Journal of Engineering Science and Technology
Vol. 19, No. 5 (2024) 1831 - 1843
© School of Engineering, Taylor's University

OPTIMIZATION OF THE COMPRESSIVE STRENGTH OF CONCRETE WITH WASTE CERAMIC TILES AS PARTIAL AGGREGATES USING RESPONSE SURFACE METHODOLOGY

KENNETH JAE ELEVADO*, IRENE OLIVIA UBAY-ANONGPHOUTH,
RONALDO GALLARDO, DANIEL NICHOL VALERIO, JAY ONG,
ANGELA RIETA, LEVIN LIZARDO, SHERWIN CHENG

Department of Civil Engineering, De La Salle University, Manila, Philippines
*Corresponding Author: kenneth.elevado@dlsu.edu.ph

Abstract

As the construction industry continues to develop, the growing problem of solid building waste disposal remains unresolved. Recent studies showed that ceramic tiles possess similar properties to conventional concrete aggregates. In this study, waste ceramic tiles were incorporated as partial coarse and fine aggregates of concrete, with 25%, 50%, and 75% replacements. Using these percentage replacements, a total of 16 mixes were prepared, and the concrete specimens were subjected to compressive strength test. Strength development was also investigated through testing the specimens at 7, 14, and 28 days of curing period. Based on the experimental results, the compressive strength increased when either fine or coarse aggregates are replaced. When both fine and coarse aggregates are replaced at the same time, the compressive strength generally decreased. In particular, the concrete mix with 75% fine and 75% coarse ceramic aggregates had the lowest nominal compressive strength with 5.72 MPa. Furthermore, Response Surface Methodology (RSM) was used to determine the optimum combination of fine and coarse ceramic tiles. Results showed that the optimum amount of waste ceramic fine and coarse aggregates is 75% and 0%, respectively, yielding 39.37 MPa nominal compressive strength. This is about 39.12% higher than the strength of the control mix, indicating that waste ceramic tiles can potentially replace the conventional concrete aggregates.

Keywords: Ceramic tiles, Concrete, Optimization, Response surface methodology, Waste aggregate

1. Introduction

As a consequence of rapid urbanization, globalization, and population growth, the global municipal solid waste generation has been increasing. Researchers have estimated that the annual municipal solid waste generation is approximately 2 billion tons, and in 2030, it is anticipated to reach 2.59 billion tons per year [1]. In the Philippines, particularly in metropolitan areas, rapid economic growth, rising standard of living, population growth, and industrialization have all contributed to an increase in waste generation.

In 2019, it is estimated that the country generated 21,4265,676 metric tons of garbage, with an estimated average per capita waste generation of 0.4 kg/day [2]. In relation to this, previous research indicates that approximately 30% of raw ceramic materials are wasted, which further adds to air, ground, and land pollution [3]. The problem is made worse by the inability to recycle enough solid waste, along with the synergy of other variables, such as local income, public participation, greenhouse gas emissions, and population [4].

In the construction industry, ceramic tile is typically used as a wall and floor finish. In the ceramic business, it is estimated that approximately 30% of the daily output of ceramic tiles is wasted [5]. These wastes typically end up in landfills, which further contributes to the growing problem of solid waste management. On the other hand, concrete is commonly used in the construction industry because of its affordability and overall performance relative to other construction materials. However, concrete production entails the use of limited natural aggregates, such as sand, gravel, and cement.

With the increasing demand for natural aggregates associated with global industrialization, repurposed resources, such as waste ceramic tiles, have been found useful as aggregates in the construction sector [5-10]. Recycling these kinds of waste from the construction industry provides environmental advantages through reducing solid waste generation that usually ends in landfills. Economic benefits can also be attained by procuring the waste ceramic tiles at zero material cost instead of purchasing the conventional concrete aggregates. However, the experimental program of the previous studies typically involved the replacement of either sand or gravel, without attempting to replace both aggregates in the same concrete mix.

In this study, the conventional fine and coarse concrete aggregates, sand and gravel, respectively, were partially replaced with waste ceramic tiles in an attempt to maximize the utilization of the said waste material in the concrete mix. The percentage replacements of both fine and coarse aggregates were limited to 25%, 50%, and 75% [11, 14-16]. Considering these percentage replacements, a total of 16 mix designs were prepared with various combinations. The concrete specimens were prepared, and the compressive strength of each specimen was tested using the applicable ASTM Standards.

