture content, MDD = maximum. dry density, SG = specific gravity

The USCS classification for the soil used in this study was found to be Poorly Graded Clayey Sand (SP-SC). This is a good soil to be used to be able to produce CEB with a compressive strength of about 2 MPa which is the recommended minimum compressive strength based on NMAC [9]. This strength is also the usual minimum strength requirement for concrete hollow blocks used in housing construction.

3.1 Statistical analysis of the strength test values

The data from the strength tests were filtered using Stata. The strength test data were processed using a 95% confidence interval to determine if a data in a group is considered as an outlier so that it can be removed. However, very few data were considered outlier.

To verify whether the difference in strength between mixes is significant, the statistical software ANOVA was used. It was found out that mixes had a significant difference between them. Furthermore, the T-Test: 2 Variables Assuming Unequal Variance was used to verify whether the increase or decrease in the strength is significant or not. In this test, the control specimen was set as the independent variable while the other specimens were set as dependent variables. This verified the hypothesis that the incorporation of GMS and PHF significantly affected the strength of the specimen.

3.2 Compressive strength of CEB

The average compressive strength of statistically validated specimens for each mix combination and for the different curing ages is tabulated in Table 2.

Table 2 Averaged compressive strengths of CEB

Mix Code of Specimen	Comp. Strength (MPa)		
	7day	14day	28day
Control	1.76	1.88	2.36
0%GMS-0.5%PHF	1.39	1.40	1.74
0%GMS-0.75%PHF	2.25	2.27	2.34
0%GMS-1%PHF	1.93	1.98	1.90
5%GMS-0%PHF	1.53	1.55	1.80
5%GMS-0.5%PHF	1.94	2.13	1.84
5%GMS-0.75%PHF	1.94	1.95	2.06
5%GMS-1%PHF	2.82	2.60	2.66
10%GMS-0%PHF	0.61	1.30	1.92
10%GMS-0.5%PHF	3.17	2.51	2.71
10%GMS-0.75%PHF	4.44	4.01	4.16
10%GMS-1%PHF	2.60	2.69	3.49

Note: Control specimens are those with a mixture of 0% GMS and 0% PHF

It can be observed that some specimens did not reach the target strength of 2 MPa, even at the 28-day. However, it can also be noted that when the amount of GMS and PHF were increased, it tends to increase the strength of the specimens, except when the amount of PHF exceed 0.75%. This shows that certain mix combination yields positive results. The results indicate that the optimal amount of GMS is 10%, except when no PHF is incorporated. In addition, the strongest CEB was produced at 10% GMS and 0.75% PHF. At 28 days, the strength of this mix is 4.16 MPa. Compared to the control, which had 2.36MPa compressive strength at 28 days, the increase is 67%.

To have a better assessment of the effect of GMS and PHF, the ratio of the compressive strength with respect to the target strength of 2 MPa was calculated and tabulated in Table 3. Values less than 1 indicate that the target strength was not reached while values greater than 1 indicate that it exceeded the target strength.

The increasing value of the ratio of the control specimen shows that it had a significant amount of strength development compared to the other specimens. Table 3 also shows that GMS as a partial binder alone (those shaded in grey) helped establish a good strength development but did not help much in surpassing the target strength. All others showed almost constant strength from 7 days to 28 days, indicating that the full strength was already attained at an early age of 7 days. This means that the incorporation of PHF together with GMS may have helped in attaining an early strength. Moreover, specimens with 10% GMS achieved the optimum strength when PHF was incorporated. Lastly, the combination that has the greatest strength increase is 10% GMS and 0.75% PHF specimens. More than double the target strength was attained at this mix proportion.

Table 3 Ratio of the averaged compressive strengths with respect to the target strength of 2 MPa

Mix Code of Specimen	Ratio		
	7day	14day	28day
0%GMS-0%PHF	0.88	0.94	1.18
0%GMS-0.5%PHF	0.69	0.70	0.87
0%GMS-0.75%PHF	1.12	1.13	1.17
0%GMS-1%PHF	0.97	0.99	0.95
5%GMS-0%PHF	0.76	0.77	0.90
5%GMS-0.5%PHF	0.97	1.06	0.92
5%GMS-0.75%PHF	0.97	0.98	1.03
5%GMS-1%PHF	1.41	1.30	1.33
10%GMS-0%PHF	0.30	0.65	0.96
10%GMS-0.5%PHF	1.59	1.25	1.36
10%GMS-0.75%PHF	2.22	2.01	2.08
10%GMS-1%PHF	1.30	1.35	1.74

Graphical representation of the effect of GMS and PHF to the compressive strength of CEB is shown in Fig. 3. Only the plot for the 28-day curing age is shown because the same trend will also be seen if plots for the 7-day and 14-day are included.

