Nigerian Journal of Environmental Sciences and Technology (NIJEST)
www.nijest.com
ISSN (Print): 2734-259X | ISSN (electronic): 2734-2603
Vol 5, No. 2 October 2021, pp 582 - 591

Utilization of Quarry Dust as a Partial Replacement of Sand in Concrete Making

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https://doi.org/10.36263/nijest.2021.02.0310

ABSTRACT

The use of crushed quarry dust as a partial replacement of river sand in concrete production was investigated in this study. This is expedient as quarry dust can be available at some locations with insufficient river sand for construction purposes. The use of quarry dust is also in concrete is also a measure necessary for improvement of concrete strength. River sand was replaced with quarry dust for different mix designs of concrete for 0% to 25% replacement levels with 5% intervals. The physical properties of river sand and quarry dust were tested and reported and the workability as well as compressive strengths of the concrete mixtures were also tested. It was observed that the slump values increased with increase in percentage replacement of sand with quarry dust. The compressive strength of cubes at 28 day curing for control mixture of 1:3:6 at 0% partial replacement of river sand with quarry dust was 12.6N/mm^2 but compressive strengths of 21.5 N/mm^2 and 26.0 N/mm^2 were gotten for 1:2:4 concrete and 1:1.5:3 concrete respectively. As the quarry dust content increased to 25%, the 28day compressive strength increased to 13.58 N/mm^2 and 21.57 N/mm^2 for the 1:3:6 and 1:2:4 mixes respectively. Compressive strength values decreased to a value of 25.72N/mm^2 for the 1:1.5:3 concrete mix. The maximum compressive strength values were reached at 20% quarry dust content at the age of 28 days for the three concrete grades investigated. The increase in compressive strength with inclusion of quarry dust was attributed to the higher specific gravity of quarry dust above river sand. The compressive strength of quarry dust concrete continued to increase with age for all the percentages of quarry dust contents. Quarry dust was recommended as a suitable partial replacement for river bed sand in concrete production.

Keywords: Compressive strength, Concrete, Fine aggregates, River sand, Quarry dust

1.0. Introduction

The use of quarry dust in concrete is desirable because of its benefits which include useful disposal of by products, reduction of river sand consumption, increasing the strength parameters of concrete, and increasing the workability of concrete (Lohani *et al*., 2012). This innovation has been found useful in concrete for different construction activities including roads, buildings, bricks, tiles etc. Concrete is an assemblage of cement, aggregate and water. The aggregates are majorly of two types, fine and coarse. The most commonly used fine aggregate is sand derived from riverbanks. Quarry dust has been used for different activities in the construction industry such as road construction and manufacture of building materials such as light weight aggregates, bricks, and tiles. It is a by-product of stone crushing. It was envisaged that crushed rock aggregates are more suitable for production of high strength concrete compared to natural gravel and sand.

Nigeria as a developing nation is seriously experiencing excessive excavation and mining of natural river sand which has negative environmental consequences (Ajamu *et al*., 2020). Besides, it has been observed that slope failures along the shorelines or riverbanks are partly attributed to the mining of river sand at the toe of the slopes and thereby creating problems of instability of the natural embankments. Replacing river sand with quarry dust would therefore be a solution to river embankment failures.

The global consumption of natural sand is too high due to its extensive use in concrete production. The demand for natural sand is quite high especially in developing countries like Nigeria, owing to rapid infrastructural growth which at times results in supply, scarcity, and other environmental concerns. As a result, construction industries in Nigeria have been bent on identifying alternative materials to replace or reduce the demand for natural sand. On the other hand, the benefits of utilizing residues or aggregates obtained as waste materials are significant in the areas such as reduction in environmental degradation and waste management costs, decrease in production cost as well as augmenting the quality of concrete (Sandeep *et al*., 2014).

Furthermore, recent building collapses in some parts of the country has been attributed to the use of low-quality building materials. This could be due to non-compliance with specifications and standards, use of substandard building materials and equipment and the employment of incompetent contractors. There is therefore the need to investigate into the possibility of discovering new innovative materials that would possibly improve the strength characteristics of concrete and so add value to the structural stability of buildings. Quarry dust is one of such materials that have been used as a partial replacement of sand in concrete with many and varied observations from different researchers (Raman *et al*., 2011; Aginam *et al*., 2016).

