Utilization of Powdered Eggshells and Green Mussel Shells as Partial Cement Replacement with Seawater in Concrete Hollow Block

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Abstract: The gradual increase in the use of concrete in construction continues to exhaust natural resources that calls for sourcing possible substitute sustainable materials. Many alternative materials are used to produce concrete using by-products or industrial waste to lessen over-dependence on natural resources. Since the production of cement leaves a lot of carbon footprints, it would be environment-friendly if something can replace or even partially replace cement. Another aspect in caring the environment is looking for solution to the depleting source of freshwater. The viability of using seawater in the production of concrete hollow blocks (CHB) is one of the facets investigated in this study. To create sustainable non-load bearing CHB, experimental investigation had been carried out on the utilization of eggshells and green mussel shells as partial cement replacement mixed with seawater. The eggshells and green mussel shells were air dried for 24 hours and then heated in an oven at 100°C in an oven for 12 hours. It was then milled and passed through a 100μm sieve to simulate the particle size of cement. There were 6 CHB specimens per mix and 36 mix ratios of both freshwater and seawater samples. The total number of specimens including 6 samples of control freshwater specimens produced was 222 CHB specimens with a dimension of 400 mm x 200 mm x 100 mm. Based on the compressive strength test, it was determined that the 10% partial cement replacement samples, resulted with a greater average compressive strength of 3.99 MPa for seawater mix than the 20% and 30% cement replacement samples at 3.94 MPa and 3.69 MPa, respectively. It was also found that the green mussel shell is more effective in increasing the strength of CHB since when the proportion of green mussel shell to the eggshell is increased, the compressive strength tends to increase. Furthermore, seawater proved to be more advantageous than freshwater in all the mix ratios in terms of compressive strength.

Key Words: partial cement replacement; concrete; CHB; mussel shells; eggshells.

1. INTRODUCTION

Within the past few years, studies in the field of Civil Engineering focused on finding sustainable alternatives that are viable or even better than conventional concrete. Incorporating waste materials as partial cement replacements has been the hot topic ever since the effects of climate change started taking its toll. A waste material that is viable are green mussel shells (GMS). Green mussel shells are of particular interest to civil engineering research due to the high Calcium Carbonate ($CaCO_3$) content of it, which is a key component of limestone, a key ingredient to cement. The Philippines, being an archipelagic country, thrives in the aquaculture sector which results to a high waste generation of these mussel shells. A study conducted by Lejano and Gagan (2017) utilized powdered green mussel shells and pig-hair fibers as partial cement replacement for concrete. They found the optimal mix ratio for pure green mussel shells is at 10% partial cement replacement wherein there was a 13% increase in strength. In another study by Lejano, Ang, and Dagdagan, green mussel shells and fly ash were used as partial cement replacement for masonry blocks with plastic waste aggregates. Their study shows that the optimal mix was still 10% and there was a 9.5% increase in strength.

Another waste material that has been incorporated in cement are eggshells (EGS). Just like GMS, eggshells have a good amount of $CaCO_3$. A study by Lejano, Barron, Saludo, Tugade, and Yokohama (2020) found out that eggshell becomes more affective as partial cement replacement when heated in an oven at $100^{O}C$ for 12 hours. The amount of eggshell used was at 5% partial cement replacement which was the optimum based on the work of Yerramala (2014).

In this study, GMS and EGS are utilized as a partial cement replacement for non-load bearing concrete hollow blocks (CHB). CHBs is a popular building material in the Philippines because it readily available, inexpensive, and suitable for a lot of construction projects. To possibly produce a more sustainable non-load bearing CHB, the effects of GMS and eggshells on the compressive strength of CHB were analyzed through various methods of statistics such as two-tailed paired t-test and multivariate analysis. The production cost and cost efficiency of the CHBs produced were also investigated.

2. METHODOLOGY

2.1 *Research Design*

This study is experimental in nature. CHBs with GMS and EGS partial cement replacements were tested to evaluate their effect on the compressive strength. Six non-load bearing CHB specimens per mixture for the 36 mixes based in Table 1 were prepared and tested to ensure the validity of the data. This resulted to a total of 216 samples. To further verify the consistency of the samples produced in the experiment a two-sample T-test on the weight of the specimens per batch of CHB mixture was conducted which turned out to be insignificant, meaning the CHB's quality were consistently produced. The cement replacement percentage, type of mixing water, and EGS to GMS ratio were the factors considered for each CHB mixture, as shown in Table 1.

