Increasing Concrete Compressive Strength with the Application of Aggregate Modification Treatment Methods on Coarse Ceramic Waste Aggregates

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Abstract: Research shows that the use of ceramic tile waste (CTW) aggregates in concrete production increases the compressive strength. However, its viability is affected by the CTW's high water absorption capacity that results to a decrease in concrete workability and strength. To address the said problem, this study used various treatment methods to decrease the absorption rate of CTW aggregates and potentially yield greater compressive strengths. The Aggregate Modification Treatments (AMT) used in the study were cement impregnation (CI), slurry wrapping (SW), and sodium silicate soaking (SS). The concrete mixes were divided into five groups that consisted of control (CTRL), untreated (UNTR), CI, SW, and SS batches. The methods used in this study followed an experimental design, where the aggregate properties, workability, and resulting compressive strength of the specimens were obtained using ASTM standards. Based on the results, all concrete mixes yielded acceptable slumps in the range of 80 mm to 100 mm. However, the assumption that the slump would increase, as the absorption rate decreases, was invalidated. This can be attributed to the surface texture of the treated CTW aggregates. The CI batches produced both the greatest increase in compressive strength from 7-day to 28-day curing periods, and greatest nominal compressive strength, while the 0.6 w/c batches generally yielded greater compressive strengths relative to the 0.5 w/c batches. Furthermore, both the relationships of slump and CTW absorption to compressive strength showed low correlations. Overall, the best concrete mixture, among all produced samples, was attained from the CI treatment method, with 25% CTW replacement and 0.5 water-cement ratio. This specific mixture resulted to a compressive strength of 46.68 MPa (16.7% stronger than the strongest control sample), and an acceptable slump of 83 mm. A cost analysis was also conducted as part of this study to determine the cost-effectiveness of performing the said AMT's.

Key Words: ceramic tile waste; aggregate treatment methods; cement impregnation; slurry wrapping; sodium silicate soaking

1. INTRODUCTION

Due to the increase in globalization and industrialization, the construction industry has been well-known to strive in achieving technological and methodological advancements in both developed and developing countries. However, due to the processes involved in this industry, environmental issues arise such as the emission of carbon dioxide, the build-up of waste from concrete production, and wastes generated from the demolition and repair of structures. The construction industry in the Philippines contributes 30% of the total wastes generated in the country (ABS-CBN News, 2018). One specific type of waste that can potentially be reused is ceramic tile waste. A study of Jacob, Aggarwal, and Kushwaha (2017) found that construction and demolition (C&D) waste accounts for roughly 75% of all trash created worldwide. Specifically, it was also stated that ceramic material takes up around 54 percent of all C&D wastes. Furthermore, Awoyera et. Al. (2018) investigated the effectiveness of utilizing both coarse and fine ceramic waste aggregates in improving concrete compressive strength. Based on the results, the greatest compressive strength was produced by a mixture using a 100% coarse aggregate replacement, which yielded a strength increase of 36.1% relative to the control sample. In addition to using waste materials for aggregate replacements, numerous studies have formulated and tested treatment methods that improve aggregate characteristics. In a study of Imam, Tafsirojjaman, and Rashid (2014), cement impregnation treated aggregates, through a mixture of 10 L water to 1 kg cement and 1% superplasticizer, displayed strength increases of 13% to 21% as compared to the control samples.

2. METHODOLOGY

2.1 *Research Design*

In this study, the specific gravity and absorption of aggregates, concrete workability, and concrete compressive strength were obtained using applicable ASTM standards. In applying the different AMT methods, the coarse aggregates and water-cement ratio of the concrete mix were modified. Gravel, which is the conventional coarse aggregate, was replaced with CTW, and water-cement ratio was also modified.

ASTM C127, ASTM C143 and ASTM C39 were used to determine the water absorption, workability, and compressive strength of all concrete samples, respectively. Graphical analyses were performed to interpret the relationships CTW replacement and slump, and CTW absorption and slump. In addition, strength comparisons were provided among control, untreated, and treated batches. These analyses were used to evaluate the effectiveness of the application of AMT methods to improve aggregate and concrete properties that meet concrete production standards.

A total of 108 samples were tested in the study. Six (6) per case, 3 of which were tested after the 7-day curing period and another 3 at the 28-day curing period.

