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Original Research Article

Utilization of Quarry Dust and Sludge in Sandcrete Block Production

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Abstract

This paper illustrates the hypothetical study conducted when using quarry dust (QD) and sludge in producing 225mm x 225mm x 450mm hollow sandcrete blocks. QD and wastewater treatment sludge (WWTS) were used to replace river sand at 10%, 20% and 30%. Proportions of 50%QD:50%WWTS and 75%QD:25%WWTS were considered for a standard cement to sand combination of 1:6. Water-cement ratio (w/c) was increased as the percentage replacement increased. Specimens were produced and cured via sprinkling for 28 days. They were subjected to compression and water absorption tests. Mix A2 having 75%QD:25%WWTS at 0.55 w/c and 10% sand replacement had the highest compressive strength and water absorption values of 3.69N/mm^2 and 6.22% accordingly. These results exceeded the NIS 87:2000 recommendation of 3.45N/mm^2 for 225mm load bearing blocks and 12.61% by ASTM C140 respectively. Therefore, QD and WWTS in right proportions can substitute river sand in producing load bearing sandcrete hollow blocks.

Keywords: Wastewater sludge, quarry-dust, sandcrete block, compressive strength, water-absorption.

Introduction

According to Merriam -Webster dictionary [1], a block can be defined as a solid piece of material (e.g. rock or wood) that has flat sides and is usually square or rectangular in shape. In the construction industry, blocks are usually produced using cement of concrete and are sometime referred to as masonry unit. Structural block are blocks that carry some degree of load. They are one of several precast concrete products used in construction. The term precast refers to the fact that the blocks are formed and hardened before they are brought to the job. The use of structural blocks in building and construction is on the increase due to the high rate of infrastructural development experienced in most developing countries including Nigeria. Even in low-cost housing, it has become a valid alternative to fired clay bricks, stabilized soil, stone, timber and other common constructions. The ingredients are available locally and are of good quality [2].

Sandcrete block is a type of structural block that is produced from portland cement, river sand and water. It is a composite material that can be molded into different shpes and sizes [3]. This type of block is the most popular block used in West Africa and especially in Nigeria [4]. Most structural sandcrete blocks have one or more hollow cavities. The most common sizes in Nigeria are; 450x225x225mm (hollow), 450x225x150x225mm (hollow), 450x125x225mm (solid), and 450x100x225mm (solid) [5].

The rise in the use of river sand for building and construction works in the world at large is quite alarming. This is as a result of the growing need to erect more and more public and private facilities that will take care of the rising population growth of many countries in the world and especially, the developing countries [6]. With the dredging of more and more sand from rivers over the years, the quantity of this natural resources is exhausting making it scarce and quite expensive. Sand dredging is also connected to so many environmental and ecological consequences, some of which are; dwindling and eroding of river banks, vanishing of deltas, leading to loss of houses and infrastructure like roads and bridges, decrease in the variety and number of fishes in the mining region etc. [7]. Hence, the use of possible materials in preference to river sand is a welcomed idea.

In the context of wastewater treatment, the term sludge refers to the solids that settle and separate out of treated water from homes, offices, hospitals, and facilities. Most often this residual is a semisolid, that is difficult to manage. It is usually disposed of into the environment (e.g., landfills). Most times, sewage sludge contains personal and pharmaceutical products, heavy metals etc. So, before they can be disposed into the environment, they must be treated. But, it has been recognized that some of the treatment procedures are not very effective at removing the contaminants. When this occurs, heavy metals find their way into the soil and then to the ground water. They also get stored up in crops around the region of sludge disposal. When these crops and water are ingested by humans, they led to very cancerous and life-threatening sicknesses and diseases. They also result to the yielding of fewer crops [8]. Therefore, other safer means of sludge disposal are being experimented.

Quarry dust is a type of dust that is generated as a bye-product from the mining and crushing of rocks at a quarry. When dried, it constitutes a health hazard especially when humans Inhales it. Quarry dust disposal in landfills also contaminate ground water and soil [9]. In order to provide safer means of disposing these wastes, several investigations are being carried out where they are used as partial or full replacement for cement or aggregates in concrete or mortar production.

