American Journal of Engineering, Technology and Society
2015; 2(2): 26-34
Published online April 10, 2015 (http://www.openscienceonline.com/journal/ajets)

Compressive Strength of Concrete Made with Quarry Rock Dust and Washed 10mm Washed Gravel as Aggregates

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To cite this article

Ephraim M. E., Rowland-Lato E. O.. Compressive Strength of Concrete Made with Quarry Rock Dust and Washed 10mm Washed Gravel as Aggregates. *American Journal of Engineering, Technology and Society*. Vol. 2, No. 2, 2015, pp. 26-34.

Abstract

This work is related to study the compressive strength of concrete using quarry dust as fine aggregate instead of sand and 10mm washed aggregate instead of conventional granite. Three mixes of 1:2½:3, 1:1½:2 and 1:1:2 (by weight) and at water-cement ratios (w/c) of 0.65, 0.60 and 0.45 for grade 20, 30 and 40 respectively were designed. However, these mixes gave characteristic strengths of 18.88N/mm^2 28.23N/mm^2 and 38.29N/mm^2 respectively equivalent to grade 15, 25, and 35 respectively. Though the aggregate/cement ratio of concrete is lower than that of conventional granite concrete, workability value compared favourably with the conventional granite concrete.Therefore the 10mm washed aggregate and quarry dust satisfied the requirements of code provision in properties studies and can serve as full replacement for conventional granite and natural river sand respectively.

Keywords

Concrete, Compressive Strength, 10mm Gravel, Quarry Dust

1. Introduction

The issue of affordable housing and construction economy continue to remain a topic both in government policies and research. Concrete remains a popular construction material worldwide and its use has witnessed tremendous increase in the recent past. Meanwhile the world supply of concrete constituents has generally suffered appreciable decline resulting in an increase in cost. This is particularly true for materials used as aggregates in concrete and because aggregate occupy about 70 percent of the volume of concrete, the need to address its availability is an important economic imperative for achieving

One of the avenues to reduce cost is in maximizing the use of local construction materials such as binders, aggregates and reinforcement in the reinforced concrete system. The search for alternative local aggregates has resulted in introduction of concrete system based on 10mm all-in gravel and quarry dust. 10mm all-in gravel aggregate occurs in great abundance in areas such as the low lying riverine areas of the Niger Delta region of Nigeria and is easily available all year round while quarry dust is a by-product from the crushing process during quarrying activities that can be used as concreting aggregates, especially as fine aggregates [6, 8, 9, 12, 13].

The ever-increasing popularity and application of these materials in structural members including foundations beams and suspended floors without standards for specification and control prompted the research of Ephraim and Ode [6] on the compressive strength of 10mm all-in gravel in order to obtain its optimum value for various mixes and declares the limits of application.

River sand is the most commonly used fine aggregate in the production of concrete but poses problem with respect to its availability, cost and environmental impact. Environmental legislation is being adopted in several countries restricting sand mining. In such a situation the quarry dust can be an economic alternative to the river sand. The use of quarry dust as a fine aggregate in concrete has received serious attention of researchers and investigators [9, 12, 13].

This research presents the study of the compressive strength of concrete made with quarry dust as a fine aggregate and 10mm washed all-in gravel as coarse material as hundred percent substitutes for crushed rock coarse aggregates. It is hoped that, the successful utilization of these materials will yield benefits arising from combination of cost reduction and environmental waste management.

2. Previous Works

2.1. Properties Aggregate

10mm all-in gravel is a naturally occurring aggregate and is classified by BS 812 part 1, 1995 as irregular to rounded smooth aggregate in texture. In an attempt to determine the suitability of concrete made with the 10mm all-in aggregate from Niger Delta region, Ephraim and Ode (2006), conducted a sieve analysis test on both washed and unwashed 10mm all-in gravel. The test result revealed that the unwashed gravel contains 5% fine, 70% medium and 20% coarse sand fractions, while the washed aggregates is composed of 2% fine, 33% medium and 65% coarse sand fractions. Its particles size distribution show that 10mm washed gravel plots within the 882, 1993 grading limits of envelop for zone A, representing coarse sand. The uniformity coefficient and coefficient of curvature of the washed materials are 8.4 and 1.0 respectively. These characteristics show that the 10mm washed gravel is well graded ($C_u > 4.0$). According to BS 882, 1993 washed 10mm all-in gravel is suitable for use as coarse aggregates for concrete.

