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COMPRESSIVE STRENGTH OF CONCRETE CONTAINING HIGH VOLUME OF QUARRY WASTE

N.Z. Rahim[1], A.Z. Awang[2*], A.R. Mohd Sam[2], C.K. Ma[2], C.L. Chin[2], W.N.F. Wan Hassan[2]

[1] Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
[2] Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Johor, Malaysia

norfazirahziela@yahoo.com, abdullahzawawi@utm.my, abdrahman@utm.my, machaukhun@utm.my, cheeloong.chin@utm.my and wannurfirdaus@utm.my

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*Corresponding author
abdullahzawawi@utm.my

ABSTRACT

Most of sand used for construction in Sabah have very high clay, silt, and dust content. This sand is not suitable for construction since it does not satisfy the standard requirement. On the other hand, quarries in Sabah produce large quantity of waste and cause serious environmental problem. In this study, the potential use of quarry waste as replacement for sand and cement in concrete was studied. The first phase of this study investigates the effect of different replacement percentage (0%, 10%, 20% and 40%) of quarry waste as cement replacement. The results showed that mortar with 10% of quarry waste as cement replacement displayed higher compressive strength. The second phase covered the effect of different percentage (25%, 50%, 75% and 100%) of quarry waste as fine aggregate replacement. It was found that this replacement has improved the strength of all mortars. The compressive strength of mortar with 75% quarry waste replacement (QWF75) was the highest among these mortars. The third phase investigated compressive strength of concrete containing high volume quarry waste (HVQW). For this, 10% of cement and 75% of fine aggregate were replaced with quarry waste. Slump test, density and compressive strength test were conducted on HVQM concrete to determine the workability, denseness, and strength of concrete. The mixture was designed for 60-180 mm slump value. The HVQW concrete has higher compressive strength compared to the control sample and met the margin strength value of the designed concrete mix. It was found that quarry waste contributed to the denseness of concrete, leading to the increase in density and compressive strength.

Keywords: *Quarry Waste, Fine aggregate, Cement, Mortar, Concrete, Density, Workability, Compressive strength.*

1.0 INTRODUCTION

Concrete is the most widely used construction materials. It is used for buildings, highway pavement, bridges, sidewalk, dams, and many other applications. For this reason, the demand for concrete has been increasing over the years. The constituents of concrete are coarse aggregate, fine aggregate, binding material, and water [1]. Recent environmental issues, restrictions on local extraction, procurement of natural sources for construction usage and upon disposal of waste material are in limelight importance. The amount of fine aggregate consumed has consequently increased due to increased use of concrete. Currently, there is a serious shortage of natural sand due to limited sources. With the increasing consumption and depletion of the natural aggregates, this shortage issue has aggravated into an environmental issue. Large depletion of natural sand source would lead to severe environmental problems such as erosion and failure of riverbank [2].

In recent years, methods have been proposed to adjust and improve the present composition of concrete. Various industrial wastes have been investigated extensively to serve as sustainable alternative for natural aggregates. These include recycled form of concrete, electronic waste, glass, quarry rock dust, waste marble powder, polyvinyl chloride (PVC) waste powder, silica fume, discarded rubber tire, ground blast furnace slag, cooper slag and fly ash have been used for concrete production [2], [3], [4] and [5]. Quarry waste can be defined as non-valuable byproduct from the extraction process in producing aggregate. Large quantity production of quarry waste caused serious environmental problems [6]. Replacing fine aggregates and cement with these quarry wastes would reduce the demand of fine aggregates and cement. This can rectify the environmental problems caused by the depletion of natural aggregate and can reduce the cost of concrete production. By doing so, natural river sand can be preserved and the environmental problems due to quarry waste can be minimized. Therefore, the use of quarry wastes in construction could lead to both economic and environment benefits [7] and [8]. Besides, quarry waste does not contain clay, silt, and organic impurities since it is a byproduct from the crushing process where rock has been crushed into various sizes. It can be produced to meet the desired sizes for fine aggregate replacement. This is an alternative way to decrease the demand of natural river sand.

The use of quarry waste in construction as fine aggregates and cement replacement has been continually studied. Quarry waste reaction improved pozzolanic reaction, concrete durability, and micro aggregate filling. Quarry waste was used as sand replacement in the concrete mixtures because its properties are good as sand [9]. Kumar et al. [1] reported that natural river sand has become scarce and very costly. Therefore, they conducted an experimental study on mechanical properties of concrete with replacement of sand with quarry dust and waste foundry sand to find an alternative material for sand. According to Azhagarsamy et al. [10], the replacement of 40% of natural sand and 60% of quarry waste by adding 15% of the mass of cement with silica fume and addition 1.0% of steel fibers proves to be optimum level to provide high performance concrete than the nominal concrete. Li et al. [11] investigated the effect of granite dust on mechanical and some durability properties of manufactured sand concrete. The results showed an improvement in the workability of the manufactured sand concrete by introducing granite waste.

The experimental test conducted by Sivakumar and Prakash [12] showed that the addition of quarry waste improved the strength of concrete. It was inferred that the quarry waste could be used as an effective replacement material for natural river sand. Ghorbani et al. [13] reported that partial replacement of cement with marble and granite dust improved the corrosion resistance of steel rebar in concrete. Ghorbani et al. [14] studied the mechanical and durability behavior of concrete with granite waste dust (GWD) as partial cement replacement under adverse exposure conditions. The results revealed that 10% and 20% replacement of cement with GWD significantly improved the corrosion resistance of concrete. Subsequently, Elmoaty [15] reported that replacement of cement with GWD improved strength and corrosion resistance of concrete. Kumar and Ram [16] found that the performance of crushed rock dust concrete is comparable to the conventional concrete due to water absorption and acid attack. Rana et al. [17] proved that partial replacement of cement with industrial waste such as fly ash, silica fume, slag, stone waste etc. contributed to sustainable construction and enhanced the durability of concrete.

In term of fine aggregate, Mir [18] discovered that quarry waste improved the mechanical properties of concrete. They concluded that quarry waste can be used as an alternative material to the natural river sand and can be introduced as a functional construction material. Khan and Candrakar [19] reported that the strength of concrete is dependent on bonding of fine aggregate which fills the voids between coarse aggregate. The replacement of natural fine aggregate with quarry waste can utilize the generated quarry waste. This reduces the need of land fill space and decreases the demand of natural sand. Improvement on compressive strength can be seen through the investigation by Patel and Shah [20]. It was reported that the optimum replacement of fine aggregates with quarry waste were 30 % for compressive strength and 20 % for flexural strength. Other researchers like Raghuvanshi and Jha [21] studied the utilization of quarry fines in cement concrete paver blocks for medium traffic. They concluded that partial replacement of natural river sand with quarry fine can improve the workability of the concrete mix.

