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Suitability of Crushed Sandcrete Block (CSB) as a Partial Replacement for Fine Aggregate in Concrete Structures

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Abstract: In concrete structures, debris generated from construction, renovation, and demolition of buildings is often referred to as construction and demolition waste. These waste materials may be very important to recycle for several reasons for instance, recycling materials such as glass, metal, concrete, and wood waste can lessen our reliance on virgin resources, preserve natural resources, and lessen the negative environmental effects of resource exploitation. The suitability of crushed sandcrete block (CSB) for use as a partial replacement for fine aggregate in concrete was examined. The physical and mechanical properties of the crushed sandcrete block and river sand were determined and compared. The specific gravity of the crushed sandcrete block was found to be 2.58 while that for river sand was 2.66. The concrete with compressive strength of 25N/mm^2 at 28 days' hydration period was calculated for the normal mixture as the control. The percentage mix of the fine aggregate was substituted with CSB in different mix proportions of 0:1(0%), 1:3(25%), 1:2(33.3%), 1:1(50%), 2:1(66.7%), 3:1(75%) and 1:0(100%) of crushed sandcrete block and river sand by weight as fine aggregate. The concrete cubes were cured, and compressive strength tests were carried out at 7, 14, and 28 days. It was observed that the 28-day density and compressive strength for concrete cubes with crushed sandcrete block alone as fine aggregate (i.e. 100%) were found to be 2420kg/m^3 and 22N/mm^2 respectively compared to the 0:1(0%) proportion which was found to be 2485kg/m^3 and 26N/mm^2 respectively. It was observed that the density and compressive strength reduced with the increasing addition of CSB in all the proportions.

Keywords: compressive strength, crushed sandcrete blocks, river sand, specific gravity

1. Introduction

In concrete structures, debris generated from construction, renovation, and demolition of buildings is often referred to as construction and demolition waste. These waste materials may be very important to recycle for several reasons for instance, recycling materials such as glass, metal, concrete, and wood waste can lessen our reliance on virgin resources, preserve natural resources, and lessen the negative environmental effects of resource exploitation [1-3]. However, the significance of recycling demolition waste stems from its ability to preserve resources, minimize waste, mitigate environmental effects, generate revenue, and encourage environmentally friendly construction methods. In the larger endeavor to transition the building and demolition sector into one that is sustainable.

In modern times the building manufacturing sector is realizing and still linking resources within its close environs in the exploration of suitable resources that can expedite the construction of civil engineering structures. Waste materials in the form of sandcrete blocks are often seen in the construction of new structures and demolition of old existing structures [4]. It is well known that the continuous production of solid waste is a significant environmental challenge. Also, large amounts of waste in the form of broken sandcrete blocks in demolition sites and block industries pose environmental issues that can be reduced by recycling the waste. Therefore, it is crucial to research and develop any technology, process, or method that can aid in effectively utilizing their use [5, 6]. A lot of research has been undertaken in the area of waste recycling and oftentimes, the use of recycled waste has proven to be more economical in construction [7].

The further findings showed that crushed waste sandcrete block (CWSB) aggregate can be recycled as fine aggregate in concrete making and be able to efficiently be substituted with the conservative fine aggregate, sand, in concrete by 50% in average strength concrete of 30N/mm2 target strength. A crushed sandcrete block (CSB) is defined as a cohesion-less sandy material acquired artificially by the mechanical vibration of a Sandcrete block [8]. It is made of constituent parts using a diameter between 0.05mm to 5mm. Sandcrete block has the following physical characteristics which include strength, durability, fire resistance, and thermal insulation. Also, the Sandcrete strength usually gives the general portrait of the value of the concrete.

In the practice of engineering, the compressive strength of a sandcrete block depends mostly on the water-cement ratio and the amount of compaction. The compressive strength of sandcrete is the degree of resistance of the block to an applied load. BS2028 gives the required mean strength as 3.45N/mm², and the least strength is 2.59N/mm² [9]. Based on the requirement the block compressive strength must be at minimum 75% of the average value. Clays and silts are frequently found in many gravel and sand deposits, and more specifically, clay in high concentrations can significantly reduce strength, according to [10].

