Pulverized blue swimming crab shell utilized as partial replacement for sand in concrete mixture

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https://doi.org/10.69721/TPS.J.2021.13.1.03

ABSTRACT

Problems in the construction today include the overexploitation of natural aggregates as well as corrosion of steel reinforcement. Studies are needed to explore alternative materials that can be used in lieu of natural aggregates. This study investigates the use of pulverized crab shell (PCS) for partial replacement of sand in concrete mixture. The properties of conventional concrete mix are compared with concrete mix with its sand replaced with 10% and 15% PCS. Properties evaluated include compressive strength and splitting tensile strength. The sodium chloride penetration in concrete with PCS is also evaluated. Analysis of variance (ANOVA) was also used to determine if there is any statistical difference among the means of samples compared. The results show that the conventional concrete mix obtained the highest compressive strength and splitting tensile strength, while showing the lowest sodium chloride penetration resistance. The concrete mix with 15% of sand replaced by PCS showed the highest chloride penetration resistance. Although the incorporation of PCS in concrete reduced the compressive strength and split tensile strength in concrete mix, this has potential for use in plastering structures near coastal areas. This is to increase resistance to penetration of chloride in concrete structures which may accelerate deterioration of steel reinforcements that has always been a problem in coastal areas. For further tests, it is recommended that before using PCS in concrete, it should be oven dried or treated and prepared for better fineness and quality. In addition, investigating the potential of heating powdered PCS for cement replacement can be a subject for future research.

Keywords: concrete, pulverized crab shell, compressive strength, sand replacement, splitting tensile strength, sodium chloride penetration

INTRODUCTION

Economic growth in any developing country depends on infrastructures available. As a country progresses, infrastructure development grows along with the demand for more material such as concrete. Concrete is the most used material in construction industry, and it undergoes various types of deterioration due to environmental effect. Concrete is made up of three major components, namely water, aggregates, and cement. The cement mixed with water acts as a binding agent. Fine and coarse aggregates occupy about 60 to 80 percent of the volume of concrete. Large volumes of fine aggregates used in concrete are from the rivers. These are used up, causing negative impacts to the environment (Chetan and Aravindan 2020). Hence, there is a need to find alternatives for aggregates, particularly the fine ones.

On another side, the amount of waste materials produced daily also increases. These are produced mainly from agriculture, industries, and bio-waste. Wastes can be used as an admixture to make green concrete structures (Liew et al. 2017). Agricultural wastes such as rice husks, bagasse, oil palm waste, corn husks, among others, have also been found as potential for aggregates and cement partial replacements (e.g. Kunchariyakun et al. 2018; Mo et al. 2020; Zawawi et al. 2020). Material wastes from shells such as from crustaceans can be used considering their availability and properties. Crab, shrimp, and lobster shell waste generation is around 6 to 8 million tons annually (Nistico 2017). Crustaceans contain high degree of mineralization, commonly calcium carbonate, that can yield mechanical rigidity (Chen et al. 2008). Shells contain three primary chemicals that can be used in the industry such as protein, chitin, and carbon carbonate (Yan and Chen 2015). Only a small amount seafood processed are used, and the surplus like the exoskeletons is frequently trashed and discarded (Mehta and Monteiro 2001). These shells consist of 20-40% protein, 20-50% calcium carbonate and 15-40% chitin (Yan and Chen 2015).

On the main goal to make use of wastes while looking for alternatives to strengthen concrete performance, studies have been done making use of marine wastes. Marine waste such as oyster shell can be crushed and sieved to optimum size to replace aggregates (Vishwakarma and Ramachandran 2017). Using crushed oyster shell leads to increase in compressive strength but reduces workability with increasing substitution rate (Yang et al. 2005). Researchers have specifically studied the effects of shells such as oyster shells for partial aggregate replacement (e.g. Yang et al. 2005; Yang et al. 2010; Ramirez et al. 2015). Mussel shells were also used as replacement for fine and coarse aggregates (Martinez-Garcia et al. 2017). Seashells, in general was also used as partial replacement for aggregates (e.g. Richardson and Fuller 2013). Binag (2016) and Lertwattanaruk et al. (2012) also investigated the use of various powdered shell wastes, mixed with cement in masonry cement mortar which showed enhanced effect. In addition, oyster shell when used as aggregate in concrete added further with metakoalin and marble powder have indicated good strength properties similar to cement produced with sand (Aye et al. 2019). Moreover, Ammari et al. (2017) investigated the compressive and flexural strengths of concrete with crushed seashells. Using 29% of seashells, results revealed slight decrease in the compressive strength comparing to the control, while the flexural strength slightly increased. Despite the reduction in strength as observed in study results in a review conducted by Mo et al. (2018), seashell wastes can be used as replacement of not more than 20% of the aggregate. This is to keep the level of strength required for non-structural purposes.