Additionally, strength development was investigated through testing the concrete specimens after 7, 14, and 28 days of curing period. The strength development provided a better understanding of the hardening of concrete mixed with waste ceramic tiles, noting also that ceramic tiles possess pozzolanic properties that aid in the long-term hardening of concrete. After gathering the experimental data, Response Surface Methodology (RSM) was used in this study to optimize the combination of fine and coarse waste ceramic tiles in the concrete mix, maximizing the nominal compressive strength of concrete. Nominal compressive strengths are typically used by structural engineers in designing concrete structures, unless cured concrete is required earlier than 28 days.

Furthermore, RSM establishes a relationship between a response, which is a pre-defined dependent variable, and one or more independent variables [11-13]. It is also utilized to optimize a response based on the impact of other independent variables. The relationship could be established graphically in contour plot, and in three-dimensional figure. In this study, the percentage replacements of waste ceramic tiles to the conventional fine and coarse aggregates of concrete were used as the independent variables in generating the RSM model, while the dependent variable corresponds to the resulting compressive strength. The generated RSM model was validated to ensure its acceptability.

2. Experimental Program

2.1. Materials preparation

American Concrete Institute (ACI) standard was followed in preparing the concrete mix design for this study [17]. Using the ACI standard, a 0.478 water-cement ratio was determined, considering the 28-MPa target nominal strength of concrete. Type 1 Portland cement was used in all mixes. Additionally, the concrete mix required 184 kilograms of mixing water per cubic meter of concrete; this was determined by considering a maximum aggregate size of 19.0 mm and a slump of 25-100 mm.

The material properties of concrete aggregates were also necessary. These were obtained through testing the aggregates using applicable American Society for Testing and Materials (ASTM) standards. The tests included specific gravity, moisture content, unit weight, and absorption of aggregates [18-20]. The results of these tests are summarized in Table 1:

Table 1. Properties of aggregates.

Description	Results
Dry rodded density of gravel (kg/m^3)	1567.84
Specific Gravity	
Cement	3.15
Gravel	2.81
Sand	2.51
Moisture Content	
Gravel	0.35%
Sand	1.57%
Absorption	
Gravel	1.64%
Sand	2.77%
Fineness modulus of Sand	2.76

After gathering all necessary data of the aggregates, the concrete design mix was prepared using American Concrete Institute (ACI) Standards. Using the material properties shown in Table 1, the mix design of a 1-cubic meter concrete batch is as follows: 4.78 kg, 11.60 kg, 30.18 kg and 24.70 kg of water, cement, coarse aggregates and fine aggregates, respectively. Prior to mixing, sieve analysis was performed on both coarse and fine aggregates to ensure that the grain size distribution of the aggregates follows the prescribed values in ASTM standard [21]. In addition, only glazed ceramic tiles were used to ensure the consistency of waste tiles that are incorporated in the concrete mix.

ASTM C-192 was used in preparing and curing concrete specimens [22]. The said ASTM Standard ensures the uniformity of preparing and curing the concrete specimens, including sample production, curing conditions, and cylinder preparations, among others. It also minimizes, if not eliminates, any experimental errors. Prior to molding the specimens in 4” x 8” cylinders, a slump test was conducted to measure the workability of concrete in accordance with ASTM C-143 [23]. Additionally, all concrete specimens underwent water curing at standard room temperature based on ASTM C-192.

In all mixes, the partial replacement of aggregates was in terms of mass, considering 25%, 50%, and 75% replacements. For example, the one cubic meter mix design requires 30.18 kg. of coarse aggregates. This indicates that a 25% replacement of coarse ceramic tiles to gravel constitutes 7.55 kg of coarse ceramic tiles and 22.63 kg of gravel. The same methodology applies to the fine aggregate replacements. The compressive strength of each concrete mix was determined after 7, 14, and 28 days of curing periods.