2.2 Experimental Setup

The experimental design of this study involves investigating the properties of aggregates, fresh concrete, and hardened concrete. This was done by producing 100 mm x 200 mm cylindrical concrete samples that incorporated untreated and treated CTW aggregates as a partial replacement to coarse aggregates in concrete. The coarse aggregate replacement values, water-cement ratios, and curing periods were 25% and 50%, 0.5 and 0.6, respectively. The AMT methods adopted in this study were based on previously conducted research on the application of cement impregnation, slurry wrapping, and sodium silicate coating at their optimal cases through utilizing treatment parameters that have produced the best results in improving waste aggregates. These treatment methods were applied to CTW aggregates to enhance their properties and the properties of waste concrete and are described as follows.

Table 1. Summary and tabulation of cases and labels.

Aggregate Modification Treatment [T]	CTW coarse aggregate replacement [C]	Water-cement ratio [W]	Case ID
Untreated (UNTR)	0	0.5	CTRL W0.5
	0	0.6	CTRL W0.6
	25	0.5	UNTR C25 W0.5
	25	0.6	UNTR C25 W0.6
	50	0.5	UNTR C50 W0.5
	50	0.6	UNTR C50 W0.6
Cement Impregnation (CI)	25	0.5	CI C25 W0.5
	25	0.6	CI C25 W0.6
	50	0.5	CI C50 W0.5
	50	0.6	CI C50 W0.6
Slurry Wrapping (SW)	25	0.5	SW C25 W0.5
	25	0.6	SW C25 W0.6
	50	0.5	SW C50 W0.5
	50	0.6	SW C50 W0.6
Sodium Silicate Soaking (SS)	25	0.5	SS C25 W0.5
	25	0.6	SS C25 W0.6
	50	0.5	SS C50 W0.5
	50	0.6	SS C50 W0.6

2.3 Preparation of Materials

Upon collection of CTW, these were manually crushed with a hammer to achieve a nominal size like that of natural aggregates used for the control setup. The prepared aggregates are shown in Figure 1.

Fig 1. Crushed CTW Aggregate.

Table 2 shows the properties of the CTW which were obtained through modifying ASTM C 127.

Table 2. Properties of Untreated CTW.

Property	Value
Specific Gravity (Dry)	1.830
Specific Gravity (SSD)	2.097
Absorption, %	14.618

2.4 Mix Design

The absolute volume method per ACI 211.1 was used in obtaining the mix design of the specimens. This method involved using the displaced volumes caused by the components of the concrete mixture. Table 3 shows the final mix design of all samples used in this study.

Table 3. Proportions of CTW Concrete Mixtures.

0.5 w/c 25% CTW Replacement	
Water Proportion, kg	2.00
Cement Proportion, kg	4.00
Coarse Aggregate Proportion, kg	4.50
Crushed CTW Proportion, kg	1.05
Fine Aggregate Proportion, kg	4.60
0.5 w/c 50% CTW Replacement	
Water Proportion, kg	2.00
Cement Proportion, kg	4.00
Coarse Aggregate Proportion, kg	3.05
Crushed CTW Proportion, kg	2.10
Fine Aggregate Proportion, kg	4.60
0.6 w/c 25% CTW Replacement	
Water Proportion, kg	2.00
Cement Proportion, kg	3.33
Coarse Aggregate Proportion, kg	5.30
Crushed CTW Proportion, kg	1.25
Fine Aggregate Proportion, kg	5.60
0.6 w/c 50% CTW Replacement	
Water Proportion, kg	2.00
Cement Proportion, kg	3.33
Coarse Aggregate Proportion, kg	3.50
Crushed CTW Proportion, kg	2.50
Fine Aggregate Proportion, kg	5.60

2.5 Aggregate Modification Treatment Methods

Three treatment methods were used in this study: cement impregnation (CI), slurry wrapping (SW), and sodium silicate soaking (SS). CI was conducted by soaking dried CTW aggregates for twenty-four (24) hours in a solution of ten (10) liters of water, and one (1) kilogram of cement. These were then dried for an hour before being incorporated into the concrete mixtures. The SW treatment involves a mixture of water, cement, and a pozzolanic material (fly ash) for this study. Once the mixture was made, the CTW aggregates were soaked in it for around an hour. Similarly, a drying time of one hour was used. Lastly, the SS treatment involves a soaking solution of water and sodium silicate (Na_2SiO_3) of a concentration of 8%. The CTW coarse aggregates were then fully submerged and soaked in this solution for 1 hour and were taken out for natural drying for an hour. After drying time, all treated aggregates were incorporated into concrete mixtures. The parameters for each treatment method are shown in in the table below.