The arthropod exoskeleton, a multifunctional for use in concrete mix (Chen et al. 2008) has not been fully explored. Minerals in crabs are deposits of calcite or amorphous calcium carbonate within the chitin-protein matrix. Crabs belong to the subphylum crustaceans, part of the arthropods, the largest phylum in the animal kingdom (Ahmed et al. 2017). Moreover, crab shell is the world's second most common natural composite material as well as most useful (Gadgey and Bahekar 2017). They have become more abundant and their disposal is becoming a problem, especially in coastal zones. Blue swimming crabs (*Portunus pelagicus*), are native in South East Asia and are widely seen in the coastal waters of the Philippines. Locally known as "kasag" (in Hiligaynon), "alimasag" (in Tagalog), and "lambay" (in Bisaya) in the Philippines, this is a tropical species that belong to the Portunidae family. Young crabs can be found in algal beds, seagrass, and seaweeds. While mature crabs are in deeper waters up to 20 m. Mature female crabs grow up to 10.56 cm, while mature males could reach 9.64 cm. Based on the 2009 Bureau of Fisheries and Aquatic Resources (BFAR) Statistics in the Philippines on highest commodities in the fishery sector, the *P. pelagicus* fishing industry ranked at 20th place. In terms of the value of processed crabmeat and fat, this type of crabs is the 4th most important fishery export of the country. This amounted to Php 1,852,785. Also, in the year 2011, the volume of exported and processed crabmeat and fat was about 5.80% of the total product exports (BFAR 2011). The *P. pelagicus* harvested at the municipal fishery sector level, was 27,920.67 MT. This accounts to 95.38% of the total harvest. The rest are from the commercial fishery contribution of only 1,353.53 MT (4.62%). The volume of harvest was accounted to 1.34% of the year's production in the fishery sector. Currently, one example of fishery is the REL Seafoods where they gathered about 15,700 kg (during "amihan" or northeast monsoon period) to 22,400 kg (during "habagat" or southwest monsoon period) per month. This produces 9,000 to 12,880 kg of crab shells per month. Considering the other bigger fisheries, combining all the generated waste will accumulate to a great volume. With this number of wastes produced in a span of time, clearly it can be a big problem if not dealt with.

These circumstances led to this study for the improvement of concrete while lessening production cost by partially replacing sand with PCS. This study aims to compare the properties of conventional concrete mixture to that of the mixture with PCS partially replacing its sand. Specifically, this study seeks to evaluate the compressive strength, splitting tensile strength, and sodium chloride penetration of concrete with PCS. Mix proportions were taken into consideration to determine the mixture with the highest workability. This study can be helpful to the innovation of cement concrete, if the compressive strength, splitting tensile strength and sodium chloride penetration depth of concrete with PCS can be close or equal to that of the conventional Portland cement concrete. The mixture can be nature-friendly since it provides solutions in the disposal problems of seafood wastes, particularly crab shell wastes.