A total of 16 design mixes were prepared. A control group, containing 0% fine and 0% coarse ceramic tiles, was also prepared. The control group served as the baseline condition against which the performance of the waste ceramic tile replacements is compared. Through the use of Mix IDs, a systematic method of labelling the mix design was introduced. The letters "F" and "C" denote the proportions of “fine” and “coarse” waste ceramic tiles in the concrete mix, respectively. For example, the concrete mix "F25C50" contains 25% fine waste ceramic tiles, 75% sand, 50% coarse waste ceramic tiles, and 50% gravel. Table 2 displays a consolidated list of Mix IDs:

Table 2. List of mix IDs.

Mix No.	Mix ID	Fine Cerami c Tiles	Sand	Coarse Cerami c Tiles	Gravel
M1	F0 C0	0%	100%	0%	100%
M2	F0 C25	0%	100%	25%	75%
M3	F0 C50	0%	100%	50%	50%
M4	F0 C75	0%	100%	75%	25%
M5	F25 C0	25%	75%	0%	100%
M6	F50 C0	50%	50%	0%	100%
M7	F75 C0	75%	25%	0%	100%
M8	F25 C25	25%	75%	25%	75%
M9	F25 C50	25%	75%	50%	50%
M10	F25 C75	25%	75%	75%	25%
M11	F50 C25	50%	50%	25%	75%
M12	F50 C50	50%	50%	50%	50%
M13	F50 C75	50%	50%	75%	25%
M14	F75 C25	75%	25%	25%	75%
M15	F75 C50	75%	25%	50%	50%
M16	F75 C75	75%	25%	75%	25%

Nine cylindrical specimens were prepared for each design mix, with 3 specimens tested on each specified curing period. Considering that there were 16 design mixes in this study, a total of 192 concrete specimens were prepared.

2.2. Compressive strength test

Each specimen's compressive strength was determined utilizing a universal testing machine, and following ASTM C-39 [24]. Prior to applying the load, the diameter and height of the specimen were measured using a caliper. This minimizes the potential errors in calculating the compressive strength of a particular specimen, regardless of using a standard 4” x 8” cylindrical mound.

After obtaining the required measurements, the specimen was placed inside the universal testing machine, with steel plates placed on top and at the bottom of the concrete specimen to ensure that the applied load is uniformly distributed. The apparatus had a constant loading of 50 MPa, with increments of 0.2 MPa/s. Each specimen was subjected to loading until the specimen failed, demonstrating that the maximum force had been attained. The corresponding compressive strength of the specimen was calculated by dividing the maximum force recorded by the average circular area on top and at the bottom of the concrete specimen.

2.3. Response Surface methodology (RSM)

RSM employs proficient numerical, statistical, and theoretical approaches to develop models for independent parameter optimization [25-26]. It permits several factors to impact one or more responses using partial factorial designs. Additionally, it is efficient in considering factor interactions, aimed at proposing sequential procedures for performing experiments. The compatibility of experimental data with built models is also validated. Among the multiple responses that the RSM generates, several extensions are utilized to identify the optimal response and desirability analysis is considered one of the most prevalent techniques for optimizing multi-response features [27-30].

As the research on waste utilization in concrete continuously expands, several previous studies used RMS in optimizing the amount of waste materials to be incorporated in concrete production, relative to a predetermined response [11, 29, 31]. Equations (1) and (2) show the general linear and quadratic functions of RSM, respectively:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i \tag{1}$$

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{k} \beta_{ii} x_{ii}^2 + \varepsilon \tag{2}$$

where y is the response, β_0 is a constant value, x_i and x_j are independent factors, ε is the error, and β_i, β_{ij} , and β_{ii} are coefficients of double interactions and linear influence.

This study used Design Experts in generating the RSM model. The nominal compressive strength of concrete, serving as the dependent variable, was optimized. On the other hand, the varying amounts of coarse and fine waste ceramic tiles represented the independent variables of the model. Based on the experimental data, and optimization constraints, which is further discussed in the next section, the program will suggest the best fit model, which can be a linear, two-factor interval, quadratic, or cubic model. The user has the option to generate the RSM model in a three-dimensional figure and a contour plot. Moreover, the RSM model is represented by an equation, which was used in validating the accuracy of the generated RSM model in this study.

3. Results and Discussions

3.1. Compressive strength

After attaining the prescribed curing periods of the concrete specimens, the compressive strength test was conducted. The control mix, containing only the conventional aggregates, achieved its target nominal strength of 28 MPa. Among the modified mixes, where waste ceramic tiles were incorporated, Mix F75C0 attained the highest nominal compressive strength, while Mix F75C75 had the lowest strength, resulting in 39.37 MPa and 5.72 MPa, respectively. The summary of compressive strength test results, and the relative change of the nominal compressive strength of the modified mixes to the control mix are shown in Table 3.

