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UTILIZATION OF AGGREGATE QUARRY WASTE IN CONSTRUCTION INDUSTRY

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ABSTRACT: The use of solid wastes as a new ingredient in construction materials is one possible innovative effort to reduce environmental degradation and to facilitate sustainable use of natural resources. The disposal of the huge amount of wastes from aggregate quarry (WAQ) is one adverse environmental effects of quarrying activities. Finding useful application of this solid waste, specifically as a substitute for fine aggregates in concrete mix, alleviates disposal problems and helps the construction industry to come up with concrete products at lesser cost. This study investigates the structural performance of concrete with WAQ as substitute for fine aggregates in a concrete mix following ASTM standards. Concrete with WAQ as fine aggregates achieved almost 78% of its target compressive strength. The reduced compressive strength is due to the finer and less-angular particles of WAQ in comparison to sand. Empirical model was formulated that can be used to predict the compressive strength of concrete with WAQ as substitute for sand. Using the formulated model, the optimum compressive strength can be achieved at 85% substitution for sand. The flexural strength of concrete with WAQ was in the range of 69% to 72% of the flexural strength of concrete without WAQ. The presence of WAQ in the concrete mixture has no significant effect in its unit weight, however, it affects the workability of the mix due to its cohesive property thus requires higher water-cement ratio. Test results proved that concrete with WAQ as substitute for fine aggregates has strength properties adequate for structural application.

Keywords: Aggregate Quarry Waste, Compressive Strength, Flexural Strength, Unit Weight

1. INTRODUCTION

Concrete is one of the most used building materials. The boom in construction industry leads to the exploitation of natural resources like river sand and gravel since these are the main source of raw materials for concrete production. The onset of shortage and increasing cost of construction materials has made it important to consider alternative materials that can be used in construction industry. Recycling waste to be potential materials used in construction has become a trend worldwide as this facilitates long term rational and sustainable use of the natural resources and reduces construction cost.

Quarrying activities generate huge amount of solid wastes which are most often dump in open fields. The disposal of aggregate quarry waste is one adverse environmental effect of quarrying activities. Improper management of this waste material can bring serious detrimental effects to the population and the environment. The use of solid wastes as new ingredient in construction materials is one possible innovative effort to reduce environmental degradation and alleviate disposal problems.

Several studies discussed the utilization of solid wastes as an alternative construction material. Recycled aggregates produced from pulsed power technology can be used as concrete component with fly ash as substitute for cement [1]. Waste carpet fiber can suitably be used as fiber reinforcement in concrete [2]. Tungsten mine waste with ground granulated blast-furnace slag is found to be feasible in the development of mortar with acceptable compressive strength [3]. Paper mill sludge, an industrial waste generated by paper mill factories is viable as partial replacement of fine aggregates in manufacturing fresh concrete intended to be used for low cost housing projects [4]. Ceramic waste and quarry dust aggregates have been found as a possible replacement for conventional crushed stone coarse and fine aggregates [5].

This study discusses the structural performance of concrete with waste from aggregate quarry (WAQ) as substitute for fine aggregates in concrete production. Specifically, it determines the compressive and flexural strength of concrete mix when fine aggregates are partially and fully replaced with WAQ in accordance with ACI 211. The study describes the most suitable concrete mix proportion with WAQ as fine aggregates that will yield the highest strength of concrete in compression and flexure. It also investigates the effect of using WAQ in the workability of concrete mix and in the unit weight of hardened concrete.

2. WASTE FROM AGGREGATE QUARRY

Waste from aggregate quarry is a by-product generated from quarrying activities during the production of aggregates. The solid wastes were collected from a quarrying site at Ternate, Cavite in the Philippines. These are waste products from crushing and washing of mountain rocks to produce coarse and fine aggregates. The residues, considered as solid wastes, are produced during the washing of crushed rocks in the siltation pond through the natural process of sedimentation. Moist samples from this source have grayish black color with soft consistency resembling that of fine sand when dry. Previous studies discussed the geotechnical characteristics of WAQ and was proven to be suitable embankment material [6,7]. Prior to experimentation, the solid wastes were dried and sieved to ensure that the grain size conforms to the ASTM requirements for fine aggregates.

