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Research Article

EFFECT OF QUARRY WASTE POWDER ON THE FRESH AND HARDENED PROPERTIES OF CEMENT MORTAR

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ABSTRACT

The mining activities create considerable problems all over the world that affect nature in several aspects. The disposal of waste materials causes contamination of water sources, environmental pollution, and the destruction of local ecology. Therefore any strategy put forward for the utilization of waste materials will help to sustainable development. This study, therefore, aims to research the possibility of utilizing quarry waste material (QWM) in cement composites. The QWM was initially dried and then ground to powder to obtain micron-sized quarry waste powder (QWP). The QWP was then incorporated into the cement mortar by using two different methods, namely, the cement substitution method and the aggregate substitution method. In both methods, the substitution ratio of QWP was set as 10, 20 and 30% by weight of cement and the fine aggregate, respectively. The fresh and hardened properties of the QWP-modified mortars were obtained by determining the flow value, fresh density, oven-dry density, water absorption, voids content, and compressive strength. Test results showed that the flow value was significantly reduced with the incorporation of QWP and that the aggregate substitution method caused higher drops in the flow value. The effect of QWP on the physical properties varied depending on the incorporation method. The substitution of QWP by cement resulted in higher water absorption, lower oven-dry density, and higher voids content compared to those of the reference. However, substituting QWP with fine aggregate did not significantly alter the water absorption and the oven-dry density but reduced the voids content. The compressive strength reduced at higher levels when QWP was substituted with cement compared to the reference. Therefore substituting QWP with fine aggregate suggests a better way of utilizing this material in cement composites where compressive strength is a significant parameter.
Keywords: Quarry waste, cement mortar, compressive strength, physical properties.

1. INTRODUCTION

Recently, the increasing population and expanding urbanization in combination with the rapid growth of construction activity causes immense demand for high-quality materials. To meet the demand, excessive mining and consumption of natural resources have increased, especially since the last decade resulting in scarcity of resources [1,2]. These mining activities have consequently created several problems such as contamination of the water sources, environmental pollution,

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and destruction of the local ecology [3]. Sustainable solutions are therefore required to overcome these issues by reus ing and/or recycling the waste materials [4]. Therefore beneficial use of wastes such as industrial and agricultural wastes has been a significant topic of interest to many researchers [5,6].

By-products due to the industrial processes are being produced in huge amounts all over the world and their handling, processing, and disposal are taking up considerable effort and increasing financial cost and environmental issues [7]. On the other hand, construction solid wastes, such as old concrete, waste glass, clay bricks, ceramic tiles, and rubbers have been explored for possible use either as supplementary cementitious material or as an aggregate [8–11].

Unlike supplementary cementitious materials, micro fillers with comparable grain size as cement, such as limestone powder, rock dust, mine tailings, seashell waste, and other inert solid wastes, generally do not show cementitious properties [12]. However, recent studies show that the incorporation of such fine materials may enhance the performance of concrete in certain ways such as improved compressive strength [13,14], improved workability [15], cost-saving and utilization of waste materials [16], and an improved bond between steel and concrete [14]. The utilization of micro fillers in cement mortar or concrete is usually by substituting cement or aggregate by different quantities [12].

As explained above, any strategy to help reduce the use of natural sources and also utilize waste materials will contribute to sustainable development and reduce arising environmental and economic issues. Therefore in this study, micron-sized quarry waste (QW) material obtained from a local ready-mixed concrete plant was used in cement mortar by substituting cement and fine aggregate at definite ratios by weight and its effect on fresh and hardened properties of cement mortar was quantitatively researched.

2. EXPERIMENTAL PROGRAM

2.1. Materials and Mix Design

In this research, ordinary Portland cement CEM I 42.5R with a specific gravity of 3.1 was used as binder in the mortar production. Siliceous sand with a particle density of 2.7 kg/dm^3 and a maximum particle size of 4 mm was used throughout the study as the fine aggregate. QW material was received in the form of a wet slurry, from a local ready-mixed concrete plant. It was initially dried in an oven at 100 °C for 24 h and then ground to powder by using a laboratory type grinder and finally sieved through 90 μm sieve to obtain quarry waste powder (QWP). The particle density of QWP was determined as 2.73 kg/dm^3. Chemical compositions of QWP and cement are presented in Table 1.