Table 1. Breakdown of factors considered in determining the total number of CHB mixtures.

Type of factor being considered	No. of factors
Cement Replacement Percentage	3
Mixing Water	2
Eggshells/Green Mussel shells	6
Total Mixture Cases	36

2.2 Experimental Setup

The non-load bearing CHB used in this research has dimension of 400 mm by 200 mm by 100 mm based on what is usually sold in the market. The samples were planned to be cured for at least 28 days but were eventually cured for 107 days because of the lockdown brought about by the Covid-19 pandemics. For compression testing, the Universal Testing Machine (UTM) was used. The said testing was done following the ASTM C140 (Standard Test Method for Sampling and Testing Concrete Masonry Units and Related Units) was applied.

2.3 Preparation of Materials

Same processing was done for the eggshells and green mussel shells. The said materials were collected from different bakeries and restaurants. They were rinsed with water to remove all the unnecessary substances and was air dried for 24 hours. Then they were manually crushed and then placed in an oven set at $100^{O}C$ for 12 hours. After oven-drying, they were grinded until they passed through a 100-micrometer sieve.

2.4 Mix Design

The researchers decided to use the CHB manufacturer's mixed design to obtain the said mix design. The researchers planned to make samples of concrete hollow block in which every sand, water, and cement was weighed for uniformity. Instead of using the volumetric measurement in controlling all the mix designs, the corresponding weight of the materials shown in Table 2 was followed. This ensures the quality of the experimental samples made.

Each CHB mix has labels, 10-0E100GF as an example. Various mixes were done in the creation of the said CHB wherein the replacement for the cement had different replacement percentages varying from 10%, 20%, and 30% of the weight of cement per mixture seen in Table 2. This corresponds to the first 2 digits in its label. The partial cement replacements per CHB mixture also have varying ratios of eggshells and green mussel shells: 0:100, 20:80, 40:60, 60:40, 80:20, 100:0. The ratio of a cement replacement in a CHB mix is seen before "E" and "G" in its label, wherein "E" stands for eggshells while "G" for green mussel shells. The type of mixing water used in a CHB mix can be determined by looking at the last letter found in the CHB label, wherein "F" stands for freshwater and "S" for seawater.

Table 2. Site's CHB design mix proportion by weight.

Cement (kg)	Sand (kg)	Water (kg)
3	54.86	6.47

The amount of water was planned to be constant in the mixed design. But due to the on-site mason's opinion (who was expert in making CHB), the amount of water was varied slightly to mold the CHBs successfully which resulted with a standard deviation of 0.388 kg. It was noticed that some of the specimens cannot be molded properly without adding water. Due to the slight variation of the amount of water leading to the variation of water-binder ratio, a single variable linear regression was done to see if its variance has a significant effect on the compressive strength of the CHBs. The slight variation of water-binder ratio turned out to be insignificant.

2.4 Production of Concrete Hollow Blocks

The CHBs were produced in a CHB manufacturing plant. To produce the CHBs, manual mixing was done because the samples to be made were of small quantity just enough to produce 6 pieces of CHB which is the capacity of the CHB making machine used. However, each batch of production has different mix proportion. The dry ingredients (sand, cement, eggshells, and green mussel shells) were added first and then were dry-mixed. Water was gradually added to the mix. The mixture was then placed into a mold in a machine that is vibrating to shape and compact the CHB. All CHBs were molded in the same manner, applying constant duration of vibration that was prescribed by the CHB manufacturer. No overall dimensions differed by more than ⅛ in which is roughly 3.2mm from the dimensions specified by the manufacturer. The CHBs were cured by water spraying daily.

2.5 Compressive Strength Test of Concrete Hollow Blocks

The methodology used for determining the compressive strength of a concrete hollow block was based on ASTM C140 (Standard Test Method for Sampling and Testing Concrete Masonry Units and Related Units). The said ASTM standard served as a guide for the proper testing procedure to be followed. Shown in Figure 1 is a picture of the actual test of the CHB specimen. The CHBs were transported from the manufacturing plant to the testing site. Proper care was observed in transporting to prevent damage to the CHBs. The CHBs were tested for their compressive strength using a UTM. The dimension of the top surface area of all samples for each CHB mixture was measured before being tested. The minimum strength of non-loadbearing concrete hollow blocks should be around 500 psi which is roughly 3.45 MPa in accordance with ASTM C129-99a.