Due to the swelling and shrinking brought on by repeated wetting and drying, clays are also harmful in concrete. According to [11] claims that the main impacts of this fine clay, silt, and dust on concrete are that they increase the amount of water required to make the concrete workable and, when present, interfere with the binding between the aggregate and cement paste. The strength, durability, and cost of aggregate may be harmed by the inclusion of clays, silts, and fine dust. Humus, loam, and other organic pollutants obstruct the chemical process of hydration. Clay, silt, and other surface coatings interfere with the bond characteristics.

According to [12], the maximum amount of harmful materials shouldn't be more than 5%. Sea sand should be cleansed before use since sea salt promotes efflorescence and corrosion of reinforcement. The silt concentration of fine waste sandcrete block aggregates is 7.05%, which is less than the 8% maximum limit allowed [13]. Also, recycling of CWSB can be used as an alternative material for fine aggregate replacement in concrete structures [14]. This research intends to find out the suitability of this crushed sandcrete block waste as a replacement for river sand in concrete structures.

2. Experimental Program

River Benue sharp sand and gravel were used in carrying out this work. The broken sandcrete blocks were obtained from Hamzato Block Industry Limited, a Sandcrete block manufacturer in Benue state, Nigeria. The waste collected from the block manufacturer was crushed by carrying them in fibre bags to protect the sand grains. The right specification of Ordinary Portland cement [9, 15] was used as the binding agent, and water used for mixing was from the public water supply.

Sieve analysis and specific gravity test were shown on the aggregates. Concrete cubes 150 x 150 x 150 moulds using 0:1(0.0%), 1:3(25.0%), 1:2(33.3%), 1:1(50.0%), 2:1(66.6%), 3:1(75.0%), and 1:0 (100%) proportion of crushed sandcrete block and river sand by weight as fine aggregate as shown in Table 1. The cubes were removed from the mold after a whole day and straightaway transferred into the water for curing at room temperature. Density and compressive strength tests were carried out at 7, 14, and 28 days. The percentage replacement of an aggregate of nine (9) cubes was formed and a total of sixty-three (63) cubes were made. Based on the results, logical conclusions were drawn, and appropriate recommendations were made.

Also, the process of selecting appropriate concrete materials and finding out their relative amounts to produce concrete with a set of minimal properties—most notably strength, durability, and the necessary consistency—as economically as feasible is referred to as mix proportion selection. Therefore, the most preferred control mix was used in this study.

Table 1
Mix proportions for control mix

Property	Control mix	CSB
Cement Kg/m³	382	382
River sand Kg/m³	2485	0
CSB Kg/m³	0	2420
Water	978.04	978.04

3. Results and Discussion

3.1. Specific gravity test

The average specific gravity of aggregates typically used in construction is about 2.68, with a range of about 2.5 to 3.0. A measure of an aggregate's strength is said to be its specific gravity. The conventional consensus is that materials with higher specific gravities are stronger [16]. A density bottled method was used to determine the specific density. First, the specific gravity bottle having a volume of 1000cm³ was weighed and recorded. The bottle was filled halfway with clean water weighed and recorded as W_2. About 100-150g of sample W_S was placed on the weighing balance and the result was noted, and water was added to the sample in the bottle then the combined weight was recorded as W_1.

The above procedure was repeated twice and the mean value was taken to attain accuracy. The specific gravity was calculated using the formula in Equation 1 and the results are presented in Table 2. The standard used for the density specific gravity, and comprehensive strength was AASHTO T 84 and ASTM C 128. The typical range of specific gravity for aggregates used in construction is 2.5 to 3.0, with an average of 2.68. Aggregate specific gravity is regarded as a strength indicator. Stronger materials are typically thought to have a higher specific gravity [17].

It can be seen that the CSB has a lower specific gravity than the sand. The lower values might be recognized for the higher fines in the CSB since the fines are smaller in size than sand elements. In this study, the mean specific gravity is 2.58 which is satisfactory as shown in Table 2.

$$G_s = \frac{W_S}{W_S-(W_1-W_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 1$$

Table 2
The specific gravity of sand and CSB

Sand				**CSB**		
Test No.	1	2	3	1	2	3
The volume of bottle cm³	1000	1000	1000	1000	1000	1000
Weight of bottle g	595	595	595	595	595	595
Weight of bottled +water+ soil W_1	1644	1643	1649	1701	1705	1704
Weight of bottled +water W_2	1551	1549	1655	1609	1620	1615
Weight of dry soil W_S	150	150	150	145	145	145
Submerged Weight W_1-W_2	93	94	94	92	85	89
GS	2.63	2.68	2.68	2.74	2.42	2.59
Mean G_S		2.66			2.58	