3. EXPERIMENTAL PROGRAM

A series of laboratory tests in accordance to ASTM standard procedures were carried out to determine the structural performance of concrete with WAQ as substitute for fine aggregates. Grain-size analysis, Scanning Electron Microscopy (SEM) test, and Energy Dispersive X-Ray Spectroscopy (EDS) were performed to determine the grain-size distribution, microfabric structure and chemical composition of WAQ, respectively. Its physical and chemical properties were analyzed and compared with that of conventional fine aggregates (sand).

To determine the compressive strength, cylindrical specimens with dimensions of 150mm diameter by 300mm high were subjected to compression test in accordance to ASTM C39. To determine the flexural strength, beam specimens with dimensions of 150mm x 150mm x 500mm were subjected to flexural strength test under a third-point loading condition following the procedure described in ASTM C78. A total of 92 cylindrical specimens and 76 beam specimens were tested.

In this study, WAQ was used as partial and full substitute for fine aggregates (sand) in a concrete mix. WAQ substitution were done in four (4) mix proportions: 25% , 50% , 75% and 100% (full substitution) designated as 25B, 50B, 75B and 100B, respectively. A conventional concrete without WAQ, referred to as trial mix and designated as 0B was used as control specimen and base data for comparison of the obtained test results. A typical concrete batch mix proportion is shown in Table 1. The percentage substitution is done by volume using a specific gravity (Gs) of 2.7 for sand and 2.57 for WAQ [6]. The slump of each mixture was maintained at 50 mm to 75mm. During the mixing process, it was observed that the 100B mixture requires greater amount of water to achieve the required slump and to make the mixture workable. The target compressive strength of the concrete mix was 28 MPa. Compressive and flexural strengths were measured after 7th , 14th, 21st, and 28th days curing period designated as 7D, 14D, 21D, and 28D curing days, respectively. Prior to testing, the specimens' weight and volume were measured to determine the unit weight of hardened concrete.

Table 1 Concrete mix proportion

	Mix Proportions				
	0B	**25B**	**50B**	**75B**	**100B**
Sand m^3 kg.	 0.028 75.60	 0.021 56.70	 0.014 37.80	 0.007 18.90	 0.0 0.0
WAQ m^3 kg.	 0.0 0.0	 0.007 17.99	 0.014 35.98	 0.021 53.97	 0.028 71.96
Gravel kg	109.8	109.8	109.8	109.8	109.8
Water liter	15	15	15	15	15 to 18
Cement bag	1	1	1	1	1

4. TEST RESULTS

4.1 Grain-Size Analysis and Chemical Composition

The distribution of grain sizes of WAQ and sand was determined using sieve analysis by mechanical method in accordance with ASTM D422. Fig. 1 illustrates the grain size distribution curve. The grain-size distribution curve shows that WAQ has more percentage of finer particles as compared to sand.

The chemical composition of WAQ was obtained from EDS test. Table 2 presents the chemical composition of WAQ in comparison to sand. The data showed that WAQ and sand consisted of the same chemical elements but with different proportions. WAQ has 5.52% more silicon, 5.99% more Iron and 1.11% more calcium as compared to sand. The elements that contribute to increase bonding of aggregates together are composed of silicon, calcium, and iron. Silicon is a significant element in cement amounting to 17%

to 25% of its chemical composition [8]. Fresh concrete containing WAQ was observed to be more cohesive and less prone to segregation as compared to concrete mix without WAQ. However, water requirement increased in concrete mix with more WAQ to improve its workability. These observed effects are due to the presence of more silicon content, similar to the effect of mineral admixture like silica fume. The presence of silica fume in concrete increases the degree of flocculation, substantially reduces bleeding by physically blocking the pores in the fresh concrete and results to improved strength properties [9].