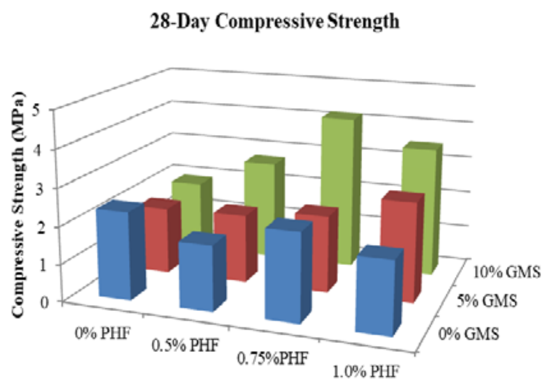

Fig.3 Graphical plot of the 28-day compressive strength as affected by GMS and PHF

By looking at the graph, the effects of GMS in CEBs can be analyzed. It can be easily seen in the 3D graphs, that the highest strength obtained is at 10% GMS and 0.75% PHF. Higher compressive strengths can be seen in the specimens with 10% GMS with any amount of PHF. In the 10% GMS combination, the 0.75% PHF has the highest strength, followed by 0.5% and 1% PHF respectively. The specimen with 5%GMS-1%PHF also performed well because its strength is near the other specimens with 10% GMS. The 5%GMS-0.75%PHF and 5%GMS-0.5%PHF did not perform well compared to the specimens with 10% GMS. The 10% GMS specimens with no PHF is even weaker compared to specimens with 5% GMS with any amount of PHF. This shows that the effectiveness of GMS in CEB is influenced by two things; the amount of GMS incorporated should be 10% and should be combined with PHF.

3.3 Flexural strength of CEB

The results of the flexural strength tests are tabulated in Table 4. The minimum strength requirement is 0.345 MPa according to NMAC. The increase or decrease in flexural strength with respect to the control specimens was calculated and also tabulated in Table 4.

Table 4 Averaged flexural strengths of CEB

Mix Code of Specimen	Strength (MPa)	Increase(+)/ Decrease(-)
0%GMS-0%PHF	0.106	0%
0%GMS-0.5%PHF	0.238	125%
0%GMS-0.75%PHF	0.357	237%
0%GMS-1%PHF	0.210	99%
5%GMS-0%PHF	0.082	-22%
5%GMS-0.5%PHF	0.025	-76%
5%GMS-0.75%PHF	0.143	35%
5%GMS-1%PHF	1.053	896%
10%GMS-0%PHF	0.206	95%
10%GMS-0.5%PHF	0.156	47%
10%GMS-0.75%PHF	0.768	626%
10%GMS-1%PHF	0.706	568%

Note: 0%GMS-0%PHF is the mixed code for the control specimens.

It can be seen in Table 4 that some of the specimens, especially the control specimen, did not pass the standard flexural strength of 0.375 MPa set by the NMAC. However, it can be observed that some combinations improved the flexural strength; the highest by as much as 896% with respect to the control specimens. This means that the incorporation of certain combinations of PHF and GMS helps in the improvement of CEBs against flexural loads. The mix with the highest compressive strength, 10%GMS-0.75%PHF, resulted to 626% increase in flexural strength with respect to the control specimens.

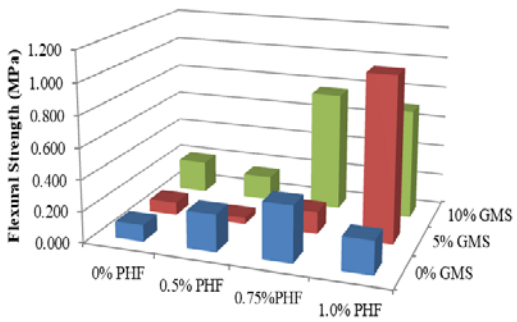

Fig.4 Graphical plot of the flexural strength as affected by GMS and PHF

In Figure 4, a 3D plot of the flexural strengths as affected by GMS and PHF is shown. The specimens with 10% GMS performed better compared to the other percentages of GMS. As for PHF, the best amount of PHF for 0% and 10% GMS is 0.75% while the best amount of PHF for 5% GMS is 1% PHF. The best combination for flexural strength is 10%GMS-1%PHF. This is followed by the mix 10%GMS-0.75%PHF. Although it comes second, it is given more emphasis because it corresponds to the highest compressive strength. For this mix, the flexural strength increased by 626% with respect to the control specimen, and 2.05 times compared to the minimum required strength of 0.375 MPa.

