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COMPRESSIVE STRENGTH OF CONCRETE WITH SEAWATER AND POWDERED EGGSHELLS AS PARTIAL REPLACEMENT FOR CEMENT

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ABSTRACT: In efforts to generate sustainable concrete, alternative mixing constituents are used. In this study, the use of powdered eggshells as partial cement replacement and seawater as freshwater replacement were explored. The experiment consisted of two phases. First phase was the investigation of 50-mm mortar cube specimens to determine the effect on the compressive strength of mortars with 5% cement replacement with powdered eggshells that were heated at varying temperatures and duration. In the preparation of powdered eggshells, the heating duration was varied at 3, 6, and 12 hours while the temperature was varied at 100^{O}C and 200^{O}C. Based on the compressive strength test results, it was determined that heating of powdered eggshells at 100^{O}C for 12 hours achieved the highest compressive strength. Results of Scanning Electronic Microscope (SEM) showed that there was formation of fiber-like structures for mixes with powdered eggshell. This is believed to be the cause of increase in strength. For the second phase, the better heating method of powdered eggshells that was determined from the first phase was adopted and was used as mixing guide for the cylindrical concrete specimens. The three water-cement ratios used in making the concrete cylinders were 0.4, 0.5 and 0.6. All water-cement ratios of concrete cylinders cured for 28 days exhibited increased compressive strength as powdered eggshells were added as partial cement replacement. It was also determined that the compressive strength further increased when both seawater and powdered eggshells were utilized in concrete. An increase up to 36.4% was observed.

Keywords: Cement Replacement, Compressive Strength, Concrete, Eggshells, Seawater

1. INTRODUCTION

The versatility of eggs as food and other usage resulted to large volume of production which in turn produces a lot of eggshell waste. In poultry hatchery plants alone, huge volume of eggshells is produced. Currently the most viable disposal is throwing them into landfill sites. Eggshells are composed of 97% calcium carbonate [1], one of the main components of cement. Hence, several researches have been conducted regarding the utilization of powdered egg shells as a partial replacement for cement in concrete. These eggshells were either, air-dried, sun-dried or oven-dried before being ground into powder. Although there are contradicting reports, results of some researchers [2]-[4] have shown that concrete with powdered eggshells have produced higher compressive strength than conventional concrete.

Another aspect of this research is the water used in concrete. Currently, the use of seawater in concrete is not allowed as stipulated in most building codes worldwide. However, shortage of freshwater is already experienced in certain areas even though they are close to the seashore. In addition, the increasing demand for water and the rising global temperatures also increase the cases of freshwater shortage. Thus the use of seawater in concrete production is worthy to investigate. Concrete with seawater as ingredient may be possible to use in structural application [5].

With the foregoing statements, this study is conducted to determine whether the utilization of eggshells and seawater are suitable alternative materials in the production of concrete; powdered eggshells as partial replacement for cement and seawater as a substitute for freshwater. The specific objectives are the following: (a) To determine the temperature and duration of heating of powdered eggshells that will produce mortar with the highest compressive strength; (b) To determine the effects of powdered eggshells and seawater on the compressive strength of concrete; and (c) To determine whether the concrete with powdered eggshells and seawater will be cost effective.

The possible use of eggshells and seawater would be beneficial in protecting the environment. Partially replacing cement with powdered eggshells will not only address eggshell waste disposal but also reduce cement consumption. Cement production is one of the largest sources of carbon dioxide emissions, thus reduction of cement consumption will result to reduction of carbon dioxide emissions. Ultimately, the use of eggshells and seawater would also address the sustainability of environmental resources. This is also in line with other researches utilizing other waste materials like fly ash, powdered mussel shells, and others as possible partial cement replacement [6].

2. METHODOLOGY

The experimental program was divided into two phases. The first phase is the test of mortar specimens while the second phase is the test of concrete specimens.

The production of mortars had powdered eggshells of different duration and temperature of heating. The duration and temperature of heating that yielded the highest compressive strength of mortar was used in the mix design of concrete.

2.1 Preparation of Eggshells

The chicken eggshells that were used were obtained from an egg hatchery plant. The hatchery plant produced eggs from a specific type of chicken called Gallus Domesticus or also known as Broiler chickens. The eggshells were subjected to initial disinfection process. This process involved cleaning with water until unnecessary substances are removed, especially the soft membranes. The eggshells were air dried for 24 hours. Then they were crushed, grinded, heated and sieved through a 100 μm sieve, similar to previous research in preparing powdered mussel shells [6]. The crushed eggshells were then placed inside the oven having two different heating temperatures, 100°C and 200°C, and three different duration of heating, particularly 3, 6, and 12 hours. Heating the crushed eggshells was done to determine the optimum duration and temperature to enhance the strength of the mortar specimens.