Quarry dust has been classified as a pozzolana with possibilities to replace cement partially. However, the utilization of it as a partial replacement of fine aggregates promises double benefits with regards to strength gain and effective waste management. Attempts have been made to investigate some properties of quarry dust and the suitability of quarry dust to partially replace sand based on those properties (Dehwah, 2012; Raman *et al*., 2011). According to Raman *et al*. (2011), the partial replacement of sand with quarry dust without inclusion of fly ash resulted in a reduction in the compressive strength of concrete paving blocks. The inclusion of fly ash at a later experiment resulted in a significant improvement of the concrete strength. Under sulphate and acid action, the durability of concrete with quarry dust as fine aggregate was better than conventional concrete (Ilangovana *et al*., 2008). An investigation by Devi and Kannan (2011), which focused on the strength and corrosion resistance behavior of inhibitors in concrete containing quarry dust as fine aggregates, disclosed that the inclusion of admixtures did not show any adverse effects on the strength of the concrete. Sivakumar and Prakash (2011) reported that inclusion of quarry dust as a partial replacement of river sand increased the strength of the concrete; this was in line with the report of Ukpata *et al*. (2012). Rahim *et al*. (2020) investigated the sustainable utilization of quarry dust in concrete. Their results revealed that 25% of quarry dust yielded optimum values to be used in concrete. In another study, Shina *et al*. (2017) observed that 50% replacement of sand by quarry dust gives higher values of compressive strength and 100% replacement of sand by quarry dust gives better result than natural sand concrete. With these disparities and different conclusions, it remains necessary to investigate into the adequacy of using quarry dust in place of conventional aggregates. This study focusses on the on the use of quarry dust as a partial replacement of river sand in concrete production.

In this study, the influence of various amounts of quarry dust on the compressive strength of different concrete mix designs was investigated for different curing ages. The three mix ratios considered in this study are 1:1.5:3, 1:2:4, and 1:3:6 and the amounts of quarry dust was varied at 0%, 5%, 10%, 15%, 20% and 25% replacement levels of river sand by quarry dust. With these variables, new mathematical models were developed to explain the influence of quarry dust addition and curing age on the compressive strength of concrete. These results helped to further clarify the nature of strength gain with quarry dust addition in concrete.

2.0. Methodology

2.1. Materials

In this investigation, all samples were made from local materials, which consisted of the following: Portland cement, fine aggregates (sand) from the Agu-Awka River, Anambra State and, quarry dust and coarse aggregate of crushed hard granite from Abakaliki, Ebonyi State, Nigeria. The quarry dust was collected from the same location as the crushed granite. Grade 42.5N cement was used. The portable borehole water was used for the purpose of this study, both for concrete mixing and curing.

2.2. Methods

The concrete mix proportions adopted were 1:1.5:3; 1:2:4; 1:3:6 and the percentage replacements of 0, 5, 10, 15, 20, and 25% of the river sand with quarry dust were adopted. A constant water cement ratio of 0.55 was used in this study. Cubes of dimension 150mm × 150mm × 150mm were cast and the compression strength determined at the ages of 7, 14, 21 and 28 days according to the specifications of BS EN 12390- 1:2000. The methods for determining the compressive strength of cores are as prescribed by BS 1881: Part 120: 1983 and by ASTM C 42. In laboratory, many techniques can be used to examine and test hardened concrete to assess a wide variety of properties. In the present study, the crushing machine was employed in crushing the concrete cube samples in a bid to determine their compressive strength values. The experimental program was designed to study the influence on the compressive strength of concrete when fine aggregate (sand) is partially replaced with quarry dust. Also investigated was the influence of age on concrete properties. Apart from these, the study also investigated the influence of the proportion of mixture on compressive strength of concrete.