According to Singh et al. [22], the feasibility of utilizing granite dust in concrete as a partial replacement for sand is well established. Studies have been conducted to investigate the compressive strength, split tensile strength, and flexural strength of this concrete. Jagadeesh et al. [23] conducted an experimental investigation that replaced 20%, 30%, 40% and 50% fine aggregate with quarry waste. The study found that compressive strength increased in tandem with the increase in percentage of quarry waste replacement. Patel and Pitroda [24] proposed that effective utilization of quarry waste in concrete can save the waste of quarry works and produces a greener concrete. Cost optimization can be achieved when sand is fully replaced by quarry waste.

The main objective set for this study is to study the potential use of quarry waste as fine aggregates and cement replacement in concrete. The scope of this study is to enhance the industry understanding of the sustainable utilization of quarry waste. This study included three phases. Phase 1 is to determine the effect of different percentage of quarry waste as cement replacement in mortar. Phase 2 is to determine the effect of different percentage of quarry waste as fine aggregate replacement in mortar. Phase 3 is to determine the compressive strength of concrete containing high volume of quarry waste. The designed concrete of grade C25/30 containing high volume of quarry waste is prepared based on the percentage of quarry waste as cement replacement in phase 1 and the percentage of quarry waste as fine aggregate replacement in phase 2. The workability and compressive strength of concrete were conducted and measured. The finding of this study is to find significant improvement of concrete compressive strength when quarry waste is used as sand and cement replacement in specified percentage.

2.0 METHODOLOGY

2.1 Materials

The materials used in this experimental test were ordinary Portland cement (OPC), coarse aggregate, fine aggregate, quarry waste and potable water.

2.1.1 Cement

Portland Cement type CEM I (42.5 N) was used throughout the study and the cement was obtained from certified manufacturer. Cement test was conducted in accordance with MS EN 197-1 and MS EN 196-3.

2.1.2 Aggregates

A series of experimental testing were carried out on coarse aggregate, fine aggregate and quarry waste in accordance with MS30. The testing included grading, elongation index, flakiness index, water absorption, clay silt and dust content, organic impurities, crushing value, chloride content, sulphate content and specific gravity.

2.1.3 Quarry Waste

Granite quarry waste was obtained from Tamparuli Quarry, Sabah. The quarry waste passing through 4.75 mm sieve was taken as fine aggregate replacement. Testing on quarry waste was conducted in accordance with MS30. The sieve analysis of quarry waste was carried out using a sieve size BS410. X-ray fluorescence (XRF) test was conducted to determine the chemical composition of quarry waste.

2.2 Preparation of Mortar and Concrete

Specimen sizes 70 mm × 70 mm × 70 mm and 150 mm × 150 mm × 150 mm were used for mortar and concrete respectively. Three layers of concrete were filled in the molds and compacted immediately using compacting bar with 25 strokes per layer to achieve full compaction. Specimens were removed from formwork after 24 hours and stored in curing water for 3, 7 and 28 days at a temperature of (20+2)^{0}C.

2.3 Composition of Mortar

Mortar was prepared according to BS EN 196. The proportion by mass shall be one part cement to three parts sand (cement:sand = 1:3) and half part water (water/cement ratio = 0.50). Table 1 shows the composition of mortar.

Table 1: Composition of Mortar

Cement (g)	Sand (g)	Water (ml)	Max Water Cement Ratio
185	555.0	92.5	0.5

2.3.1 Mortar Mix Proportions of Mortar in Phase 1

Five mortar mixes containing 0%, 10%, 20%, 30%, 40%, of quarry waste as cement replacement (QWC) were prepared. Mortar with 0% quarry waste used as a control sample (CS). The mortar mix proportions are shown in Table 2.

Table 2: Mortar mix proportions in phase 1.

% of Quarry Dust Content	Cement (g)	Quarry Waste (g)	Sand (g)	Quantity of Water (ml)	No. of sample
CS	185.0	0	555	92.50	9
QWC10	166.5	18.5	555	92.5	9
QWC20	148.0	37.0	555	92.5	9
QWC30	129.5	55.5	555	92.5	9
QWC40	111.0	74.0	555	92.5	9
Total no. of sample					45

2.3.2 Mortar Mix Proportions of Mortar in Phase 2

Four mortar mixes containing 25%, 50%, 75% and 100% of quarry waste as fine aggregates replacement (QWF) were prepared. Mortar with 0% of quarry waste in phase 1 used as control sample in phase 2. The mortar mix proportions are shown in Table 3.

Table 3: Mortar mix proportions in phase 2.

% Of Quarry Dust Content	Cement (g)	Sand (g)	Quarry Waste (g)	Quantity of Water (ml)	No. of sample
QWF25	185	416.25	138.75	92.50	9
QWF50	185	277.50	277.50	92.50	9
QWF75	185	138.75	416.25	92.50	9
QWF100	185	0	555.00	92.50	9
Total no. of sample					36

2.4 Composition of Designed Concrete in Phase 3

Table 4 shows the composition of designed concrete. Concrete proportion was prepared according to the method of concrete mix design described in Building Research Establishment (BRE).

Table 4: The composition of designed concrete

Volume	Cement (Kg)	Water (Kg or Liters)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water Cement Ratio
Per m^3 (To nearest 5 kg)	435	225	930	795	0.5
Per trial mix of 0.05 m^3	21.75	11.25	46.5	39.75	0.5

2.4.1 Designed Concrete Mix Proportion in Phase 3

The designed concrete mixture of high volume of quarry waste (HVQW) was prepared. Based on the results from phase 1 and phase 2, the optimum percentage of cement and fine aggregates replacement were adopted into HVQW concrete mix. In this study, the percentage of replacement for cement and fine aggregates were 10 % and 75%, respectively. The mix proportion of the designed HVQW concrete is tabulated in Table 5.

Table 5: Designed HVQW concrete mix proportion in phase 3.

