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Partial Cement Replacement with Fly Ash and Powdered Green Mussel Shells for Masonry Blocks with Plastic Waste Aggregates

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Abstract: Inclusion of waste materials in concrete is done in an effort to address environmental concerns and to possibly enhance concrete properties. Previous studies have incorporated fly ash and powdered green mussel shells into concrete as partial cement replacement. The studies have shown that these materials have the potential to increase the compressive strength and to lower the cost. Another study used plastic waste as partial substitute for aggregates in masonry blocks, popularly known in the Philippines as CHB (concrete hollow blocks). However, it resulted to a decrease in compressive strength. With fly ash and powdered mussel shell being able to improve the strength of concrete mixes, this study was done to investigate whether the same materials would be able to improve the strength of CHB with plastic waste aggregates. The study used varying amounts of fly ash and powdered mussel shell as partial replacement to cement in CHB with and without plastic waste aggregates. A total of 320 CHB specimens were tested in the study. The decrease in strength due to the addition of 2.5% plastic waste aggregates was compensated with the addition of fly ash and/or powdered mussel shells. Fly ash was found to be more effective at 30% cement replacement, while 10% for powdered mussel shells. However, when the two were combined as cement replacement, beneficial effects were seen only at certain select mixes. At combined fly ash and mussel shells, the recommended cement replacement is 20% for CHB with plastic waste aggregates while 10% for CHB without plastic waste aggregate.

Key Words: cement; concrete; CHB; fly ash; mussel shells; masonry; plastic waste

1. INTRODUCTION

In recent years, multiple studies have been conducted with the goal of sustainable environment through waste utilization. In the construction sector, there were studies that incorporate different waste materials into concrete. One of the popular substitutes is fly ash (FA), a waste material from coal plants. Numerous researches have shown that partial cement substitution with FA increases its compressive strength. One study is by Razi et al, 2016, which investigated the performance of ordinary Portland cement mortar with FA incorporated into the mix. They found that the optimum mix was at 10% cement replacement by weight. Although the optimum cement replacement is at 10%, relatively high strength mortar could still be achieved up to 60% cement replacement. An earlier study by Lam et al, 2000, found that FA is more effective when the water-cement ratio is low. Thus, this may also be fitting to CHB which has low water-cement ratio.

The use of powdered green mussel shells (hereinafter referred to as MS) in concrete mixes has also been proven to increase the compressive strength of concrete. Studies by Ngo et al, 2014, and Gagan & Lejano, 2017, showed that partial substitution of cement with MS resulted in a higher compressive strength. They found that the highest strength was at 10% cement replacement by weight with MS.

In this study, FA and MS are used in masonry blocks, which are more popularly known in the Philippines as CHB (concrete hollow blocks). Although CHB undergoes a different production process compared to concrete, the quality of CHB still depends on the combination of aggregates, cement, and water. Thus, this study aims to investigate the effects of FA and MS in the compressive strength of CHB. Currently, there are no studies about the utilization of MS and FA in CHB.

Another aspect of this study is the use of plastic waste aggregates (PWA) as partial replacement to the sand in CHB. The studies of Cuartero et al, 2016, and Alcantara et al, 2016, have incorporated PWA in CHB. The results of both studies showed a decrease in the compressive strength of the CHB due to PWA. Hence, it is thought that the addition of FA and MS could augment the loss in strength of CHB due to PWA. This research specifically aims to: (1) determine the effects of FA and MS to the compressive strength of CHB with and without PWA, and (2) identify the mixes which produced the largest increase in compressive strength.

2. METHODOLOGY

This study uses experimental approach. The results that will be needed to address the objectives are the compressive strength of the tested CHB.

2.1 Mix Design

Various mixes with different cement replacement were adopted in the production of CHB with and without PWA. For CHB with PWA, 2.5% of sand was replaced with PWA by weight. This is based on the previous findings that the 2.5% sand replacement with PWA produced CHB with the highest strength (Cuartero et al, 2016). They also observed that the compressive strength decreased when the amount of PWA was increased.

In this study, the CHB had three cement replacements: 10%, 20%, and 30% of the total weight of cement. Each cement replacement had five different proportion of MS to FA (MS:FA). The proportions are 0:100, 25:75, 50:50, 75:25, and 100:0. Since there were 2 cases of sand replacement with PWA (0 and 2.5%), the combination resulted to 30 mixes. In addition, there were also 2 control mixes with no cement replacement; one with 0% and the other with 2.5% sand replacement with PWA. Thus the total is 32 mixes. For each mix, the specimens were tested on the 14th and 28th day of curing. Five specimens were prepared for each case resulting to a total of 320 specimens.