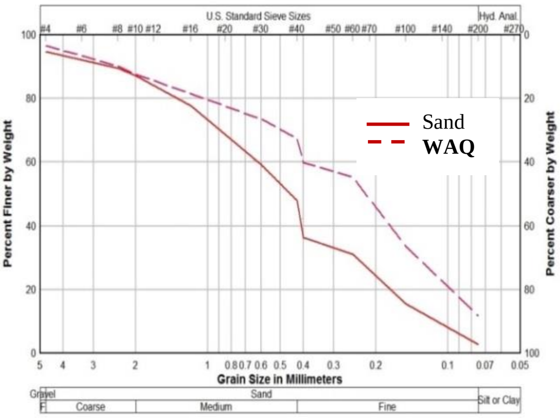


Fig. 1 Grain-size distribution curve of WAQ and sand

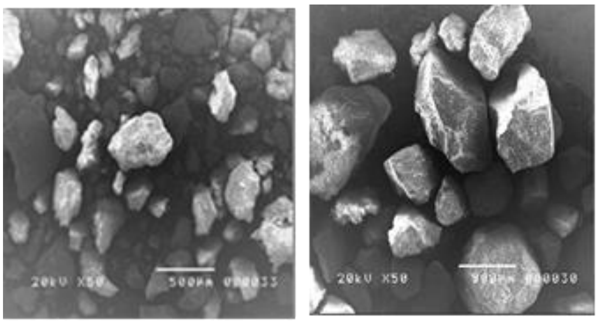
Table 2 Chemical composition of WAQ and sand

Element	WAQ	Sand*
	%	%
Magnesium (Mg)	0.59	2.06
Aluminum (Al)	8.15	6.33
Silicon (Si)	24.43	18.91
Potassium (K)	1.00	0.43
Calcium (Ca)	2.77	1.66
Iron (Fe)	6.92	0.93
Sodium (Na)	1.10	3.68
Total Carbon (C) and Oxygen (O)	55.41	34.00

* from Gallardo & Adajar (2006) [4]

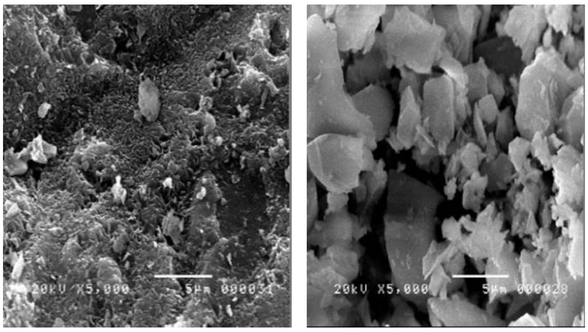
4.2 Microfabric Structures

The micro-fabric structure of WAQ and sand was obtained using the Scanning Electron Microscope (SEM). As seen in Fig. 2a, WAQ has smaller grain sizes than sand. Its structure consisted of a combination of rounded and sub-angular grains with more silt-size grains while sand is comprised of angular grains of uniform-size particles. At higher magnification (Fig. 2b), the micro fabric of WAQ appears to be assemblages of clustered platy particles while sand's grain consisted of flaky particles arranged in some random direction with large inter-assemblage pore spaces depicting loose packing.



WAQ Sand

Fig. 2a Micrographs at 50X magnification



WAQ Sand

Fig. 2b Micrographs at 5000X magnification

4.3 Compressive Strength

A tabulated summary of the compressive strength of concrete specimens with different variations of WAQ can be seen in Table 3.