3.2. Particle-size grade and concrete mix

The particle sizes were determined using the sieve analysis of different sizes of sieves with different apertures to obtain the particle-size grading of the aggregates as shown in Table 3 and the grading curve is shown in Fig, 1. The objective of designing concrete mix is to find the most economical and suitable proportion of the constituents of the aggregate. According to the total weight approach, the concrete mix was created utilizing the properties of the materials. The batching of aggregate was done by weight using a 25-kilogram ELE weighing machine. This was determined to produce concrete having the relevant quantities for the given mix.

It was shown that more water was required to achieve the same workable consistency at a higher percentage replacement with CSB. This points toward the higher the percentage placement with CSB, the more porous the resulting concrete [18]. The broader surface was put on the plate and held by legs after the slump test apparatus had been cleaned.

Figure 1
Particle size distribution curve

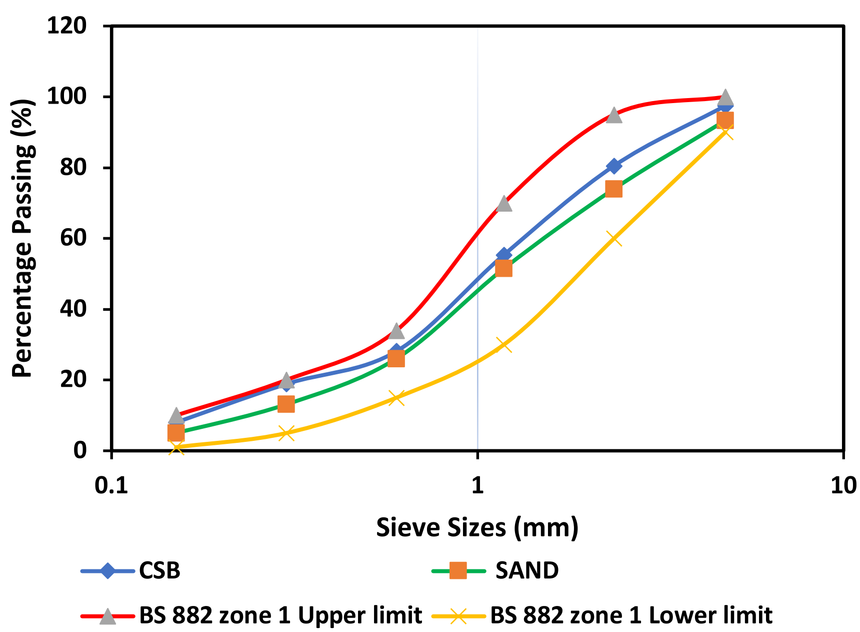

Figure 2
Compressive strength versus age curve

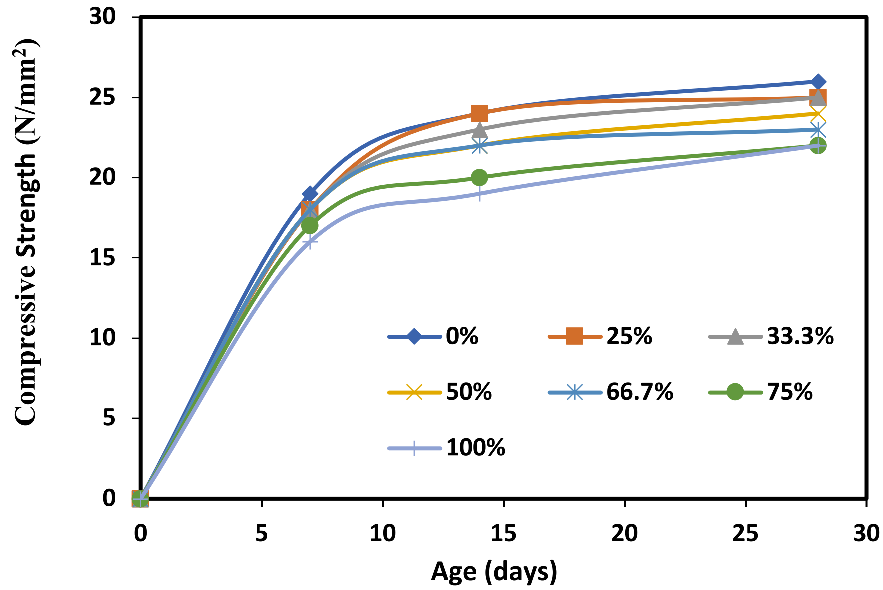

Figure 3
Density versus age curve

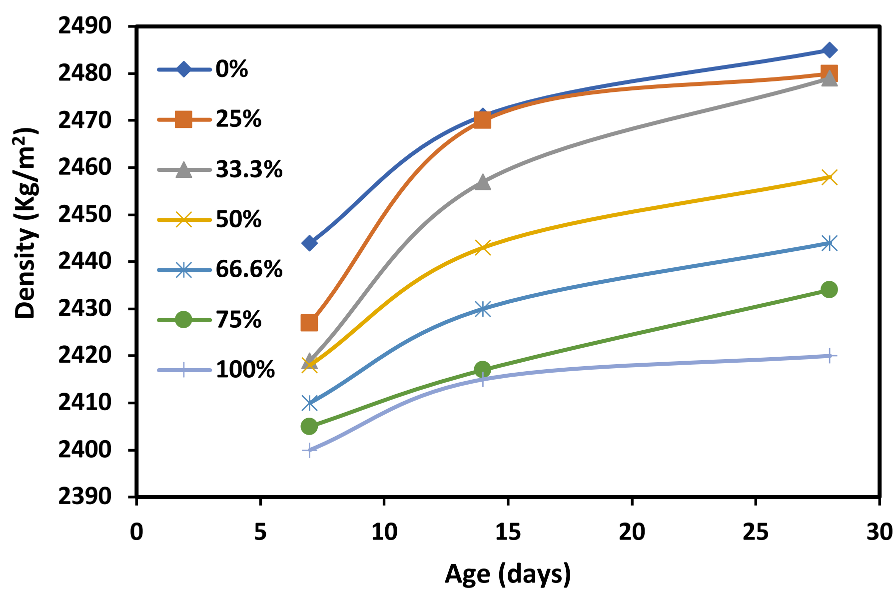

Table 3
Sieve Analysis showing percentage passing of CSB and sand

Sieve size	% Passing(CSB)	% Passing (sand)	BS 882 limit for zone 1
4.75mm	97.47	93.30	90- 100
2.36mm	80.52	74.01	60- 95
1.18mm	55.36	51.50	30- 70
600µm	28.11	26.05	15- 34

300µm	18.86	13.10	5 -20
150µm	8.00	5.03	0 -10
Pan	0	0	0

The concrete mix was filled in the apparatus in four layers, each layer tamped 25 times with a 600mm metal rod of 16mm diameter and finished with a float. The device was carefully raised and set down on the plate close to the concrete. The droop is the disparity in height. Fig. 2 showed that when the CSB content increased, the tested cubes' compressive