Effects of Perna Viridis and Zeolite on the Properties of Self-Compacting Concrete

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Abstract: In this study, Perna Viridis, commonly known as green mussel shell or tahong in the Philippines, and zeolite, a natural mineral, were selected as the alternative partial replacement for cement in self-compacting concrete (SCC). SCC is advantageous in construction because of easier placement due to its high workability; reduced time of on-site construction and repair; and improvement of the safety of construction workers by eliminating the use of industrial vibrators. To determine the suitability of Perna Viridis and zeolite as alternatives, the individual and combined effects of both materials on the fresh and hardened properties of SCC were evaluated. The fresh properties of the experimental SCC mixes were tested using Abrams cone test and L-box test, while the hardened properties were evaluated using the compressive strength test and splitting tensile strength test. The cement replacement increments were measured as percentages of the weight of cement. Specifically, 5, 10, and 15% replacements were used. The results of the tests revealed that Perna Viridis and zeolite have both positive and negative effects on the properties. It was observed that the addition of zeolite reduced the filling ability. The passing ability was initially improved and peaked at 5% zeolite, but was reduced at larger percentages. Both the compressive and tensile strengths were also improved by zeolite. As for Perna Viridis, its addition improved the mix's filling ability while reducing the passing ability. Also, both the compressive and tensile strengths were reduced by Perna Viridis. However, equal amount of Perna Viridis and zeolite seems to improve both the compressive and tensile strength, but slightly reduced both the filling and passing ability. Even though the filling and passing ability decreased, it was observed to have values very close to that of the control mix.

Key Words: self-compacting; concrete; zeolite; perna viridis; cement; replacement

1. INTRODUCTION

Certain problems are currently present in the construction industry, such as the scarcity of cement in rural areas and not being able to meet the annual increase in cement consumption. Alternative or replacement to cement may therefore be a solution to this problem. Materials added to Portland cement are also called supplementary cementitious materials (SCMs) that contribute to the enhanced properties of hardened concrete through hydraulic or pozzolanic activity. Typical examples are fly ash, slag cement, and silica fume. SCMs are often added to make concrete mixtures more economical, increase strength, or improve other concrete properties.

The main objective of this study is to determine the effects of powdered Perna Viridis shells (commonly known as green mussel shell or tahong in the Philippines) and natural zeolite on the properties of fresh and hardened self-compacting concrete (SCC). By doing this, the possibility of the use of these materials as SCM may be evaluated.

Self-compacting concrete (SCC) is a special type of concrete that can compact or consolidate under its own weight. The advantages of SCC over the conventionally-vibrated concrete are the following: it reduces the on-site repairs and construction time; it is easier to cast and place due to its high workability; and it improves the safety of construction workers by eliminating the use of industrial vibrators.

Globally, waste from shellfish can accumulate up to 8 million tons annually, 1.5 million coming from Southeast Asia alone. The common practice is to dispose of these wastes in landfills. This is done despite these shells being rich in compounds that are useful in major industries. The richest among these compounds is calcium carbonate ($CaCO_3$) (Yan & Chen, 2015). These shells have the potential to be used as partial replacement for cement in concrete rather than further contributing to the amount of waste in the environment. Moreover, due to being a waste material, these shells will also contribute to reducing the cost of concrete.

Studies utilizing shells with $CaCO_3$ content in conventionally-vibrated concrete, have been conducted in several parts of the world. A local study showed that powdered shells have improved the compressive strength of concrete but reduced its overall workability (Talagtag et.al., 2014). Another study (Lertwattnaruk, et.al., 2012) reveals similar results for the compressive strength of masonry.

Natural zeolite is another material used in this study. It is obtained through mining. Natural zeolite is formed during volcanic eruption when molten lava and thick ash flow into the sea resulting to a chemical reaction between the ash and the salt in the water. Different studies have reported the use of natural zeolite as alternative for cement in concrete. For the fresh properties, natural zeolite was able to improve the segregation resistance (Ahmadi et al., 2003). It was also found that the workability was reduced at a constant rate proportional to the amount of zeolite (Madandoust et al., 2013). For the hardened properties, the inclusion of natural zeolite resulted to improved compressive strength, tensile and flexural strengths (Satone et al., 2016).

Studies about SCC are very scarce in the Philippines, much so for SCC mixed with powdered Perna Viridis shells and natural zeolite. This is the motivation of this study, to know the effects of powdered Perna Viridis shells and natural zeolite on SCC and its properties.

2. METHODOLOGY

Experimental tests were conducted by preparing different mixes of self-compacting concrete. The mixes were varied by partially replacing cement with powdered Perna Viridis shells and zeolite at different percentage.