Osuji and Egbon [10] in their work "Optimizing compressive strength characteristics of hollow building blocks from granite quarry dust and sand" observed that as the percentage of granite content increased, water absorption, permeability and porosity reduced. They also noted that the inclusion of the granite fines improved the grading of the sand which assisted in enhancing the compressive strength of the block. For the 1:6 cement-sand mixture, highest 28 days compressive strength value of 4N/mm^2 was recorded at 15% replacement of sand with granite. Compressive strength of 3.50 N/mm^2, 3.73N/mm^2, 3.45 N/mm^2 and 3.33 N/mm^2 were attained at 0%, 10%, 15%, 20% and 25% replacement of sand with granite fines.

Kaosol [11] observed that 10% and 20% sand replacement with water treatment sludge can be used for producing load bearing hollow blocks. A cost reduction of 0.64 and 1.05 respectively was achieved when compared with the conventional mixture. He further stated that 30%, 40% and 50% replacements of sand with the sludge could only be used for making non load bearing hollow blocks. As the content of sludge increased in the mix, the water absorption increased. Highest water absorption of 18.70% was experienced at 50% replacement. 6.56% and 5.52% water absorption readings were obtained from 10% and 20% replacements accordingly.

Febin *et al*. [9], used quarry dust (QD) powder to make concrete blocks. Manufactured sand was substituted with QD at 0%, 15%, 30%, 45% and 60%. They observed that the split tensile and compressive strength increased as the percentage replacement increased. However, the impact strength dropped. Sorptivity, abrasiveness and the acoustic absorption reduced after exceeding 30% replacement. From the studies of Patel, et al. [12], it was generally seen that mortar made from natural sand and cement had lower compressive strength value than the ones produced from quarry dust and cement. However, they both attained similar values of compressive strength at 28 days. Mortar produced from cement, QD and bacteria reached the peak strength levels at 7, 14, and 28days. Ultimate strength of 31.01MPa was reached at a bacteria concentration of 107cells/ml after curing for 28 days. Water absorption of cement-sand mortar was higher than the cement-quarry dust mortar. Lowest water absorption of 1.26 was obtained from the cement-quarry dust-bacteria mortar at a bacteria concentration of 107cells/ml.

In their investigation, Dhananjaya and Basavaraj [13] combined Portland cement, coarse aggregate, sand, quarry dust, lime sludge, fly ash and water in making concrete. Overall, they noted that 10% replacement of cement with fly ash and sludge respectively yield the same strength at 60 days as conventional concrete in 28days. For the concrete made from cement and sludge, increase in the percentage of sludge reduced the compressive strength of the concrete. Prakesh and Rao [14]) worked on the compressive strength of quarry dust as fine aggregate in concrete. They stated that a 40% replacement of sand with quarry dust gave an ultimate strength result when compared to the normal concrete. They observed that percentage replacements of 50% and above led to the drop of concrete strength. The workability of the concrete dropped as the percentage replacement of sand with quarry dust increased. 0.45 water-cement ratio gave better results than at 0.5.

MATERIAL AND METHODS

MATERIALS

Portland cement, river sand, granite chippings, waste water sludge, quarry dust (QD) and potable water were used for the study. The Dangote grade 42.5 grade cement acquired from Eziobodo in Owerri-West Local Government Area (LGA), Imo State, Nigeria. The properties and composition of this cement comply with the Standard Institute of Nigeria [15]. Sand was collected from Otamiri River in Owerri-West LGA. The sand was dried by spreading them out in the laboratory for five days before use. This was done to ensure that there was no free surface water and that the water-cement ratio reflected the actual water content available for the hydration of cement. QD of granite origin obtained from Unity Asphalt Construction Limited, quarry division Eluoma, Agunchara in Abia State, Nigeria was used. This material had no trace of moisture and was completely dried.

The sludge was gotten from Enugu municipal water treatment plant, Enugu, Nigeria. It was dried and grinded in order to get a smooth dry sludge particle. Potable water clean and fit for drinking was used for mixing of the Constituent of the sandcrete mixture. It was obtained from a borehole at the premise of the Federal University of Technology, Owerri, Imo State, Nigeria.