Fig. 1. Testing the compressive strength of Concrete.

3. RESULTS AND DISCUSSION

3.1 Effects of Green Mussel Shells (GMS)

The compressive strength of CHB with pure powdered GMS cement replacements mixed with freshwater and seawater in the different cement replacement percentages can be seen in Table 3. The specimens with pure GMS cement replacement mixed with seawater in Table 3, the CHB with the 10% cement replacement of GMS produced the highest compressive strength. This is consistent with findings of Lejano and Gagan (2017) that the optimum cement replacement of GMS is at around 10%. The results showed a noticeable trend wherein the compressive strength of the specimens decreased with an increase in replacement percentage after 10%. The majority of the CHB sample that was mixed with seawater resulted with greater strength than those that were mixed with freshwater. It was evident that there was an interaction between seawater and high calcium-carbonate materials that resulted in higher compressive strength. It showed similar findings as compared with the study of Wang, et al. (2020) that using seawater as mixing water yields higher compressive strength than using conventional fresh water on concrete mixtures.

Table 3. Average compressive strength of CHBs with 100% powdered green mussel shells as cement replacement.

Cement Rep. (%)	Fresh Water Comp. Strength (MPa)	Seawater Comp. Strength (Mpa)
10	3.24	3.99
20	3.14	3.94
30	3.61	3.69

For the freshwater samples with pure GMS partial cement replacement, show the same trend with the seawater samples except at 30% partial cement replacement wherein it suddenly increased. Although, this may indicate that the strength maybe increased at 30% cement replacement, it will be presented later in Section 3.4 that this is just a statistical aberration.

3.2 Effects of Powdered Eggshells (EGS)

The compressive strength of CHBs with pure EGS cement replacements mixed with freshwater and seawater in the different cement replacement percentages can be seen in Table 4. From all the CHB mixed with freshwater, the 10% cement replacement sample had the highest attained compressive strength among all specimens with pure EGS.

Table 4. Average compressive strength of experimental CHB with 100% powdered eggshells as cement replacement.

Cement Rep. (%)	Fresh Water Comp Strength (Mpa)	Seawater Comp Strength (Mpa)
10	3.55	3.42
20	2.64	2.86
30	3.36	3.52

By observing the change of value of the strength with respect the cement replacement, an up and down trend can be seen. However, the statistical analysis resulting to a model generated from all the experimental compressive strength in Section 3.4 will show an inverse relationship between the compressive strength and cement replacement percentage for pure eggshells. The results of the experiment suggest that findings from the previous studies by Yerramala (2014) that 5% cement replacement may be the optimum ratio.

3.3 Effects of Combined EGS and GMS

The compressive strength of CHBs with combined powdered GMS and EGS in varying ratios and cement replacement percentages mixed with freshwater and seawater can be seen in Figure 2 and Figure 3, respectively. In the figures, it is seen that the mixture10-20E80GF for freshwater samples and mixture 10-80E20GS for seawater samples yielded the highest compressive strength of 4.17 MPa and 3.97 MPa, respectively. Both are at 10% cement replacement. It is also observed in figures 2 and 3 that the specimens mixed with seawater showed significantly higher peak compressive strengths when compared to specimens mixed with freshwater. There were no obvious or distinct significant trends to be seen, hence a statistical analysis is done in the next section (Section3.4) to establish the trend.

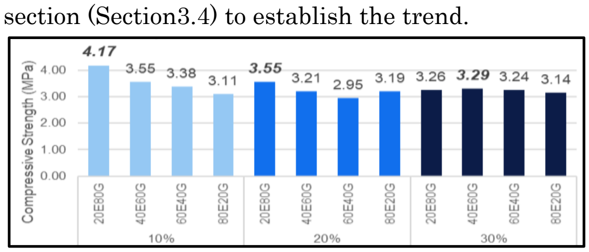

Fig. 2. Compressive strength plot of CHBs with GMS and EGS cement replacements mixed w/ fresh water.