2.1 Mix design

Presently, there is no standard mix design for SCC. However, numerous organizations directly associated with the production of SCC have developed their own SCC mix designs. In this study, the "Specification and Guidelines for Self-Compacting Concrete" (EFNARC, 2012) was used as basis. The guidelines recommends the following: air content at 2%, coarse aggregate content < 50% of solid volume, fine aggregate > 40% of mortar volume, water-powder ratio in volume ranges from 0.8 to 1.0, powder content ranges from 400 to 600 kg/m^3, and water < 200 liters. However, these proportions are not restrictive and many mixes can fall outside of the ranges (Su et al., 2001). In this study, the following material proportions are fixed in one cubic meter of concrete: 633 kg cement, 810.84 kg sand, 686.23 kg gravel, 220 kg water, and 7.6 liter superplasticizer.

2.2 Experimental program

Four different percentages of powdered Perna Viridis shells, specifically 0, 5, 10 and 15%, were used as partial replacement to cement (Talagtag, et.al., 2014). Similar percentages of zeolite were also used as replacement for cement, as taken from a previous study (Clemente, 2015). The control mix is with no cement replacement. A total of 16 mixes were investigated. Ten concrete cylindrical specimens were prepared per mix, 5 for compression and 5 for split-tensile strength test. The code used for each mix is P#Z#, P for Perna Viridis and Z for zeolite. The value # is the percentage cement replacement. For example, P5Z10 means 5% Perna Viridis and 10% zeolite.

Each mix was evaluated for filling ability, passing ability and segregation resistance, which are the needed criteria to establish a concrete mix as SCC. Although there are other tests that can be used to evaluate the workability of concrete, such as J-ring, V-funnel, U-box, fill-box, etc., the filling ability was evaluated using Abrams cone test (ASTM C 1611) and the passing ability was evaluated using the L-box test (BS EN 12350-10). Segregation of aggregates was visually evaluated.

2.3 Materials used

Perna Viridis shells were heated in a pan for three hours and continuously stirred until they became brittle. They were then crushed and required to pass through a 1.19 mm sieve. This is based on the procedure adopted in the previous study to turn the shells into powdered form (Gagan and Lejano, 2016). The zeolite used in this study is a natural mineral in powdered form. The cement used is Type 1 Portland cement. Gravel is 3/8" and obtained from Porac, Pampanga and washed sand was obtained from Angono, Rizal.

3. RESULTS AND DISCUSSION

The effects of Perna Viridis and zeolite on the properties of fresh and hardened concrete are presented here. The different mixes were considered to have satisfied the criteria of SCC when they exhibited segregation resistance and satisfied the filling ability and passing ability.

3.1 Effect on properties of fresh concrete

Using the Abrams cone test, the acceptable range for slump flow of 600 to 900 mm was used to determine the filling ability of the SCC mix. Typical acceptable slump flow is shown in Fig. 1. A graph depicting a summary of the measured slump flow is shown in Fig. 2. It was observed that all mixes except the 15% replacement of zeolite satisfied the minimum slump flow requirement. This suggests that the maximum amount of zeolite that can be introduced into an SCC mix should be less than 15% cement replacement. The slump flow was initially improved and peaked at 5% zeolite, but was reduced at larger percentages. In addition, mixes P0Z15 and P5Z15 exhibited no flow at all. It was also observed that the mix with the best flow diameter is mix P5Z10, while the mix with the lowest flow is mix P15Z15. Note also that P15Z15 did not pass the criteria for filling ability.

Fig. 1. Photo of slump flow within 600 to 900 mm

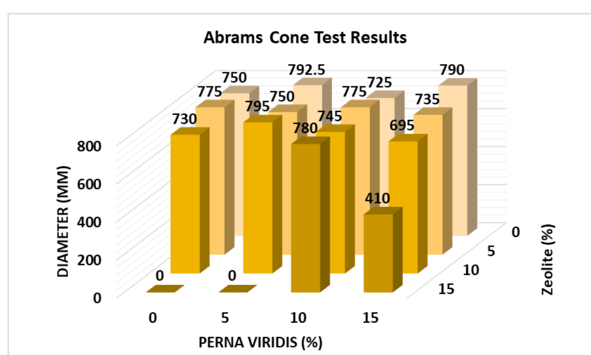

Fig. 2. Flow diameters from Abrams cone test results

The passing ability of concrete was measured using the L-box test. The L-box used in this study is shown in Fig. 3. The test was performed by filling up the vertical portion of the box to the brim while the horizontal portion is closed off using a sliding cover. After the SCC had settled for 60 seconds, the cover was removed and the content was allowed to flow. The passing ratio is the ratio of height of SCC at both ends of the L-box once the SCC stopped flowing. The acceptable range for the ratio is from 0.8 to 1.0, A zero passing ratio means that either the concrete did not flow up to the other end or did not flow at all.