METHODS

Materials and Sample Preparation

Materials used in this study were prepared and are discussed here. Materials include sand, coarse aggregates, cement, water, PCS and paraphernalias such as molds, and tamping rods. The sand, cement, and gravel used here are locally available materials brought from New Sankim Construction Supply, in Muntinlupa, Metro Manila. These conforms with the standards set by the Department of Public Works and Highways (DPWH). The sand that was used are fine aggregates of maximum size of 4.75 mm with specific gravity of 2.58. The coarse aggregates used has maximum size of 20 mm. The specific gravity and absorption ratio of the coarse aggregates were 2.75 and 0.56%, respectively. The aggregates were washed before mixing it with other materials to form the concrete mixture. On the other hand, type I ordinary Portland cement was utilized in this study. For the hydration of cement, a water-cement ratio of 0.4 was used so that for every unit weight of cement there should be 0.4-unit weight of water. For the PCS, the blue swimming crab shells were used. The shells were obtained from REL Seafoods, Pena, Cawayan Masbate. The crab shells were pulverized using a grinder mill after placing under the sunlight for 24 hours to remove its water content (Figure 1). The coarse and fine crushed shells were separated by grading. Grading showed that more than 94% of the PCS are between 150-600 μm. All the materials were prepared based on the Department of Public Works and Highways (DPWH) standards that also conform to American Society for Testing and Materials (ASTM) specifications and standards. The experimental design for mixtures used for preparing the samples are detailed in Table 1.

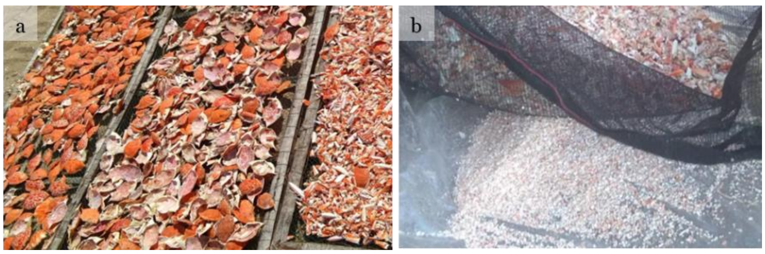

Figure 1. Crab shells before and after grinding. a) Sun dried crab shells, and b) Pulverized crab shells.

Table 1. Experimental design showing the different tests on concrete mixtures with different percentages of pulverized crab shell (PCS).

Test	Concrete Mix (% PCS)	Number of Specimens	Volume of Materials Used (kg m-3)				
			Cement	Sand	Gravel	PCS	Water
Compressive strength	0/Control	3	470	490	981	0	188
	10	3	470	441	981	49	188
	15	3	470	417	988	73	188
Split tensile strength	0/Control	3	474	494	988	0	190
	10	3	474	444	988	49	190
	15	3	474	420	988	74	190
Sodium chloride penetration test	0/Control	3	474	494	988	0	190
	10	3	474	444	988	49	190
	15	3	474	420	988	74	190

Before preparing the concrete samples for testing, slump test based on ASTM (2020b) was performed. This is to assess the consistency of freshly mixed concrete. The measured slump of freshly mixed concrete was at 75±25 mm while the air content volume was at 5.0±1%. Freshly mixed concrete was placed into the mold in three layers, each tamped 25 times. The cylindrical molds used for preparing samples for the compressive strength test have dimensions of 150 mm for its diameter and 300 mm for its height. While the cylindrical molds used for preparing samples for the splitting tensile strength and sodium chloride penetration tests have dimensions of 100 mm for its diameter and 200 mm for its height. Specimens were removed from the molds after 24 hours and were cured in water at 23±2°C until the testing date. A total of 27 samples including the mixtures with 0%, 10% and 15% PCS were made for the tests conducted in this study as detailed in Table 1. The samples were cured for 28 days. The three samples each with 10% and 15% PCS prepared for sodium chloride penetration test, were ponded in sodium chloride solution for another 28 days. The concentration of the solution is 35 grams of sodium chloride per liter of water.

Testing Process

After preparation of samples as discussed above, these were subjected to the three tests including compressive strength test, splitting tensile strength test, and the sodium chloride penetration test. The compressive and splitting tensile strength test were done to investigate long-term mechanical properties of the concrete mix. While the sodium chloride penetration test was conducted to evaluate the ability of the concrete with the PCS to minimize penetration for concrete steel reinforcement protection. All tests were conducted at the DPWH Bureau of Research and Standards located in Quezon City, Metro Manila, Philippines.

