

COMPRESSIVE STRENGTH MODELLING OF CONCRETE MIXED WITH FLY ASH AND WASTE CERAMICS USING k -NEAREST NEIGHBOR ALGORITHM

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ABSTRACT: Excessive materials are being manufactured, and along with it are the waste products that are being produced due to the rapid growth of industries. In the Philippines, wastes such as fly ash and damaged ceramics are being considered as a construction material since there are recent researches that proved their properties are comparable to cement and aggregates. In this study, compressive strength tests (ASTM C 39) were conducted to obtain the compressive strength of the concrete mixed with varying amounts fly ash and waste ceramics. Moreover, specimens were also subjected to varying days of curing to assess their strength development. Due to the availability of a wide range of data, machine learning model, such as the k -nearest neighbor, were also considered; it can predict an unknown target parameter without consuming tremendous time and resources. Thus, this study aimed to provide a k -nearest neighbor model that will serve as a reference to predict the compressive strength of concrete while incorporating waste ceramic tiles as a replacement to coarse aggregates while varying the amount of fly ash as a partial substitute to cement. The k -nearest neighbor model used was validated to ensure the predictions are acceptable.

Keywords: Compressive strength, waste utilization, fly ash, ceramics, nearest neighbor

1. INTRODUCTION

Waste utilization has been one of the considerations in the construction industry towards sustainability. With the growing demand in the construction industry, excessive materials are being manufactured, and along with it, are the waste products that are being produced. In the Philippine context, there is an existing problem with regards to fly ash since the country mostly relies on coal-based electricity generation. There is also no ash industry in the Philippines that exists to consume all the fly ash wastes produced, which amounts to approximately 300,000 tons per annum [1]. As a result, the fly ash utilization in the country is underdeveloped. Moreover, most of the construction and demolition wastes worldwide are composed of ceramic materials [2] and these waste materials are only disposed of in landfills.

To address sustainability, these wastes, such as damaged ceramic tiles and fly ash, are being considered as a construction material since there are recent researches that proved their properties are comparable to cement and aggregates [3-8].

Due to the availability of a wide range of data gathered during the experiment, machine learning model, such as the k -nearest neighbor, were also considered; it can predict an unknown target parameter without consuming tremendous time and resources. The k -nearest neighbor (k -NN) algorithm was used because it is mainly employed

for measuring the similarity of a set of objects based on some measures of distance and is one of the oldest pattern classifier methods with no required pre-processing [9]. Thus, this study aimed to provide a k -nearest neighbor model that will serve as a reference to predict the compressive strength of concrete while incorporating waste ceramic tiles as a replacement to coarse aggregates while varying the amount of fly ash as a partial substitute to cement.

2. METHODOLOGY

Mix design of the specimens was prepared referring to the American Concrete Institute standards [10]. Moisture content, specific gravity, and absorption tests [11-12] of the components of concrete and as well as its unit weight and voids [13] were the prerequisites in preparing for the mix design. The summary of the results is shown in Table 1. In this study, the tests are similar to previous studies [14-15] for the formulation of the mix design of the study. Similarly, chemical analysis of fly ash used in the experiment was conducted [16].

This study incorporated the use of waste ceramic tiles in replacing gravel as the coarse aggregates in the design mix with the following substitutions: 0%, 18.25%, 37.5%, 56.25% and 75%. The percentages of replacements of ceramic tiles were patterned after the previous studies [8,

17]. On the other hand, Type 1 Portland Cement was also replaced by fly ash in this study considering five replacements: 0%, 12.5%, 25%, 37.5% and 50%. All replacements of both waste ceramic tiles and of fly ash were in terms of mass percentage. The control mix had pure cement and gravel. Considering the replacements of waste ceramic tiles and fly ash and the output from the Design of Experiments (DOE) conducted, a total of 17 mixes were prepared in this study.