Fig. 3. Photo of L-box used, side view and front view

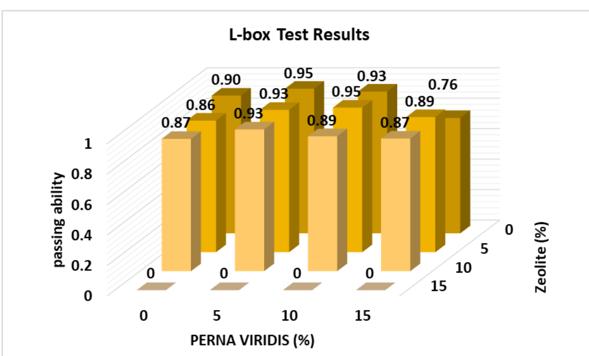

Fig. 4. Plot of passing ratios from the L-box tests

L-box test results showed that all mixes were adequate except for the mixes with 15% zeolite replacement, which failed to flow in the L-box. It was observed that increasing the amount of Perna Viridis to 5% and 10% increased the passing ratio of the mix, while increasing the amount of zeolite by the same percentage yielded a lower passing ratio. This suggests that the addition of zeolite makes the SCC mix more cohesive and viscous, thus reducing the passing ability of the mix. The SCC mix with the highest passing ratio is mix P10Z5, while the mix with the lowest passing ratio is mix P15Z0.

Equal amount of Perna Viridis and zeolite seems to slightly reduce both the filling and passing ability, however the values are still satisfactory and very close to the values obtained for the control mix.

All mixes that satisfied the passing and filling ability were also observed to exhibit good segregation resistance. Subsequently, mixes which cannot be classified as SCC were not included in the strength test.

3.2 Effect on Strength of SCC

All of the 28-day compressive strength values exceeded the 21 MPa target strength. In fact, the highest strength recorded is almost 65 MPa. The compressive strength ranges from 35.8 to 64.9 MPa. It was observed that as the percentage of zeolite was increased, the compressive strength also increased. Conversely, as the Perna Viridis percentage was increased, the compressive strength decreased. It was also observed that the higher compressive strength was obtained when the amount of zeolite is greater than or equal to the amount of Perna Viridis.

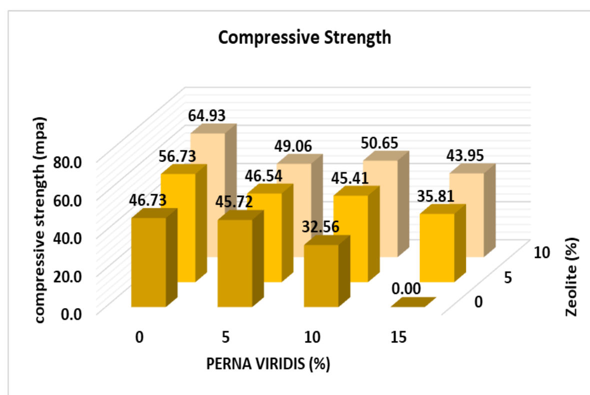

Fig. 5. Compressive strength test results

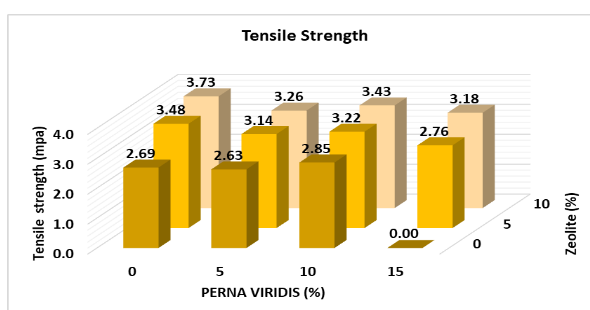

Fig. 6. Split tension strength test results

For the tensile strength, the observed trend was similar to that of the compressive strength of concrete. The tensile strength recorded ranges from 2.7 to 3.7 MPa. Furthermore, it was observed equal amount of Perna Viridis and zeolite tends to improve the compressive and tensile strength.

3.3 Overall Effect

In order to determine the overall best mix that will produce SCC, each mix was scored based on the following parameters: compressive strength, flow diameter, and passing ratio. A score from 0 to 1 was assigned for the value of the parameter of a given mix; 0 for the lowest value and 1 for the largest value. The rest were interpolated. Shown in Table 1 is the summary of score given for each mix per parameter.