The determination of moisture content (w) of the fine aggregate samples was performed based on the BS 5930 and ASTM D 2216 using the oven drying method. The apparatus utilized for the activity included a non-corrodible sample container with its lid, a balance, a thermostatically controlled electric oven, desiccators and a pair of tongs. Eq. (1) is the expression for moisture content determination.

$$w = \frac{Mass\ of\ water}{Mass\ of\ soil\ solids} \tag{1}$$

The determination of specific gravity (*Gs*) of the samples was performed based on the ASTM D854–10 and BS 1377-2. Basic apparatus used in the investigation included: a pycnometer with its washer and cap; a glass rod for stirring; vacuum pump; a balance; drying oven; desiccators; distilled water and a thermometer. Particle size distribution analysis was done based on BS 1377-2 and was undertaken for the fine aggregates (sand) whereas the slump test for concrete consistency was carried out based on the specifications of BS 5328. The slump test was conducted to determine the workability of the ready mixed concrete just before its placement at final position inside the mould. Concrete destructive compression test was then utilized in determining the compression strength of the concrete. This concrete was poured in the mold and tempered properly so as not to have any voids. Three (3) cubes were crushed per curing age using the compression testing machine, whereas the slump test for concrete consistency was carried out based on the specifications of BS 5328.

3.0. Results and Discussion

3.1. Particle size distribution analysis and material classification

Figure 1 shows the particle size distribution curves for the river sand and the quarry dust all together. Both are well graded soil samples. For the effective size (D_{10}), the diameters corresponding to 10% of the samples finer in weight for both samples were0.25mm and 0.08mmwhile the median size (D_{50}) which gives an average particle size for the samples were 0.60mm and 1.34mm for the river sand and quarry dust respectively. The grain size diameters (D_{60}) corresponding to 60% finer in weight on the grain size distribution curves were 0.75mm and1.67mm. Similarly, D_{30}, which is the grain size corresponding to 30% finer in weight on the grain size distribution curves were 0.43mm and 0.55mm.

It is the effective size (D_{10}) to which permeability (k) is related. The resulting coefficients of permeability ($k = 10(D_{10})^2$) which gives the ratio between the discharge velocity and the corresponding hydraulic gradient of the samples were 0.625mm/s and 0.064mm/s. The coefficients of uniformity (C_u) which are the shape parameters defined as ($C_u = D_{60}/ D_{10}$) were 3.0 and 20.88, while the other shape parameters (coefficient of curvature) defined as [$C_c = (D_{30})^2 / (D_{10} \times D_{60})$] were 0.99 and 2.26 for the sand and quarry dust, respectively.

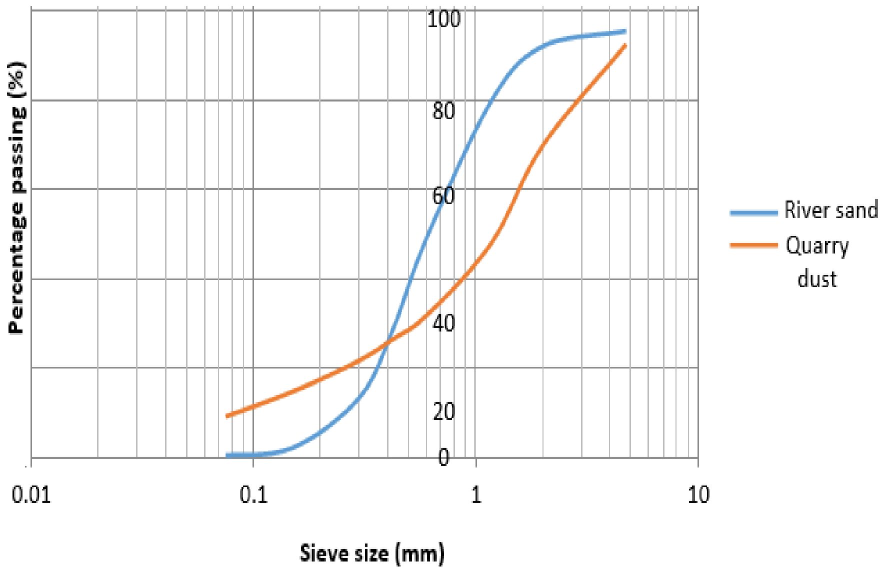

Figure 1: Particle size distribution curve for both the quarry dust and river sand

The coefficients of uniformity indicated the grading of the soil samples. For both the river sand and the quarry dust, more than 50% of the coarse fraction passed the No.4 sieve (4.75mm), hence classified as sandy, and also more than 50% passed the No.200 sieve (0.075mm), hence fine grained. In addition to these, percentage of fines was less than 12% for both samples, hence classified as clean sands. Additionally, since the coefficients of curvature for both samples are between 1 and 3, and the coefficients of uniformity are greater than 6, hence they are classified as being well graded sands (SW). The grading or size distribution of aggregate was an important characteristic because it determined the paste requirement for workable concrete. With particles of uniform size the spacing was the greatest, but when a range of sizes were used the void spaces were filled and the paste requirement lowered. The more these voids were filled, the less workable the concrete became. These index parameters deduced from the particle size distribution analysis are summarized in Table1 and they are in accordance with the requirements of BS EN 933-1 (2012).