METHODS

Various tests were performed during this study and they include; grain size distribution analysis and bulk density tests on aggregates, physio-chemical property test of the sludge, compressive strength and water absorption test on the hardened hollow blocks.

Grain size distribution of aggregates

The grain size distribution analysis of sand obtained from Otamiri river and dried sludge from waste water treatment plant were carried out in accordance with [16]. This was done to determine the various sizes of particles present in the samples so as to classify the aggregate and know it suitability for use in block production. The sizes of sieve used were; 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3m, 0.15mm, 0.075mm and the receiver. The results obtained are illustrated in Table 2, Table 3 and Fig. 1 respectively.

Bulk density test on the aggregates

Bulk density gives valuable information regarding the volume that graded aggregates will occupy in concrete. It refers to the mass of material per unit volume, including the voids between the particles. The dry method was adopted for the determination of the bulk densities of river sand and QD and was carried out in accordance with [17, 18]. The net weight of the aggregate in the container was determined and the bulk density was calculated in kg/m^3. Results obtained are shown in Table 4.

Physio-chemical property test on sludge

Physical and chemical property tests were conducted on the waste water sludge, to know if the material was suitable for use in block production. The results obtained are presented in Table 5.

Material proportioning and preparation

This refers to determining the quantity in weight of each constituent in the sandcrete mix. The hollow block mold of 225mm x 225mm x 450mm with a 40% void was used to prepare the specimen. A standard mix of 1:6 (cement-sand) combination was adopted. Sand substitution by QD and sludge of 10%, 20% and 30% were investigated at 0.55, 0.6 and 0.65 water-cement ratio respectively. The water content was increased as the percentage of sand replacement (with QD and sludge) rose. This was done since the sandcrete workability dropped as more QD and sludge were introduced into the mixture.

When preparing the specimen, the floor surface was cleaned, wetted and dried to prevent loss of water and excess water being added into the mix. Batching of the materials was achieved by using a weighing balance of 50kg capacity. The inside surface of the metal mold was lightly coated with medium viscosity oil and then placed on a clean, level and firm surface. Mixing of the constituents was manually done using shovels. Proportions of washed and dried river sand and dried QD, were measured out and mixed until a constant color was reached. Dried and grinded waste water sludge was measured out and added to the mixture. Cement was also added and the whole process of mixing continued until a uniform color was achieved. Potable water was finally included and the mixing continued until the color of the paste was uniform.

The mixture was loaded into the molds, compacted manually and demolded immediately. For compression test, 4 specimens were prepared for each mix leading to a total of 24 blocks. While, for the water absorption test, 3 specimens were made for each mix resulting to a total of 18 blocks. They were all inscribed for identification. Curing of the blocks was done by sprinkling of water twice every day for 28 days before testing. Proportions for producing one block for each mix design considered are presented in Table 1.

Table-1: Mix proportion for producing the blocks

Mix label	Cement (PC)	River Sand	Quarry dust	Sludge	Water-cement	% repl of sand	% quarry dust - % sludge	PC (Kg))	River Sand (Kg)	Quarry dust (Kg)	Sludge (Kg)	Water (Kg)
A1	1	5.4	0.3	0.3	0.55	10	50-50	4	21.6	1.2	1.2	2.2
A2	1	5.4	0.45	0.15			75-25	4	21.6	1.8	0.6	
B1	1	4.8	0.6	0.6	0.6	20	50-50	4	19.2	2.4	2.4	2.4
B2	1	4.8	0.9	0.3			75-25	4	19.2	3.6	1.2	
C1	1	4.8	0.6	0.6	0.65	30	50-50	4	16.8	3.6	3.6	2.6
C2	1	4.8	0.9	0.3			75-25	4	16.8	5.4	1.8	

Bulk density of hardened blocks

The bulk density of sandcrete block is largely a function of the aggregate density, its size, grading, degree of compaction or aeration and the block form. Before, the blocks were crushed, they were weighed and the mass obtained was recorded. The bulk densities were then determined by dividing the mass of the blocks by the volume of the blocks as shown in Equation 1.

$$\rho = m/v \qquad (1)$$

Where, ρ is the bulk density of block in Kg/m^3; *m* is the mass of block in Kg; *v* is the volume of the block in meters (m)