Table 3 Compressive strength of concrete with varying percentage of WAQ

Average Compressive Strength (MPa)					
Curing Day	0B	25B	50B	75B	100B
7D	21.07	11.68	10.02	17.18	12.62
14D	24.23	14.64	13.13	19.12	14.94
21D	26.28	15.88	14.70	21.51	18.95
28D	28.44	17.28	15.93	22.19	20.61

The control specimen (0B) reached the target compressive strength of 28 MPa at the 28th day curing period. Concrete with WAQ (25B, 50B, 75B, and 100B) have compressive strength lower than 0B. This was observed in all curing periods (7D, 14D, 21D, and 28D). Of the mix with WAQ, the 75B mix achieved the highest compressive strength and attained an almost 78% of the target strength while the 50B mix has the least compressive strength which is almost 56% of the target strength at 28th day curing period.

Figure 3 shows the compressive strength against the curing period of the specimens. It was observed that the increase in compressive strength with respect to curing period of concrete with WAQ follows the same trend as the increase in strength of the control specimen. The compressive strength increase ranges from 7% to 17% per week. The 75B mixture can be considered to have early compressive strength development since the achieved strength at 7th day is almost 77% of its 28th-day strength.

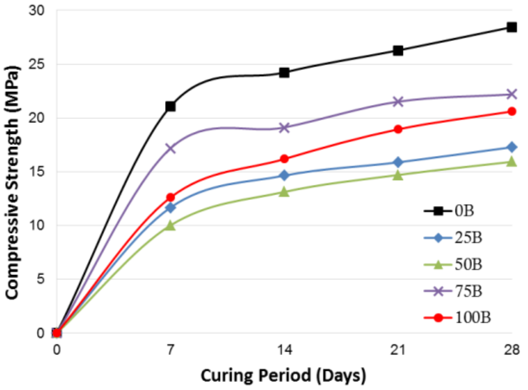


Fig. 3 Compressive strength vs. curing period

Figure 4 shows the relationship between the compressive strength and the WAQ substitution in a concrete mix.

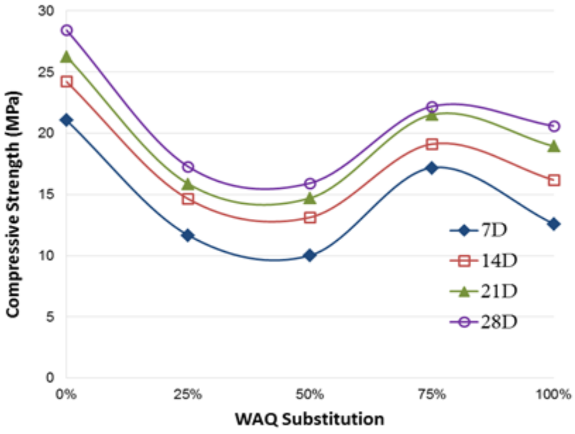


Fig. 4 Compressive strength vs. WAQ Substitution

The addition of WAQ resulted to a decrease in compressive strength. Comparing the compressive strengths with that of 0B mix, the maximum decrease in strength was observed in 50B mix while the minimum decrease was noted in 75B mix. The decrease in compressive strength can be attributed to the finer particles of WAQ in comparison to sand as seen from the grain-size distribution curve (Fig. 1). Moreover, the shape of WAQ particle is rotund and less angular than sand as seen from SEM results (Fig. 2a and Fig. 2b). Finer and less angular particles are factors that can contribute to reduction in particles' frictional resistance, thus can lead to reduction in compressive strength [10]. However, when the percentage of WAQ was more than 50%, it started to gain a slight increase in compressive strength. When WAQ was more predominant in quantity than sand, as in the case of 75B, it contributed positive results which can be attributed to its cohesive property, thus increases the bonding resistance between particles. From test results, the positive effect of cohesiveness was observed when the quantity of WAQ was more than the quantity of sand. However, at 100B mix, the cohesive property of WAQ produced negative effect in terms of the workability of the concrete mix. More water has to be added in the mix to attain the desired slump and to make the mix more workable, thus resulted to reduction in compressive strength.