The QWP was introduced into the mortar mixes by substituting the cement and fine aggregate by 10, 20 and 30% by weight. The reference mortar was designed to have an equal volume portion of cement paste (50% by vol.) and fine aggregate (50% by vol.), and the water to cement ratio was fixed at 0.5. Mix proportions are presented in Table 2. The mixes were coded according to the QWP substitution method and by the substitution ratio, where C represents cement substitution, and A represents the aggregate substitution by QWP, respectively. The numbers 10, 20 and 30 represent the substitution ratios, respectively.

Table 1. Chemical composition and physical properties of QWP and cement

Oxide content	Chemical composition (wt. %)	
	QWP	Cement
SiO_2	54.78	19.89
Al_2O_3	14.97	4.74
Fe_2O_3	8.02	3.98
CaO	5.95	62.22
MgO	3.49	1.23
SO_3	0.35	3.74
K_2O	1.78	0.26
Na_2O	2.48	0.83
TiO_2	1.08	-
P_2O_5	0.17	-
Cr_2O_3	0.03	-
MnO	0.16	-
ZnO	0.02	-
SrO	0.02	-
Cl	0.01	0.03
Loss on ignition	6.54	2.12

Table 2. Weight of the constituents (in kg) for 1 m^3 mortar

Mix ID	Cement	Water	Sand	QWP
Reference	608.0	304	1350	-
C10	547.2	304	1350	60.8
C20	486.4	304	1350	121.6
C30	425.6	304	1350	182.4
A10	608.0	304	1215	135.0
A20	608.0	304	1080	270.0
A30	608.0	304	945	405.0

2.2. Testing Procedure

The workability of the mortar mixes was determined by measuring the flow value according to EN 1015-3. A truncated conical mould with height of 60 mm, internal diameter of 100 mm at the bottom and 70 mm at the top was filled with fresh mortar. The mortar was introduced in two equal layers and each layer was compacted by 15 strokes of a tamper. The mould was then vertically raised and the mortar was spread out by jolting the flow table 15 times. The diameter of the mortar was measured in two directions at right angles and the average value was recorded as the flow diameter. The unit weight of the fresh mortar mixes was determined by proportioning the mass of mortar to the volume it occupied. The compressive strength was determined on 50x50x50 mm cubes at 3, 7 and 28 days in accordance with ASTM C109 and 3 samples were used for each mix to determine the average compressive strength. The samples were demolded 24 h after the production and were cured in water at a temperature of 21±2 °C until the testing date. The water absorption, oven-dry density and voids content of the samples were determined according to ASTM C642 on two samples with diameter and height of 100 mm and 50 mm, respectively, at the age of 28 days.

3. RESULTS AND DISCUSSION

The fresh properties of mortar mixes are presented in Table 3. Fresh density and flow values varied between 2164-2221 kg/m^3 and 107-191 mm, respectively. The substitution of QWP by cement and fine aggregate resulted in slight drops in the fresh density. The reduction became rather significant at substitution ratios beyond 10%. The workability of the mortar mixes was significantly reduced by QWP substitution; comparing the two replacement methods, the incorporation of QWP as fine aggregate replacement resulted in greater reductions in the flow values. This is mainly due to the fineness of the QWP particles; since its particle size is lower than the fine aggregate it substitutes, reduction in workability is therefore a predictable outcome. Therefore it should be noted that, in QWP-modified mortars, in order to control the workability at the desired value, higher water content should be employed. This could also be achieved by utilizing a superplasticizer at desired dosages without changing the water content if strength is of concern.