Table 4. Treatment Parameters.

AMT	Cmt. (kg)	Fly Ash (kg)	Water (L)	Sod. Sil. (mL)	Soak-ing (hr)	Dry -ing (hr)
CI	1	0	10	0	24	1
SW	10	1.5	10	0	1	1
SS	0	0	10	800	1	1

2.6 Compressive Strength Test of Concrete Cylinders

ASTM C39/C39M was used to determine the compressive strength of the concrete specimens. The test was conducted using the universal testing machine of De La Salle University, Manila, where the maximum load at which the concrete specimen failed was recorded. The resulting compressive strength was obtained by dividing the maximum load by the cross-sectional area of the cylindrical concrete specimen measured prior to testing.

2.7 Slump Test

Slump tests were conducted in accordance with ASTM C143. The mold was first dampened. Once it was set, the mold was filled with the concrete mix until ⅓ of the capacity was reached. The concrete layer was then rodded with the tamping rod for a total of 25 strokes. Once the first layer had been set, the next ⅓ of the mold was then filled with concrete. The rodding strokes had a depth that was just enough to penetrate the previous layer. These steps were then repeated for the final top layer of the mold. Once all layers have been filled, the top surface was smoothed out. After doing so, the mold was then lifted vertically. The slump was then recorded as the difference between the heights of the slump cone and slumped mixture.

3. RESULTS AND DISCUSSION

3.1 Absorption of CTW Aggregates

The absorption of aggregates was determined before and after the application of the treatment methods. These were compared with the absorption of untreated CTW aggregates. The results for the changes in absorption are shown in Table 5. As shown in this table, the greatest decrease in absorption was observed on aggregates treated using SW, while CI treatment resulted to the least decrease in absorption.

Table 5. Absorption Values for each CTW Group.

CTW Group	Absorption (%)	Decrease with respect to UNTR (%)
UNTR	14.618	-
CI	12.963	11.322
SW	6.997	52.571
SS	10.811	26.043

3.2 Slump Test Results

All batches obtained a slump within the target range of 80 mm to 100 mm. Although changes were expected due to the increase in replacement value and water-cement ratio, the study of Abdullah, Noor, Kamarudin, and Ruzaidi (2014) share the same observations, where similar values for workability were obtained considering waste and conventional concrete aggregates. Nonetheless, the most workable mixtures were produced in using SS method. This can be attributed to the coating it has provided with the use of sodium silicate, compared to the cement and water mix used in CI and SW. The SS treatment produced aggregates with smoother surfaces which could have decreased the internal friction acting among concrete components.

The slump results are compared with their respective replacement values in Figure 2. As shown in the said figure, the assumption that an increase in CTW replacement would decrease concrete workability was invalidated. This was observed when the percentage replacement on mixes SS C50 W0.6, SW C25 W0.6, and UNTR C25 W0.6 was increased from 25% to 50%. This is highly associated to the size and surface texture of gravel used compared to CTW aggregates. Based on a study conducted by Rawarkar and Ambadkar (2018), using larger aggregates can increase workability. Although the waste aggregates in this study were smaller in size, the general assumption that the slump would increase as the absorption rate is decreased was also invalidated. This may indicate that the absorption of CTW aggregate within a mixture may not affect workability in a predicable manner for this replacement range. The SS-treated CTW aggregates produced concrete mixtures with the greatest slump. despite having a 26.043% decrease in absorption relative to using CI and SW methods. This is shown in Figure 3.

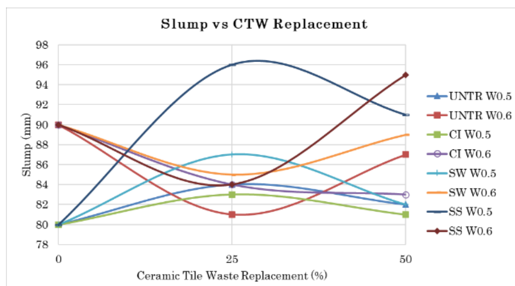

Fig. 2. Replacement Value vs Slump.