Table 3. Compressive strength test results.

Cluster	Mix ID	Compressive Strength (MPa)			
		7 days	14 days	28 days	Relative Change
Control	F0 C0	21.31	23.98	28.30	*n/a*
Single Replacement	F0 C25	22.49	24.79	28.83	1.87%
	F0 C50	25.36	29.52	32.92	16.33%
	F0 C75	28.60	32.06	32.94	16.40%
	F25 C0	22.10	25.33	32.07	13.32%
	F50 C0	24.88	31.32	38.54	36.18%
	F75 C0	30.09	37.04	39.37	39.12%
Double Replacement	F25 C25	23.24	26.56	28.37	0.25%
	F25 C50	4.32	4.82	8.09	-71.41%
	F25 C75	11.13	10.88	10.85	-61.66%
	F50 C25	3.54	7.04	12.95	-54.24%
	F50 C50	5.46	4.25	17.60	-37.81%
	F50 C75	9.34	9.05	9.68	-65.80%
	F75 C25	2.53	4.54	7.88	-72.16%
	F75 C50	2.92	4.29	5.85	-79.33%
	F75 C75	3.07	3.49	5.72	-79.79%

Results show that when either sand or gravel is replaced with waste ceramic tiles, the compressive strength generally increases. Among the modified mixes that consider single replacement, F75C0 produced the greatest strength at all curing periods. The said result is associated with the pozzolanic property of fine ceramic tiles when incorporated in the concrete mix. In a similar study, the results acquired using a scanning electron microscope demonstrated a clear increase in the amount of portlandite in recycled ceramic fines over time [32]. Portlandite is a significant bonding agent in cement and concrete, supporting the values reached after 28 days of curing period for mixes that only considered fine aggregate replacement. This behavior is comparable to related studies [33, 34].

On the other hand, when both sand and gravel are replaced with waste ceramic tiles, the compressive strength of concrete generally decreases as the percentage replacement is increased, and only F25C25 surpassed the 28-MPa target nominal strength. Similar studies showed a 30-40% reduction in compressive strength when fine and coarse recycled ceramic tiles were incorporated into the conventional mixture. The said study further indicated that the loss in the strength of concrete may have been caused by the high-water absorption of both fine and coarse waste ceramic tiles, which resulted in a dry mixture and ultimately weaker concrete [5-6, 13].

Moreover, the nominal compressive strength of the modified mixes was compared to that of the control mix. An analysis of variance (ANOVA) was performed using Statistical to determine whether there was a statistically significant difference between the nominal compressive strength of each modified mix and the control mix. Typically, studies consider a null hypothesis to denote that there is no significant difference between the two samples being compared, but the alternative hypothesis suggests that there is a significant difference [35, 36].

In terms of single substitution, only F0C25 had nominal compressive strength properties that are comparable to that of the control mix. The nominal compressive strength of the control mix was 28.30 MPa, while F0C25 was 28.83 MPa, which was 1.87% higher than the control mix. All other modified mixes that considered single replacement had higher nominal compressive strengths than the control mix that are considered to be statistically different than the control mix.

The box and whisker plot of F0C25 is shown in Fig. 1. Both samples' means are relatively near to one another, and their ranges of values are close, indicating that there are some commonalities between the samples. The p-value and z-value were found to be 0.687 and 0.100, respectively, indicating that it was able to achieve the target nominal strength of 28 MPa.

Fig. 1. Box and whisker plot of F0C25.

In terms of double replacement, results showed that among all the modified mixes, only F25C25 had nominal compressive strength properties that are comparable to that of the control mix. The nominal compressive strength of F25C25 was 28.37 MPa, which was 0.25% higher than the control mix. Similarly, Fig. 2 shows the box and whisker plot of F25C25. Compared to the control sample, the range of results of F25C25 was relatively narrow. The sample's standard deviation was 0.335, suggesting the obtained values were comparable. With a p-value of 0.738, the difference is statistically insignificant, indicating that there are no statistically significant similarities. In addition, the calculated z-value of 1.112 indicates that the target nominal strength of 28 MPa was achieved.