Table 1. Summary of material properties

Description	Results
The dry rodded density of gravel	1567.839 kg/m ³
Specific Gravity of Cement	3.150
Specific Gravity of gravel	2.812
Specific Gravity of sand	2.505
Moisture Content of gravel	0.349%
Moisture Content of sand	1.566%
Absorption of gravel	1.639%
Absorption of sand	2.765%
Fineness modulus of Sand	2.760
Chemical Compounds of Fly Ash	
Silicon Dioxide (SiO ₂)	49.6%
Aluminum Trioxide (Al ₂ O ₃)	26.7%
Ferric Oxide (Fe ₂ O ₃)	4.26%
Calcium Oxide (CaO)	8.2%
Magnesium Oxide (MgO)	5.9%
Sulfur Trioxide (SO ₃)	0.83%

In order to have a systematized way of labeling the specimens, Mix IDs were used in the study. The acronyms “F” and “C” refer to fly ash and waste ceramic tiles, respectively. The number that immediately follows the acronym signifies its percentage replacement to either cement or gravel. For example, the mix ID “F50C75” refers to the mix with 50% fly ash, 50% Type 1 Portland Cement, 75% waste ceramic tiles and 25% gravel. Mix IDs are shown in Table 2:

Table 2. Mix IDs of the specimen

Mix No.	Mix ID	Fly Ash Content	Ceramic Tiles Content
M1	F0 C0	0.00%	0.00%
M2	F50 C0	50.00%	0.00%
M3	F50 C 37.5	50.00%	37.50%
M4	F25 C37.5	25.00%	37.50%
M5	F37.5 C 18.75	37.50%	18.75%
M6	F25 C0	25.00%	0.00%
M7	F25 C 18.75	25.00%	18.75%
M8	F12.5 C 37.5	12.50%	37.50%
M9	F37.5 C37.5	37.50%	37.50%
M10	F0 C37.5	0.00%	37.50%
M11	F37.5 C56.25	37.50%	56.25%
M12	F12.5 C 18.75	12.50%	18.75%
M13	F25 C56.25	25.00%	56.25%

M14	F12.5 C56.25	12.50%	56.25%
M15	F50 C75	50.00%	75.00%
M16	F0 C75	0.00%	75.00%
M17	F25 C75	25.00%	75.00%

Washed sand and river gravel were used as the conventional fine and coarse aggregates of concrete, respectively while substituting the later with glazed ceramic tiles. Although replacements were considered in the coarse aggregates of concrete, it was ensured that the sizes in each mix still adhere to the standards through performing sieve analysis [18] in all mixes. The waste ceramic tiles were manually crushed, if needed, and sieved to ensure that the grain size distribution follows the standard stipulations [18].

Considering 25-100 mm slump and a maximum size of 19.0 mm of the aggregates, the estimated mixing water that should be used is 184 kilogram per cubic meter of concrete. In addition, no chemical admixture was used in the study.

Furthermore, the water-cement ratio that was considered in this study upon further interpolation is 0.478. It was derived by having a target nominal compressive strength of 28 MPa, which is typically used in the industry. This water-cement ratio was kept constant for all mixes. A total of 306 specimens were prepared to accommodate the curing at 3 ages: 7, 28 and 56 days.

Moreover, compressive tests were performed after the specified day of curing to determine the physical properties of the specimens. The load was applied to the specimen, and the maximum load that the specimen could carry was recorded. With this, the compressive strength was computed by simply dividing the maximum compressive load that the specimen was able to carry by its average cross-sectional area.

Once the data are available *k*-NN modeling commenced. Each *k*-NN model consists of a data case having a set of independent variables labeled by a set of dependent outcomes, the research *k*-NN model classification of is shown in Fig. 1. The independent and dependent variables can be either continuous or categorical. In the study the dependent and independent variables are shown in Table 3:

Table 3. Dependent and Independent Variables

Dependent Variable(s)	Independent Variable(s)
1. 7-Days Compressive Strength	1. Fly Ash %
2. 28-Days Compressive Strength	2. Ceramics %
3. 56-Days Compressive Strength	

The *k*-nearest neighbor model used was validated to ensure the predictions are acceptable.