Compressive strength test on hardened blocks

The blocks were crushed after twenty-eight days of curing in water at room temperature using and electric universal testing machine (UTM). Maximum crushing load of the machine is 1000kN. They were placed in between two steel plates and the plates are wide enough as to cover the top and bottom of the blocks. The switch of the machine was turned on, then force was gradually and increasingly being applied to the blocks until they failed in compression. The load (F) at which the failure occurred was observed and recorded. The compressive strengths of the blocks were determined using Equation 2. Four samples each were tested for a particular mix number and the average values taken as the compressive strength for the mix. The results obtained are presented in Fig. 2.

$$F = P/A \qquad (2)$$

Where, P is the crushing load in newton (N); A is the cross-sectional area of the block in mm^2; and F is the compressive strength in N/mm^2.

Water absorption of hardened blocks

The blocks for this test were cured in water for 28 days, dried in the oven until constant weights were achieved and recorded. The dried specimens were immersed in water for 24 hours. On removal from water, they were reweighed within three minutes of removal to determine the quantity of water absorbed. Equation 3 was used to determine the percentage water absorption of the blocks. Three blocks were tested for each mix number and the average taken as the water absorption of the mix. The results obtained are shown in Table 6.

$$\%\ Absorption = ((M_2 - M_1)/M_1) * 100 \qquad (3)$$

Where; M_1 = mass of dry sample and M_2 = mass of wet sample (after 24hrs in water)

RESULTS AND DISCUSSION

Sieve analysis

The results of the grain size distribution analysis conducted on the river sand and QD are presented in Table 2, and Table 3 as follows;

Table-2: Grain size distribution of sand

Sieve size (mm)	Mass of empty sieve (g)	Mass of sieve + soil (g)	Mass of soil retained (g)	Cumulative mass of soil retained (g)	Cumulative % passing	Cumulative % retained
4.75	373.29	382.13	8.84	8.84	99.47	0.53
2.36	353.09	443.71	90.62	99.46	94.04	5.96
1.18	398.21	896.28	498.07	597.53	64.17	35.83
0.60	372.63	880.22	507.59	1105.12	33.73	66.27
0.30	318.27	738.92	420.65	1525.77	8.50	91.50
0.15	298.38	325.56	27.18	1552.95	6.87	93.13
0.075	311.1	312.84	1.74	1554.69	0.10	
Pan	273.02	274.65	1.63	1556.32		
						∑ = 293.24
Fineness modulus = 293.24/100 = 2.93						

Table-3: Grain size distribution for QD

Sieve size (mm)	Mass of empty sieve (g)	Mass of sieve + soil (g)	Mass of soil retained (g)	Cumulative mass of soil retained (g)	Cumulative % passing	Cumulative % retained
4.75	373.29	379.36	6.07	6.07	99.64	0.36
2.36	353.09	534.52	181.43	187.50	88.92	11.08
1.18	344.24	711.18	366.94	554.44	67.23	32.77
0.60	372.63	734.70	362.07	916.51	45.83	54.17
0.30	318.27	561.75	243.48	1159.99	31.44	68.56
0.15	298.38	574.00	275.62	1435.61	15.15	84.85
0.075	311.1	463.90	152.80	1588.41	6.12	
Pan	273.02	376.62	103.60	1692.01	0	∑ = 251.78
Fineness modulus = 251.78/100 = 2.52						

Comparing Table 2 and Table 3 accordingly to the fine aggregate grading zone table of IS 383 [19], it can be concluded that the sand falls within zone 1 while the QD falls within zone 2. This implies that the sand is coarse in nature while the QD is a bit finer than the sand. Fig.1 reveals that the coefficient of uniformity (Cu) for the sand and quarry dust were 2.18 and 3.17 proportionately. Also, the coefficient for curvature (Cc) for the sand and quarry dust were 0.99 and 0.98 accordingly. As stated in ASTM D-2487 [20], an aggregate is well graded if Cu ≥6 and 1<Cc<3. However, in this study none of the fine aggregates satisfied this condition. Thus, the river sand and quarry dust are poorly graded. The fineness modulus of 2.93 for sand and 2.52 for the quarry dust, further validate that the aggregates are coarse and fine sand respectively.