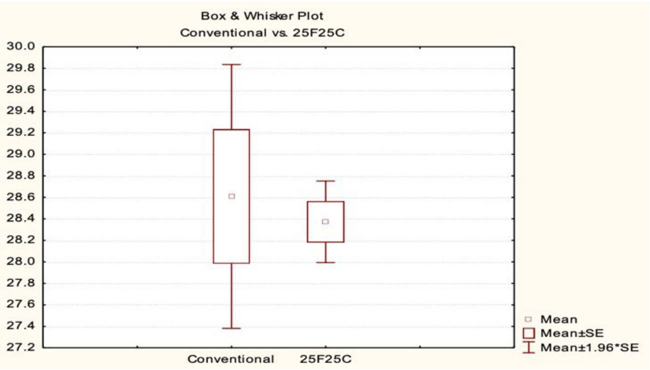

Fig. 2. Box and whisker plot of F25C25.

3.2. Optimization using RSM

In generating the RSM model, the percentage replacements of fine and coarse aggregates, denoted as "%F" and "%C", respectively, acted as independent variables, while the resulting nominal compressive strength, labelled "fc", served as the independent variable or the model's response. Both %F and %C were maintained to be in the range of 0.0 to 0.75, based on the parameters considered in the study, while fc was maximized. The said optimization constraints are summarized in Table 4:

Table 4. Optimization constraints for RMS.

Name	Goal	Limit	
		Lower	Upper
%F	Within range	0	0.75
%C	Within range	0	0.75
fc	Maximize	n/a	n/a

Considering the optimization constraints and the experimental results obtained, a two-factor interaction (2FI) model was determined to be the best model among all other possible models, such as linear, quadratic and cubic. The determination of the best-fit model was based on the sequential p-value and adjusted and predicted R-squared values. The regression equation of the generated RSM model is shown in Eq. (3). This model may also be used in predicting the compressive strength of concrete when varying the percentage replacement of fine and coarse waste ceramic aggregates.

$$fc = 29.63 + 2.59\%F - 2.58\%C - 59.21\%F\%C \qquad (3)$$

where fc is the predicted nominal strength (MPa), %F is the percentage replacement of fine waste ceramic tiles to sand, and %C is the percentage replacement of coarse waste ceramic tiles to gravel.

Based on the provided solution, and considering the constraints, the optimum amount of waste ceramic tiles in the concrete mix, to attain the maximum nominal compressive strength, is 75% and 0% of fine and coarse aggregates, respectively. This combination yielded the highest desirability of 0.768 among several combinations obtained. Using the RSM model, the said combination yielded 31.57-

MPa nominal strength. This is consistent with the actual results, as presented in Table 3, wherein F75C0 also recorded the maximum nominal compressive strength. The results also indicate that considering single replacement of waste ceramic tiles produce better compressive strengths than double replacement, and that focusing such replacement on fine aggregates is better than coarse aggregates. The three-dimensional surface plot and contour plot are presented in Fig. 3.

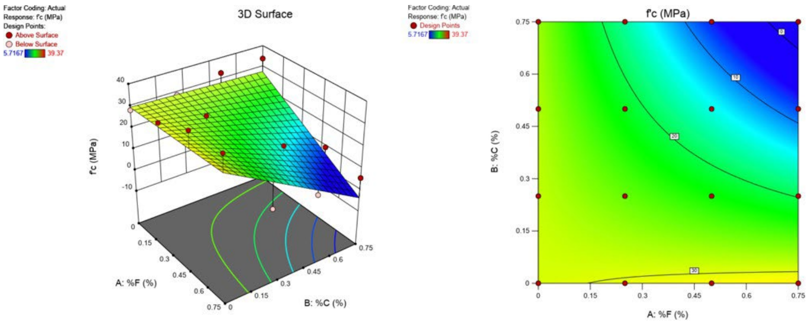

Fig. 3. RSM surface plot (left), and contour plot of fc vs %C and %F (right).

The surface and contour plots provide a better representation of the experimental data of this study. Both plots indicate that the nominal compressive strength of concrete incrementally increases when either sand or gravel is replaced with waste ceramic tiles. Additionally, higher strength was obtained when the fine aggregates were replaced, compared to replacing the coarse aggregates. On the other hand, replacing the fine and coarse aggregates at the same time resulted in an incremental decrease in strength.