2.2 First Phase: Test of Mortar Specimens

The mortar samples used for compressive test were 50 mm cube specimens. The mortar cubes had a sand to cement ratio of 2.75 to be mixed at a water-cement ratio (W/C) of 0.5. All proportions are by weight. Furthermore, a 5% constant partial replacement of the total weight of cement with powdered eggshell was adopted based on the findings of previous researches [2], [3].

Thirty two (32) cases of mortar cubes were prepared to evaluate effects of the four parameters considered. For each case, 5 specimens were tested, for a total of 160 specimens. Shown in Table 1 are the codes used for naming the different cases of mortar specimens. The name of the specimens was based on the parameters in the following order: heating temperature of eggshells, type of water, curing age, and duration of heating of eggshells.

Table 1 Codes for naming the mortar specimens

Temperature (^{O}C)	Water Type	Curing (days)	Duration (Hours)
100	F=freshwater	7	III=3
200	S-seawater	28	VI=6
			XII=12

The code names were based on the four parameters. For example, the mortar specimens with code name 100F7-III is identified as follows: the first code "100" refer to 100^{O}C heating temperature, the second code "F" means that freshwater was used, the third code "7" refers to specimens cured for 7 days, and the last code "III" means the heating durations was 3 hours. There were also specimens without cement replacement. The codes used for these specimens were only the water type and curing age, that is, F7, F28, S7, and S28. For the specimens with powdered eggshells that were not heated, "0" was added for the heating duration, that is, F7-0, F28-0, S7-0, and S28-0. It should be noted that specimens F7 and F28 served as the control specimens for 7-day and 28-day curing, respectively.

Scanning Electron Microscope (SEM) analysis was done to the mortar specimens to determine the microscopic structural changes that occurred due to the presence of powdered eggshells and seawater.

2.3 Second Phase: Test of Concrete Specimens

Concrete cylindrical specimens measuring 100 mm in diameter by 200 mm in height were prepared with the following parameters considered: water-cement ratio, W/C (0.4, 0.5 and 0.6); type of water (freshwater or seawater), and with or without cement replacement. Table 2 shows the codes used in naming the specimens. For example, a specimen named 0.4FX refers to concrete specimen with W/C=0.4, "F" for freshwater, and "X" for no partial replacement of cement.

Table 2 Codes for naming the concrete specimens

W/C	Water	Cement Replacement
0.4	F=freshwater	X=None
0.5	S=Seawater	E=With
0.6		

The adopted percentage of partial cement replacement with powdered eggshells was also 5%. The preparation of powdered eggshells used in this phase was one that produced the highest compressive strength in the mortar test in phase 1. For the parameters considered, 12 cases of concrete mixes were prepared. Five concrete cylinders had to be made for the compression strength test, for a total of 60 concrete cylindrical specimens.

After mixing the concrete, fresh concrete properties (slump, wet density and air content of the concrete) were evaluated. Curing of concrete was done for 28 days. Freshwater was used in curing concrete. After curing the specimens were subjected to compressive strength test.

3. RESULTS AND DISCUSSION

The main output of this research is the evaluation of the effects of powdered eggshells and seawater on the strength of mortar and concrete. In addition, other data and experiment results will be presented in this section.

3.1 Properties of Materials Used

Table 3 shows the properties of Portland cement, fine aggregates (sand), coarse aggregates (gravel), and water that were used in this study. These properties were used in the design of the mix proportion of mortar and concrete.

Table 3 Properties of materials used

Material Properties	Values
Specific gravity of Cement	3.16
Specific gravity of CA	2.804
Specific gravity of FA	2.353
Absorption of CA (%)	1.18
Absorption of FA (%)	3.80
Dry-rodded density of CA (kg/m^3)	1813
Fineness modulus of FA	2.76
Density of seawater (kg/m^3)	1025.8
Salinity of Seawater (%)	3.7

Note: FA=fine aggregates, CA=coarse aggregates

Table 4 Properties of powdered eggshells

Classification of Powdered Eggshells	SG
Air-dried eggshells for 24 hours	2.466
Heated at 100ºC for 3 hours	2.393
Heated at 100ºC for 6 hours	2.466
Heated at 100ºC for 12 hours	2.505
Heated at 200ºC for 3 hours	2.495
Heated at 200ºC for 6 hours	2.486
Heated at 200ºC for 12 hours	2.534

Note: SG=specific gravity

The material property of eggshell was measured in terms of the specific gravity. Shown in Table 4 are the values of the specific gravity of powdered eggshells as affected by heating temperature and duration. It may be noticed that the specific gravity increased as the heating temperature and duration were increased.