Sample	Cement (Kg)		Fine Aggregate (Kg)		Coarse Aggregate (Kg)	Water (L)	No. of Sample
	QWC	OPC	QWF	Sand			
HQVW	2.18	19.57	34.88	11.62	39.75	11.25	9

2.5 Testing Procedure

Slump test was conducted in accordance with MS 26-1-2:2009 to determine the workability of fresh concrete mix. Density of mortar and concrete was obtained to determine the compactness and denseness of the mortar and concrete. Compressive strength test was carried out in accordance with BS EN 12390-3. Compressive strength test was conducted on mortar and designed concrete after curing for 3, 7 and 28 days to evaluate the effect of quarry waste as fine aggregate and cement replacement. Compression test machine with rated capacity of 1500 kN was used to test the compressive strength. During the compression test, a constant rate of loading within the range of 0.6 ± 0.2 MPa/s (N/mm^2.s) was applied to the specimen.

3.0 RESULTS AND DISCUSSION

3.1 Cement

The physical properties of cement are shown in Table 6. The compressive strength, initial setting time and soundness of cement results met the requirement of MS EN 197-1 and MS EN 196-3.

Table 6: Physical properties of cement

Properties	Results	MS EN 197-1
Compressive Strength (MPa)		
2 days	22.0	$\geq$ 20 MPa
28 days	45.0	$\geq$ 42.5 MPa
		MS EN 196-3
Initial Setting Time	187	$\geq$ 45 min
Soundness (expansion) mm	0.5	$\leq$ 10 mm

3.2 Coarse Aggregates

The properties of coarse aggregate are shown in Table 7. From the results, it can be observed that the test results are within the limits specified. The grading of coarse aggregate is also within the grading limit as presented in Figure 1. Good quality aggregate is needed to ensure the structural performance of concrete. These results showed that coarse aggregates used in this study met the requirement and is suitable for making concrete.

Table 7: The properties of coarse aggregate

Properties	Test Methods	Results	Limits
Grading	MS30	Table 3.5	As shown in Table 3.5
Elongation Index	MS30	19.30%	Not exceeding 30%
Flakiness Index	MS30	19.56%	Not exceeding 35%
Water Absorption	MS30	0.73%	Not exceeding 8%
Aggregates Crushing Value	MS30	17.56%	Not exceeding 40%
Chloride Content	MS30	0.01%	Not exceeding 0.06 by weight of chloride ions
Sulphate Content	MS30	0.01%	Not exceeding 0.44% by weight of SO_3
Specific Gravity	MS30	2.69	-

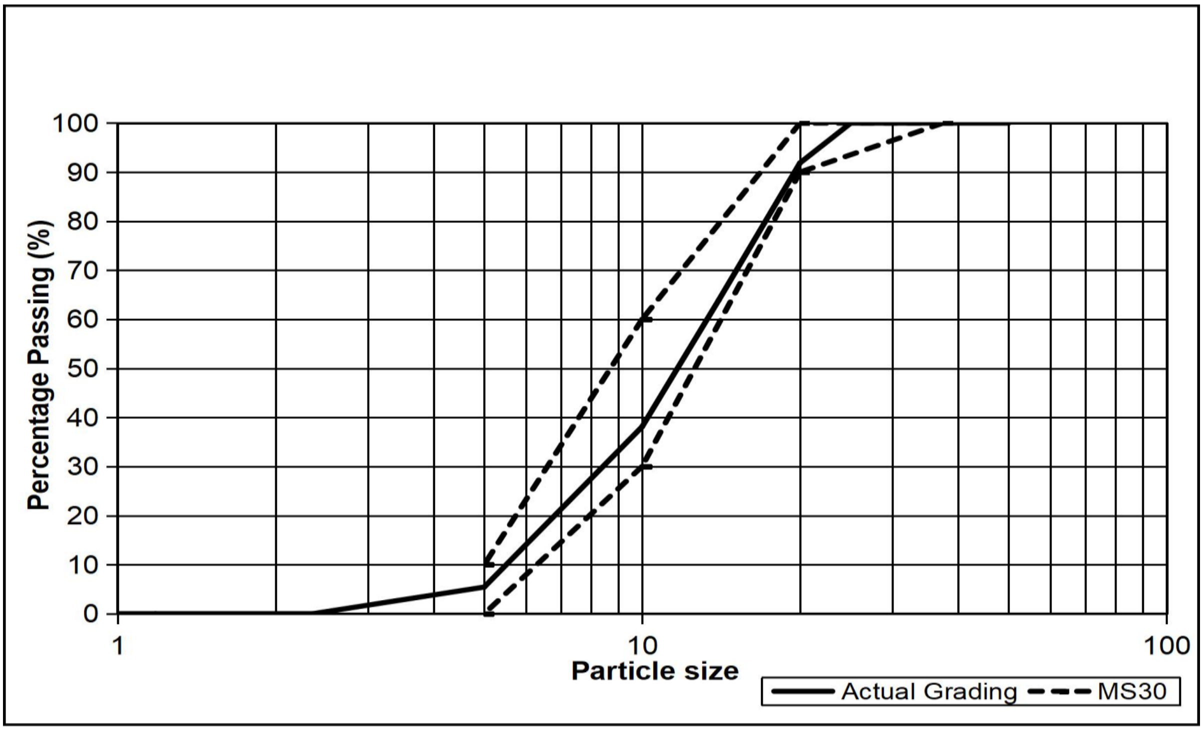

Figure 1 Grading of Coarse Aggregate

3.3 Fine Aggregates

Table 8 shows the properties of fine aggregate. The result showed that the properties of fine aggregate are within the limits specified. Therefore, the fine aggregate is suitable to be used for making concrete. The grading of fine aggregate is within the grading limit fine (F) as shown in Figure 2. This showed that the fine aggregate is well graded.