The average of physical properties of the mixes such as water absorption by mass, oven-dry density, and voids content are listed in Table 4. Test results showed that substituting QWP by cement resulted in higher water absorption and the increase in substitution ratio further increased this property. However, substituting fine aggregate (sand) by QWP only slightly increased the water absorption. The oven-dry density was slightly reduced by the incorporation of QWP, the increase in QWP replacement ratio resulted in higher reductions in all mixes, compared to the reference mix. The voids content increased when cement was replaced with QWP, however substituting fine aggregate with QWP reduced the voids content up to about 5%, compared to the reference mix which demonstrates that the QWP is capable of filling the voids within the cement matrix when substituted with the fine aggregate. On the other hand, cement substitution provides lower density compared to the other mixes.

Table 3. Fresh properties

Mix ID	Fresh density (kg/m^3)	Flow value (mm)
Ref	2221	191
C10	2214	160
C20	2202	154
C30	2164	139
A10	2210	130
A20	2185	107
A30	2175	116

Table 4. Physical properties

Mix ID	Water absorption (%)	Oven-dry density (kg/m^3)	Voids content (%)
Ref	8.6	2061	19.2
C10	9.6	2014	19.2
C20	9.9	2004	20.9
C30	10.6	1990	22.1
A10	8.8	2048	18.2
A20	9.0	2032	18.5
A30	9.0	2021	18.4

The compressive strength test results and the standard deviation values are presented in Table 5, and the strength development of the mixes are plotted in Figure 1. Substituting QWP with both cement and fine aggregate resulted in drops in compressive strength and increasing the QWP ratio resulted in higher drops. Comparing the two substitution methods, aggregate substitution was found to be a better way of utilizing QWP considering the compressive strength. The compressive strength results of A10 mix were found to be close to those of the reference mix at all ages, which may indicate an optimum amount to be used in the cement matrix without causing a significant reduction in the compressive strength.

Table 5. Compressive strength

Mix ID	Compressive strength (MPa)		
	3d	7d	28d
Ref	31.7 (1.3)	37.6 (1.1)	44.0 (0.9)
C10	26.5 (0.9)	30.4 (0.8)	36.9 (0.6)
C20	21.5 (1.1)	24.8 (0.7)	29.8 (1.0)
C30	18.2 (0.8)	21.3 (1.2)	25.6 (1.3)
A10	32.4 (1.0)	33.7 (2.0)	42.9 (2.2)
A20	28.1 (0.7)	30.4 (0.7)	37.9 (1.5)
A30	22.2 (0.7)	26.7 (0.6)	30.2 (0.8)

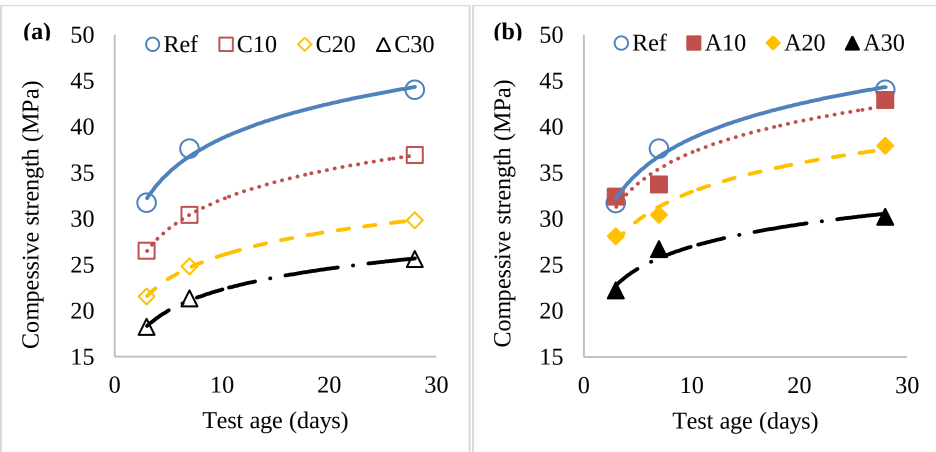

Figure 1. Compressive strength development of mortar mixes where QWP is used as: (a) cement replacement, (b) aggregate replacement