3.2 Results of Tests of Mortar Specimens

The variation of temperature and duration of heating of the powdered eggshells for the mortar cubes affected their compressive strength. The compressive strength data were statistically analyzed using the software ANOVA in order to determine whether the differences within each case are significant or not. The result of the analysis says that the strengths of the specimens in each case (5 specimens per case) are statistically similar. Furthermore, the average strength per case is statistically different from the other cases. This statistically verifies that the addition of powdered eggshells and use of seawater have an effect on the strength of mortar specimens.

3.2.1 Compressive strength of mortar at 7 days

Shown in Table 5 is the summary of the average compressive strengths of the mortar cubes and their corresponding percentage difference with respect to the control specimens (F7).

The partial replacement of air-dried powdered eggshells (F7-0) resulted to a stronger mortar cubes by 23% compared to the control specimen at 7 days. It was also noticed that the strength decreased by 11% when seawater was added by comparing F7 and S7. Among the mortars mixed with freshwater, the highest increase was for 100F7-VI, which was 32% greater than the control mortar (F7). For the mortars mixed with seawater, the highest increase was for 200S7-XII, which was 33% greater than the control mortar (F7).

Table 5 Compressive strength of mortar at 7 days

Specimen Case	Compressive Strength (MPa)	Percentage Increase
F7 (control)	12.42	0.0%
F7-0	15.33	23.4%
100F7-III	13.38	7.7%
100F7-VI	16.43	32.3%
100F7-XII	15.73	26.7%
200F7-III	13.62	9.7%
200F7-VI	13.88	11.8%
200F7-XII	13.35	7.5%
S7	11.08	-10.8%
S7-0	15.83	27.5%
100S7-III	9.86	-20.6%
100S7-VI	15.37	23.8%
100S7-XII	12.32	-0.8%
200S7-III	9.86	-20.6%
200S7-VI	11.77	-5.2%
200S7-XII	16.49	32.7%

Although, the strength of mortar cubes has increased in the freshwater group, there was a decrease in strength in some mortar cubes in the seawater group. This may mean that the certain combinations of seawater and powdered eggshell tend to decrease the strength development at 7 days.

3.2.2 Compressive strength of mortar specimen at 28 days

Shown in Table 6 is the summary of the compressive strength of 28-day mortar specimens. The compressive strength gathered from the 28-day mortar cubes had generally exhibited increase in strength compared to the 7-day age mortar cubes. In contrast to the 7-day mortar cubes, the use of seawater increased the strength by 8.2% by comparing F28 and S28. Powdered eggshells exposed to longer duration of heating resulted to higher strength, except for the seawater group with the powdered eggshells exposed to 200^{O}C. This may indicate that overheating the powdered eggshells results to quality degradation. This is further manifested in 200S28-XII, which resulted to strength lower than the control specimen.

For better visualization of the trend of the 28-day compressive strength as affected by powdered eggshell and seawater, the data in Table 6 are plotted in Figure 1 as bar graph. A trend of increasing strength can be seen in the Fig.1. The freshwater and seawater groups show increasing strength with the increase in heating duration for those exposed to 100^{O}C. Also, using seawater as substitute to freshwater further increased the strength of the mortar cubes. Furthermore, 100S28-XII produced the highest strength, an increase of 48.7%. Based on the test results, the most promising preparation of powdered eggshells is by heating at 100^{O}C for 12 hours.