Table 8: The properties of fine aggregate

Properties	Test Methods	Results	Limits
Grading	MS30	Table 3.7	As shown in Table 3.7
Water Absorption	MS30	0.93%	Not exceeding 8%
Organic Impurities	MS30	0.1%	Not exceeding 0.4%
Clay, Silt and Dust	MS30	0.86%	Not exceeding 3% by weight or 8% by volume
Chloride Content	MS30	0.02%	Not exceeding 0.06% by weight of chloride ions
Sulphate Content	MS30	0.03%	Not exceeding 0.44% by weight of SO_3
Specific Gravity	MS30	2.67	-

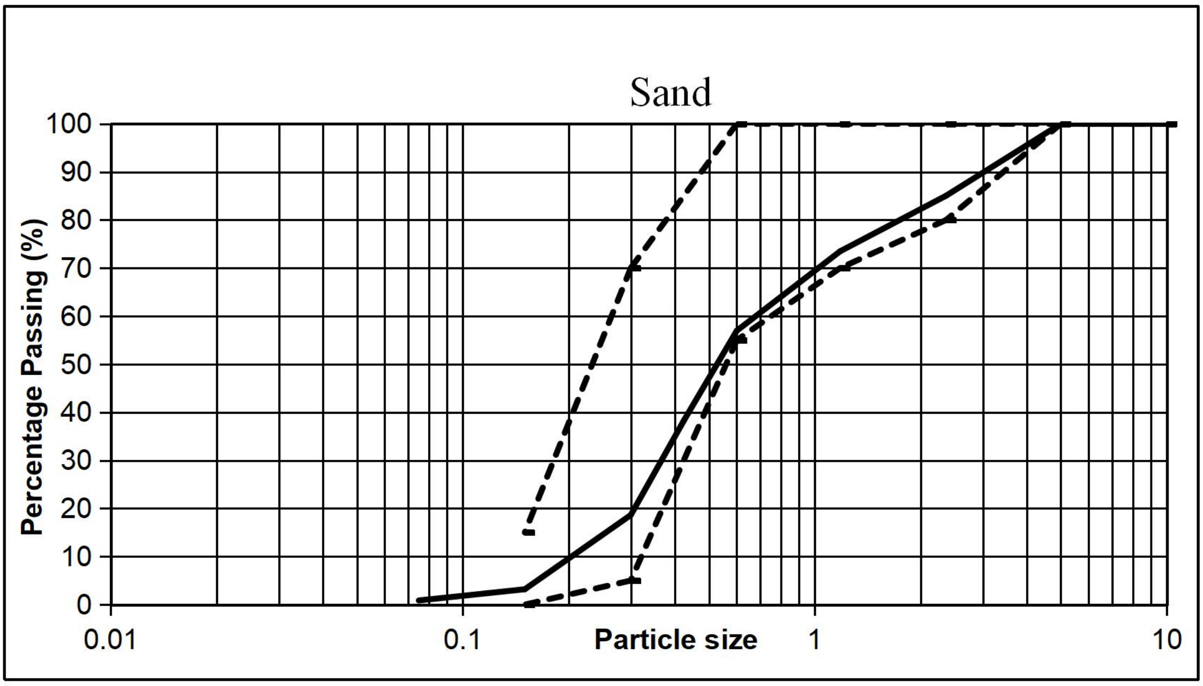

Figure 2 Grading of Fine Aggregate

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3.4 Quarry Waste

Table 9 shows the properties of quarry waste. The properties of quarry waste were evaluated based on the limits of fine aggregate. This is to ensure that the quarry waste has the potential to replace fine aggregate. The results showed that the properties of quarry waste are within the limits specified for fine aggregate. This means that the quarry waste is suitable to be used as fine aggregate replacement. The grading of quarry waste within the grading limit C as presented in Figure 3. The grading also showed that quarry waste is coarser than fine aggregate.

Table 9: Physical Properties Of quarry waste

Properties	Test Methods	Results	Limits
Grading	MS30	Table 3.7	As shown in Table 3.7
Water Absorption	MS30	0.6%	Not exceeding 8%
Chloride Content	MS30	0.01%	Not exceeding 0.06 by weight of chloride ions
Sulphate Content	MS30	0.01%	Not exceeding 0.44% by weight of SO_3
Specific Gravity	MS30	2.69	-

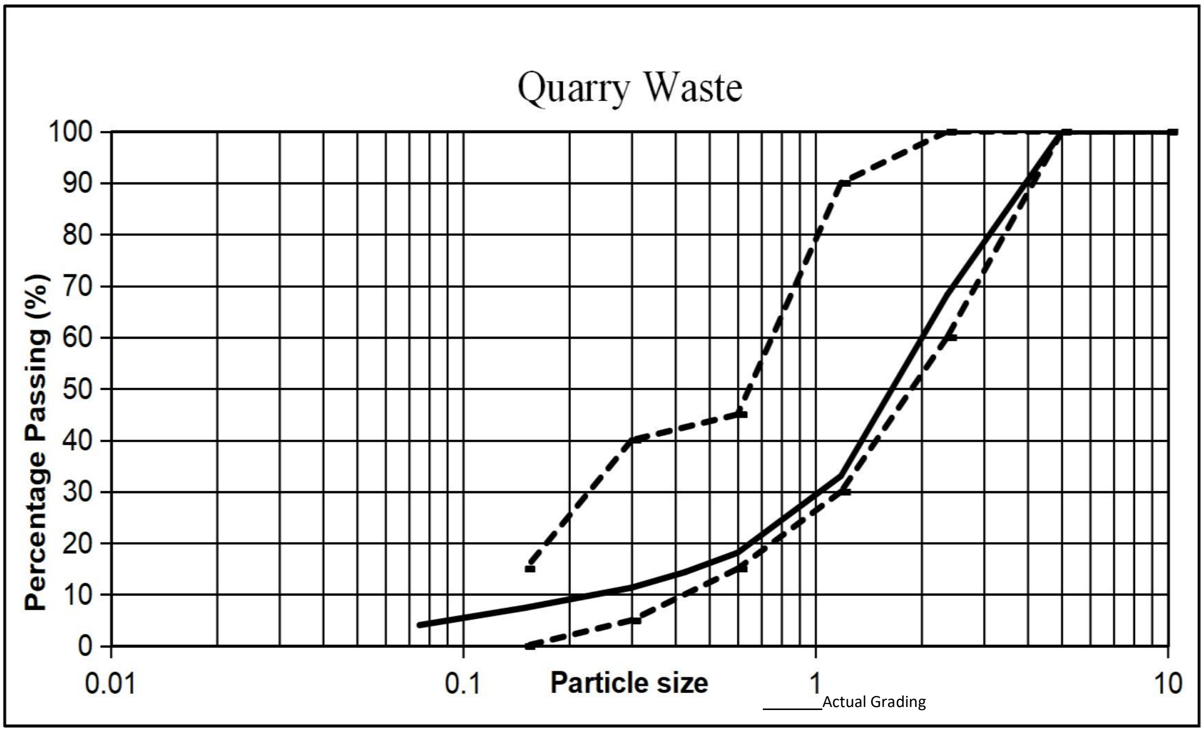

Figure 3 Grading of Quarry Waste

3.4.1 Chemical Composition of Quarry Waste

Table 10 shows the chemical composition of quarry waste. The results showed that the quarry waste is mainly composed of silicon dioxide and aluminium oxide. The reactive aluminosilicate and calcium aluminosilicate components of quarry waste is present in oxide forms such as silicon dioxide, aluminium oxide and calcium oxide. The aluminosilicate parts react with lime to produce additional cementitious materials. These components tend to contribute to concrete strength at a faster rate when these components are present in finer fractions.