Table 1: Deductions from particle size distribution analysis

Parameters	River Sand	Quarry Dust
Effective size (D_{10})	0.25	0.08
First quartile (D_{25})	0.40	0.34
30% passing (D_{30})mm	0.43	0.55
Median size (D_{50})	0.60	1.34
60% passing (D_{60}) mm	0.75	1.67
Third quartile (D_{75})	1.00	2.50
Uniformity coefficient., $C_u = D_{60}/D_{10}$	3.00	20.88
Coefficient of curvature, $C_c = (D_{30})^2/D_{60}*D_{10}$	0.99	2.26
0.5 Sorting coefficient, $S_0 = (D_{75}/D_{25})$	1.58	2.71
Coefficient of permeability, $k = 10(D_{10})^2$mm/s	0.625	0.064
Percentage sand%	95.63	92.64
Percentage gravel%	4.37	7.36

3.2. Specific gravity

The specific gravity (*Gs*) of the aggregates was taken as the ratio of its mass to the mass of an equal volume of water. The results of specific gravity analysis for the rivers and the quarry dust are presented in Table 2. The quarry dust had a higher specific gravity (*Gs*) value of 2.66, while the river sand had a lower value of 2.49.

The specific gravity of samples indicated how many times the samples were heavier than water. The higher the specific gravity of the sample, the higher the density of concrete made with and the higher was the force required to crush it and the higher was the corresponding strength of the concrete. Conversely a lower specific gravity of sample would result in lower density of concrete. Specific gravity was a means to decide the suitability of the aggregate (Arumugam, 2014) indicates porous, weak and absorptive materials, whereas high specific gravity indicates materials of better quality. The specific gravity was also used as a measure of aggregate quality as porous aggregates that exhibited deterioration does have low specific gravities, implying that the river sand had a lower quality in terms of specific gravity. The opinion is that the quarry dust with higher specific gravity is expected to be denser and possibly performs better in a concrete mix than river bed sand.

Table 2: Specific gravity determination for the River Sand and the Quarry Dust

Specimen number/sample	Quarry dust	River sand
Pycnometer bottle No.	90	91
Mass of empty clean pycnometer(grams)Wp	37.44	53.91
Mass of empty pycnometer +dry soil (grams)Wps	63.49	74.07
Mass of pycnometer +dry soil +water(grams)WB	153.61	165.76
Mass of pycnometer +water(grams)WA	137.37	153.70
W0=Wps-Wp	26.05	20.16
Specific gravity (Gs), Gs= $\frac{W0}{Wps+[WA-WB]}$	2.66	2.49

3.3. Consistency test

Slump was taken as the drop in concrete height when the cone full of concrete was lifted. The analysis was done as a means of evaluating the consistency and workability of the concrete mix. The results of the slump analysis for a concrete mix of 1:2:4 for different percentages of partial replacement of river sand with quarry dust are presented in Table 3. The slump test gave an approximate indication of the workability of the wet concrete mix. It was suitable for quality control purposes and detecting changes in workability. Workability is related to the compatibility, mobility and stability of fresh concrete. The slump test measured the fluidity of concrete. Under conditions of uniform operation, changes in slump indicate changes in materials, mix proportions or the water contents. The measured slump values of quarry dust with constant water/cement ratio i.e., w/c ratio (0.55) were 41, 45, 48, 50, 53, and 60mm for 1:2:4 concrete mix with (0, 5, 10, 15, 20 and 25%quarry dust) replacement of the river sand respectively. The variations of slump values with quarry dust percentages are shown. It was observed that the slump value increases with increase in percentage replacement of sand with quarry dust for the same w/c ratio. A significant increase was observed at 25% replacement of quarry dust. It can be attributed to the extra fineness of quarry dust which requires greater amount of water for the mix ingredients to get closer packing.