Despite attaining 0.768 desirability in generating the RSM model, the solution was still verified using regression analysis. The values obtained using Eq. (3) were treated as the predicted data and compared to the actual experimental values. The plot of these data is presented in Fig. 4.

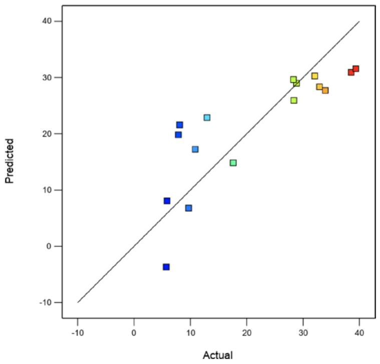

Fig. 4. Actual values vs. predicated values.

After plotting the actual data against the predicted values in Fig. 4, an R-squared value of 0.676 was attained. This indicates that the experimental values and the predicated values using the RSM model have a strong correlation [37, 38]. Because of this, the generated RSM model is considered statistically acceptable.

4. Conclusion and Recommendations

This study aims to optimize the use of waste ceramic tiles, serving as a partial replacement to the conventional fine and coarse aggregates of concrete, to maximize the resulting compressive strength. The percentage replacements of both fine and coarse aggregates with waste ceramic tiles were limited to 25%, 50%, and 75%. Below is a summary of the findings of this study:

- F75C0 and F75C75 had the highest and lowest nominal compressive strengths among the modified mixes, with 39.37-MPa and 5.72-MPa strengths, respectively.
- The compressive strength of concrete is increased when either sand or gravel is replaced with waste ceramic tiles. On the other hand, when both sand and gravel are replaced in the same concrete mix, the resulting compressive strength generally decreases as the percentage replacement is increased. This is likely because of the effectively lower water content in the concrete mix due to the high absorption rate of ceramic tiles. The dry mixture, compared to single replacement mixes, hindered the hydration process of concrete, which resulted in an ultimately weaker concrete.
- All concrete mixes that considered double replacement did not achieve the target nominal compressive strength of 28 MPa, except for F25C25, which yielded 28.37 MPa of strength.
- F0C25 and F25C25 have nominal compressive strengths that are statistically similar to the control mix (F0C0). The strengths of the said mixes are 28.83 MPa and 28.37 MPa, respectively.
- The experimental results suggest that combining both coarse and fine waste ceramic tiles in concrete is generally not desired. However, combining both ceramic tile aggregates at small percentage only until 25% replacement may still be beneficial.
- Using the experimental data, an RSM model was generated. Based on the RSM model, the optimum amount of waste ceramic fine and coarse aggregates is 75% and 0%, respectively. The optimum combination was based on a two-factor interaction model, which was the best fit model among all other possible models. The said combination attains the maximum nominal compressive strength of concrete of about 31.57 MPa.
- Using the corresponding equation of the generated RSM model, the resulting compressive strength of concrete can be predicted, with the percentage replacements of waste ceramic fine and coarse aggregates as independent variables.
- The RSM model was validated using Pearson's correlation. With a 0.676 R-squared value, the predicted and actual data have a strong correlation, indicating that the model is statistically acceptable.
- Based on the experimental results, the use of waste ceramic tiles is a viable option in concrete production, particularly as a replacement to the conventional fine and coarse aggregate. However, in order to maximize the use of waste ceramic tiles in concrete, the said waste material may only serve as alternative to either fine or coarse aggregate.

Furthermore, to improve this study, future researchers are recommended to:

- Focus the next studies on replacing either fine or coarse aggregate of concrete with waste ceramic tiles, disregarding the benefit of double replacement. If double replacement is desired, replacing the aggregates at small increments of up to 25% replacement, possibly at 5% intervals, is recommended.
- Test other mechanical properties of concrete, such as tensile and flexural strengths, to support the feasibility of using waste ceramic tiles as an alternative to the conventional concrete aggregates. This study only tested the compressive strength of concrete, as it is typically the main performance requirement in structural designs.
- Consider adding superplasticizers in the concrete mix or applying aggregate modification techniques, noting that waste ceramic tiles have a higher absorption rate than conventional aggregates. The effectively lower water content in the concrete mix due to the high absorption rate of ceramic tiles is suspected to have hindered the concrete to undergo proper hydration process, causing the decrease in compressive strength considering double replacement.
- Examine the chemical properties of fine waste ceramic tiles, considering that other studies claim that the said aggregate possesses a pozzolanic property. Correspondingly, extend the curing period to up to 56 days or longer, if possible, to have a better understanding of the strength development of concrete. This study only considered up to 28 days of curing period due to time constraints.
- Investigate the potential use of fine ceramic tile wastes as an alternative to cement at low intervals.