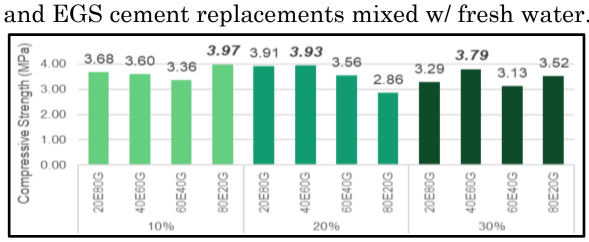

Fig. 3. Compressive strength plot of CHBs with GMS and EGS cement replacements mixed with seawater.

Distinct trends were more apparent when the results from combined EGS and GMS were presented in compiled and summarized forms. Table

5 shows the summary of the mean compressive strength of CHBs according to the partial replacement used. "EGS^" refers to the mean compressive strength of CHBs with a higher EGS ratio than GMS and vice versa for "GMS^". Based on Table 5, it is apparent that the green mussel shell had greater influence with higher mix ratios on the compressive strength of the CHBs as compared when using higher EGS ratio in combined cement replacement mixtures. Additionally, the pairing of the green mussel shells and seawater resulted in a higher strength gain. Looking into the percent difference between the freshwater and seawater, a positive value for the percent difference means that seawater indeed increases the compressive strength. An average of 6.44% increase in compressive strength was evident from all the samples when comparing the seawater and freshwater mixtures.

Table 5. Summary of the Mean Compressive Strength Based on Partial Cement Replacement Type

Partial Cement Rep.	Fresh Water (MPa)	Seawater (MPa)	Percent Diff.
PURE EGS	3.18	3.38	6.39
*EGS^	3.17	3.40	7.35
PURE GMS	3.33	3.88	16.39
*GMS^	3.51	3.70	5.62

3.4 Predictor Model Equation

A multilinear regression analysis considering 3 independent variables was conducted using a software, MedCalc. This resulted to the predictor model equation for the compressive strength of the CHB (fc_m) shown in Eq. 1.

$$fc_m = -0.0042\,X + 0.2682\,Y - 0.8855\,Z + 3.6883 \quad \text{(Eq. 1)}$$

where:
X = Ratio of Powdered Eggshells (%)
Y = Type of mixing water
Z = Percentage of Cement Replacement (%)

The overall P-value of the model is 0.0022 while X coefficient had 0.0061, Y coefficient had 0.0096, and Z coefficient had a P-value of 0.1657. The constant value of percentages cement replacements for a set of varying ratios of cement replacement could be the for the P-value of Z coefficient. Based on the constants of the equation, it turned out that statistically, the ratio of powdered eggshell in the cement replacements (i.e., EGS to GMS ratio) has less influence on the compressive strength of CHB. The type of water and the percentage of cement replacement have stronger influence on the compressive strength. The code used for the Y variable are 0 for freshwater and 1 for seawater. The Figures 4 and 5 shows the graph of the predicted compressive strength of CHBs mixed with freshwater and seawater respectively using Eq 1. The X-axis in figure 4 and 5 corresponds to the ratio of powdered eggshells and green mussel shells and cement replacement percentage of CHB mix while the Y-axis corresponds to its predicted compressive strength. It can be noticed that the generated predictor model produces an inversely proportional trend between the compressive strength and the cement replacement percentage of the CHBs.

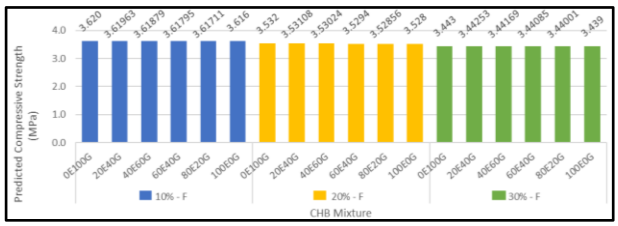

Fig. 4. Graph of the Predicted Compressive Strength of the Specimens mixed with Freshwater.

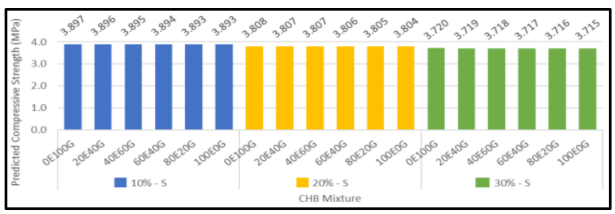

Fig. 5. Graph of the Predicted Compressive Strength of the Specimens mixed with Seawater.