Table 6 Compressive strength of mortar at 28 days curing

Specimen Case	Compressive Strength (MPa)	Percentage Increase
F28 (control)	18.09	0.0%
F28-0	20.24	11.9%
100F28-III	18.92	4.6%
100F28-VI	19.53	8.0%
100F28-XII	23.86	31.9%
200F28-III	20.60	13.9%
200F28-VI	21.22	17.3%
200F28-XII	24.64	36.2%
S28	20.26	12.0%
S28-0	19.58	8.2%
100S28-III	23.87	32.0%
100S28-VI	26.46	46.3%
100S28-XII	26.90	48.7%
200S28-III	21.77	20.3%
200S28-VI	23.17	28.1%
200S28-XII	16.76	-7.4%

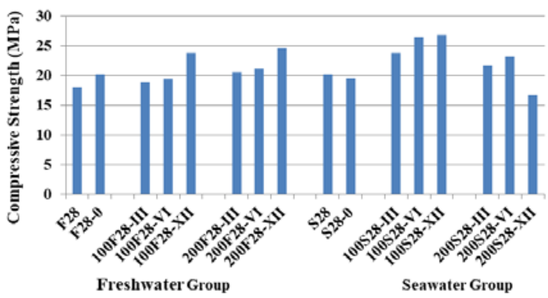


Fig.1 Plot of 28-day compressive strength of mortar specimens

3.3 Results of Tests of Concrete Specimens

Mix designs based on 0.4, 0.5 and 0.6 water-cement ratio were made for the experimental program. The designed mix proportions are shown in Table 7. The powdered eggshells that were used were heated at 100^{O}C for 12 hours. The resulting fresh concrete properties of the different mixes were almost the same. The average values obtained were as follows: slump=74mm, air content=2.4%, and wet density=2363kg/m^3. It appears that the powdered eggshells and seawater have little effect on the properties of fresh concrete.

Table 7 Mix proportion per cubic meter of concrete

W/C	Water (kg)	Cement (kg)	Gravel (kg)	Sand (kg)
0.4	221	553	1126	451
0.5	218	432	1090	471
0.6	205	342	1131	620

Shown in Table 8 is the summary of the average compressive strength of concrete specimens as affected by seawater and powdered eggshells. Also indicated in the Table 8 are the percentage increases with respect to the control specimens (0.4FX, 0.5FX, and 0.6FX). Statistical analysis was also done similarly to what was done in the mortar. The results also validated the similarity of results of strength test per case, and the significant different between cases. To have a good visualization of the results, a graphical representation of Table 8 is presented in Figure 2.

Table 8 Compressive strength of concrete

Specimen Case	Compressive Strength (MPa)	Percentage Increase
0.4FX	30.38	0.0%
0.4FE	34.96	15.1%
0.4SX	37.51	23.5%
0.4SE	38.42	26.5%
0.5FX	27.28	0.0%
0.5FE	29.31	7.4%
0.5SX	34.00	24.6%
0.5SE	37.21	36.4%
0.6FX	24.73	0.0%
0.6FE	25.07	1.4%
0.6SX	25.28	2.2%
0.6SE	28.53	15.4%

Note: F=freshwater, S=seawater, X=no replacement, E=cement replacement with powdered eggshells

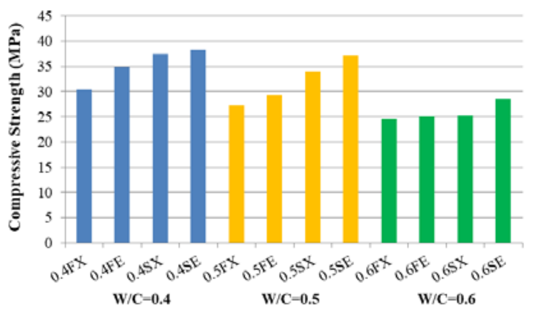
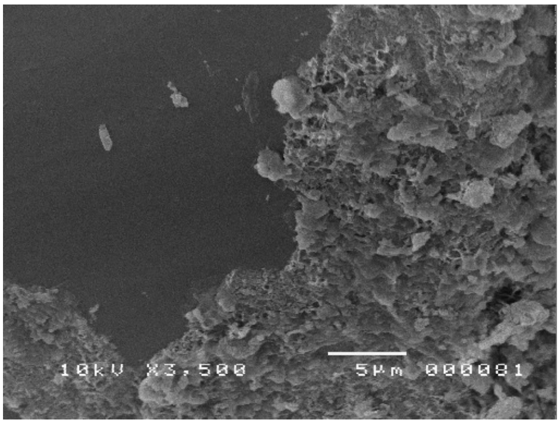