Table 10: Chemical composition of quarry waste

Chemical Composition	Quarry Waste (%)
SiO_2	57.9
Al_2O_3	15.30
Fe_2O_3	7.47
CaO	7.96
MgO	2.48
Na_2O	3.19
K_2O	3.20
SO_3	0.0998
TiO_2	0.762

From the result of chemical composition of quarry waste, it was showed that the total percentage of SiO_2, Al_2O_3 and Fe_2O_3 is 80.67% which is more than 70% and met the requirement in ASTM 618 (15) (Class N). Therefore, quarry waste can be used as cement replacement to produce additional cementitious materials.

3.5 Slump Test

The slump test was conducted on concrete containing high volume of quarry waste. This concrete proportion was designed based on the results of 10% quarry waste as cement replacement in phase 1, and 75% quarry waste as fine aggregate replacement in phase 2. The mixture was designed for 60-180 mm slump value. Table 11 shows the results of slump test for control sample and high volume quarry waste concrete.

Table 11: Slump value

Mixture	Slump (mm)
Control Sample	110

HVQW = 75% QWF + 10% QWC	112

3.6 Compressive Strength

3.6.1 Compressive Strength Results in Phase 1

Figure 4 shows the average compressive strength of the mortar specimens. This figure showed that the compressive strength of QWC10 is about 3% higher than CS. Quarry waste could have beneficial effects by filling the pores of in concrete. This result is in good agreement with the previous studies conducted by Ghorbani et al. [13] and Ghorbani et al. [14]. The pore filling effect of fine quarry waste enhanced the density and compressive strength of concrete [9].

Quarry waste reacts with the available lime and alkali in concrete and produces additional cementitious compounds. The following equations represents the pozzolanic reaction of SiO_2 (silica from quarry waste constitutes) with lime (CaOH) produce additional calcium silicate hydrate (C-S-H) gel:

Cement reaction : $C_3S + H_2O \rightarrow$ C-S-H + CaOH

Pozzolanic reaction : CaOH + $SiO_2 \rightarrow$ C-S-H

This continual pozzolanic reaction allows quarry waste concrete to gain strength over time.

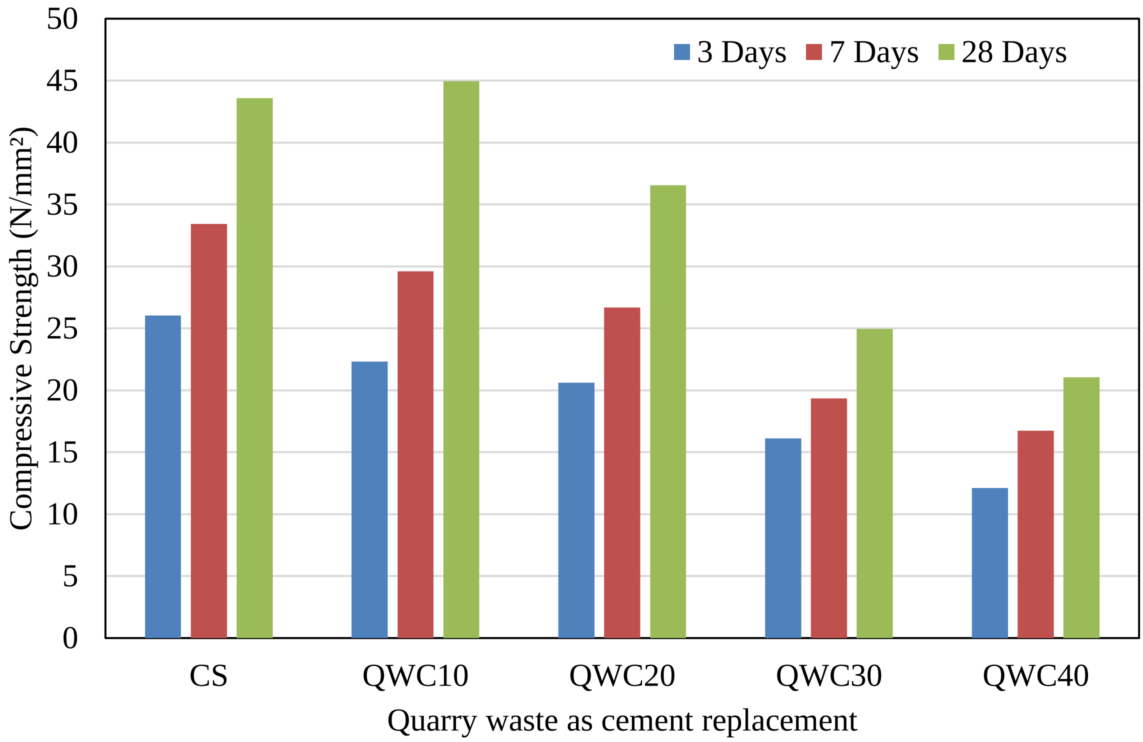

Figure 4 The average compressive strength of all mortars

However, the compressive strength decreases when the cement replacement is more than 10%. The compressive strength decreased by 16%, 43% and 52% for QWC20, QWC30 and QWC40, respectively. QWC40 displayed the worse result with 52% reduction in compressive strength. This is due to the insufficient cement content to fully activate the pozzolanic reaction [17].

3.6.2 Compressive Strength Results in Phase 2

Figure 5 presents the average compressive strength of mortar containing different percentage of quarry waste as fine aggregate replacement and compared to control sample. This figure indicates that the replacement of fine aggregates with quarry waste has improved the compressive strength of all mortars at any test ages.