3.4 Results of Drip Erosion Tests

The drip erosion test results indicate the durability of the CEB against water.

Table 5 Rubric for a quality checklist of CEB subjected to drip test

Criteria	Description	Point Deduction
1	Cracks when lifted	-50
2	Easily dented	-10
3	Corners break off	-15
4	Edges break off	-15
5	Easily Scratched	-10
6	Fractured to pieces	-50
7	Cracks appeared	-25
8	Erosion occurred	-25

Presented in Table 5 is the rubric that was developed to evaluate the specimens subjected to the drip test. The rubric consists of 8 damage criteria. Criteria 1-5 are artificial damages, while 6-8 are natural damages. Artificial damages are damages occurring during the handling of the block after the test, while natural damages occur during the drip test itself. With these criteria, the score of the block, which is initially 200 points at the start, will be decreased for each damage criterion that will happen. The point deduction assigned for each criterion depends on the quality of the block as described by the criteria.

Table 6 Drip erosion test results

Mix Code of Specimen	Criteria								Score
	1	2	3	4	5	6	7	8	
0%GMS-0%PHF			x	x	x				160
0%GMS-0.5%PHF	x	x	x	x				x	85
0%GMS-0.75%PHF		x	x	x	x	`			150
0%GMS-1%PHF	x				x				140
5%GMS-0%PHF	x	x	x	x	x	x	x	x	0
5%GMS-0.5%PHF	x		x	x		x	x		45
5%GMS-0.75%PHF	x	x	x	x	x			x	75
5%GMS-1%PHF	x		x		x				125
10%GMS-0%PHF	x	x	x	x	x		x	x	50
10%GMS-0.5%PHF			x	x					170
10%GMS-0.75%PHF			x						185
10%GMS-1%PHF			x	x					170

Note: x indicates that damage criterion occurred

Shown in Table 6 is the tabulation of the results of the drip erosion test. By this scheme, the drip erosion performance of the specimens can be compared to each other. The higher the score means better performance. As observed in the drip test, the control specimen performed fairly well with a score of 160 points. The worst performance is that of 5%GMS-0%PHF wherein all damage criteria were observed. In terms of GMS, the best performing specimens are those with 10%GMS. It can also be observed that specimens with 0% GMS had better scores than the 5% GMS. In general, it seems a higher amount of PHF tends to improve the drip erosion performance of the specimens. Lastly, among those tested, the best performing specimen is 10%GMS-0.75%PHF, with a score of 185.

4. CONCLUSION

Based on the results of the experiment, the following conclusions were arrived at:

GMS and PHF have the capacity to improve the performance of CEB. It was observed that GMS and PHF combination helped in attaining early full strength development. However, only certain mix combinations of GMS and PHF improved the performance of CEB. There were mix combinations that even exhibited poorer performance than the control specimen.

The combination of GMS and PHF proved to be an effective combination. Specimens with either PHF only in their mix or GMS only in their mix had lower compressive and flexural strength compared to specimens with both GMS and PHF in their mix.

In terms of compressive strength, the best mix among those tested is 10%GMS-0.75%PHF. With this mix, the compressive strength was increased by 67% with respect to the control specimens, and more than doubled as compared to the target compressive strength of 2MPa.

In terms of flexural strength, the highest strength was obtained in 5%GMS-1%PHF followed next by 10%GMS-0.75%PHF. For the 10%GMS-0.75%PHF, the increase was 626% with respect to the control specimen.

In terms of the drip erosion test, the specimen 10%GMS-0.75%PHF exhibited the best performance. This shows that the GMS-PHF combination is effective in making CEBs durable against water exposure.

In general, it may be said that among those tested the best mix proportion to recommend is 10%GMS-0.75%PHF.

5. ACKNOWLEDGMENTS

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