The testing for compressive strength follows the standards according to Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTMC 2020a). The compressive strength test was performed after grinding the loading surface of the samples for smooth finish. The loads were applied using the universal testing machine (UTM) with a capacity of 2000 kN. The load was applied at the rate of 140 kg cm^{-2} per minute until the sample fails. Compressive strength was calculated using equation 1, where $f'c$ is the compressive strength in megapascals (MPa), P_{max} is the maximum applied load in Newtons (N), and A is the cross-sectional area in mm^2.

$$f'_c = \frac{P_{max}}{A} \qquad \text{Eq. 1}$$

The splitting tensile strength of concrete is one of the basic and important properties which greatly affect the extent and size of cracking in structures. The splitting tensile test procedure followed the standards for testing of cylindrical concrete based on Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM 2020c). This test is used to evaluate the shear resistance of concrete. The test samples are set on the UTM so that the two ends of the specimen were lying on the same axial place. The UTM is then set, and load is continuously applied on the specimen without shock at a rate within the range 0.7 to 1.4 MPa per minute. The breaking load is then recorded. Then, the splitting tensile strength was calculated using equation 2, where *T,* is the splitting tensile strength in MPa, P is the maximum applied load in N, l is the length in mm, and d is the diameter in mm.

$$T = \frac{2P}{\pi l d} \qquad \text{Eq. 2}$$

The penetration depth of sodium chloride was done using the application of 0.1 mol/liter of silver nitrate ($AgNO_3$) solution into the exposed sides of concrete samples after it was split in half (He et al. 2012). The molarity of $AgNO_3$ were measured using an online molarity calculator (Merck 2020). The $AgNO_3$ solution was sprayed onto the exposed sides. Then, sections with white and brown color appeared with clear color change boundary. Eight points were identified, and depth penetration were measured (Figure 2). The depth of the white color zone was measured and recorded as the chloride penetration depth. The zone with the brown color zone resembles the area without chloride penetration.

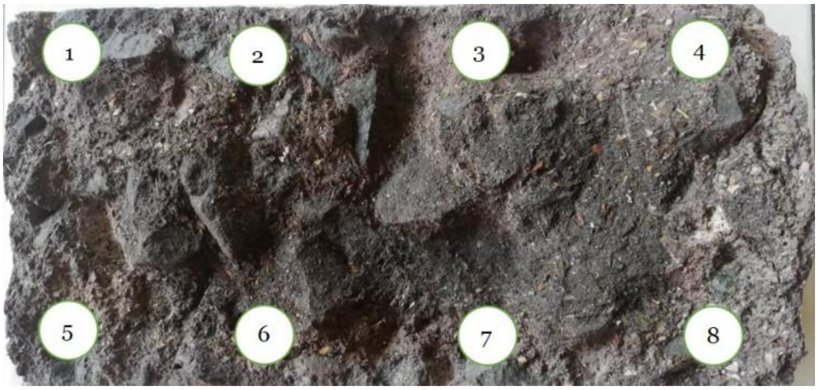

Figure 2. Sections in the fractured concrete where penetration depth of sodium chloride was measured.

Statistical Analysis

One-way analysis of variance (ANOVA) was used to determine if there is a significant difference among the means of the samples tested at the level of significance of 0.05. This shows statistical differences between the properties of the conventional concrete mix and concrete with 10% and 15% PCS, in terms of their compressive strength, splitting tensile strength, and sodium chloride penetration depth. QI Macros (2019) for Microsoft Excel was used to run the single factor ANOVA.

RESULTS

Compressive Strength Test

The results showed that control concrete samples have the highest compressive strength, followed by the samples with 10% and 15% PCS, and are significantly different ($P<0.05$). The compressive strength of samples containing 10% and 15% PCS which are 12.79 and 9.37 MPa respectively, were comparatively lower than that of the control which is 23.80 MPa (Figure 3). A decrease from 23.80 MPa to 12.79 MPa, with 46.26% can be observed between control samples and 10% PCS samples while a decrease from 23.80 MPa to 9.37 MPa, with 60.63% can be observed between control samples and 15% PCS samples.