strength decreased. This might be explained by the CSB aggregates' increased fine content and greater w/c ratio. Figure 3 displays the varied cube densities created by varying sand substitution percentages using CSB aggregates. The density of the concrete was found to decrease with increasing CSB replacement.

As a result, the CSB aggregate is said to be lighter than sand. Because the bonded and cemented hydrate disintegrates during crushing, the CSB aggregates lose their compaction, which leads to an increase in the fines content. The cubes were subjected to compressive strength tests in a testing apparatus operated by an electrohydraulic pump with a 1560kg capacity that complies with [19-25]. The same rate of loading was used for all tests. Each cube was weighed before being inserted between two metal plates in the testing apparatus. The load was applied to each sample until failure occurred, and the load at failure was noted. The compressive strength of the cubes was calculated as the loads at failure divided by the effective cube areas, measured in square millimeters. Table 3 below provides a summary of the laboratory's results.

3.3. Compressive strength

Linear regression models were developed and provided a means of predicting the dependent variable (compressive strength of concrete) given the proportions of the independent variables (% CSB replacement, w/c ratio, and slump). The multiple linear regression methods were incorporated using statistical software for data science (STATA). The generated models to predict the concrete compressive strength containing CSB are summarized in Table 4. The results show very highly significant models. It is seen that all the models are statically significant and perhaps represent predictable trends. The regression models so developed were evaluated for their significance using the coefficient of determination, R^2, standard error of the estimates, and T-test.