4. CORRELATIONS BETWEEN PHYSICAL and MECHANICAL PROPERTIES

In this section, the test results obtained are used to establish correlations between the available physical and mechanical test data and to statistically analyze the results. The relationship between compressive strength and oven-dry density (Fig. 2) yielded a high correlation with an R^2 value of 0.87, however, the correlation between compressive strength and voids content (Fig. 3) was found to be weaker with an R^2 value of 0.54. The compressive strength of the mortar mixes showed an increasing trend with increased oven-dry density, on the other hand, the compressive strength was found to be inversely correlated with the voids content.

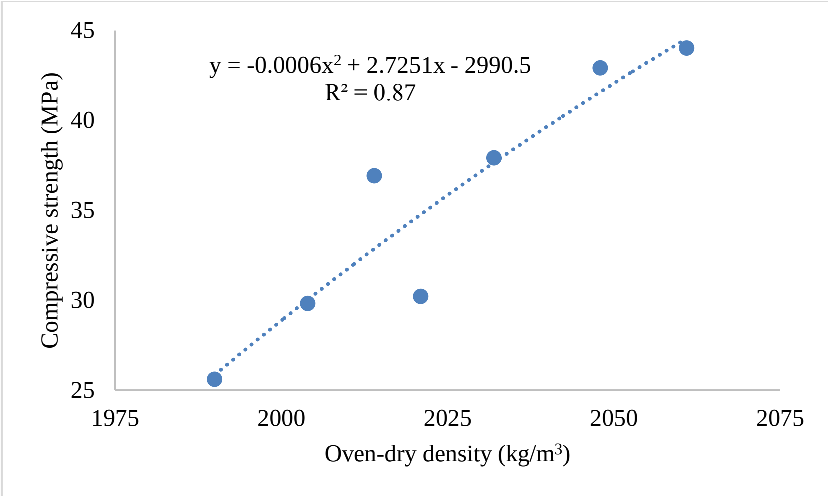

Figure 2. The relationship between compressive strength and oven-dry density

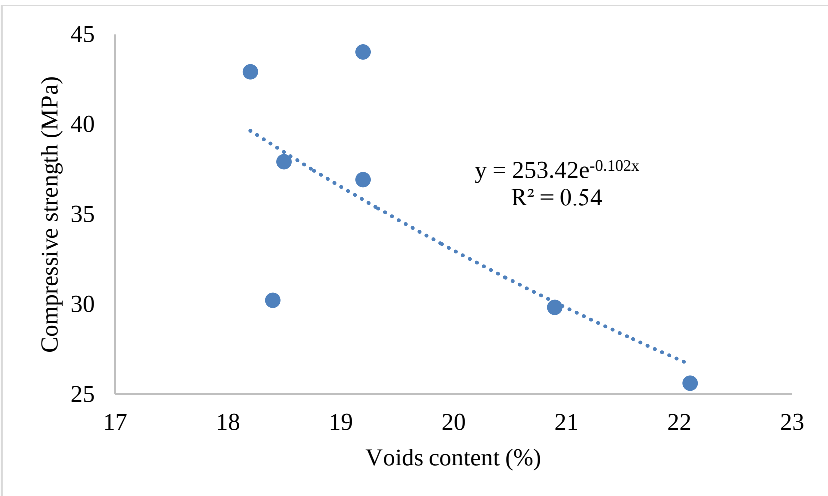

Figure 3. The relationship between compressive strength and voids content

Figures 4-7 show the relationship between mechanical and physical properties of the mortar mixes as a function of QWP substitution by cement (QWP-C) and by fine aggregate (QWP-A). The equations developed and the coefficient of determination values (R^2) are presented in Table 6. The figures clearly show that the cement substitution method yields lower compressive strength and density and higher water absorption and voids content, compared to the aggregate substitution method, at all ratios. The regression analysis of the test results shows that there is a strong correlation between the tested parameters and that the mechanical and physical properties of the QWP-modified cement composites can be predicted by using the equations provided in Table 6.