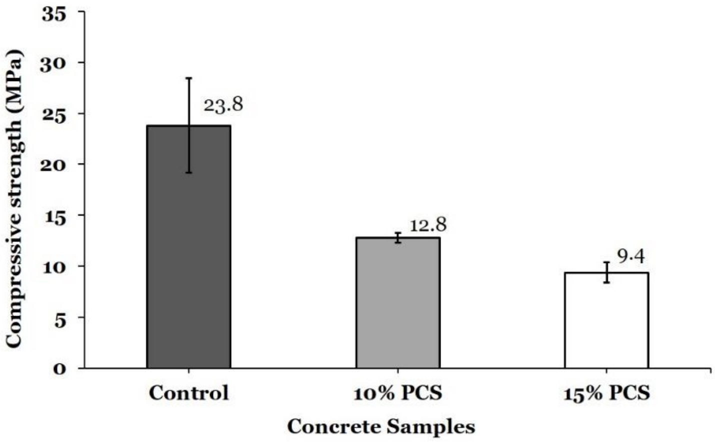

Figure 3. Average (±SD) compressive strength of concrete added with different percentages of pulverized crab shell cured for 28 days.

Splitting Tensile Strength Test

The result show that splitting tensile strength of samples containing 10% and 15% PCS with 3.62 and 3.65 MPa respectively was comparatively lower than that of the control with 7.36 MPa (Figure 4). Anova test further showed that these are significalty different (P<0.05). It is observed that control samples have the highest splitting tensile strength. The strength from 7.36 MPa to 3.62 MPa, shows a 50.82% decrease between control samples and 10% PCS samples. A decrease 50.41% from 7.36 MPa to 3.65 MPa is evident between control samples and those with 15% PCS.

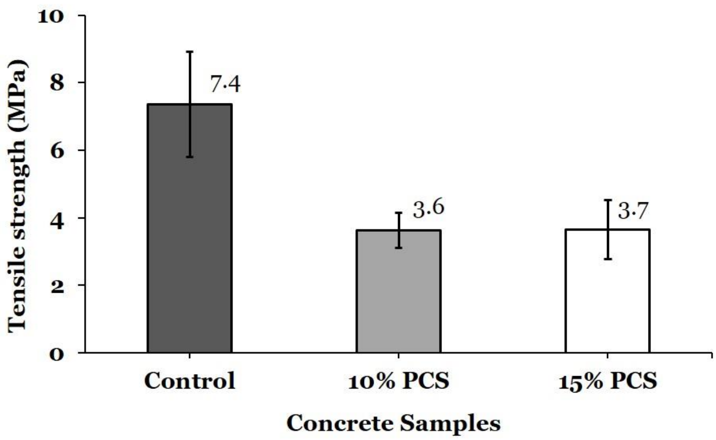

Figure 4. Average (±SD) of splitting tensile strength of concrete mixture added with different percentages of pulverized crab shell after curing for 28 days.

Sodium Chloride Penetration Test

As mentioned earlier, penetration depth of chloride was determined after spraying 0.1 mol L^{-1} of $AgNO_3$ solution onto the fractured concrete samples. The results in Figure 5 shows that the control mixture had the highest average value of penetration depth. The penetration depth of samples containing 10% and 15% PCS with 1.43 and 1.14 cm is comparatively lower than that of the control with 2.10 cm. Comparing the means of the sodium chloride penetration test results of the samples, the calculated *P*-value of 0.001 is less than the significance level of 0.05.

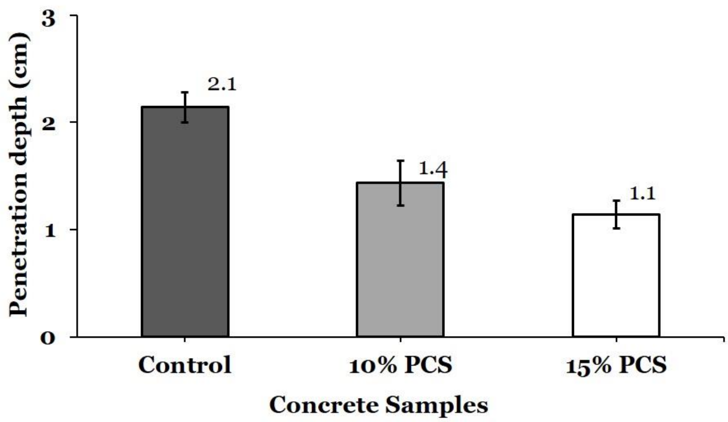

Figure 5. Average (±SD) sodium chloride penetration depth on concrete samples added with different percentage of pulverized crab shell (PCS).