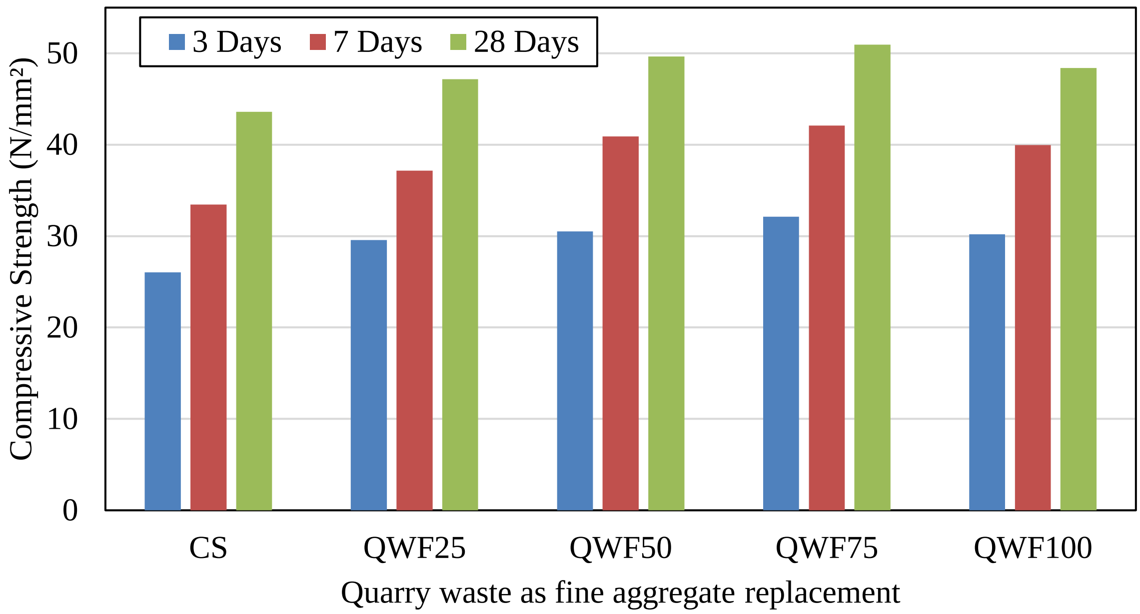

Figure 5 The average compressive strength of all mortars

Figure 5 shows that QWF75 has the highest compressive strength among the specimens. The compressive strength of QWF100 was about 3% lower than QWF50 and 6% lower than QWF75. These results showed that quarry waste is comparable in strength with natural sand. This finding is found to be similar with the previous studies by Raghuvanshi and Jha [21] and Shrivastava and Dangi [25] which reported improvement in strength up to 80% fine aggregate replacement.

3.6.3 Compressive Strength Results in Phase 3

Figure 6 presents the average compressive strength of HVQW Grade C25/30 and control sample. This result showed that the compressive strength of designed HVQW concrete was higher compared to the control sample. It is noticed that the 3-day strength of HVQW was lower than control sample. However, the 7-day and 28-day strength of HVQW were higher than the control sample. This is due to the additional binder produced in concrete by the 10% quarry waste as cement replacement.

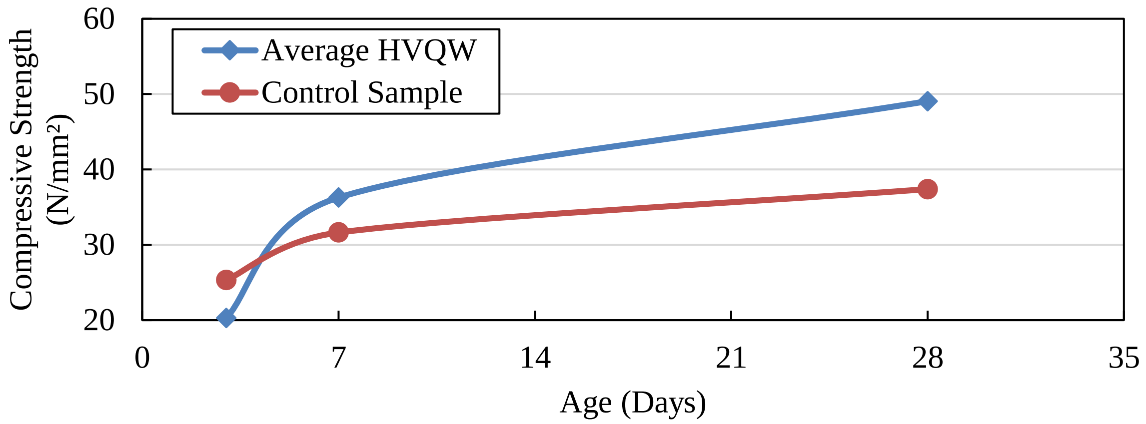

Figure 6 The average compressive strength of HVQW Grade C25/30

3.7 Density

3.7.1 Density of Mortar in Phase 1 and Phase 2

Figure 7 shows the relationship between compressive strength and density of mortar at 28 days in phase 1. The results showed that density of QWC10 was higher compared to the control sample. However, specimens with higher percentage of cement replacement were shown to have lower density compared to control sample. It is also noticed that the compressive strength is in proportion with the density of concrete.

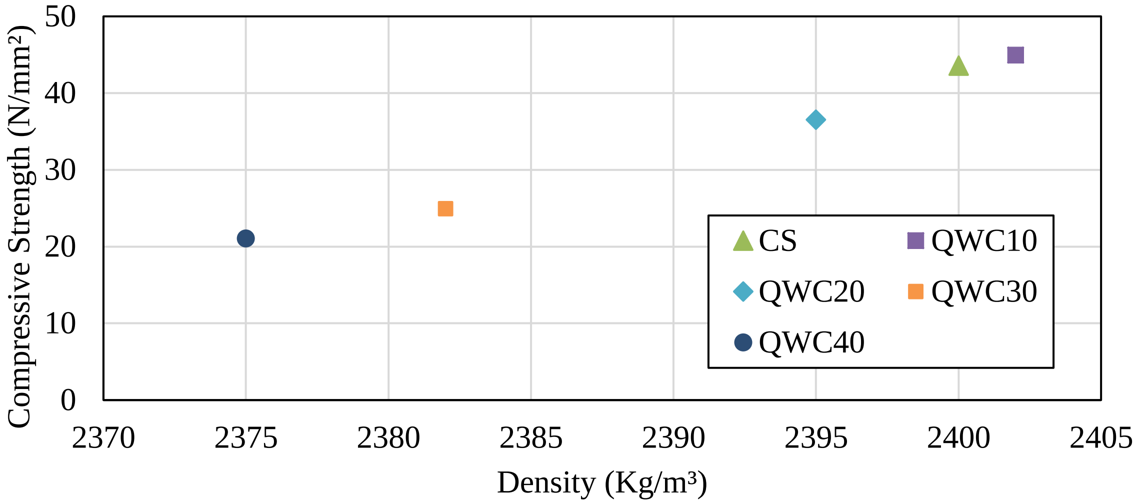

Figure 7 relationship between compressive strength and density

Figure 8 shows the relations between density and compressive strength of mortar at 28 days in phase 2. From the figure, it is observed that density and compressive strength of concrete increased as the replacement percentage increased. The density of mortar containing quarry waste increased by about 0.3%, 0.4%, 0.6% and 0.4% for WQF25, QWF50, QWF75 and QWF100.