4.3.1 Formulation of Empirical Model to Predict the Compressive Strength

The compressive strength for each percentage WAQ substitution was presented in normalized form by dividing the experimental data with the compressive strength of the control specimen. The normalization of data was done to obtain a model that will predict the compressive strength of concrete mix with WAQ substitution at any target compressive strength and at any curing period. Figure 5 shows the normalized graph of the compressive strength against the percentage WAQ substitution. The data points were plotted in a scattered matter and yielded a trend line equation in the form:

$$fc = \left(-7.505x^4 + 11.001x^3 - 2.176x^2 - 1.656x + 1\right)fco \tag{1}$$

where:

fc = the compressive strength of concrete with $x\%$ WAQ

fco = the compressive strength of concrete without WAQ (control specimen)

x = WAQ substitution (in decimal form, i.e. 25% is 0.25)

The equation has a coefficient of determination, $R^2 = 0.9631$. The coefficient of determination, R^2 closed to 1.0 indicates that the model fits the data well. From the equation obtained, the optimum WAQ percent substitution for sand is at 85% in order to produce the highest compressive strength of the concrete mix with WAQ.

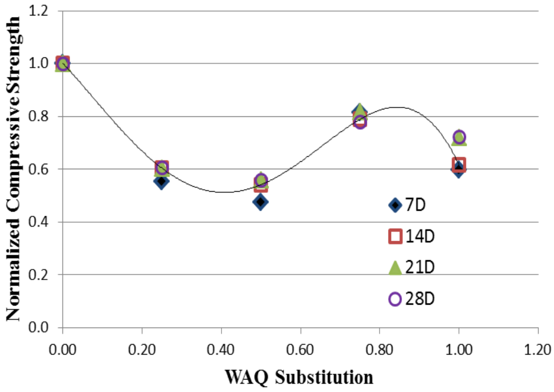


Fig. 5 Normalized compressive strength vs. WAQ substitution

4.3.2 Statistical Analysis on Compressive Strength

To verify the predictive capability of the proposed model, the compressive strength (*fc*) calculated using the proposed model was compared with the measured values from experimentation. Statistical analysis using T-test for paired samples was performed to determine if there is a significant difference between the measured values and the predicted values. The paired T-test results for 16 number of observations with a level of significance equals to 0.05 ($\alpha = 0.05$) showed a t_{stat} value (0.466) less than $t_{critical}$ (1.753) and the *p*-value (0.324) greater than 0.05. It can be stated that, at 95% confidence level, there is no significant difference between the measured compressive strengths and the predicted compressive strengths using the formulated model. The strength of association between measured *fc* and the predicted *fc* was verified using the Pearson's correlation coefficient and the data are presented in a scatter plot as shown in Figure 6. The scatter of data points is nearer to a straight line which means that there is a linear positive correlation between the measured and predicted *fc*. The analysis yielded a Pearson correlation value of 0.97 indicating a very strong association between the two variables (measured and predicted *fc*) [11]. It can be concluded that the proposed model (Eq. 1) can be used to predict the compressive strength of concrete with WAQ as substitute for fine aggregates as a function of the compressive strength of control specimen at any curing period.