DISCUSSION

Effects of the addition of PCS were evaluated against conventional concrete samples. The properties that were evaluated include compressive strength, splitting tensile strength, and resistance to sodium chloride penetration. Findings in terms of compressive strength revealed that control samples with 23.8 MPa compressive strength, has the highest compressive strength compared to that of samples with 10% and 15% PCS with 12.79 and 9.37 MPa, respectively. This indicates that addition of PCS to the concrete reduces the compressive strength of concrete. This was confirmed using single factor ANOVA results. The addition of PCS to concrete mix as partial replacement of sand, is consistent with the findings in past studies where seashells were used for partial replacement of aggregates (e.g. Richardson and Fuller 2013; Ramirez et al. 2015; Ammari et al. 2017; Martinez-Garcia et al. 2017). However, results in this current study are contrary to findings in some studies where 10% oyster shells were used as replacement of sand (Yang et al. 2005) and 30% oyster shells were used to replace aggregates (Aye et al. 2019).

For the splitting tensile strength test, results show that the 10% and 15% PCS with 3.62 and 3.65 MPa, respectively, indicate lower strength than the control samples. Statistical analysis result shows that there is a significant difference between the means of the control mix and the mix with 10% and 15% PCS. This indicates that the addition of PCS significantly decreased the splitting tensile strength of the concrete. The findings here is consistent with the results found in the study of Martinez-Garcia et al. (2017) where mussel shells were used to replace sand in concrete mixture. Further, results from this current study is contrary to the results in Ramirez et al. (2015) where sample tensile strength values were near those of the control when replacing 10% of sand with oyster shells.

In terms of sodium chloride penetration, the 10% PCS with 1.43 cm gives a lower value of chloride penetration compared to the control mix. Hence, showing that the addition of PCS has the potential of reducing the permeability of chloride in concrete. This was also supported through the statistical analysis results. This result is like the study of Javier et al. (2017) where the potential of using admixture in improving the permeability of concrete mixture against sodium penetration using 10% rice husk, was conducted.

The above discussions show that the addition of PCS to concrete mix resulted to decreased compressive and splitting tensile strength. While results here are not consistent with some of the results in past studies, most of the studies that used sea shells for aggregate replacement showed similar results. The preparation of crab shells, without heating in the current study may have added to the reduction in the strength of concrete with PCS. It is therefore recommended that before grinding and adding PCS to concrete, it should be heated for 24 hours in an oven to remove the excess water content. It is necessary to treat and prepare the PCS for better fineness and quality.

In addition, this current study shows that addition of PCS helps prevent the penetration of salt into the concrete mixture. With this, it is recommended that addition of PCS for application of plaster in mortar can be helpful for protection against salt penetration. This especially will be helpful to structures in coastal areas where sodium penetration has always been a problem. Before using, PCS should also be oven dried and crushed to finer sizes, for better results. In addition, heating powdered PCS to bring about properties similar to cement and use it for cement replacement can also be studied in the future.

ACKNOWLEDGMENTS

The researchers would like to thank the Department of Public Works and Highways, Bureau of Research and Standards, for allowing the experimental work to be done in the laboratory. Special thanks to Engr. Cielo de Guzman for her help in the logistical arrangements. Gratefulness also goes to the two anonymous reviewers who gave valuable comments which contributed much to the improvement of this manuscript.

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ARTICLE INFO

Received: 06 May 2020
Revised: 16 August 2020
Accepted: 15 October 2020
Available online: 27 October 2020

Role of authors: MBBL – developed the concept, wrote and finalized the paper; KAVA - conducted the experiments and compiled the data; CCC – conducted the experiments and compiled the data; HRL Jr. – analyzed the data, and wrote and revised the paper.