Researchers had found that the particles size of quarry dust is very close to sand when is observed visually. Thus the physical properties of quarry dust may be examined by using the Standard for fine aggregate [9, 11, 12, 13].

2.2. Properties of Concrete

2.2.1. Workability of Fresh Concrete

Workability is the ease with which freshly mixed concrete can be placed, compacted and finished without segregation [13]. It is the amount of useful internal work necessary to produce fully compacted concrete [11].

The effect of water/cement ratio on the workability of concrete has been studied in several works. Ephraim and Ode [6] studied the suitability of concrete made with the 10mm all in all aggregate. The research revealed that the mobility and workability of fresh 10mm gravel concrete exhibit trends similar to those of normal concrete mixes within the water cement ratio range of 0.45 - 0.90.

Ilangovana et al [8] in their investigation on the strength comparison of concrete made with quarry dust and conventional natural sand examined their workability measured in terms of slump values, V-B time and compacting factor. The test results yielded slump values of 90mm, 60mm and 40mm for grade 20, 30 and 40 concrete respectively with natural sand as fine aggregate. The correspondent values for concrete with quarry dust as fine aggregate were 80mm, 70mm and 30mm for the same concrete grades respectively.The overall workability value of quarry dust concrete is less compared to conventional concrete for a given water/cement ratio .The above findings were confirmed by other researchers [12,13].

2.2.2. Compressive Strength

Several studies have been conducted on the strength of concrete. Ephraim and Ode [6] in their work on the suitability of concrete made with the washed 10mm all-in aggregate yielded a characteristic strength value of about $20.80 N/mm^2$ at the optimum water-cement ratio of 0.50

On the use of quarry dust as a fine aggregate Ilangovana et al [8] used 150 mm x 150 mm x 150 mm cube test specimens to determine its compressive strength. The specimens were cast using M20, M30 and M40 grade concrete with 20mm crushed granite as coarse aggregates. The study showed that the compressive strength of quarry dust concrete is comparatively 10-12 percent more than that of similar mix of conventional concrete. Studies reported elsewhere supported these findings [11,13].

Other researches on the subject matter reveal contrary results and opinions [7, 12, 13]. The influence of partial replacement of sand with quarry dust on the compressive strength and pull-out force of concrete was investigated by Nagaraj & Zahida, [12]. Four concrete mixes, with two water-binder ratios of 0.40 and 0.45 were used in this study. Replacement proportion of 20% sand with quarry dust was applied in all the concrete mixes except in the controlled concrete mix. All concrete cube specimens were cured in dry air in the curing room at $20^{O}C$, and their compressive strength and pull-out force were measured after 7, 14, 28 and 56 days of curing. Test results indicated that concrete incorporating quarry dust without mineral admixtures exhibited a lower compressive strength but a higher pull-out force than the controlled concrete at all ages. Inclusion of fly ash of 10% by weight as binder into the quarry dust concrete resulted in an increase in the compressive strength and pull-out force in almost all conditions. The quarry dust concrete with 10% silica fume as admixture exhibited the highest compressive strength and pull-out force.

From the foregoing review it can be seen that – a general appraisal of the properties of concrete made with 10mm all-in washed gravel aggregate as coarse aggregate and quarry dust as fine aggregate has not been explored.

The author believes that a combination of 10mm all-in washed gravel and quarry rock dust will mobilize the beneficial effects of both materials and yield a concrete with adequate improved strength and durability. The application of quarry dust will engage stock piles of otherwise waste materials and generate economic revenue to the community where they abound. The 10mm gravel is abundant in the Niger Delta Region where crushed granite aggregate is imported. This study will therefore establish proper justification and generate engineering parameters for increased application of these local materials thereby reducing environmental waste and harnessing local resources for a full economic benefit.

3. Materials and Methods

3.1. Materials

The materials used for research are basically 10mm washed gravel all round aggregate collected from Emoha as coarse aggregates and Quarry Rock Dust collected from Crush Rock Limited as fine aggregate. The water used was fit for drinking, conforming to BS3148 (1970). The cement used was the ordinary Portland cement produced by Dangote Cement Company and conforming to EN 196-1:1987; 196-6:1989.

Plate 1. *Determination of Slump Workability*

3.2. Experimental Programme

The experimental programme is presented in Table 1 showing the tests conducted the number of samples tested, the standards used and the parameters investigated.