The compressive strength and density of QWF100 is slightly lower compared to QWF75. This could be due to the coarser particle size of quarry waste compared to sand. This resulted in occurrence of voids in QWF100. In QWF75, the voids between quarry waste could be filled by the sand. Leading to denser mortar and hence higher strength.

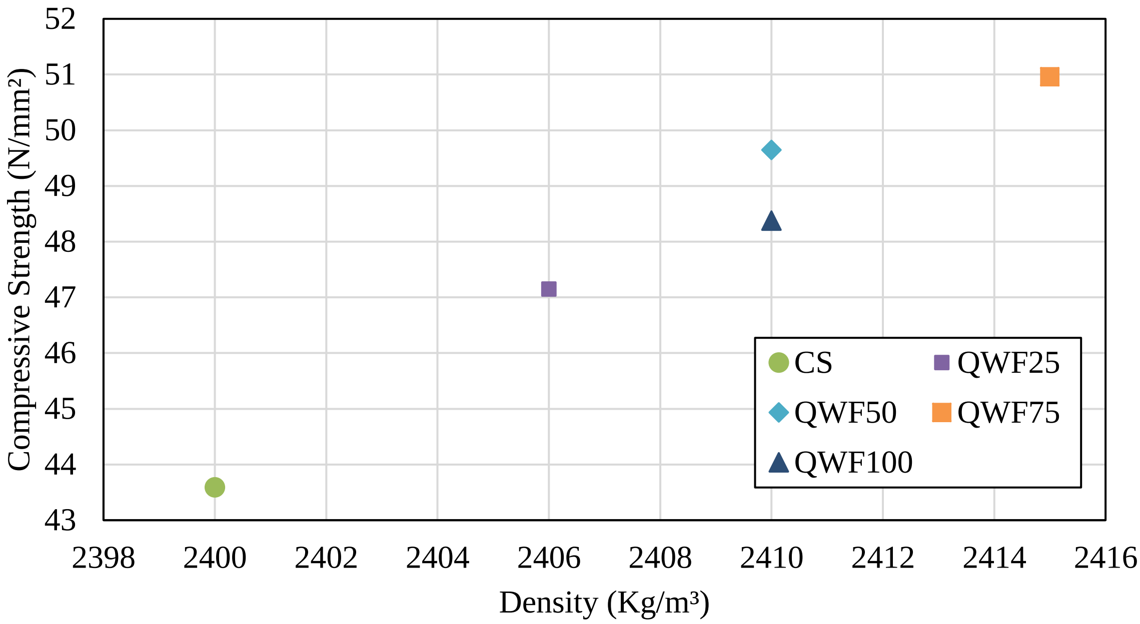

Figure 8 Relationship between compressive strength and density.

3.7.2 Density of Concrete in Phase 3

Figure 9 presents the relationship between compressive strength and density of concrete at 28 days. The results indicated that the compressive strength increased as the density of concrete increased. The density and compressive strength of concrete containing high volume of quarry waste (HVQW) were higher than control sample (CS). This indicated that the quarry waste contributed to the denseness of concrete and high compressive strength.

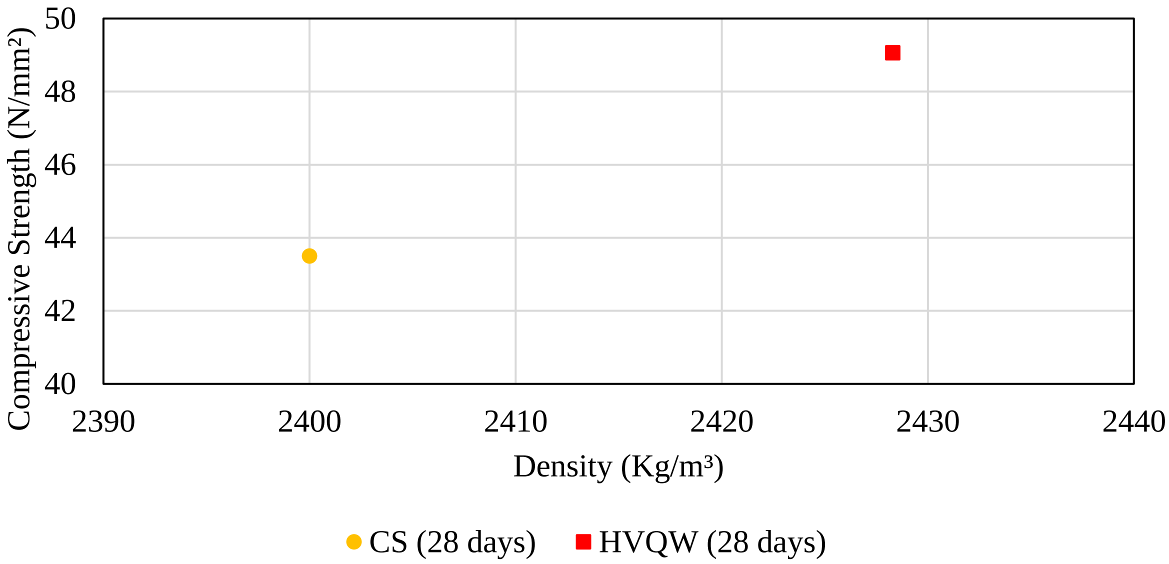

Figure 9 Relationship between compressive strength and density of HVQW concrete.

3.8 Failure Pattern of Concrete and Mortar

Failure pattern of high volume of quarry waste (HVQW) concrete are shown in Figure 10. Failure pattern of control sample, mortars of quarry waste as cement replacement (QWC10, QWC20, QWC30 and QWC40), mortars of quarry waste as fine aggregate replacement (QWF25, QWF50, QWF75 and QWF100) are shown in Figure 11. As evidenced from the figure, the failure cracks are approximately parallel to the direction of the applied compressive load. The failure shape of concrete cubes looks similar to an hourglass shape due to shear stress. The failure modes of these specimens indicated that the compression tests were satisfactorily conducted, in which the highest stress occurred at the center.