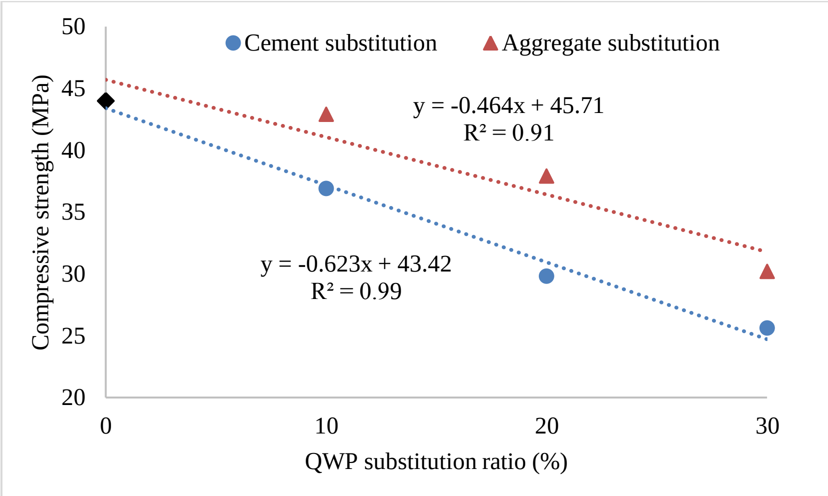

Figure 4. Compressive strength as a function of QWP replacement ratio

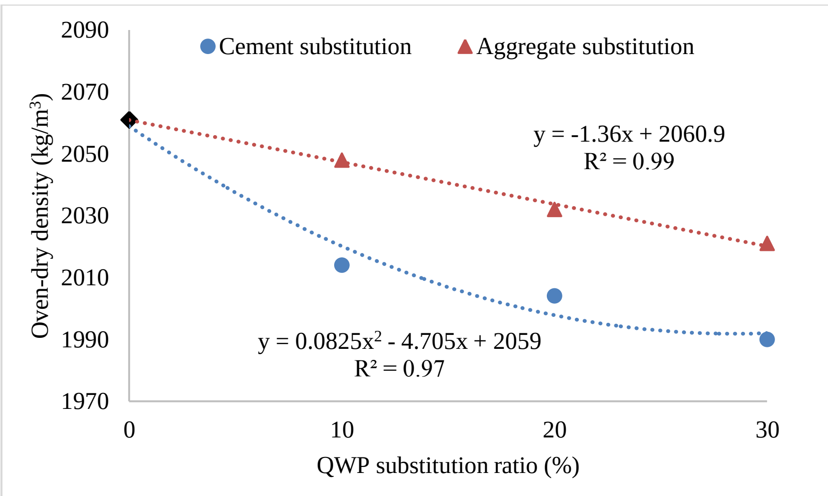

Figure 5. Oven-dry density as a function of QWP replacement ratio

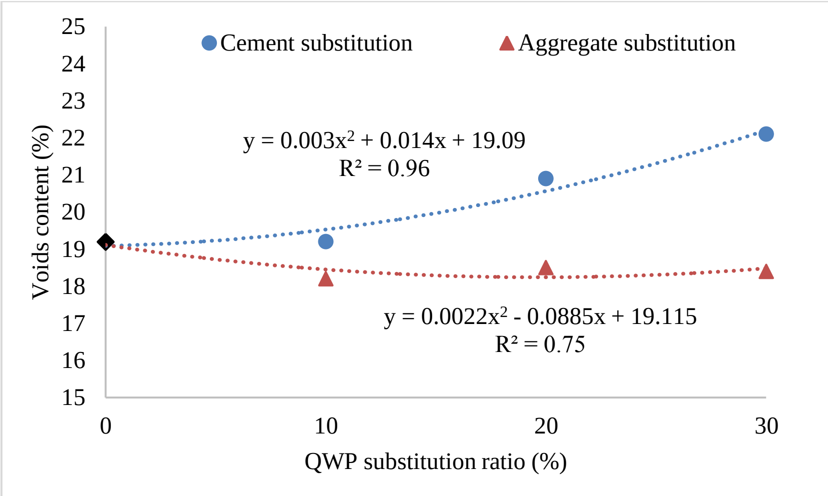

Figure 6. Voids content as a function of QWP replacement ratio

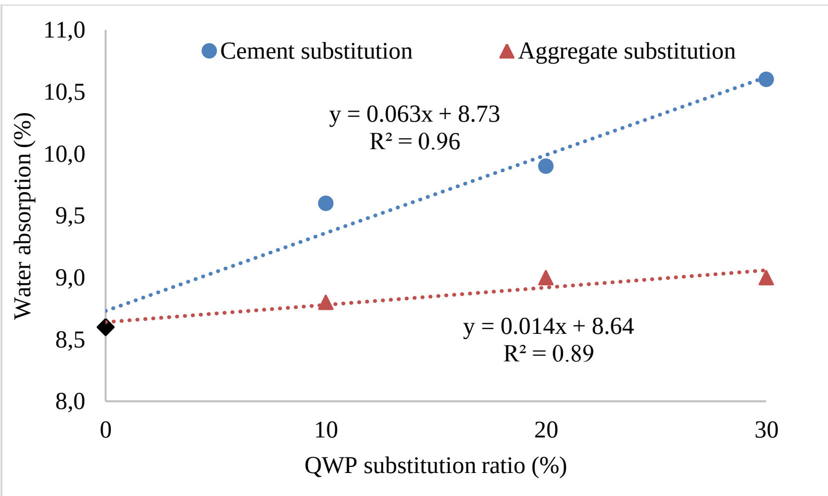

Figure 7. Water absorption as a function of QWP replacement ratio

Table 6. Statistical evaluation of the test results

Dependent variables	Independent variables	Relationship	Coefficient of determination (R^2)
Compressive strength (CS, MPa)	QWP-C ratio (%)	CS= -0.623(QWP)+43.42	0.99
	QWP-A ratio (%)	CS= -0.464(QWP)+45.71	0.91
Oven-dry density (ODD, kg/m^3)	QWP-C ratio (%)	ODD= 0.0825(QWP)^2-4.705(QWP)+2059	0.97
	QWP-A ratio (%)	ODD= -1.36(QWP)+2060.9	0.99
Voids content (VC, %)	QWP-C ratio	VC= 0.003(QWP)^2+0.014(QWP)+19.09	0.96
	QWP-A ratio (%)	VC= 0.0022(QWP)^2-0.0885(QWP)+19.115	0.75
Water absorption (WA, %)	QWP-C ratio (%)	WA= 0.063(QWP)+8.73	0.96
	QWP-A ratio (%)	WA= 0.014(QWP)+8.64	0.89

5. CONCLUSIONS

This study researches the possible utilization of QWP in cement composites. Based on the test results, significant outcomes are listed as follows:

- The incorporation of QWP in cement mortar reduced the workability, substituting QWP by fine aggregate caused higher drops in the workability compared to the cement substitution method. The density of the QWP-modified fresh mortars, on the other hand, was slightly reduced.
- Substituting QWP with cement increased the water absorption and voids content and reduced the oven-dry density compared to the reference mortar. The aggregate substitution method was found to slightly increase the water absorption and slightly reduce the oven-dry density and the voids content, which shows that by this method a more compact cement matrix can be obtained compared to the cement substitution method.
- The compressive strength generally reduced by the incorporation of QWP into the cement matrix, however, the aggregate substitution method provided higher strength values compared to the cement substitution method. The compressive strength of A10 mix was found to be comparable to that of the reference at all test ages suggesting an optimum substitution ratio where strength is a major concern.
- The equations developed between physical and mechanical properties and the QWP substitution ratio may be used to predict the performance of QWP material in cement mortars and can be used as a helpful start point for other experimental studies using inert materials with similar properties.

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