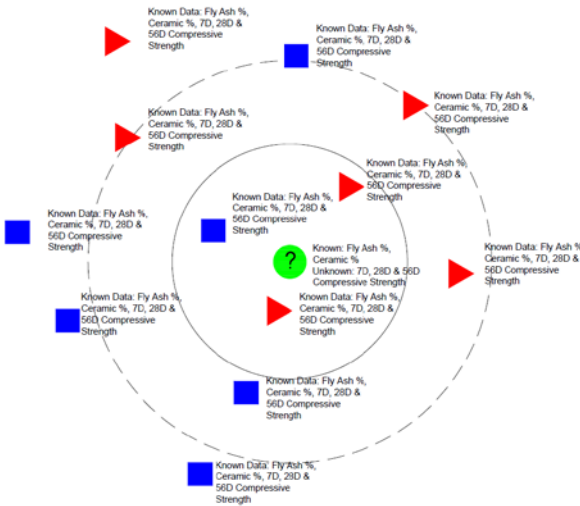


Fig. 1. k-NN model classification for the study

3. RESULTS & DISCUSSION

3.1 Compressive Strength

The compressive strengths of the conventional mix at 7, 28 and 56 days of curing periods were 21.645 MPa, 28.302 MPa, and 28.722 MPa, respectively. This implies that the 28-MPa target nominal strength was achieved. Moreover, F50C0 (M2) and F25C75 (M17) consistently achieved the minimum and maximum compressive strengths among all mixes at all ages. The results are shown in Table 4:

Table 4. Compressive strengths of all mixed

MIX No.	MIX ID	Compressive Strengths (MPa)		
		7-day	28-day	56-day
M1	F0 C0	21.65	28.30	28.72
M2	F50 C0	19.07	26.34	28.41
M3	F50 C 37.5	21.68	27.85	33.88
M4	F25 C37.5	27.29	37.21	39.20
M5	F37.5 C 18.75	24.97	32.14	35.44
M6	F25 C0	25.51	33.88	38.09
M7	F25 C 18.75	27.78	34.51	38.95
M8	F12.5 C 37.5	30.96	37.44	41.57
M9	F37.5 C37.5	25.07	33.83	35.97
M10	F0 C37.5	29.00	32.14	38.00
M11	F37.5 C56.25	27.46	34.49	38.32
M12	F12.5 C 18.75	26.00	34.06	37.90
M13	F25 C56.25	25.15	34.17	38.28
M14	F12.5 C56.25	27.53	27.23	36.36
M15	F50 C75	24.53	33.21	41.78
M16	F0 C75	24.86	33.95	39.66
M17	F25 C75	32.06	38.11	44.70
	Minimum	19.07	26.34	28.41
	Maximum	32.06	38.11	44.70

Compressive strength tests were conducted at three curing periods: 7 days, 28 days and 56 days. A sample plot is shown in Fig. 2. This was done in order to have a representation of the compressive strengths of all mixes at early, nominal and late stages for further analysis. The results are shown in Fig. 3.

It could be inferred that M17 or F25C75 consistently had the highest compressive strengths among all the other mixes at all stages. On the other hand, M2 or F50C0 had the least compressive strengths at all periods. However, it could be seen that at the 56-day period, the compressive strength of F50C0 is very close to but not greater than the strength of the conventional mix. This tremendous increase in the strength of F50C0 from its 28-day strength is due to the pozzolanic reaction.

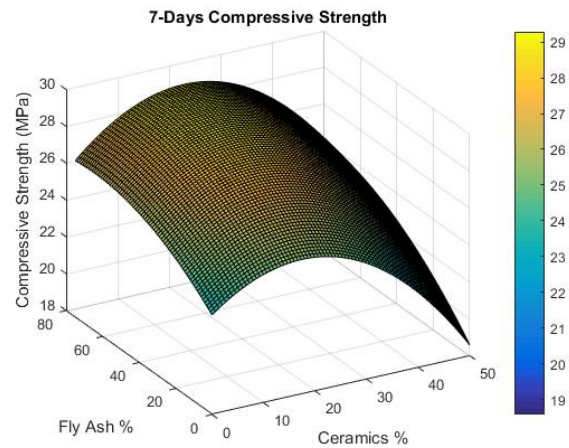


Fig. 2. 7-Days Compressive Strength (Early)