The regression analysis result for the concrete compressive strength at 7 days was derived from the different variables computed such as % CSB replacement, w/c ratio, and slump.

$$Y = 22.27393 - 0.0702338X_1 - 32.34895X_2 + 0.2223371X_3 \quad \text{Eq. 2}$$

In equation 2, y is the expected or predicted compressive strength. X_1, X_2, and X_3 are % CSB replacement, w/c ratio, slump with a coefficient of - 0.0702338, -32.34895and +0.2223371 as their corresponding coefficient of determination respectively, the value 22.27393 is the constant term. The Square of correlation coefficient R^2 is 0.8640 and this implies that 86.4% of the changes in compressive strength are caused by the CSB while the remaining 13.6% are due to other factors.

Also taken into consideration was the concrete's compressive strength after 14 days. The same variables used in the model were entered to generate an equation of the form.

$$Y = 61.90176 + 0.0105538X_1 - 88.0118X_2 + 0.1642964X_3 \quad \text{Eq.3}$$

Equation 3 shows the relationship between y (compressive strength) and X_1, X_2, and X_3 are % CSB replacement, w/c ratio, slump with coefficients of + 0.0105538, - 88.0118 and +0.1642964 as their corresponding coefficient of determination respectively. The value 61.90176 is the constant term. The square of correlation coefficient R is 0.9645 and this implies that 96.45% of the changes in compressive strength are caused by the CSB while the remaining 3.55% are due to other factors.

The coefficient of determination was used to assess the significance of the equation (regression model), which was created using the compressive strength of concrete for a 28-day curing period.

$$Y = 49.04478 - 0.0171403X_1 - 59.86917X_2 + 0.1489433X_3 \quad \text{Eq.4}$$

Equation 4 shows also the relationship of y (compressive strength and X_1, X_2, and X_3 are % CSB replacement, w/c ratio, slump with the coefficient of – 0.0171403, –59.86917 and +0.1489433 respectively. The value 49.04478 is the constant term. It is also seen that the square of correlation coefficient R^2 is 0.9753 and this implies that 97.53% of the changes in compressive strength are caused by the CSB while the remaining 2.47% are due to other factors. Figure 4, shows that the compressive strength of the concrete increases with an increase in the percentage replacement of sand from 0% to 150%.

The compressive strength was also observed to increase progressively as the curing age increased, indicating the effect of curing age on concrete strength. Also, the correlation analysis of compressive strength with CSB %, with density, with W/C as presented in Figures 5, 6 and 7 shows that the compressive strength decreases as the density increases. The linear regression model in Table 5 shows that the density and compressive strength reduced with the increasing addition of CSB in all the proportions. Also, there is a proportional decrease in the compressive strength as the number of density decreases. However, in the study region, the optimal CSB content for the partial replacement of fine aggregate in concrete is 50% for 30N/mm^2 design characteristics strength.

Figure 4
Percentage Replacement with CSB (%)

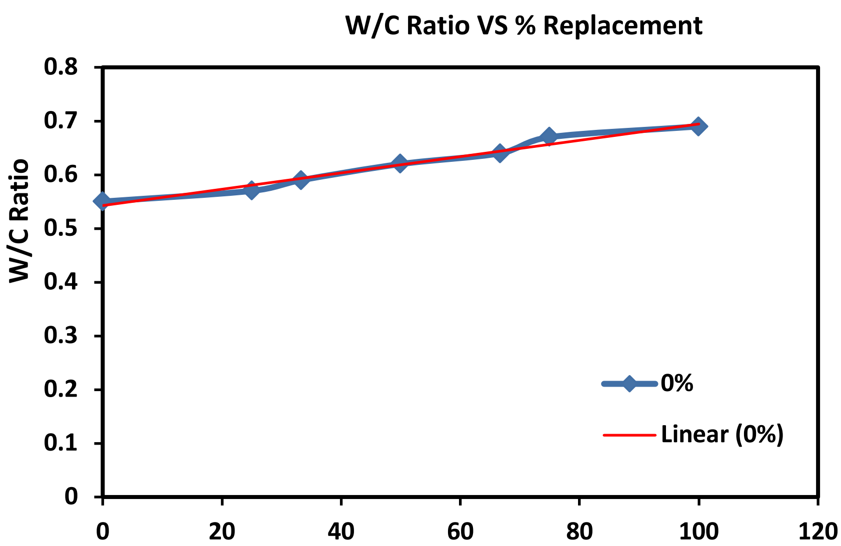

Figure 5
Correlation graph showing the relationship between compressive strength with CSB %, with density, with W/C for 7 days