Compressive strength for the mixes were Carried out in accordance with BSEN206 2001: part 3. Three mixes of mix proportions 1:2:3; 1:1½:2 and 1:1:2 batched by weight and with water/cement ratios 0.40, 0.45, 0.50, 0.55, 0.60, 0.65 and 0.70, were considered

The workability tests on freshly mixed concrete were carried out using the slump test was carried out in accordance with ASTMC 143 – 90a and BS 1881: Part 102:1983. A total of 144 cubes were tested for the three mixes and water cement ratios at ages of 3, 7, 14 and 28 days.

Plate 2. *The Concrete cube under crushing*

Plate 3. *Samples of the crushed concrete cubes*

Table 1. *Experimental Progamme*

S/N	Experiment	Standards	Mix Proportions/No			Total Number	Parameter investigated
			1:2:3	1:1½ :2	1:1::2		
1.	Sieve Analysis	BS 812: Part 103: 1995					Particles Size Distribution
2.	Specific Gravity Tests	BS812: Part 2:1995-1999					Specific Gravity
3.	Density Tests - Tests	BS 812: Part 2: 1995					Density
4.	Workability	BS1881-102.					Slump
5.	Compressive test 7 days, 14 days, 21 days, 28 days 150 x150x150 cube.	BSEN 201-1 (2002) replacing BS 1881:1983	48	48	48	144	F_{CU} (characteristic strength).

4. Results and Discussion

4.1. Physical Properties of Materials

The graphical analysis of the particles size distribution test for 10mm washed all-in aggregate and quarry dust are presented in Figure 1 and 2 respectively. The analysis of plot in Figure. 1 shows that the 10mm washed all-in aggregate consist of 30% gravel, 60% sand and 10% silt. The analysis of plot in Figure. 2 shows that the quarry dust consist of 5% gravel, 35% sand and 60% silt. The results obtained from the particles size distribution test for 10mm washed all-in aggregate indicates that 70% fall within the all-in aggregate envelop of BS 882, 1992. While that of the quarry dust falls within the overall limits of fine aggregate.

Also, the analysis yielded values of fineness modulus of 4.75 and 2.66 for 10mm all-in washed gravel and quarry dust respectively. The values obtained further confirm that the 10mm all-in washed gravel falls within coarse materials while that of the quarry dust can be classified as fine aggregate [9, 11, 14]

The summary of the physical properties of the aggregates obtained from various tests are presented in Table 2 below.