References

1. Kaza, S; Yao, L.C.; Bhada-Tata, P.; and van Woerden, F. (2018). *What a waste* 2.0*: A global snapshot of solid waste management to* 2050. *Urban Development*. World Bank Publications.
2. Department of Environment and Natural Resources. (2021). DENR News Alerts. Retrieved June 18, 2023, from https://denr.gov.ph/news-events-category/news-alerts/.
3. Ahmad, J. et al. (2023). A review on ceramic waste-based concrete: A step toward sustainable concrete. *Reviews on Advanced Materials Science*, 62(1). 20230346.
4. Tinio, M.M.R.; Rollon, A.P.; and Moya, T.B. (2019). Synergy in the urban solid waste management system in Malolos City, Philippines. *Philippine Journal of Science*, 148(1), 73-97.
5. Lejano, B. et al. (2024). Enhancing compressive strength in concrete with waste ceramic tiles: Effects of selected aggregate modification treatments, water-cement ratio and curing periods for decision tree regression analysis. *Journal of Engineering Science and Technology*, 19(3), 744-761.
6. Fu, S.; and Lee, J. (2024). Recycling of ceramic tile waste into construction materials : A review. *Developments in the Built Environment*, 18,100431.
7. Elevado, K.; Galupino, J.; and Gallardo, R. (2018). Compressive strength modelling of concrete mixed with fly ash and waste ceramics using k-nearest neighbor algorithm. *GEOMATE Journal*, 15(48), 169-174.

8. Suchithra, S.; Sowmiya, M.; and Pavithran, T. (2022). Effect of ceramic tile waste on strength parameters of concrete-a review. *Materials Today: Proceedings*, 65, 975-982.
9. Meena, R.V.; Jain, J.K.; Beniwal, A.S.; and Chouhan, H.S. (2022). Sustainable self-compacting concrete containing waste ceramic tile aggregates: Fresh, mechanical, durability, and microstructural properties. *Journal of Building Engineering*, 57, 104941.
10. Xu, F.; Lin, X.; Zhou, A.; and Liu, Q. (2022). Effects of recycled ceramic aggregates on internal curing of high performance concrete. *Construction and Building Materials*, 322, 126484.
11. Clemente, S.J.C.; Lejano, B.A.; Macmac, J.D.; and Ongpeng, J.M.C. (2023). Optimization of self-compacting concrete using response surface methodology. *ASEAN Engineering Journal*, 13(2),135-143.
12. Anisuzzaman, S.M.; Joseph, C.G.; and Ednu, O.M. (2023). Optimisation of spray drying operating conditions of tomato slurry using response surface methodology. *Journal of Engineering Science and Technology* (*JESTEC*), 18(1), 112-135.
13. Elevado, K.J.T.; Gallardo, R.S.; and Galupino, J.G. (2019). Compressive strength optimization of concrete mixed with waste ceramics and fly ash. *GEOMATE Journal*, 16(53), 135-140.
14. Zhang, L. et al. (2023). Effect of ceramic waste tile as a fine aggregate on the mechanical properties of low-carbon ultrahigh performance concrete. *Construction and Building Materials*, 370, 130595.
15. Paul, S.C.; Faruky, S.A.; Babafemi, A.J.; and Miah, M.J. (2023). Eco-friendly concrete with waste ceramic tile as coarse aggregate: Mechanical strength, durability, and microstructural properties. *Asian Journal of Civil Engineering*, 24(8), 3363-3373.
16. Elevado, K.J.T.; Galupino, J.G.; and Gallardo, R.S. (2018). Artificial neural network (ANN) modelling of concrete mixed with waste ceramic tiles and fly ash. *GEOMATE Journal*, 15(51), 154-159.
17. American Concrete Institute. (1991). Standard practice for selecting proportions for normal, heavyweight and mass concrete, *ACI* 211.
18. American Society for Testing and Materials. (2018). Specific gravity and absorption of fine aggregates. American Society for Testing and Materials, *ASTM C*-128.
19. American Society for Testing and Materials. (2018). Specific gravity and absorption of coarse aggregates. American Society for Testing and Materials, *ASTM C*-127.
20. American Society for Testing and Materials. (2018). Unit weight and voids in aggregate. American Society for Testing and Materials, *ASTM C*-29.
21. American Society for Testing and Materials. (2016). Standard specification for concrete aggregates, *ASTM C*-33.
22. American Society for Testing and Materials. (2021). Standard practice for making and curing concrete test specimens in the laboratory, *ASTM C*-192.
23. American Society for Testing and Materials. (2012). Standard test method for slump of hydraulic-cement concrete, *ASTM-C*-143.
24. American Society for Testing and Materials. (2021). Standard test method for compressive strength of cylindrical concrete specimens, *ASTM C*-39.