Figure 10 High volume of quarry waste concrete

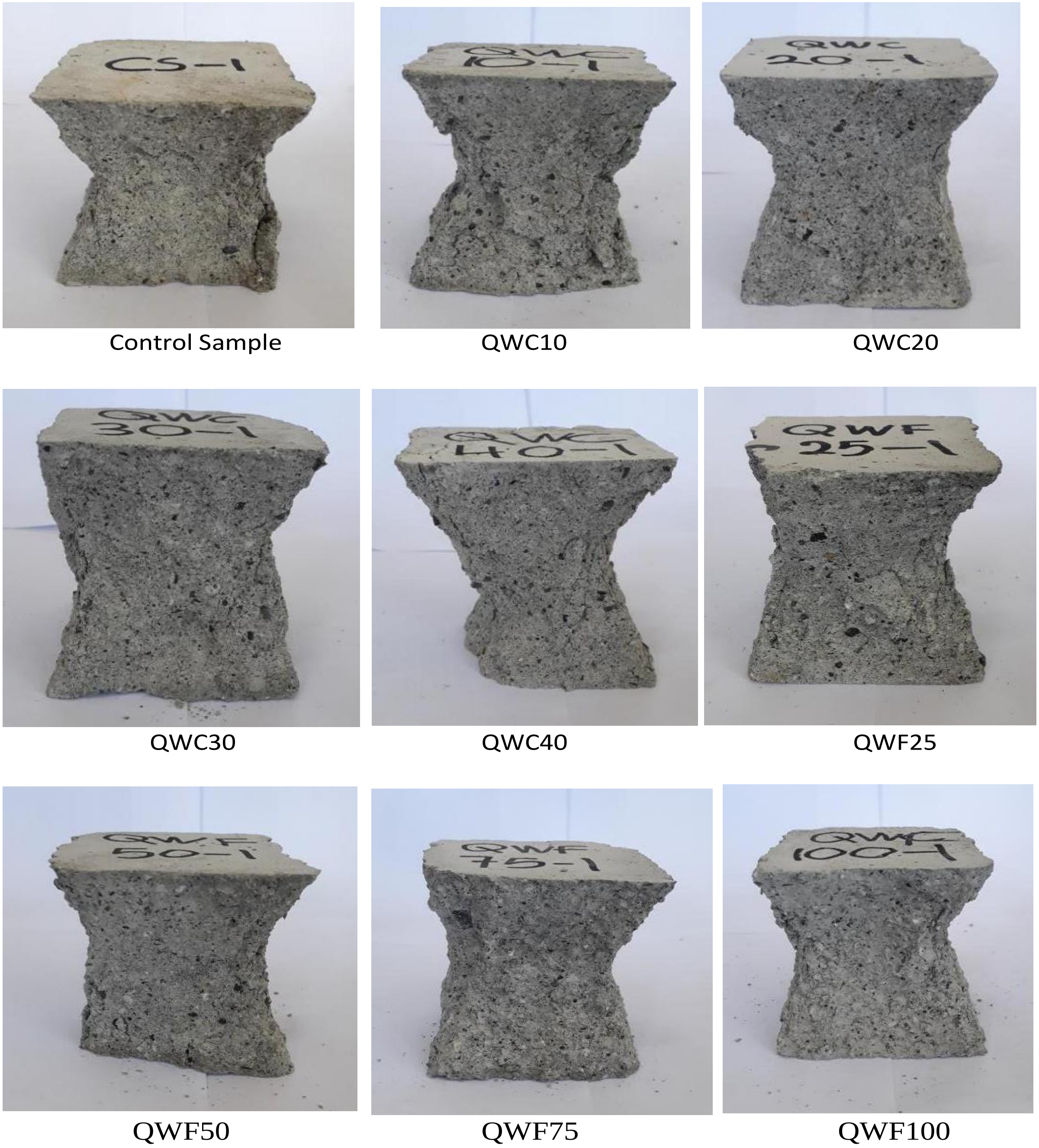

Figure 11 Failure pattern of control sample mortar and mortars of quarry waste as cement and fine aggregate replacement

4.0 CONCLUSION

Based on the experimental test results, it is viable to use quarry waste as fine aggregate and supplementary cementitious material in concrete. Several conclusions can be made as follows:

1) The physical properties and chemical composition of quarry waste indicate that quarry waste can be used as cement and fine aggregate replacement. The chemical composition of quarry waste shows that the quarry waste is mainly composed of silicon dioxide and aluminum oxide. The reactive aluminosilicate such as silicon dioxide of quarry waste reacts with lime to produce additional cementitious materials. These components contribute to concrete strength development at a faster rate when these components are present in finer fractions.

2) Mortar with 10% cement replacement with quarry waste showed the highest compressive strength among the samples in phase 1. The increase in compressive strength may be due to the pore filling effect of very fine quarry waste. Besides, the additional binder produced by quarry waste from the reaction with lime allowed continual strength development over time.

3) Compressive strength decreased when the percentage of cement replacement with quarry waste exceeds 10 %. This reduction in the compressive strength was between 16 to 52% for mortar containing 20 to 40% quarry waste as cement replacement. The compressive strength decreased due to reduction of cement content as a binder of the cement paste.

4) The replacement of fine aggregates with quarry waste has significantly improved the compressive strength of all mortars. This applies regardless of the percentage of quarry waste replacement as fine aggregates at all tested ages. Quarry waste contributes to the denseness of concrete leading to higher compressive strength.

5) The compressive strength of mortar with 75% fine aggregate replacement with quarry waste (QWF75) showed highest compressive strength compared to other mortar mixes. This is because the least void is present in concrete at this replacement percentage. The remaining 25 % fine aggregate was able to fill up the void in concrete.

6) Based on the results from phase 1 and phase 2, it is proposed to replace 75% of fine aggregate and 10% of cement with quarry waste to produced concrete with high compressive strength. It was found that higher compressive strength could be achieved with this proposed percentage replacement.

7) The failure cracks on samples are approximately parallel to the direction of applied load. Failure patterns in concrete cubes looks similar to an hourglass shape due to shear stress. This indicated the tests have been conducted satisfactorily, in which the highest stress occurs at the center of the specimens.

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