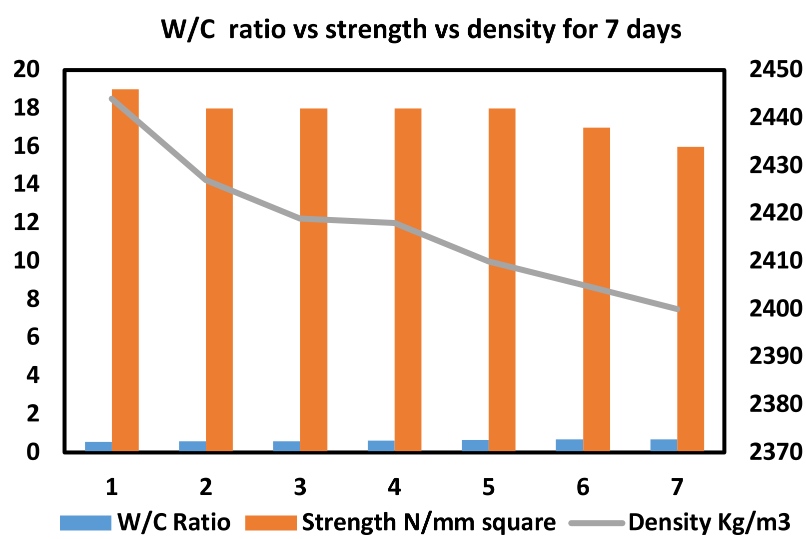

Figure 6
Correlation graph showing the relationship between compressive strength with CSB %, with density, with W/C for 14 days

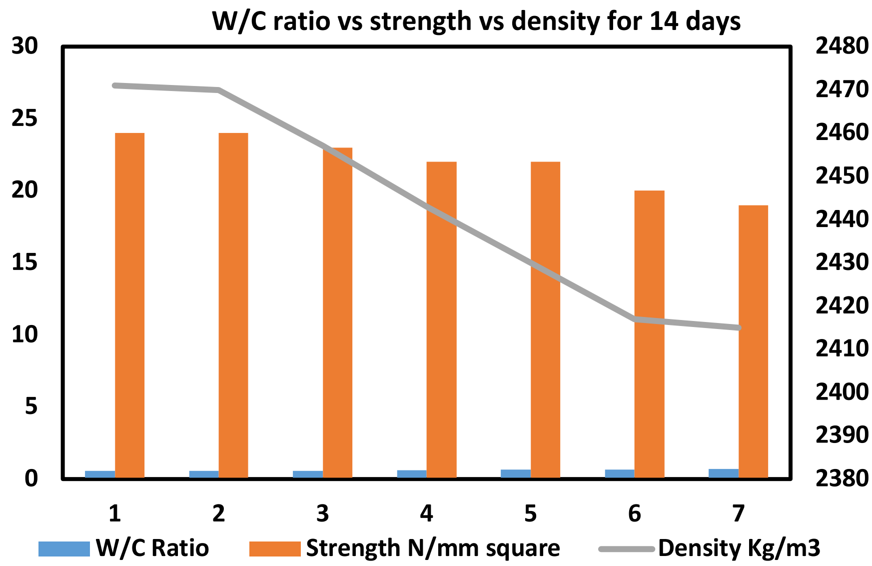

Figure 7
Correlation graph showing the relationship between compressive strength with CSB %, with density, with W/C for 28 days