The amount of ingredients added was based on the recommendations of the expert masons. The final amount was half a bucket of cement, 7 buckets of sand, and 12 liters of water. Thus, the mix design had a 1:14 cement-sand ratio (by volume). For better control of the mix, the corresponding weight of materials is used in preparing the materials instead of the volumetric measurement. The basic mix design (without cement replacement) is given in Table 1. The cement and aggregate replacement was done by replacing a percentage of the weight. The amount of water was maintained throughout the experiment considering the moisture content of sand.

Table 1. Design mix proportion by weight

CHB Type	Cement (kg)	PWA (kg)	Sand (kg)	Water (kg)
w/ PWA	6.8	0	94.5	12
w/o PWA	6.8	2.36	92.14	12

2.2 Preparation of Materials

The green mussel shells, locally known as Tahong, that was used for this study was obtained from Cavite. The first step to transform the shells into powder was to crush them manually using a hammer. Then, using a manual coffee grinder, the crushed shells were pulverized. To eliminate the inherent moisture, the pulverized shells were subsequently placed in a heated pan while thoroughly mixing it for about 20 minutes. Lastly, only particles passing the 1-mm sieve were used.

The fly ash that was used was obtained from a coal-fired power plant in Calaca, Batabgas. The FA obtained was already in powdered form and needed no further processing since it was already homogeneous and clean based on visual inspection.

For the PWA, discarded PET (Polyethylene Terephthalate) bottles have to be collected and shredded into small pieces. To facilitate this process, PET bottles that were already shredded were bought from a junk shop in San Pascual, Batangas. The particle size of the typical shredded PWA was found to be ½ inch.

Ordinary Portland cement and tap water were used as binder. The aggregate used was washed sand that was readily available near the production site.

2.3 Production of CHB

The production of CHB was done using a typical vibrating machine. The first step in the production was dry-mixing the materials together. Then, water was slowly added. Afterwards, the mixture was gradually placed into the mold of the machine while the machine was vibrating until the CHB mold was properly filled and compacted. The molds used are for the CHB having dimensions shown in Fig.1. After removal of the CHB from the mold, they were cured by sprinkling them with water either for 14 days or 28 days.

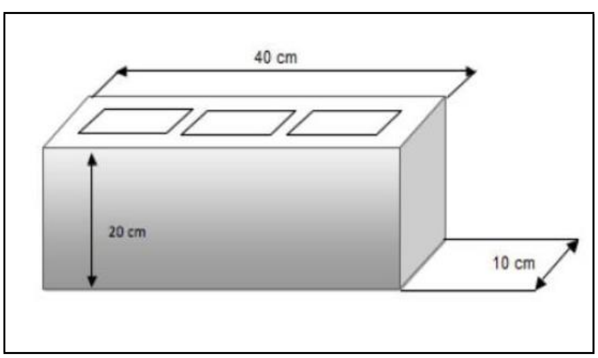

Fig. 1. Dimensions of CHB produced

2.4 Testing procedure

The compressive strength of CHB specimens was obtained using a Universal Testing Machine (UTM). The test was done on the 14th day and 28th day reckoned from the production date. Compression testing and preparatory procedures were done following ASTM C140 (standard test methods for sampling and testing concrete masonry units) and ASTM C9016-(solid and hollow concrete units made from cement, water, aggregates with or without the inclusion of other materials). Shown in Fig. 2 is the UTM used. Also shown is a picture of tested CHB.

Fig. 2. Picture of UTM (left) and tested CHB (right)

3. RESULTS AND DISCUSSION

The specific gravity of cement, fly ash, and MS were determined and found to be 3.16, 2.70, and 2.28, respectively. The specific gravity for the shredded PET bottles is 1.38, while 2.66 for sand.

The data in the experiment are the averaged compressive strength of the CHB specimens for each case. Each averaged value of compressive strength was compared to the Philippine National Standard (PNS) for non-loadbearing CHB which is 2.1 MPa and to the compressive strength of the control CHB, i.e. without cement replacement and without PWA.

3.1 Effect of PWA

To verify results of previous studies, the compressive strength of CHB with PWA was compared to that of conventional CHB (with no cement replacement). This is shown in Table 2.