25. Clemente, S.J.C.; Lejano, B.A.; Macmac, J.D.; and Ongpeng, J.M.C. (2023). Optimization of self-compacting concrete using response surface methodology. *ASEAN Engineering Journal*, 13(2), 135-143.
26. Sinkhonde, D. (2023). Modeling and experimental studies on energy consumption and properties of concrete containing waste brick powder and waste tire rubber for sustainable construction. *Cleaner Engineering and Technology*, 13,100631.
27. Galupino, J.; and Adajar, M.A. (2023). Response surface modelling of performance of concrete with bauxite laterite soil and fly ash. *GEOMATE Journal*, 25(107), 9-16.
28. Behera, S.K.; Meena, H.; Chakraborty, S.; and Meikap, B.C. (2018). Application of response surface methodology (RSM) for optimization of leaching parameters for ash reduction from low-grade coal. *International Journal of Mining Science and Technology*, 28(4), 621-629.
29. Lejano, B. et al. (2024). Experimental investigation of utilizing coconut shell ash and coconut shell granules as aggregates in coconut coir reinforced concrete. *Cleaner Engineering and Technology*, 21, 100779.
30. Tantoco, C.J.A. et al. (2023). Response surface methodology and artificial neural network optimization and modeling of the saccharification and fermentation conditions of the Polyhydroxybutyrate from corn stover. *Philippine Journal of Science*, 152(1), 357-374.
31. Sinkhonde, D.; Onchiri, R.O.; Oyawa, W.O.; and Mwero, J.N. (2021). Response surface methodology-based optimisation of cost and compressive strength of rubberised concrete incorporating burnt clay brick powder. *Heliyon*, 7(12), e08565.
32. Jiménez, J.R. et al. (2013). Use of fine recycled aggregates from ceramic waste in masonry mortar manufacturing. *Construction and Building Materials*, 40, 679-690.
33. Medina, C. et al. (2016). Durability of recycled concrete made with recycled ceramic sanitary ware aggregate. Inter-indicator relationships. *Construction and Building Materials*, 105, 480-486.
34. Madhavi, E.; Rao, A.; Shekar, A.; and Prbhaker, M. (2016). Experimental study of coarse aggregates and fine aggregates replaced by ceramic waste and quarry dust. *International Journal of Innovative Research in Science, Engineering and Technology*, 5(4), 4661-4664.
35. Yunus, M.; and Alsoufi, M.S. (2020). Application of response surface methodology for the optimization of the control factors of abrasive flow machining of multiple holes in zinc and Al/SiCp MMC wires. *Journal of Engineering Science and Technology*, 15(1), 655-674.
36. Lejano, B.A. et al. (2019). Compressed earth blocks with powdered green mussel shell as partial binder and pig hair as fiber reinforcement. *GEOMATE Journal*, 16(57), 137-143.
37. Liu, J. et al. (2022). Modeling and analysis of fiber-reinforced high-performance concrete strength prediction based on nonlinear programming. *Construction and Building Materials*, 322, 126421.
38. Wu, X.; Shen, Y.; and Hu, L. (2022). Performance of geopolymer concrete activated by sodium silicate and silica fume activator. *Case Studies in Construction Materials*, 17, e01513.