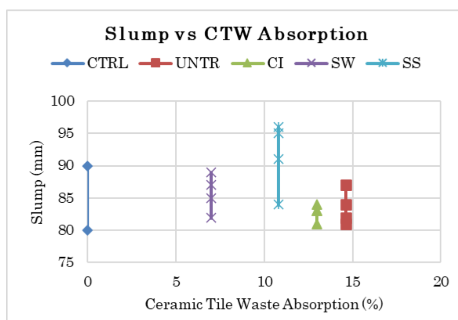

Fig. 3. CTW absorption vs Slump.

3.2 Compressive Strength Test Results

Considering that the lowest recorded compressive strength out of all samples is 31.17 MPa (SW C25 W0.6), it was found that all other cylinder samples were able to meet the designated target strength. According to the results, 0.5 w/c ratio batches with untreated or treated CTW aggregates generally produced lower compressive strengths compared to their respective control batches. The same was observed for the samples cured for 28 days except for the CI batches. The CI treated aggregates mixtures produced a compressive strength of 46.68 MPa (CI C25 W0.5), which was 6.67 MPa higher than that obtained by the control samples (40.01 MPa, CTRL W0.5). The greatest deviation from the compressive strength of the control batch having a 0.5 water-cement ratio was batch SW C25 W0.5 with a strength difference of -9.97 MPa. The opposite was observed for batches having a 0.6 w/c ratio where their strengths were similar or higher than the control batches, except for SW C25 W0.6, which had a difference of -1.48 MPa when compared to CTRL W0.6. Overall, the cement impregnation batches produced the greatest compressive strengths ranging from 39.81 MPa (CI C50 W0.6) to 46.68 MPa (CI C25 W0.5). This noticeable increase in compressive strength due to cement impregnation is attributed to the filling of pores, as seen in the reduction of absorption, and the development of cement coating around the CTW, effectively reinforcing the aggregate and altering its properties towards that of conventional aggregate.

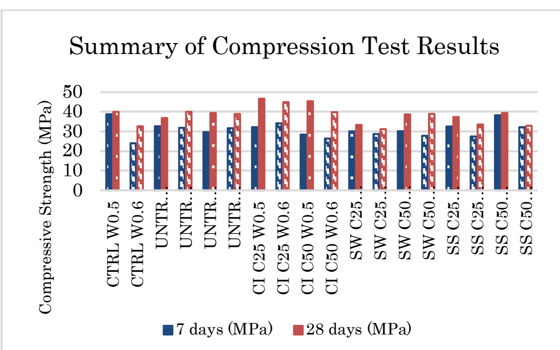

Fig. 4. Summary of Compressive Strengths.

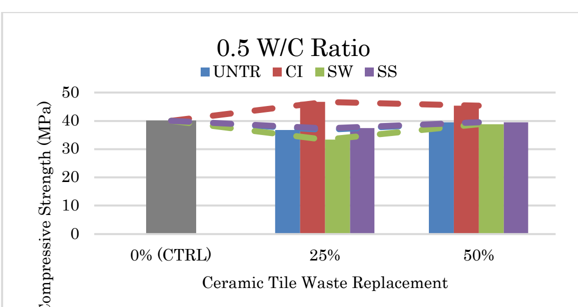

Fig. 5. Replacement Value vs Compressive Strength (w/c = 0.5).

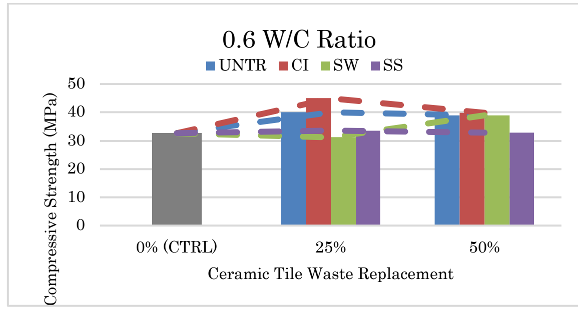

Fig. 6. Replacement Value vs Compressive Strength (w/c = 0.6).

3.3. Strength Development Results

With regards to strength development, the order from the least to greatest improvement based on average 7-day to 28-day curing is as follows: control, sodium silicate, untreated, slurry wrapping and cement impregnation. The sample with the greatest amount of strength increase of 17 MPa is found among the CI batches, specifically CI C50 W0.5 and the least improvement of 0.72 MPa is found among the SS batches, specifically SS C50 W0.6.