3.4 Cost Analysis

The cost analysis was done using the mixture without cement replacement as benchmark. The cost of each mixture with cement partially replaced with GMS and EGS was calculated. The unit cost of GMS and EGS were found to be lower than cement making it cheaper when more GMS and/or EGS were used. Cheaper CHB was also produced when seawater was used. The cost efficiency of each mixture was calculated by dividing the cost with its corresponding experimentally obtained strength. Lower value would mean more cost efficient CHB. The calculated cost efficiencies for CHB with fresh water and for CHB with seawater are shown in Figure 6 and Figure 7, respectively. For CHB mixed with seawater, the most cost-efficient is 10-0E100GS, which has a cost efficiency of P2.64/MPa. Overall, the most cost-efficient CHB was the 10-20E80GF at 2.53 Php/MPa.

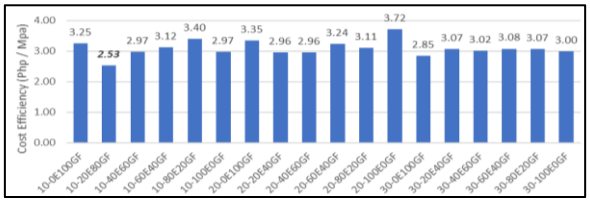

Fig. 6. Cost-efficiency of CHB mixed with mixed with fresh water.

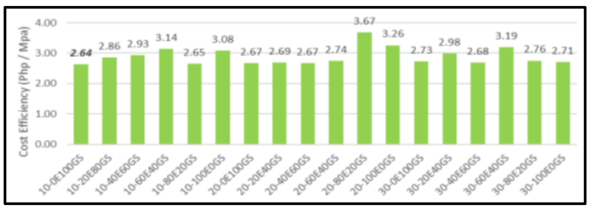

Fig. 7. Cost-efficiency of CHB mixed with mixed with seawater.

4. CONCLUSIONS

The study shows a significant increase in compressive strength at certain amounts of high calcium carbonate material, especially GMS, as a partial cement replacement when mixed with seawater than with freshwater. The specimens with 10 percent cement replacement yielded the highest compressive strength in both freshwater and seawater CHB mixtures. The results from combining powdered EGS and GMS showed findings that using higher GMS ratio replacements produced a notable increase on the compressive strength for both types of mixing water. Using pure powdered GMS as partial cement replacement mixed with seawater yielded the highest compressive strength among the CHBs with partial cement replacements. The ideal mix ratio with combined cement replacements for CHBs mixed with freshwater is 10-20E80GF while 10-0E100GS for CHBs mixed with seawater.

Based on the cost analysis, the production cost of the samples with partial cement replacement was expectedly cheaper than the control samples. On the cost efficiency of the experimental samples, the seawater samples have a better cost-efficiency ratio.

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6. REFERENCES (use APA style for citations)

ASTM Standard C129-99a, 2000 (2017),. "Standard Specification for Nonloadbearing Concrete Masonry Units," ASTM International, West Conshohocken, PA, 2017, DOI:.10.1520/C0129-17, www.astm.org.

Lejano, B., Ang, R. and Dagdagan, V. (2019). Partial Cement Replacement with Fly Ash and Powdered Green Mussel Shells for Masonry Blocks with Plastic Waste Aggregates", Proceedings of DLSU Research Congress 2019, June 19-21, 2018, DLSU, Manila.

Lejano, B, Barron R., Saludo, P., Tugade, J. and Yokohama K. (2020). Compressive Strength of Concrete with Seawater and Powdered Eggshells as Partial Replacement for Cement", International Journal of GEOMATE, May 2020, Vol. 18, Issue 69, pp. 52-58.

Lejano, B. & Gagan, J. Optimization of Compressive Strength of Concrete with Pig-Hair Fibers as Fiber Reinforcement and Green Mussel Shells as Partial Cement Substitute, International Journal of GEOMATE, March 2017, Vol. 12, Issue 31, pp. 37-44. ISSN:2186-2990

Wang, J., Xie, J., Wang, Y., Liu, Y. and Ding, Y.(2020). Rheological properties, compressive strength, hydration products and microstructure of seawater-mixed cement pastes. Cement and Concrete Composites, 114. doi: 10.1016/j.cemconcomp.2020.103770.

Yerramala A. (2014) Properties of Concrete with Eggshell Powder as Cement Replacement. The Indian Concrete Journal, Vol. 88, No.10, pp. 94-102.