Table 3: Slump test analysis

Percentage of quarry dust replacement	Slump(mm)
0	41
5	45
10	48
15	50
20	53
25	60

The slump test was only used to determine the quality of concrete from batch to batch within a given mix design, it measured the fluidity of concrete. Since there were no admixtures in the concrete (just cement, aggregates and water) slump was a fair indicator of water content. The more water that was in the mix, the more the cement particles were dispersed. The more the cement particles were dispersed, the weaker the hardened paste was, and conversely, the lower the slump the higher the final strength. Under the conditions of uniform operation, changes in slump indicated change in materials, mix proportions or the water contents. In the slump test carried out, the slumps of 41mm to 60mm were classified true in concrete mixes, i.e., the water contents were not enough to cause shear.

3.4. Compressive strength of concrete

The summary results of concrete compressive strength of the different mixtures (1:3:6,1:2:4 and 1:1.5:3) based on the partial replacement of river sand with different percentages of quarry dust (0,5,10,15, 20 and 25) are presented in Tables 4 and Figures 2, 3 and 4.

Table 4: Summary of concrete compressive strength (N/mm^2) as a function of age, mix ratio and percentage partial replacement of fine aggregates with quarry dust

Concrete age (days)	Concrete compressive strength (N/mm^2) at various percentage composition of quarry dust as partial replacement of fine aggregates						Percentage increase In compressive strength
	0%	5%	10%	15%	20%	25%	0% -20%
1:3:6 Concrete mix ratio							
7	9.50	9.53	9.69	10.01	10.49	10.19	10.42
14	10.50	10.55	10.72	11.08	11.60	11.27	10.48
21	11.50	11.56	11.76	12.15	12.72	12.36	10.61
28	12.60	12.71	12.92	13.35	13.98	13.58	10.95
1:2:4 Concrete mix ratio							
7	16.10	16.33	16.75	17.22	17.64	16.18	9.57
14	17.80	18.07	18.53	19.06	19.52	17.90	9.66
21	19.60	19.81	20.32	20.89	21.40	19.63	9.18
28	21.50	21.77	22.33	22.96	23.52	21.57	9.40
1:1.5:3 Concrete mix ratio							
7	19.50	19.94	20.00	20.12	20.30	18.54	4.10
14	21.60	22.07	22.14	22.27	22.45	20.52	3.94
21	23.70	24.20	24.27	24.42	24.63	22.50	3.92
28	26.00	26.59	26.67	26.83	27.07	25.72	4.12

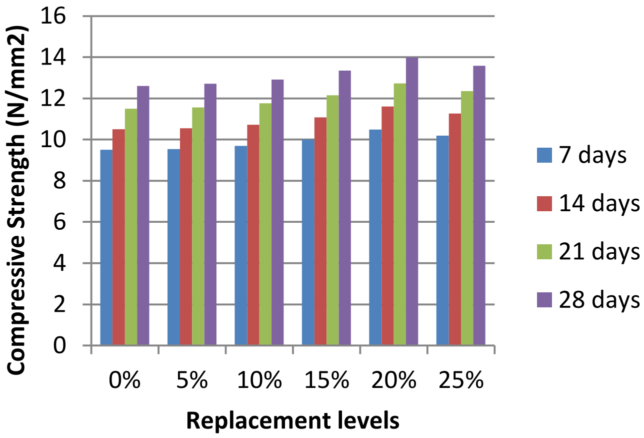

Figure 2: Summary of the variation of concrete compressive strength (N/mm^2) for 1:3:6 mix as a function of age and percentage replacement of fine aggregates with quarry dust

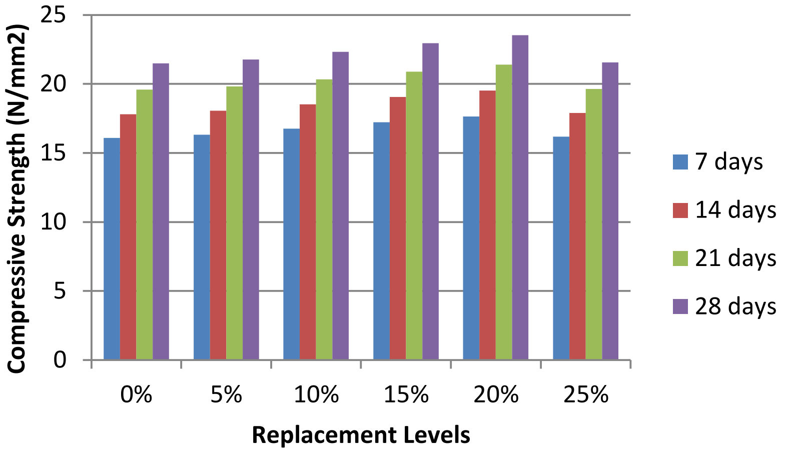

Figure 3: Summary of the variation of concrete compressive strength (N/mm^2) for 1:2:4 mix as a function of age and percentage replacement of fine aggregates with quarry dust