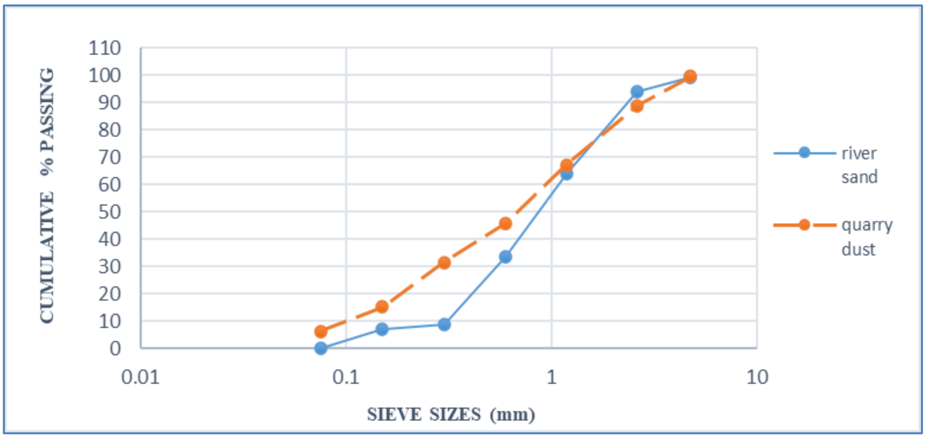

Fig-1: Gradation curve for river sand and QD

Bulk density of fine aggregates

The results of bulk density for the aggregates are shown in Table 4. It can be seen that the bulk density for the sand is 1510.31kg/m^3 while that for quarry dust is 1650kg/m^3. With respect to Awodiji [21], these aggregates fall under normal weight.

Table-4: Bulk density of sand and QD.

	River sand			Quarry Dust		
Trial run	Trial 1	Trial 2	Trial 3	Trial 1	Trail 2	Trial 3
Mass (kg)	6.35	6.34	6.34	6.94	6.92	6.92
Volume of bottle (m^3)	0.0042	0.0042	0.0042	0.0042	0.0042	0.0042
Bulk density (kg/m^3)	1511.90	1509.52	1509.52	1652.38	1647.62	1650
Average bulk density (kg/m^3)	1510.31			1650		

Physio-chemical property test on sludge

The results of the physio-chemical property test conducted on the water treatment sludge are presented in Table 5. A total percentage of 53.2% was obtained after adding the oxides of silicon, aluminium and iron. Comparing this result to that of Table 1 of ASTM C618 [22], it can be seen that the sludge is a Class C pozzolanic material. This also means that it has some degree of cementitious properties as well. Bulk density of sludge is 1270Kg/m^3 while its specific gravity is 1.55.

Table-5: Test result of water treatment sludge

Chemical property	
Element	Result (%)
Silicon oxide, (SiO_2)	20.4
Aluminum oxide, (Al_2O_3)	29.6
Iron oxides, (Fe_2O_3)	3.2
Calcium oxide, (CaO)	37.7
Magnesium oxide, (MgO)	2.7
Sodium oxide, (Na_2O)	0.4
Potasium oxide, (K_2O)	1.3
Sulphates, (SO_4)	0.67
Physical property	
Property	Value
Bulk density	1270kg/m^3
Specific gravity	1.55

Bulk density of hardened hollow blocks

The results of the bulk densities for the hardened blocks are shown in Fig 2. Mix label A1 had the highest bulk density of 2049.59Kg/m^3 and the lowest value of 1912.46Kg/m^3 was from mix C1. Bulk densities for B1 and C2 were almost equal although C2 is composed of a 30% replcacement of sand while B1 is having a 20% replacement of sand. In C2, the sand is replaced with more of QD and less of Sludge unlike in B1 where the sand is replaced with same proportion of QD and sludge. Since the bulk density of the quarry dust is more than that of the sand and that of the sludge is less than that of sand, block C2 experienced improved average density than block B1 even though C2 had a higher w/c ratio.

