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DENSITY AND WATER ABSORPTION COEFFICIENT OF SANDCRETE BLOCKS PRODUCED WITH WASTE PAPER ASH AS PARTIAL REPLACEMENT OF CEMENT

ABSTRACT

The literature is flooded with scientific information on most durability properties except water absorption coefficient of masonry units like sandcrete blocks. Also, while waste papers disposal is a systemic problem due to ineffectiveness of waste management system in developing countries, the price of cement is on the increase. This situation, ultimately, causes a bane in achievement of low-cost housing development considering the fact that sandcrete blocks are predominantly used as walling elements for such undertakings. In this study, solid core sandcrete blocks were produced with waste paper ash (WPA) utilized as partial replacement of cement at 5 % and 10 % volumetric levels. Chemically, the WPA was found to show similarity with cement in terms of SiO_2, Al_2O_3, and CaO contents. Density and water absorption coefficient of the block samples were determined. While density ranged from 1682 to 1872 kg/m^3, water absorption coefficient varied from 27.04 to 23.49 kg/m^{2}h$^{0.5}$. Statistically, no significant difference was revealed at $p < 0.05$ between experimentally-measured water absorption coefficients and those obtained using the model developed for prediction based on density of the samples. Thus, utilization of WPA as described herein could help to reduce the cost of procuring cement and in turn, enhance low-cost building construction. Also, with the developed model (showing dependence of water absorption coefficient on density), durability of sandcrete blocks exposed to moisture –prone environment could be easily predicted.

Keywords: *Angle of repose; building; coefficient of uniformity; durability property; waste*

INTRODUCTION

Challenges faced by humans in this 21st century are diverse and enormous with attendant threat that requires an urgent attention for possible solutions. For instance, the persistence of ineffective waste management systems in developing countries warrants waste disposal by indiscriminate dumping, landfilling, or open burning (depending on the nature and form of the waste). Such practices have detrimental effects on the environment and health [1, 2]. According to Robert et al [3], wastes are items regarded to have no usefulness again and need to be disposed of immediately without minding the effects of the disposal technique adopted. A typical example of such items is waste paper. Notably, some researchers have adopted recycling/valorization of waste papers into value-added products as a measure to salvage the environment from associated disposal menace. For instance, Nathaniel et al [4] used waste

newspapers with wood dust to develop composite panels for structural applications. Also, composite ceilings capable of improving thermal insulation performance in buildings have been produced by utilizing waste newspapers with plaster of Paris [5] or coconut husks [3]. Again, incorporation of waste paper (either by addition, substitution, or replacement) with fine aggregate, coarse aggregate, or cement brings about increase in mechanical properties of concrete [6, 7]. Not only that, Mitikie and Waldtsadik [8], Subanndi [9], Meko and Ighalo [10], and Azar et al [11] reported that improvement in compressive strength of concrete is possible by inclusion of waste paper ash as a partial cement replacement material. Even at that, waste papers still remain under-utilized. This, obviously, is because paper is a necessity of civilization and so, there can be no halt in its production [12]. On global scale, 300 million tons of paper are produced annually [13] and as posited by McKinney [14], paper and paper products constitute 25 – 40 % of the total wastes generated. Now, since increasing tendency in daily production of papers can cause the resulting wastes to be generated in appreciable amounts [15, 16] leading to average waste paper generation of 4.85 tons [17], there is a need to consider additional possible ways of managing the wastes.

Another serious challenge is affordability of a safe and durable housing (building) for habitation. For such construction undertaking, sandcrete blocks are predominantly used [18]. In the construction industry, sandcrete blocks are produced from a mixture of sand, cement, and water in prescribed quantities [19]. Notably, incessant rise in the cost of building materials, of which cement is very prominent, has made achievement of sustainable housing development a mirage. Hence, the search for possible solutions to the problems encountered became necessary. In recent times, ashes derived from some agricultural wastes have been found to be promising partial substitutes for cement in sandcrete blocks production. For example, partial replacements of cement with certain proportions of rice husk ash [20–22], guinea corn husk ash [23], groundnut shell ash [24], and coconut shell ash [25] yield sandcrete blocks that can perform satisfactorily. Such attempts could help to solve the disposal problems associated with those waste materials and also reduce the cost of procuring cement for production of sandcrete blocks needed for building construction. This is because the wastes used in deriving the respective ashes are cheap. However, their continuous availability is in doubt (if not difficult) due to the fact that they are generated as a result of harvesting/processing of the agricultural produce and these processes are season – specific.

Observably, sandcrete blocks have been scrupulously examined in terms of compressive strength, thermal properties, and durability properties (like water absorption, sorptivity, permeability, porosity). One of such studies was conducted and reported by Oyekan and Kamiyo [20]. Unfortunately, there is a dearth of information on water absorption coefficient of sandcrete blocks. Unlike water absorption, this property gives specific information on a porous material as a function of time. Such information can help to effectively predict the durability of sandcrete blocks intended for use as walling elements especially in areas that are prone to attack by water. Since incessant rise in the costs of conventional materials for construction, increase in waste generation capacity, and inefficient waste management are among factors that significantly hinder the development [26] there is an urgent need to proffer a practical solution to the evolving scenario in order to ensure sustainable construction opportunities. Considering the aforementioned circumstances, this study has been designed to appraise water absorption coefficient of sandcrete blocks developed with waste paper ash (WPA) as a partial replacement of cement. In addition, a model for prediction of water absorption coefficient would be developed as a function of density of the blocks. The choice of density is premised on the fact that, apart from being a standard requirement for verifying the quality of sandcrete blocks [19], it can be easily determined.