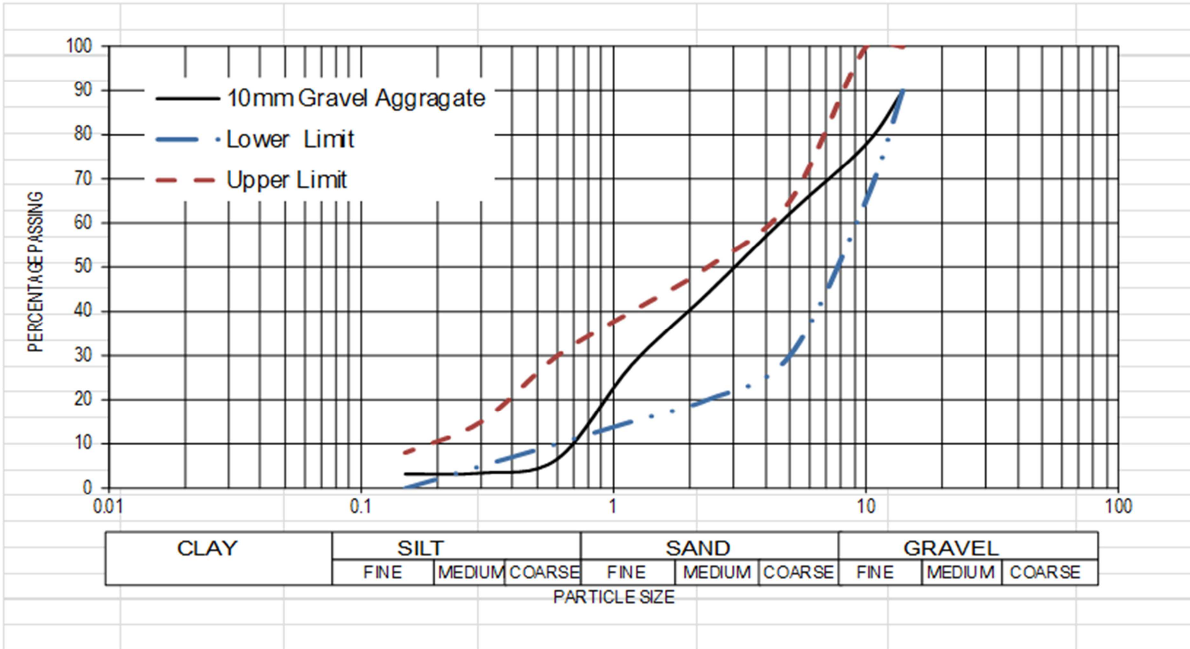

Figure 1. *Particles size distribution plot for 10mm washed aggregate*

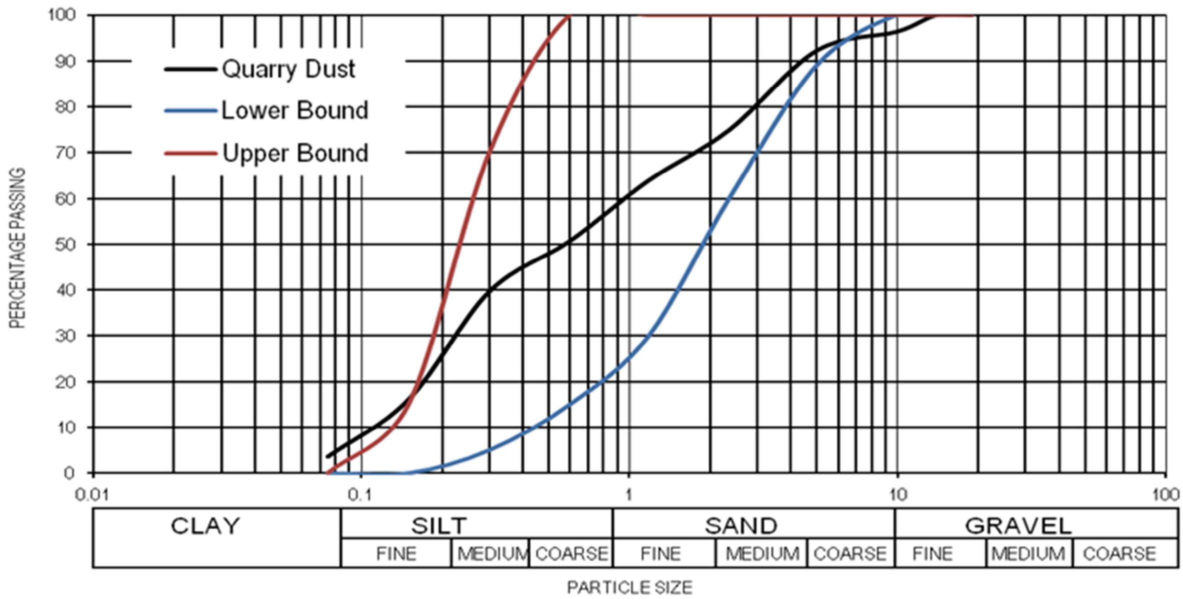

Figure 2. *Particles size distribution plot for Quarry Dust*

Table 2. *Physical Properties of Aggregates*

Properties	10mm washed gravel	Quarry dust	Standards BS 882, 1995
Coefficient of uniformity	5.71	8.18	8.18
Coefficient of curvature	3.21	1.67	1.67
Fineness modulus	4.75	2.66	3.00
Specific gravity	2.72	2.80	2.70
Water absorption (%)	1.21	0.35	2.50
Bulk density (kg/m^3)	1830	1620	1800

The results obtained from the water absorption analysis yielded the average values of 1.21% and 0.35% for the 10mm washed all-in aggregate and quarry dust respectively. These values is far below the maximum limit of 2.50% recommended in BS 882 ,1995 for aggregate for concrete works The water absorption results and its analysis are presented in Appendix 3.

4.2. Workability of Fresh Concrete

On the workability of concrete made with 10mm washed all-in gravel and quarry dust, the variation of slump value with water/cement ratio is shown in Figure 3 while Figure.4 shows the variation of slump value with aggregate/cement ratio for the mixes 1:2:3, 1:1½:2 and 1:1:2. The curve pattern is similar to that of conventional granite concrete.