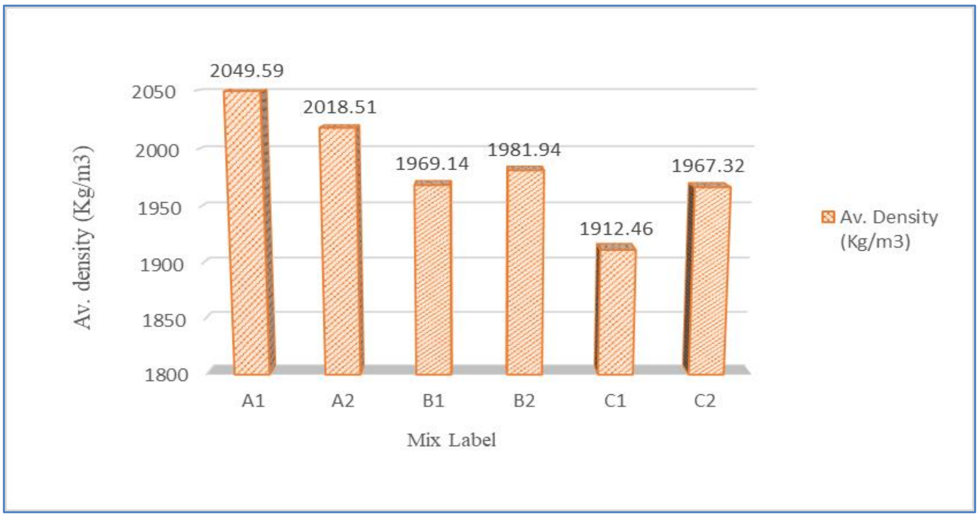

Fig-2: Average density of the hardened blocks

Compressive strength of blocks

The values of the compressive strength of the selected mix ratios investigated are shown in Fig. 3. Overview, it can be seen that for each of the 3 standard mixes experimented, the variation that had 75% QD - 25% sludge had improved strength results than those having 50%QD – 50% sludge. Mix label A2 had topmost compressive strength reading of 3.69N/mm^2. This is at a 10% replacement of sand with 75%QD and 25% sludge at w/c of 0.55. According to NIS 87 [3], the lowest strength required for sandcrete block to be used for structural works is 2.5N/mm^2 for 150mm blocks and 3.45N/mm^2 for 225mm hollow blocks. Only mix label A2 satisfied this condition since all blocks considered are 225mm. But, mix A1 was a little below the bench mark. These values confirm the findings of Kaosol [11] that 10% sand replacement with sludge produces maximum compressive strength in hollow block production.

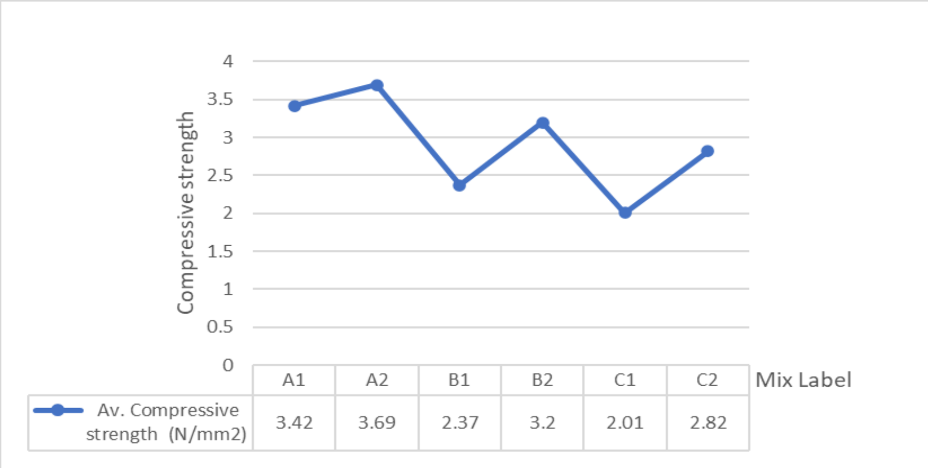

Fig-3: Relationship between mix labels and compressive strength (N/mm^2)

Mix C1 gave the lowest strength of $2.01N/mm^2$ at 30% sand replacement with 50%QD and 50% sludge content with w/c of 0.65. Although the strength of the blocks reduced as % replacement of sand and w/c increased, it is seen that mix label C2 with 30% replacement of sand with 75%QD and 25%sludge at 0.65 w/c had a higher strength than mix label B1 having a 20% replacement of sand with 50%QD and 50%sludge. This may be due to the fact that the more the content of QD in the mix the better the grading of the fine aggregate. With improved grading comes better compressive strength value [10]. Also, mix C2 had lower % sludge content than B1.