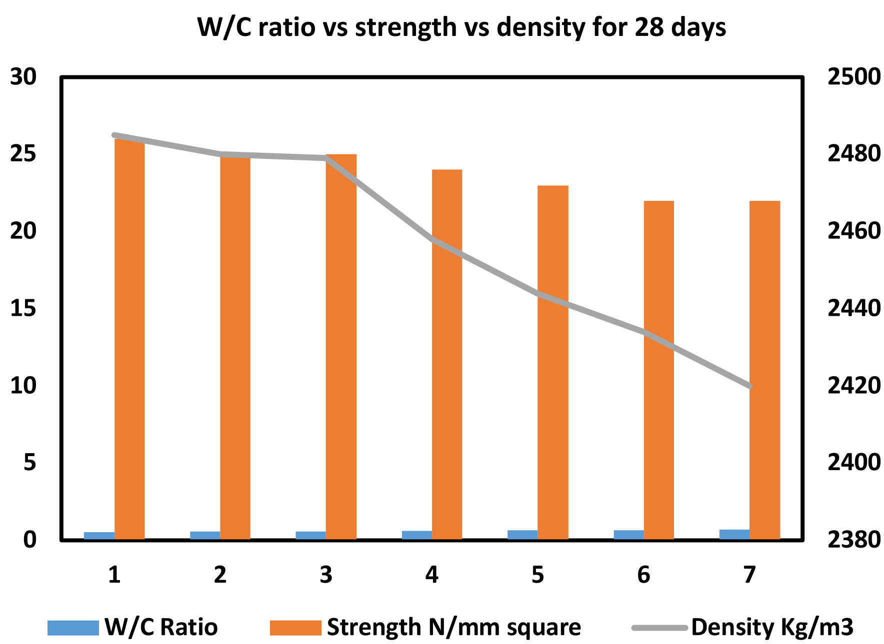

Table 4
Laboratory results of W/C, Slump test, Density, and Compressive Strength

			7 Days		14 Days		28 Days	
Ratio	W/C Ratio	Slump (mm)	Density Kg/m^3	Strength N/mm^2	Density Kg/m^3	Strength N/mm^2	Density Kg/m^3	Strength N/mm^2
0:1(0.0%)	0.55	65	2444	19	2471	24	2485	26
1:3(25%)	0.57	72	2427	18	2470	24	2480	25
1:2(33.3%)	0.59	79	2419	18	2457	23	2479	25

1:1(50%)	0.62	86	2418	18	2443	22	2458	24
2:1(66.7%)	0.64	92	2410	18	2430	22	2444	23
3:1(75%)	0.67	98	2405	17	2417	20	2434	22
1:0(100%)	0.69	105	2400	16	2415	19	2420	22

Table 5
Linear regression models

model	days	Equations	R^2	Adjusted R^2
1	7	$Y = 22.27393 - 0.0702338X_1 - 32.34895X_2 + 0.2223371X_3$	0.8640	0.7281
2	14	$Y = 61.90176 + 0.0105538X_1 - 88.0118X_2 + 0.1642964X_3$	0.9645	0.9289
3	28	$Y = 49.04478 - 0.0171403X_1 - 59.86917X_2 + 0.1489433X_3$	0.9753	0.9507

4. Conclusion

It can be concluded that the crushed Sandcrete block is the most significant variable in the three equations and it shows that the compressive strength from each of the equations increases in significance as the age of curing increases. Also, it was noted that the R^2 increased from 86.4%, 96.5%, and 97.5% in every case from 7, 14, and 28 days of curing. As a result, the model can be used to forecast the compressive strength of concrete. The above information implies that CSB can be utilized as a partial substitute for river sand in ordinary construction projects, particularly in locations where river sand is scarce and leftover Sandcrete blocks are easily accessible. As a result of their negligible rate of decay, these shattered Sandcrete bricks will pose less of a hazard to our environment. From this study, the following conclusion can be drawn:

- CSB met the aggregate requirement for the zone 1 grading limit of fine aggregate and is, therefore, suitable for use as a partial replacement for river sand in concrete.
- CSB can be used to create concrete with lesser weight, which results in lower dead loads when building with concrete.
- The strength of CSB-sand concrete decreases with increasing amounts of crushed Sandcrete block.
- The workability of CSB-sand concrete decreases as the CSB content increases.
- The model developed for the prediction of the expected compressive strength of concrete was suitable and worthwhile.
- CSB can be utilized while building erosion structures. Also, the compressive strength of CSB can be improved using steel fibers.

Recommendations

Further studies are recommended to determine the performance of CSB concrete in an aggressive environment. The durability and freeze-thaw resistance of CSB-sand concrete can be further investigated to determine its performance during harsh cold climatic conditions.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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