The optimum water/cement ratio values for mixes 1:2:3, 1:1½:2 and 1:1:2 were 0.65, 0.60 and 0.40.The corresponding slump values were 65mm, 40mm and 20mm for concrete of 1:2:3, 1:1½:2 and 1:1:2 mixes respectively. From Figure.4, it can be deduced that increase of aggregate/cement ratio decreases workability for constant water/cement ratio

Comparing the above slump values with those obtained by Ilangovana et al [8], it could be concluded that for the given water/cement ratio, the overall workability value of concrete made from 10mm washed all-in gravel aggregate and quarry dust is less compared to conventional concrete.

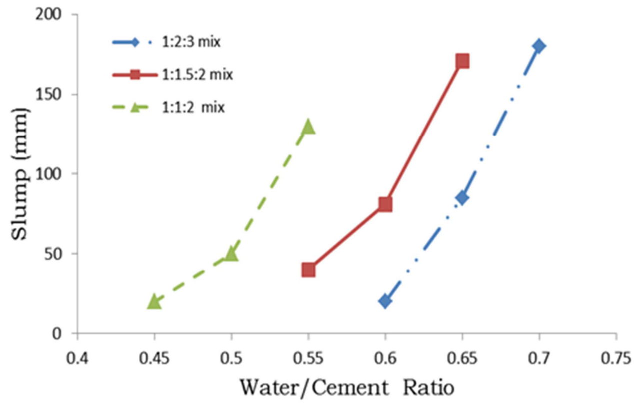

Figure 3. *Variation of Slump values with Water/Cement Ratio for various Mixes*

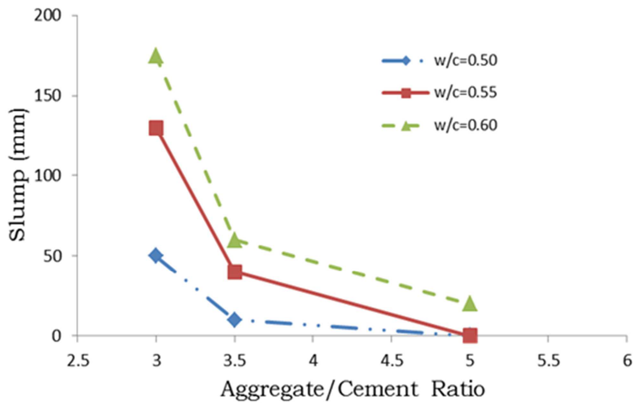

Figure 4. *Variation of Slump values with Aggregate/Cement Ratio for various Mixes*

4.3. Properties of Hardened Concrete

4.3.1. Density

The results of density of the concrete cube made from 10mm washed all-in aggregate and quarry dust are presented in Table 3.

Table 3. *Density of concrete made from 10mm washed all-in gravel and quarry dust as Aggregates*

Properties	(1:2:3)			(1:1½:2)			(1:1:2)		
W/C	0.6	0.65	0.7	0.55	0.60	0.65	0.45	0.50	0.55
Density(kN/m^3)	22.80	23.10	22.10	24.30	24.50	23.00	24.00	24.40	23.50

Table 4. *Compressive strength of concrete made from 10mm gravel and quarry dust as Aggregates*

Properties	1:2:3			1:1½:2			1:1:2		
W/C	**0.6**	**0.65**	**0.7**	**0.55**	**0.60**	**0.65**	**0.45**	**0.50**	**0.55**
Slump(mm)	20	65	170	40	81	171	20	50	130
7 days f_m (N/mm^2)	8.44	14.44	8.24	19.85	19.85	16.96	28.15	22.67	20.39
14 days f_m (N/mm^2)	10.22	16.59	10.15	22.32	22.22	20.22	33.28	27.58	25.93
28 days f_m (N/mm^2)	11.73	20.13	13.68	30.40	29.97	25.91	40.99	35.28	28.81
σ (N/mm^2)	0.45	0.76	0.76	1.42	0.46	0.80	1.58	0.47	0.31
28 days f_{cu} (N/mm^2)	10.97	18.88	10.35	28.06	28.23	23.93	38.29	34.51	28.32

From Table 3, it was observed that the density of concrete made from 10mm washed all-in gravel and quarry dust varies with water/cement ratio and is maximum at the optimum water/cement ratios of 0.65, 0.60 and 0.50 for 1:2:3, 1:1½:2 and 1:1:2 mixes respectively. Also, in Table 3, it could be deduced that the aggregate/ cement (a/c) ratio has a significant effect on density of concrete. 1:2:3 mix with aggregate/cement ratio of 5 has an average density of $22kN/m^3$ while mixes 1:1½:2 and 1:1:2 with aggregate/cement ratio of 3.5 and 3 respectively had an average density of $24kN/m^3$ same as for normal conventional granite concrete. In accordance with BS5238 (1997), part1, concrete with densities between $20kN/m^3$ and less than $26kN/m^3$ are classified under normal weight concrete.