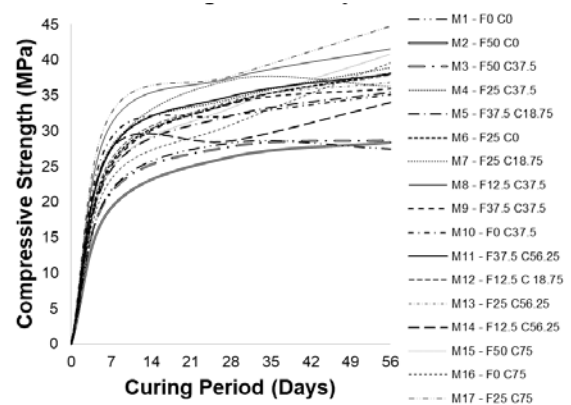


Fig. 3. Strength development of the mixtures

All compressive strengths at the 56-day period exceeded the strength of the conventional mix. Similarly, it is due to the pozzolanic reaction brought by fly ash and the waste ceramic tiles as well. Furthermore, it could be observed from the same Fig. that there is a slight difference between the projection of the strength development of M14

or F12.5C56.25 and of the conventional mix (M1 or F0C0).

The conventional mix attained 30.76%, 32.7% and 1.48% increase in the compressive strength from 7 to 28, 7 to 56 and 28 to 56 days of curing periods, respectively. The 1.45% increase from 28 to 56 days was observed to be the least percentage increase among all mixes; next to it was the compressive strength of F25C37.5 with only 5.36% increase. In terms of the least percentage increase at 7 to 28 and 7 to 56 days, F12.5C56.25 and F0C37.5 provided the least increase with only 1.10% and 31.03%, respectively.

The maximum percentage increase at 7 to 28, 7 to 56 and 28 to 56 days of curing periods were observed at F50C0, F50C75 and F12.5C56.25 with 38.12%, 70.32%, and 33.55%, respectively. The tremendous increase of F50C75 from 7 to 56 days was brought about by the pozzolanic reaction since it was established that both waste materials used, fly ash and glazed ceramic tiles, possessed pozzolanic properties.

A sample of the pozzolanic reaction is shown in Figs 4 and 5 where Scanning Electron Microscopy (SEM) images were captured at 7 and 28 days of curing periods. As seen in the Figs, less interparticle voids were present at the SEM image of the latter. This suggests that fibrillation occurred as the curing period was increased, which is an effect of the pozzolanic properties of both fly ash and waste ceramic tiles (WCT).

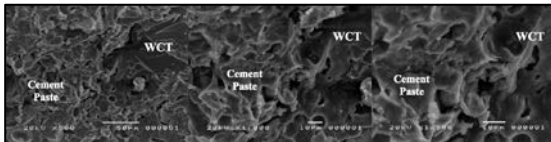


Fig. 4. SEM images of the F25C75 (M17) at 7-day curing period (from left to right: 500X, 100X and 1500X magnifications)

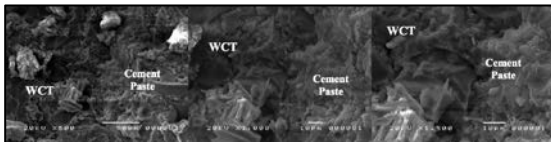


Fig. 5. SEM images of the F25C75 (M17) at 28-day curing period (from left to right: 500X, 100X and 1500X magnifications)

The 28-Days compressive strength as optimized. The percentage replacements of fly ash and waste ceramic tiles (labeled “%F” and “%C”, respectively) were accounted along with its corresponding treated data. In terms of the optimization constraints, %F and %C were maintained to be in range at 0 to 0.5 and 0 to 0.75,

respectively, while maximizing the compressive strength (labeled “f’c”). Table 5 shows the summary of the optimization constraints considered:

Table 5. 28-Days Strength optimization constraints

Name	Goal	Lower Limit	Upper Limit
% F	is in range	0.00	0.50
% C	is in range	0.00	0.75
f’c	maximize	26.34	38.11

With the optimization, it could predict the resulting compressive strength given the percentage replacements of fly ash and waste ceramic tiles. With 0.92 desirabilities, Equation 1 was the generated.

$$f'c = 30.01565 + 33.35915 \%F + 0.98742 \%C + 8.83664 \%F \%C - 79.86914 (\%F)^2 + 2.53592 (\%C)^2 \quad (\text{Eq. 1})$$

Where:

f’c = predicted strength (MPa);

%F = percentage of fly ash;

%C = percentage of waste ceramic tiles.