Water absorption of the blocks

Water absorption provides an idea of the amount of the total volume of pore within a concrete matrix. The more its value, the weaker the compressive strength of the concrete cover. Water absorption values shown in Table 6 ranged from 6.22% at 10% replacement to 14.34% at 30% replacement. Therefore, as the percentage replacement of sand increased, water absorption also increased. Besides, mixes with 75% QD and 25%sludge had better water absorption than their counterpart having 50%QD and 50% sludge. Also, mixtures having more percentage of WWTS experienced escalated values of water absorption. This result conforms to the findings of Abdul-Salim et al. [23] where the percentage water absorption increased as the % inclusion of WWTS rose in the production of fired clay bricks. This occurred because WWTS usually contains organic matters that absorb water very easily [23]. The optimum value of 6.22% was obtained at 10% replacement for the 75%QD-25%sludge mix. All mixes except C1 and C2 had their % water absorption above the 12.61% recommended for hollows sandcrete blocks by ASTM C140 [24]. As much as possible, the use of 30% river sand substitution with QD and WWTS must be avoided since it will result to durability problems as a result of high-water absorption properties. This discovery also aligns with the findings of Abdul-Salim *et al*. [23].

Table-6: Water absorption results

Mix label	% QD -% sludge	Water absorption %
A1	50% - 50%	9.24
A2	75% - 25%	6.22
B1	50% - 50%	11.95
B2	75% - 25%	9.52
C1	50% - 50%	14.34
C2	75% - 25%	13.15

Fig 4 shows the relationship between the compressive strengths and water absorption of the mixes. Generally, it can be seen that the compressive strength of the various mixes increased as the water absorption reduced. This means that increase in the volume of pore spaces within the concrete matrix led to more assimilation of water due to the sludge content. This then reduced the strength of the concrete.

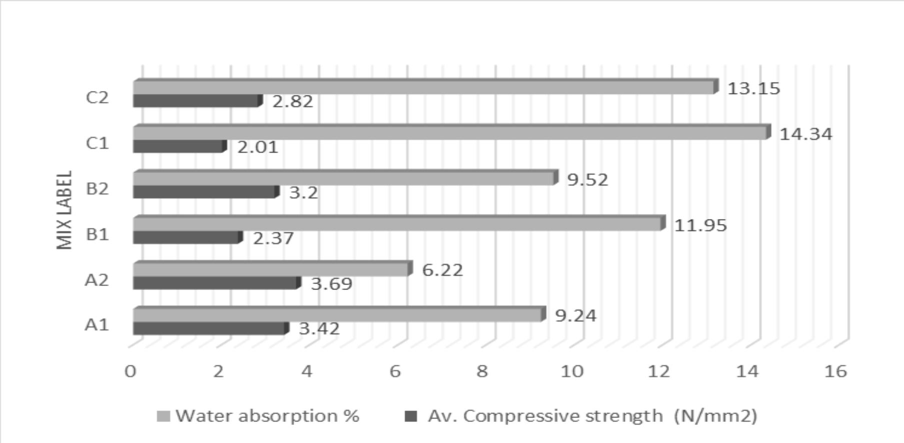

Fig-4: Relationship between compressive strength (N/mm^2) and workability (%)

CONCLUSIONS

The use of QD and WWTS in making sandcrete hollow blocks is indeed one sure way of solving the waste management challenges that are associated with these two bye-products and the over dependence on mined river sand. In this paper, QD and WWTS were successfully used in making load bearing hollow sandcrete blocks having good durability properties. For cement-sand combination of 1:6, 10% optimum replacement of river sand with QD and WWTS is recommended. Best combination of 75%QD and 25%WWTS at 0.55 w/c should be adopted in order to achieve a load bearing block. As much as possible, 30% sand replacement with QD and WWTS should be avoided because it generates lower strength and absorbs so much water.

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