Table 1. Scores of the mixes per parameter

Mix Code	Parameters					
	fc' (MPa)		Flow Dia.(mm)		Passing ratio	
	Value	score	Value	Score	Value	score
P0Z0	45.1	0.39	750	0.55	0.90	0.44
P0Z5	57.1	0.76	775	0.80	0.86	0.00
P0Z10	64.9	1.00	730	0.35	0.87	0.11
P5Z0	47.7	0.47	792	0.97	0.95	1.00
P5Z5	48.9	0.51	750	0.55	0.93	0.78
P5Z10	52.2	0.61	795	1.00	0.93	0.78
P10Z0	32.6	0.00	725	0.30	0.93	0.78
P10Z5	45.4	0.40	775	0.80	0.95	1.00
P10Z10	54.0	0.66	745	0.50	0.89	0.33
P15Z5	35.8	0.10	735	0.40	0.89	0.33
P15Z10	44.0	0.35	695	0.00	0.87	0.11

In order to determine the overall best mix, the average of the three parameter scores was evaluated and the summary of values is presented in Fig. 8. The ranking is based on the average score. When the score is higher, the mix is better. Based on the results, the three mixes that produced the most satisfactory SCC are the following: P5Z0, P5Z10, and P10Z5. Although the strengths of these mixes were not significantly greater than the control mix, the workability of these mixes is the most suitable for SCC. However, when cost is considered in the evaluation, P10Z5 seems to be the best choice among the three because it has the highest Perna Viridis content. Cost of the mix becomes lower when more Perna Viridis is used as cement replacement. This is because Perna Viridis is a waste material and can be considered to have zero cost. To have a more detailed cost analysis, a summarized cost evaluation based on the cost of binder for a 10-liter concrete is shown in Table 2. The current prices of cement and zeolite were used in the calculation, that is, P6/kg and P5.4/kg, respectively.

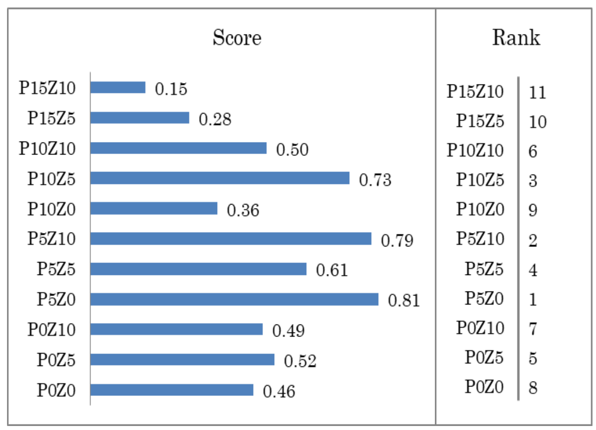

Fig. 8. Ranking based on score

Table 2. Cost analysis based on cost of binder

Mixes	Cost	Difference from P0Z0	% Diff.	Rank
P0Z0	₱ 49.37	--- -	0.0%	11
P0Z5	₱ 48.62	-₱ 0.75	-1.5%	10
P0Z10	₱ 47.85	-₱ 1.52	-3.1%	9
P5Z0	₱ 46.91	-₱ 2.47	-5.0%	8
P5Z5	₱ 46.15	-₱ 3.23	-6.5%	7
P5Z10	₱ 45.39	-₱ 3.99	-8.1%	6
P10Z0	₱ 44.44	-₱ 4.94	-10.0%	5
P10Z5	₱ 43.68	-₱ 5.69	-11.5%	4
P10Z10	₱ 42.92	-₱ 6.46	-13.1%	3
P15Z5	₱ 41.21	-₱ 8.16	-16.5%	2
P15Z10	₱ 40.45	-₱ 8.92	-18.1%	1

However, if the basis for selection is the compressive strength, the three mixes showing the highest strength are P0Z10 (64.9 MPa), P0Z5 (56.7 MPa), and P10Z10 (50.6 MPa). Again, if cost is considered, then P10Z10 seems to be the better choice. These findings tend to point that the most viable cement replacement by Perna Viridis in SCC is from 5 to 10%. However, this needs further verification, and it is recommended that that further study be conducted using smaller interval of percentages of Perna Viridis and zeolite.

4. CONCLUSIONS

Based on the experimental results, the following may be concluded:

As solo partial cement replacement, Perna Viridis tends reduce the compressive and tensile strength of SCC. On the other hand, zeolite tends to increase the compressive and tensile strength of SCC. Perna viridis and zeolite have erratic effect on the passing and filling ability of SCC.

At equal percentage replacements, Perna Viridis and zeolite improved the compressive and tensile strengths, however they slightly reduced the filling and passing ability of SCC.

Overall, it can be concluded that Perna Viridis and zeolite, when combined, are suitable alternatives for cement in SCC because of their positive combined effects on both fresh and hardened properties, specifically filling ability, passing ability, compressive strength, and tensile strength. Among those tested, the best mix in terms of strength, workability and cost is the combination of 10% Perna Viridis and 5% Zeolite cement replacement.

5. ACKNOWLEDGMENTS

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