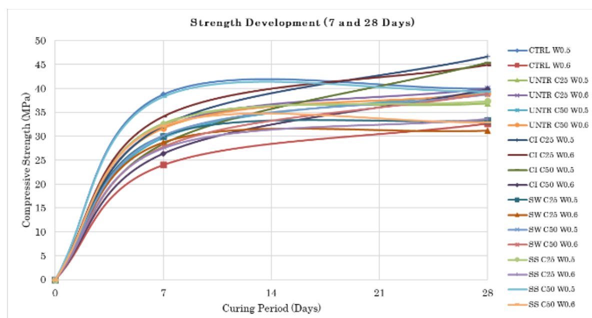

Fig. 7. Batch Strength Development Curves.

3.4. Cost Analysis

The cost effectiveness of each mixture was determined through the use of the absolute volume method. The price of each batch was calculated by proportioning the actual volume of each batch to the unit cost of the materials per cubic meter/kilogram/ml. Upon analyzing the price of each treatment, it was observed that the most cost-effective treatment was that of the Cement Impregnation treatment since its average treatment cost is almost similar to that of the cost per control batch (Php 28.52 per CI treatment vs Php

28.03 per control batch). The cost-effectiveness of the CI treatment is also emphasized by the increase in compressive strength as compared to the other treatments. The Slurry Wrapping and Sodium Silicate treatment methods had average treatment costs of Php 43.31 and Php 63.99 respectively due to the inclusion of other materials other than cement such as fly ash and sodium silicate.

4. CONCLUSIONS

The study was able to make the following conclusions:

- All treatment methods incorporated in the study reduced the CTW aggregate absorption.
- The concrete mixtures that underwent Sodium Silicate treatment exhibited the best workability. However, no improvement in the compressive strength was obtained.
- The Cement-Impregnated concrete mix exhibited the greatest 28-day compressive strength. On the other hand, the slurry wrapped concrete samples was found to be the least effective in improving concrete strength.
- Out of all the mixtures produced in this study, the mixture of CI C25 W0.5 was found to be the optimum mix. This is due to the resulting high compressive strength after 28 days of curing period, without significant effect to its workability.
- Generally, when increasing the CTW replacement in concrete mixes from 25% to 50%, mixes with 0.5 w/c ratio showed better results that those with 0.6 w/c ratio. Based on the experimental results, using a 0.6 w/c ratio would more likely yield a decreasing compressive strength.
- CI was found to have the greatest cost-effectiveness among all treatment methods since it is the cheapest treatment method, and it produced the greatest improvement in compressive strength as well.

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6. REFERENCES

ABS-CBN News. (2018, April 10). *How construction can go 'green'.* ABS. Retrieved from: https://news.abs-cbn.com/business/04/10/18/how-construction-can-go-green.

Aggarwal, A., Jacob, A.E., & Kushwaha, Y.K. (2017). Utilization of Ceramic Waste as a Replacement of Aggregates and Its Effect on Variation of Expenditure. *International Journal of Engineering Research Online. 5.* 262-268.

Awoyera, P.O., Ndambuki, J.M., Akinmusuru, J.O., & Omole, D.O. (2018) Characterization of ceramic waste aggregate concrete, HBRC Journal, 14:3, 282-287, DOI: 10.1016/j.hbrcj.2016.11.003.

Elevado, K. J. T., Galupino, J. G., & Gallardo, R. S. (2019). Compressive Strength Optimization of Concrete Mixed With Waste Ceramics and Fly Ash. *International Journal, 16*(53), 135-140.

Imam, M. O., Tafsirojjaman, T., & Rashid, M. M. (2014). Treatment of recycled aggregate by impregnation of OPC to improve concrete properties. *Treatment of recycled aggregate by impregnation of OPC to improve concrete properties*, 601-606.

Rawarkar, K., & Ambadkar S. (2018). A Review on Factors Affecting Workability of Concrete. *A High Impact Factor, Monthly, Peer Reviewed Journal*, 7(8), 9087-9089.

Shahedan, N. F., Abdullah, M. M. A. B., Hussin, K., Sandu, I., Ghazali, C. M. R., Binhussain, M., & SANDU, Z. Y. A. V. (2014). Characterization and design of alkali activated binder for coating application. *technology*, *3*, 9.