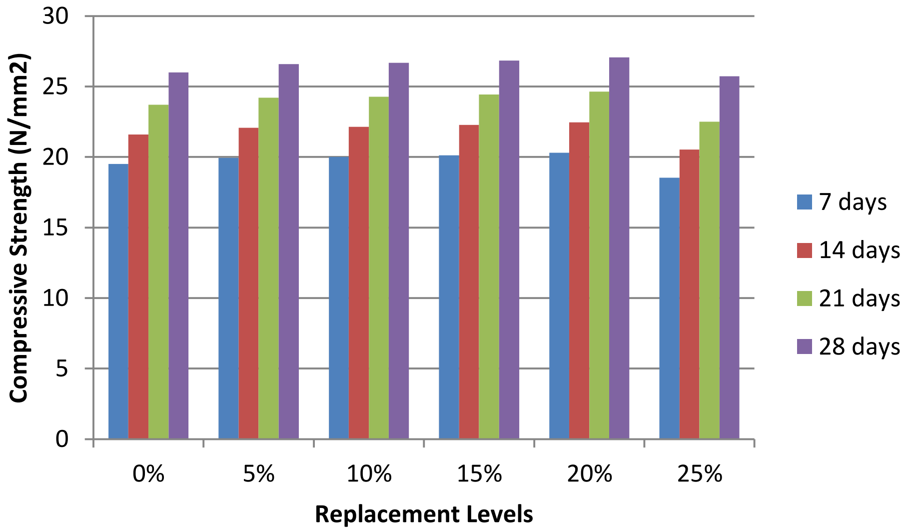

Figure 4: Summary of the variation of concrete compressive strength (N/mm^2) for 1:1.5:3 mix as a function of age and percentage replacement of fine aggregates with quarry dust

It was observed that the compressive strength of cubes at 28day curing for control mixture of 1:3:6 at 0% partial replacement of river sand with quarry dust were 12.6N/mm^2, 21.50 N/mm^2 for 1:2:4 concrete and 26.0N/mm^2 for 1:1.5:3 concrete. As the quarry dust content increased to 25%, the 28day compressive strengths decreased to values of 13.58N/mm^2 for a 1:3:6 mix, 21.57N/mm^2 for a 1:2:4 mix, and 25.72 N/mm^2 for 1:1.5:3 concrete mix respectively. The maximum compressive strength values were reached at 20% quarry dust content at the age of 28 days for the three grades of concrete grades. As the dust content exceeded 20%, the compressive strength decreases. Similar results have also been reported in Nazma and Madhavi (2020). For the specimen of quarry dust content of 0% and 15% the dust particles amount were not enough to fill all the voids between cement paste and aggregate particles, hence they had lower compressive strength values than specimens of 20% dust content. It can be perceived that the compressive strength of the cubes at 28 days of curing for the control mix was 12.6N/mm^2 and the strength increased by 1.35%, 13.85% for mix 1:2:4 and 1:1.5:3respectively in comparison with control mix 1:3:6. There were 6.8, 10.8 and 2.4% increments in compressive strengths for concrete mixes of 1:3:6, 1:2:4 and 1:1.5:3 at 20% partial replacement of the river sand with quarry dust in comparison with the control mixes at 0% partial replacement. As the dust particles exceeded 20%, flaky particles or higher fines increased water demand which led to higher water cement ratio and segregation of concrete resulting in non-uniform distribution of cement paste. This consequently led to a decrease in compressive strength. Similar reports were made in Sakthivel *et al*. 2013; Madzura *et al*., 2015) and Chiemela *et al*. (2015). Sakthivel et al. (2013)

obtained the highest compressive strength of 45.55MPa with 10% wt. of quarry dust and observed a decreasing trend of 32.78MPa, 29.33Mpa and 26.33Mpa as quarry dust content exceeded to 20%, 30% and 40 %wt. But, the compressive strengths of quarry dust concrete continue to increase with age for all the percentages of quarry dust contents. The trend line second order polynomial equations and the R^2 values relating the concrete compressive strength with curing days at different percentage replacement of river sand with quarry dust are shown in Table 5. Compressive strength is denoted by '*y*' and curing days is denoted by '*x*' in the model equations.