Table 2. Effect of PWA on the compressive strength

Curing Age	Compressive strength		Percentage Difference
	0% PWA	2.5% PWA	
14 days	2.41 MPa	2.02 MPa	-16.2%
28 days	2.63 MPa	2.05 MPa	-22.1%

The results showed that the compressive strength decreased by 16% and 22% on the 14th day and 28th day, respectively. Only the CHB without PWA and cured for 28 day attained a strength of 2.63 MPa which satisfy the PNS requirement of 2.1 MPa. Thus, 2.63 MPa is used as the control strength for 28-day, while 2.41 MPa is used as control strength for 14-day.

3.2 Effect of Green Mussel Shells (MS)

This section discusses the mixes with MS only as cement replacement. The result for this is summarized in Table 3, for CHB without PWA. The compressive strength of the specimen reached its highest at 10% MS (shaded in gray). The increase is around 9.5%, both at 14th-day and 28th day curing. This is similar to the trend found by Gagan and Lejano, 2017, wherein the strength of concrete increased up to 10% MS, then decreased at higher MS percentage.

Table 3. Effect of MS on CHB without PWA

Mussel Shell (MS)	14-Day		28-Day	
	Comp. Strength	% Diff.	Comp. Strength	% Diff.
0%	2.41	0.0%	2.63	0.0%
10%	2.64	9.5%	2.88	9.5%
20%	2.13	-11.6%	2.09	-20.5%
30%	1.32	-45.2%	1.17	-55.5%

For CHB with PWA, the highest strength at 14th day is at 20% MS (shaded in gray), while the highest strength at 28th day is 10% MS (shaded in gray). This finding is based on the test results listed in Table 4. This suggests that less amount of MS tends to result to higher strength of CHB with PWA at later age (as compared to CHB without PWA). Note that the percentage difference is calculated based on the strength of control specimen (2.63 MPa), that is, CHB without PWA, MS and FA.

Table 4. Effect of MS on CHB with 2.5% PWA

Mussel Shell (MS)	14-Day		28-Day	
	Comp. Strength	% Diff.	Comp. Strength	% Diff.
0%	2.02	-16.2%	2.05	-22.1%
10%	2.69	11.6%	3.19	21.3%
20%	2.96	22.8%	2.69	2.3%
30%	1.42	-41.1%	1.94	-26.2%

3.3 Effect of Fly Ash (FA)

This section discusses the mixes with fly ash (FA) only as cement replacement. The results are listed in Table 5 for CHB without PWA. The compressive strength of the specimens increased as the amount of FA was increased. The highest increase is 28.9% at 30% FA (shaded in gray). The increase in strength with age is also manifested. This trend is similar to the findings of Thomas, 2007, wherein the increased amount of FA resulted to higher compressive strength at later age.

Table 5. Effect of FA on CHB without PWA

% Flyash (FA)	14-Day Strength		28-Day Strength	
	Comp. Strength	% Diff.	Comp. Strength	% Diff.
0%	2.41	0.0%	2.63	0.0%
10%	2.49	3.3%	2.70	2.7%
20%	-	-	2.99	13.7%
30%	2.70	12.0%	3.39	28.9%

For CHB with PWA, the compressive strengths at 14th and 28th day show similar trend. This is shown in Table 6. Moreover, most of the specimen decreased in strength. Only the 30% cement replacement with FA showed increase in strength and only by 3.4% (shaded in gray). This means that FA alone is not enough to improve the strength of CHB with PWA.

Table 6. Effect of FA on CHB with 2.5% PWA

% Flyash (FA)	14-Day		28-Day	
	Comp. Strength	% Diff.	Comp. Strength	% Diff.
0%	2.02	-16.2%	2.05	-22.1%
10%	1.44	-40.2%	1.24	-52.9%
20%	2.28	-5.4%	2.56	-2.7%
30%	2.12	-12.0%	2.72	3.4%

3.4 Effects of Combined FA and MS

In general, only certain mixes with combined FA and MS resulted in increase in compressive strength with respect to the control. It seems that predictable results are obtained when only one material is used as cement replacement. When combined, there is randomness in the strength increase especially for CHB with PWA.

For strength development (from 14 day to 28 day), the usual increase of strength with age was observed. Due to limited space, only strength at 28th day will be discussed.

For CHB without PWA, only the 10% cement replacement produced higher strength with respect to the control. The highest strength gain is at 75:25 MS-FA proportion. It has a compressive strength of 3.38 MPa, with an increase of 28.5% as indicated in Table 7 (shaded in gray).