Most researchers on concrete [13] are in accord with the principle that, other things being equal and within certain limits, the strength of concrete increases with the quantity of cement used and with the density or solidity of the resulting concrete.

4.3.2. Compressive Strength

The result from the cube tests are summarized in Table 4. The characteristic strength is calculated from the standard expression:

$$f_k = f_m - 1.64\sigma \qquad 1$$

where

f_k = Characteristic strength.

f_m = mean strength.

σ= standard deviation.

The calculated characteristic compressive strengths (f_{cu}) for 1:2:3, 1:1½:2 and 1:1:2 are $18.88N/mm^2$, $28.23N/mm^2$ and $38.29N/mm^2$ at 0.65, 0.60 and 0.45 water/cement ratio respectively.

The relationship between compressive strength and age or duration of wet curing is shown in Figure. 5. The growth pattern of strength is not linear for all the test mixes and specimen from 7 days to 28 days. There is little strength growth between 21 and 28 days. The variation shows that the compressive strengths at age of 7,14 and 21 days constitute average values of about 70%,80% and 95% of the 28th days cube strength. These values are comparable to 67%, 80% and 95% obtained by Ephraim and Ode [6] and other related studies on concrete with gravel and quarry dust as aggregates [8, 9].

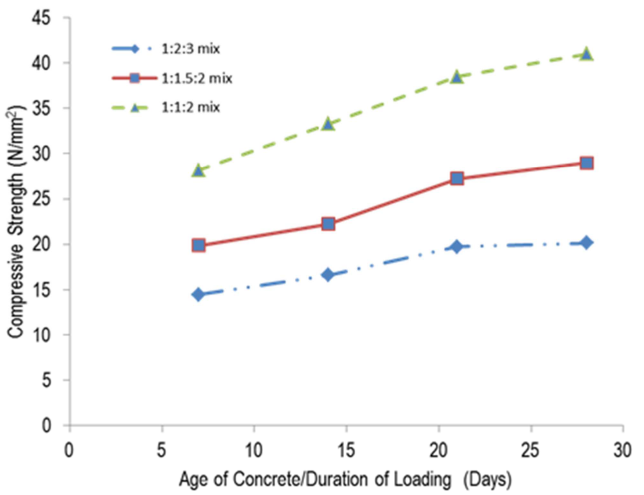

Figure 5. *Variation of Compressive Strength with Age/Duration of Wet Curing*

(i) Effect of Water/Cement Ratio on Strength

The variation of compressive strength with water/cement ratio is shown in Figure 6 the curve patterns are similar to that of a conventional concrete where for a degree of hydration, the water/cement ratio determine the porosity of the cement gel which further influences the strength of the concrete. From Figure 4.6, the compressive strength of concrete made with 10mm washed gravel and quarry dust decreases with increase in the water/cement ratio reaching its optimum values of 0.65, 0.60 and 0.45 for 1:2:3, 1:1½:2 and 1:1:2 mixes respectively