Table 5: Model Equations for the variation of concrete compressive strength (N/mm^2) with age (days)

Concrete mix	Model equation	R^2
	Zero percent quarry dust replacement of the river sand	
1:3:6	$y=-0.0245x^2+1.0743x+0.98$	0.9180
1:2:4	$y=-0.0413x^2+1.8194x+1.6571$	0.9192
1:1.5:3	$y=-0.050x^2 +2.2069x+2.0057$	0.9190
Five percent quarry dust replacement of the river sand		
1:3:6	$y=-0.0277x^2+1.1962x +0.949$	0.9075
1:2:4	$y=-0.474x^2 +2.0546x+0.7848$	0.9088
1:1.5:3	$y=-0.0579x^2+2.5093x +1.988$	0.9081
Ten percent quarry dust replacement of the river sand		
1:3:6	$y=-0.0281x^2+1.2191x+0.5998$	0.9071
1:2:4	$y=-0.0245x^2+1.0743x+0.9801$	0.9078
1:1.5:3	$y=-0.0245x^2+1.0743x+1.0092$	0.9080
Fifteen percent quarry dust replacement of the river sand		
1:3:6	$y=-0.0291x^2+1.2597x+1.4128$	0.9081
1:2:4	$y=-0.05x^2 +2.16684x+0.4562$	0.9079
1:1.5:3	$y=-0.0585x^2+2.534x+0.8557$	0.9081
Twenty percent quarry dust replacement of the river sand		
1:3:6	$y=-0.0305x^2+1.3193x+0.4877$	0.9076
1:2:4	$y=-0.0512x^2+2.2193x+0.7811$	0.9079
1:1.5:3	$y=-0.0589x^2+2.553x+1.2863$	0.9078
Twenty-five percent quarry dust replacement of the river sand		
1:3:6	$y=-0.0296x^2+1.2818x+0.3198$	0.9078
1:2:4	$y=-0.047x^2 +2.0355x+1.0913$	0.9079
1:1.5:3	$y=-0.0512x^2+2.2907x+0.3398$	0.9033

4.0. Conclusions

This study focused on the use of quarry dust as a partial replacement of river sand in concrete production. The influence of various amounts of quarry dust on the compressive strength of different concrete mix designs was investigated for different curing ages. The three mix ratios considered in this study are 1:1.5:3, 1:2:4, and 1:3:6 and the amounts of quarry dust was varied at 0%, 5%, 10%, 15%, 20% and 25% replacement levels of river sand by quarry dust. Based on the results, it was concluded that;

1. The compressive strength of concrete with different proportions of quarry dust generally increased with increase in curing age. This confirms that inclusion of quarry dust would not hinder the temporal gain of compressive strength of the concrete.
2. All the mixtures containing quarry dust performed better than the control mixtures. This shows that quarry dust can be used as partial replacement of concrete for all types of concrete mixtures.
3. Based on the slump tests, the workability of the fresh concrete mixtures increased with higher amounts of quarry dust. This further encourages the use of quarry dust in concrete.
4. Maximum compressive strength for all the mix designs was recorded for the 20% replacement level. Beyond 20% replacement, the strength reduced. This was attributed to higher amounts of fines in the mixtures.

These show that quarry dust is a viable partial replacement of river sand in concrete. It is recommended that the replacement level be limited to 20% for optimum performance. Implementation of this recommendation can be a solution in places with insufficient river sand as well as improvement to the strength of concrete.

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Cite this article as:
Aginam C. H., Nwakaire C. M., Onodagu P. D. and Ezema N. M. 2021. Utilization of Quarry Dust as a Partial Replacement of Sand in Concrete Making. *Nigerian Journal of Environmental Sciences and Technology*, 5(2), pp. 582-591. https://doi.org/10.36263/nijest.2021.02.0310