Fig.2 Plot of 28-day compressive strength of concrete specimens

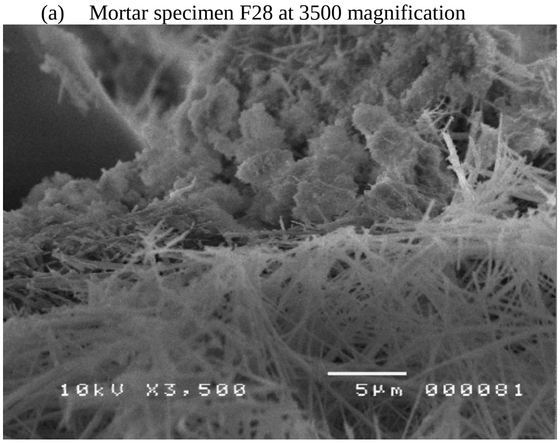
The results validated the known concept that as the W/C decreases, the strength of concrete increases. In general, the use of powdered eggshell increased the concrete strength. It seems that it is more effective at lower W/C (0.4 and 0.5). Furthermore, the use of seawater in mixing of concrete resulted to a higher strength. Among the concrete specimens, the highest increase was for 0.5SE at 36.4%. For concrete mixed with freshwater, the highest increase was for 0.4FE at 15.1%.

3.4 Results of SEM Analysis

Mortar samples were subjected to the scanning electron microscope (SEM) analysis. Typical results are presented in Fig.3. The picture at the top in Fig.3 is a 3500 magnification of the mortar without eggshells, mixed with freshwater, and cured for 28 days. The picture at the bottom of Fig.3 is a 3500 magnification of the mortar with powdered eggshells, mixed with seawater, and cured for 28 days.



(a) Mortar specimen F28 at 3500 magnification



(b) Mortar specimen 100S28-XII at 3500 magnification

Fig.3 SEM comparison of mortars without and with powdered eggshells

Comparison of the two pictures showed fiber-like microscopic structures that were found only on specimens containing powdered eggshells.

These fiber-like structures were formed on grain surfaces like needles with sharp ends and were seen gathering in void spaces. It is believed that the increase in strength is caused by these fibers. More of these fibers were observed to be present when seawater was used.

3.5 Cost Analysis Results

Determining the effect of seawater and powdered eggshells on the cost of concrete is necessary for commercial and economical applications. The unit cost of each material used is tabulated in Table 9. Since seawater can be freely obtained from the seaside, the assumed cost was zero. Powdered eggshells can be assumed to cost zero but since it involved the process of cleaning, crushing, grinding and heating, it was estimated to cost 4.30 Php/kg.

Table 9 Unit cost of materials used

Material	Cost per Kilogram
Portland Cement	5.250 Php/kg
Sand	0.530 Php/kg
Gravel	0.661 Php/kg
Freshwater	0.035 Php/kg
Seawater	0.000 Php/kg
Eggshell Powder	4.300 Php/kg

Table 10 Cost analysis of concrete

Specimen Case	Cost /Volume (Php/m^3)	Cost Efficiency (Php/MPa)
0.4FX	3885	128
0.4FE	3859	110
0.4SX	3893	104
0.4SE	3867	101
0.5FX	3236	119
0.5FE	3212	110
0.5SX	3244	95
0.5SE	3220	87
0.6FX	2870	116
0.6FE	2854	114
0.6SX	2878	114
0.6SE	2861	100

With the unit cost of the materials known, the cost of concrete per cubic meter can be easily calculated. Table 10 shows these values for the different specimen case. Lower W/C resulted to more expensive concrete. However, the addition of powdered eggshells and seawater lowered the cost of concrete. Enumerated also is the cost-efficiency which can be calculated by simply dividing the cost of concrete per cubic meter with the measured strength of the specimen. The lowest value is the most cost-efficient. Among the specimens considered, the specimen with W/C=0.5, using seawater, and with powdered eggshells (0.5SE) is the most cost efficient.

4. CONCLUSIONS

The use of powdered eggshells as partial replacement for cement and seawater as a substitute for freshwater were found to be suitable alternatives for conventional concrete materials. However, certain combination of powdered eggshells and seawater tends to delay the strength development as manifested in the results of strength test of 7-day mortar specimens. On the other hand, the 28-day mortar specimens generally resulted to enhanced strength due to the addition of both powdered eggshells and seawater. It was also observed that the powdered eggshell produced the highest mortar strength (among those tested) when heated at $100^{O}C$ for 12 hours.

The strength of concrete increased when powdered eggshell were used, especially when W/C is low. The strength further increased when using both seawater and powdered eggshells. Among those tested, the highest obtained is for concrete with W/C=0.5, using seawater, and with powdered eggshells. The increase was 36.4%.

Utilizing seawater and powdered eggshells in concrete was determined to be cost-efficient, and most cost-efficient at W/C=0.5.

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