Table 7. Effect of combined MS and FA on CHB without PWA

% Cement Replacement	MS:FA Proportion	Comp. Strength (MPa)	% Diff.
10	75:25	3.38	28.5%
10	50:50	3.09	17.5%
10	25:75	2.41	-8.4%
20	75:25	2.43	-7.6%
20	50:50	2.46	-6.5%
20	25:75	2.57	-2.3%
30	75:25	1.20	-54.4%
30	50:50	1.42	-46.0%
30	25:75	1.64	-37.6%

It was also observed that at 30% cement replacement, the strengths were low such that none of the MS-FA proportions did not even reached the minimum PNS requirement of 2.1 MPa.

To have a better visualization of the strength variation, the values tabulated in Table 7 are plotted in Fig. 3. It can be easily seen that the strength is higher at 10% cement replacement. The highest strength is at 75:25 MS-FA proportion.

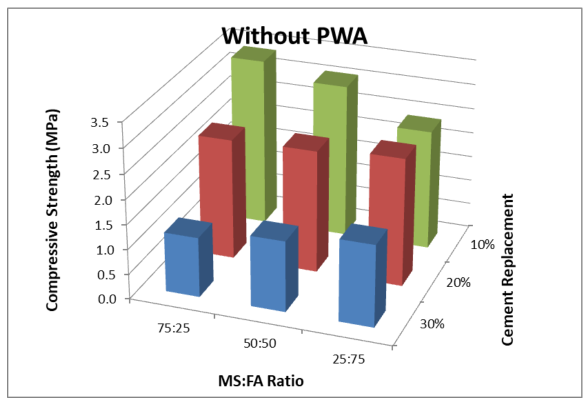

Fig. 3. Plot of compressive strength as affected by MS and FA combination for CHB without PWA

For CHB with 2.5% PWA, the compressive strength test results for different proportions of MS against FA are tabulated in Table 8.

Table 8. Effect of combined MS and FA on CHB with 2.5% PWA

% Cement Replaced	MS:FA Proportion	Comp. Strength (MPa)	% Diff.
10	75:25	2.71	3.0%
10	50:50	2.42	-8.0%
10	25:75	1.24	-52.9%
20	75:25	3.03	15.2%
20	50:50	3.14	19.4%
20	25:75	3.37	28.1%
30	75:25	2.08	-20.9%
30	50:50	2.13	-19.0%
30	25:75	2.22	-15.6%

All mixes in the 20% cement replacement increased in strength, with the highest increase at 25:75 MS-FA proportion. It has a compressive strength of 3.37 MPa, an increase of 28.1% (shaded in gray). This is almost the same amount of increase that is observed in CHB without PWA.

Again, to have better visualization of the strength variation the values tabulated in Table 8 are plotted in Fig. 4. It can be easily seen that the strength is higher at 20% cement replacement. The highest strength is at 25:75 MS-FA proportion.

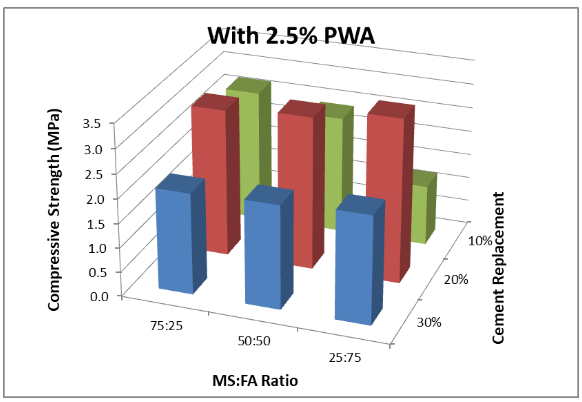

Fig. 4. Plot of compressive strength as affected by MS and FA combination for CHB with 2.5% PWA

4. CONCLUSIONS

It was verified that the strength of CHB decreased with the addition of PWA. However, it was shown also that the decrease due to the 2.5% PWA can be augmented by MS and FA. Based on test results it may be concluded that partial cement replacement with FA or MS increased the compressive strength of CHB even with PWA. In particular, MS was found to be more effective at 10% cement replacement, while 30% for FA.

When MS and FA were combined as cement replacement, beneficial effects were seen at certain mixes only. The effect of combined MS and FA is different for CHB without PWA and CHB with 2.5% PWA. The recommended cement replacement is 20% for CHB with PWA and best at 25:75 MS:FA proportion. While for CHB without PWA, the recommended cement replacement is 10%, specifically at 75:27 MS:FA proportion.

5. ACKNOWLEDGMENTS

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