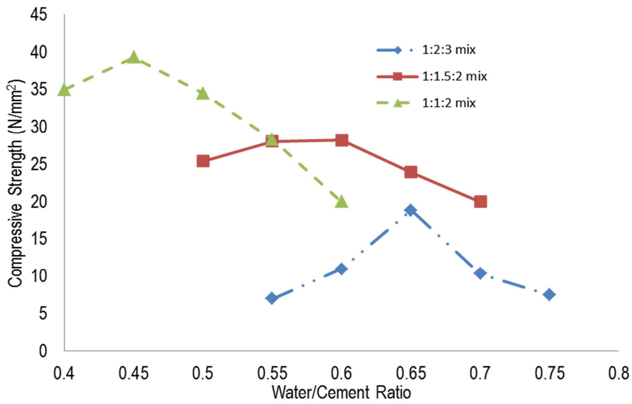

Figure 6. *Variation of Compressive Strength with Water/Cement Ratio*

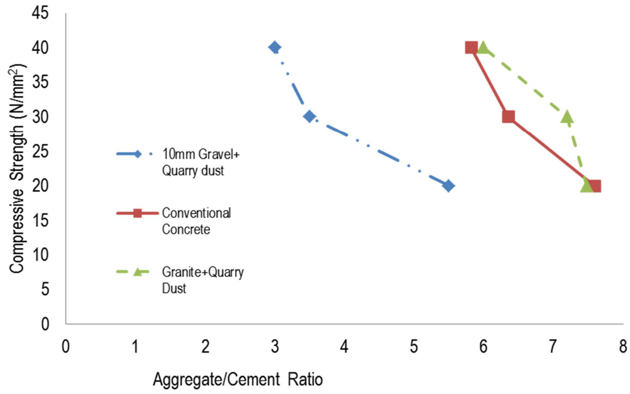

Figure 7. *Variation of Compressive Strength with Aggregate/Cement Ratio*

(ii) Effect of Aggregate/Cement Ratio on Strength

The variation of compressive strength with aggregate/cement ratio is shown in Figure 7 below for concrete made with 10mm washed all-in gravel and quarry dust, conventional concrete and concrete made with granite chippings and quarry dust as aggregates

In can be deduced that for a given water/cement ratio and a particular compressive strength, the aggregate/cement ratio of concrete made from 10mm washed all-in gravel and quarry dust, is lower than the other two aforementioned types of concrete. With the above comparison it follows that more cement is required for concrete made with 10mm washed all-in gravel and quarry dust than that of conventional crushed granite concrete achieve a particular strength of concrete. Though cement is more expensive than aggregate, the cheaper cost of 10mm all-in gravel and quarry dust when compared with crushed granite and river sand coupled with the environmental effect will compensate for the higher quantity of cement required for the 10mm washed all-in gravel and quarry dust concrete. Hence, a cheaper and more environmentally friendly concrete will be produced.

5. Conclusion

The study reported herein was aimed at studying the various combination of 10mm washed all-in gravel as coarse aggregate and quarry rock dust as fine aggregate to produce concrete with adequate strength. The following conclusions were drawn from the experimental tests conducted in this study:

5.1. Physical Properties of Aggregates

a. The particles size distribution test for 10mm washed all-in gravel indicates that 70% fall within the all-in aggregate envelop of BS 882 (1992), while that of the quarry dust falls within the overall limits of fine aggregate. The analysis of test result gives the coefficient of uniformity and curvature of 5.71 and 3.21 respectively for the gravel and 8.18 and 1.67 respectively for the quarry dust.

b. The analysis particles size distribution test results gives fineness modulus of 4.75 and 2.66 for 10mm washed all-in gravel and quarry dust respectively. These values satisfy the requirement of BS 882 (1992) and confirm that the 10mm washed all-in falls within the grading limits of course materials while that of the quarry dust can be classified as fine.

c. The specific gravity values are 2.72 and 2.80 for the 10mm washed all-in and quarry dust respectively while their density test yielded the values of 1830kg/m^3 and 1620kg/m^3 respectively.

d. The water absorption analysis yielded the average values of 1.21 and 0.35 for the 10mm washed all-in and quarry dust respectively.

e. Therefore the 10mm washed all-in and quarry dust satisfied the requirements of BS 882 (1992) in properties studies and can serve as full replacement for conventional granite and natural river sand respectively.

5.2. Properties of Fresh and Hardened Concrete

a. The workability test results gave slump values of 65mm, 40mm and 20mm with corresponding water/cement ratio of 0.65, 0.60 and 0.45 for mixes 1:2:3 ,1:1½:2 and 1:1:2 concrete respectively. Therefore, workability of concrete made with 10mm washed aggregate and quarry dust can be described as medium.

b. In accordance with BS5238, part1, 1997.the densities of the concrete are between 20kN/m^3 but less than 26kN/m^3, hence can be classified under normal weight concrete.

c. The calculated characteristic compressive strengths for 1:2:3, 1:1½:2 and 1:1:2 mixes are 18.88N/mm^2, 28.23N/mm^2 and 38.29N/mm^2 at 0.65, 0.60 and 0.45 water/cement ratio respectively. These corresponding concrete grade are 15, 25 and 35 respectively.

h. Thus, it can be concluded that the full replacement of conventional granite and natural sand with 10mm washed aggregate and Quarry Rock Dust respectively, in concrete is possible.