The effects of cement and coarse aggregates modification as previously discussed were also observed –an increase in %FA resulted to an increase in strength up to an optimum amount and an increase in %WCT yielded an increase in strength. The combination of both waste materials was gradually producing higher compressive strengths.

3.2 k-Nearest Neighbor Algorithm Model

k-Nearest Neighbor (k-NN) algorithm is one of the simplest classification algorithms and it is one of the most used learning algorithms [19-20]. k-NN predictions are based on the intuitive assumption that objects close in distance are potentially similar, it makes good sense to discriminate between the K nearest neighbors when making predictions [21].

In the k-Nearest Neighbor (k-NN) algorithm, the following were considered, shown in Table 6:

Table 6. Considerations in the k-Nearest Neighbor (k-NN) algorithm

Description	Value
Sample Size	75%
Testing Size	25%
v-Value	10
Seed	1000

The resulting k -optimal is 2, which means that there are 2 closest training samples were selected based on a distance metric and voted for the most number of samples per class.

To validate, the Observed Compressive Strength vs. Observed Compressive Strength by the k -Nearest Neighbor (k -NN) algorithm were compared. A line that shows equality between the variable observed (Experimental Data) on the horizontal axis of a diagram and the variable predicted (k -Nearest Neighbor (k -NN) algorithm) on the vertical axis. The plots should be near the equality line to ensure the predictions are acceptable, shown in Fig. 6.

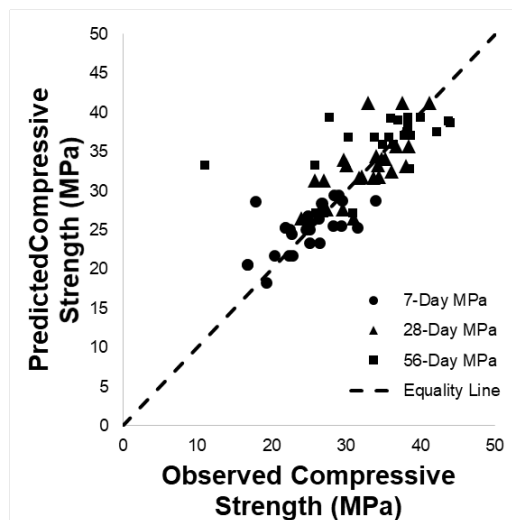


Fig. 6. Equality line of the k -Nearest Neighbor (k -NN) algorithm Model

As seen in Fig. 6, it could be said that although there were some data points far from the equality line, most of the data points were still close to the projected line. This means that there was a small residual observed between the experimental data and the theoretical or projected data.

4. CONCLUSIONS & RECOMMENDATIONS

Based on the test results, the conventional mix attained its target nominal strength with 28.302 MPa. Among all modified mixes, F50C0 and F25C75 resulted in the least and highest compressive strengths at all ages with 26.343-MPa and 38.112-MPa nominal strengths, respectively. All mixes had an increasing nominal compressive strength when waste ceramic tiles replacement was also increased except for the mix with 12.5% fly ash replacement, where the strength decreased from 37.5% to 56.25% waste ceramic tiles substitution. In terms of cement variation, all combinations showed an increasing nominal strength up to an optimum amount. Based from the

experimental data, all combinations have shown an optimum amount of 20% to 30% fly ash replacement except for the mix with 37.5% waste ceramic tiles replacement, which had an optimum amount of 10% to 20% fly ash substitution. Moreover, all combinations with 50% fly ash substitution attained less compressive strengths relative to mixes with 0% fly ash replacement.

The pozzolanic reaction has played a major role in the strength development of the modified mixes considering that both waste materials used, ceramic tiles and fly ash, possessed pozzolanic properties.

The k -Nearest Neighbor (k -NN) algorithm provided a model that can predict based on the intuitive assumption that objects close in distance are potentially similar. The Observed Compressive Strength vs. Observed Compressive Strength by the k -Nearest Neighbor (k -NN) algorithm was compared, and their plots are near the equality line, thus, acceptable.

To further improve the conduct of the study, it is recommended to provide superplasticizers or other additives in the mixes in order to address the high absorption rate of ceramic tiles that lead to poor workability. In this way, it could result to better applicability in the construction industry. In addition, the fly ash and waste ceramic tiles replacement could be limited to 0% to 30% and be extended to 0% to 100% substitutions.

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