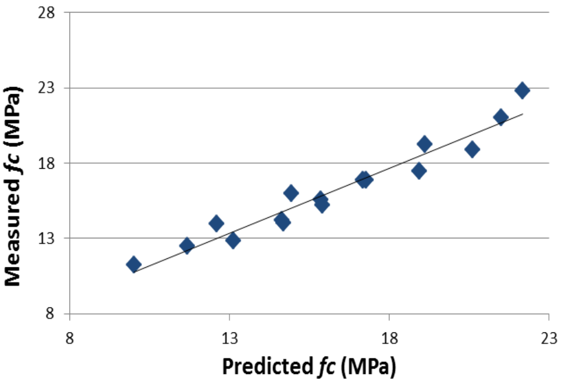


Fig. 6 Correlation of measured *fc* with predicted *fc*

4.4. Flexural Strength

The Modulus of Rupture of concrete represents its flexural strength. It is the capacity of concrete to resist failure in bending. The average flexural strength of the specimens is presented in Table 4. It was observed that the flexural strength of concrete with WAQ was in the range of 69% to 72% of the flexural strength of control specimen (0B). The reduced flexural strength can be attributed to the smooth surface texture of WAQ. Smooth texture of aggregate results to weaker bond between the concrete paste and the aggregates, thus leads to lower strength. Furthermore, the flexural strength of concrete with WAQ was found to be 12% to 18% of its compressive strength. This is in agreement with the findings of National Ready Mixed Concrete Association [12] that the flexural strength of conventional concrete is about 10% to 20% of the compressive strength.

Table 4 Flexural strength of concrete with varying percentage of WAQ

WAQ SUBSTITUTION	FLEXURAL STRENGTH (MPa) AT 28TH DAY
0B	4.25
25B	2.98
50B	3.08
75B	2.94
100B	3.26

4.5 Unit Weight of Hardened Concrete

The unit weight of hardened concrete is critical to the performance of the structure. Concrete with lower density indicates the presence of more voids. The grading and size distribution has a significant contribution to the unit weight of concrete. It is expected that when the particles are of uniform size, the void spaces between particles are greater. But when a varying range of sizes is used, the void spaces are filled resulting to a larger unit weight. The unit weight of hardened concrete was obtained to determine the effect of WAQ substitution and the results are presented in Table 5. The unit weight of hardened concrete with WAQ was slightly lower than the unit weight of 0B mix. The decrease in unit weight was in the range of 1% to 2% which can be considered as insignificant. This was attested by the result of statistical analysis. Statistical test of One-way ANOVA yielded a *P*-value greater than 0.05. This indicates that the presence of WAQ in the concrete mixture did not produce significant reduction nor increase in its unit weight.

Table 5 Unit Weight of Concrete Cylinders in KN/m^3

Curing Day	0B	25B	50B	75B	100B
7D	23.40	23.13	23.34	23.23	23.16
14D	23.37	22.9	23.09	22.99	22.93
21D	23.28	23.10	23.29	23.18	23.13
28D	23.92	23.34	23.54	23.44	23.37

5. CONCLUSION

The structural performance of concrete with waste from aggregate quarry (WAQ) as a substitute for sand was investigated. The following conclusions were drawn from the experimental results:

Waste from aggregate quarry contains more silicon, iron, and calcium as compared to sand. These are elements that caused concrete mixture with WAQ to have an increased cohesive property. SEM results showed that WAQ has finer, less-angular particles than sand. The finer particles of WAQ and presence of more Silicon, Iron, and Calcium elements produced positive effect in terms of cohesive property of the concrete.

Concrete with WAQ as fine aggregates achieved an almost 78% of the compressive strength of concrete without WAQ. Empirical model was formulated that can be used to predict the compressive strength of concrete with WAQ as substitute for sand. Using the formulated model, the highest compressive strength can be achieved at 85% WAQ substitution for sand. The flexural strength of concrete with WAQ was in the range of 69% to 72% of the flexural strength of concrete without WAQ and was found to be 12% to 18% of its compressive strength. The reduced compressive and flexural strengths can be attributed to the finer, less-angular particles and smooth surface texture of WAQ in comparison to sand

The presence of WAQ in the concrete mix has no significant effect on the unit weight of hardened concrete, however, it affects the workability of the mix due to its cohesive property thus requires higher water-cement ratio.

Test results proved that waste from aggregate quarry can be used as substitute for fine aggregates in a concrete mix and produced strength properties adequate for structural application. This study offers an effective waste management solution for WAQ and introduces an alternative material in concrete production thus contributing to a sustainable development.

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