Appendix 1

Determination of particles size distribution and fineness modulus.

Table 4. *Determination of Fineness Modulus of 10mm Aggregate*

Sieve Size (mm).	Wt. Retained	Cumulative Wt. Retained	Cumulative % Retained
14	36	36.00	10.14
10	42.60	78.60	22.14
5.00	55.40	134.00	37.75
2.36	64.50	198.50	55.92
1.18	57.60	256.10	72.14
0.600	75.50	331.60	93.41
0.300	11.20	342.80	96.56
0.150	0.70	343.50	96.76
0.075	0.10	343.60	96.79

Fineness Modulus of Quarry Dust =∑ Cumulative % retained)/100
= (22.14+ 37.75 + 55.92 + 72.14 + 93.41 + 96.56+ 96.76)/100 = 4.75
Coefficent of Uniformity Cu = D60/D10 = 0.90/0.11 = 8.16
Coefficent of Curvature Cc= D302/(D10xD60) = 0.232/(0.11x 0.9) = 1.67

Table 5. *Determination of Fineness Modulus of Quarry Dust*

Sieve Size (mm).	Wt. Retained	Cumulative Wt. Retained	Cumulative % Retained
14	0.00	0.00	0.00
10	9.00	9.00	3.58
5.00	10.40	19.40	7.71
2.36	43.40	62.80	24.97
1.18	27.70	90.50	35.98
0.600	33.30	123.80	49.22
0.300	27.80	151.60	60.28

Sieve Size (mm).	Wt. Retained	Cumulative Wt. Retained	Cumulative % Retained
0.150	59.20	210.80	83.82
0.075	31.40	242.20	96.30

Fineness Modulus of Quarry Dust = ∑Cumulative % retained)/100
= (3.58 + 7.71 + 24.97 + 35.98 + 49.22 + 60.28+ 83.82)/100 = 2.66
Coefficent of Uniformity Cu = D60/D10 = 4.0/0.7 = 5.71
Coefficent of Curvature Cc = $D30^2/(D10xD60) = 3.0^2/(0.7x\ 4.0) = 3.21$

Appendix 2

Table 6. *Specific Gravity Results.*

S/No	1	2	3	4
Sample Type	**10mm washed aggregate**		**Quarry Rock Dust**	
Weight of empty jar (m1) (g)	24.00	24.00	24.70	24.70
Weight of empty jar + Sample (m^2) (g)	33.80	34.00	34.70	34.30
Weight of jar + Sample + Water(m^3) (kg)	82.60	82.70	82.30	82.10
Weight of jar + Water (kg)(m4)	76.40	76.40	75.90	75.90
Mass of oven-dried sample (g) (m^5)	9.71	9.86	9.96	9.57
$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_4)}$	2.72	2.70	2.78	2.82
Average Gs	2.71		2.80	
Water Absorption $= \frac{m_2 - m_1 - m_5}{(m_2 - m_1)} \times 100$	0.99	1.43	0.40	0.30
Average Water =Absorption %	1.21		0.35	

Appendix 3

Table 7. *Particles Density Results.*

S/No	1	2	3	4
Sample Type	**10mm washed aggregate**		**Quarry Rock Dust**	
Mass of mould (kg) (m^1)	1800	1800	1800	1800
Mass of mould + Sample (kg) (m^2)	3546	3566	3508	3488
Mass of oven-dried sample (kg) (m^3)	1520	1490	1324	1355
Volume of mould (cm^3) (m^4)	825	825	825	825
Wet Desity $\rho_b = \frac{m_2 - m_1}{m_4}$ Mg/m^3	2.12	2.14	2.07	2.04
Average ρ_b Mg/m^3	2.13		2.06	
$\rho_d = \frac{m_3}{m_4}$ Mg/m^3	1.84	1.81	1.60	1.64
Average ρ_b Mg/m^3	1.83		1.62	

Appendix 4

Table 8. *Workability Test Result.*

Mix proper.	Water/Cement Ratio	Slump
1:2:3	0.45	Nil
	0.50	Nil
	0.55	Nil
	0.60	20mm
	0.65	85mm
	0.70	180mm
1: 1½:2	0.45	Nil
	0.50	Nil
	0.55	40mm
	0.60	60mm
	0.65	171mm
1:1:2	0.40	Nil
	0.45	20mm
	0.50	50mm
	0.55	130mm

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