EXPERIMENTAL

Materials acquisition and description

Portland Limestone cement (CEM II B-L 32.5R, manufactured by Lafarge Africa PLC), potable water (from borehole), waste newspapers and river-bed sand (fine aggregates passing 4.75 mm sieve) were utilized in this study. The water was free from suspended particles, salts and oil contaminations. Also, the aggregates were clean and free from all deleterious matters and were gathered from various building construction sites. All these materials were collected in large quantities within Akwa Ibom State, Nigeria.

Preparation of Waste Paper Ash (WPA)

The surfaces of the waste newspapers were cleaned to remove impurities from them. Then after, the papers were shredded and the pieces produced were burnt into ash by means of an incinerator (Model i8-20S) operated at 850^{o}C. On cooling completely, the as-prepared ash was put in cellophane material and kept for use.

Analysis of the materials

The cement and WPA were, each, divided into two portions. In each case, one portion was analyzed for chemical composition [27]. Also, the sand materials were graded and their coefficient of uniformity was determined [28] after which those having different values were selected until about 90 % of the total collection was achieved. By fixed funnel method employing inverse tangent rule [16], static angle of repose was determined for each selected sand as well as the cement and WPA (using their remaining portion). Figure 1 shows the microstructure of the WPA obtained using Electron Microscope (Philips XL – 30).

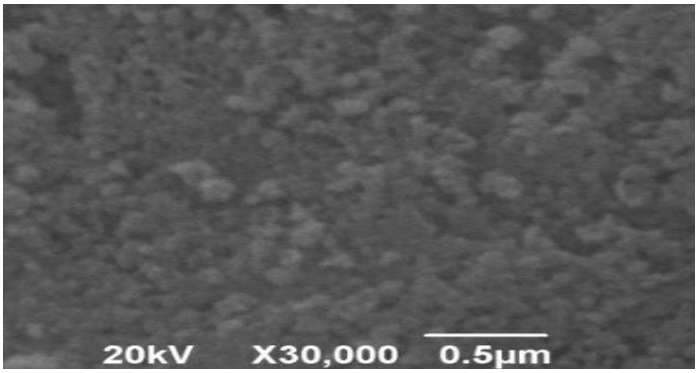


Fig. 1. Microstructure of the WPA

Mix proportions of the materials

Ten of the selected sand materials were randomly chosen and coded (to ease in identification) for use in development of block samples with 10 % content of the WPA as partial substitute for cement. The remaining ones were also coded but for use in production of block samples with 5 % fractions of the WPA utilized as partial replacement of cement. Consideration of 5 % and 10 % fractions in this work was based on the previous findings that up to 10 % proportion of WPA could yield a masonry unit of desirable properties [2]. Table 1 shows the mix design adopted in this study. Batching of the materials was by volume method. Adoption

of 1:6 ratio of cement to sand was based on the specification for general purpose application of the cement type used in this work (as indicated on its bag) which also showed compliance with mix design recommended in BS 2028 [29] for sandcrete blocks.

Table 1 Research mix design

Sand (Fine aggregate) code	Proportion of WPA (%)	Ratio of cement (with WPA) to sand	Ratio of water to cement (with WPA)
A01	10	1:6 (constant)	0.5 (constant)
A02	10		
A03	10		
A04	10		
A05	10		
A06	10		
A07	10		
A08	10		
A09	10		
A10	10		
A11	5		
A12	5		
A13	5		
A14	5		
A15	5		

Production of sandcrete block samples

In each case, the batched constituents were thoroughly mixed. When an even color was attained consistently, the mixture was poured into a steel mold measuring 150 mm x 110 mm x 70 mm. The moment the mixture reached half of the mold, it was tamped with 10 strokes using a tamping bar over the cross-section of the mold. After that, more quantity of the mixture was poured into the mold and tamped likewise until it was filled to its brim. Each tamped mixture, on demolding, became a fresh sandcrete block sample. Using each aggregate, the block samples were produced in triplicates under same laboratory conditions and they were subjected to curing after 24 hours.



Fig. 2. One of the developed samples

The curing was carried out by splashing water on them twice daily (morning and evening) for 14 days. This duration was based on minimum of 10 days specified [30] for the cement type utilized in this work. At the end of curing, the block samples were allowed to dry completely

before they were examined for the intended properties. One of the prepared samples is shown in Figure 2.

Investigation of the intended properties

The density of each block sample was evaluated as the ratio of mass to volume, expressed mathematically thus [19, 31 – 34]

$$D = \frac{M}{V} \qquad (1)$$

where D= density, M = mass, and V = volume of the sample.

To assess water absorption coefficient, a block sample was suspended from a scale by means of a strong wire and then made to rest centrally above water contained in a transparent vessel. The scale was calibrated and its level was adjusted until the sample penetrated the water to about 4mm from its lower end as shown in Figure 3. Immediately, timing of water penetration into the sample was commenced. After every 5 minutes, the mass of the block sample was noted. This process was allowed until about 30 minutes elapsed. At each considered time, the mass of water absorbed was determined (as the difference between the dry mass of the sample and the scale reading at that instant). Using the data obtained for each sample, water absorption coefficient, w was deduced graphically in line with the relation.

$$\mathrm{w} = \frac{M_a}{(A\sqrt{t})} \qquad (2)$$

where M_a = mass of the absorbed water, A = area of the surface through which water penetrates the block vertically, and t = duration for water penetration.

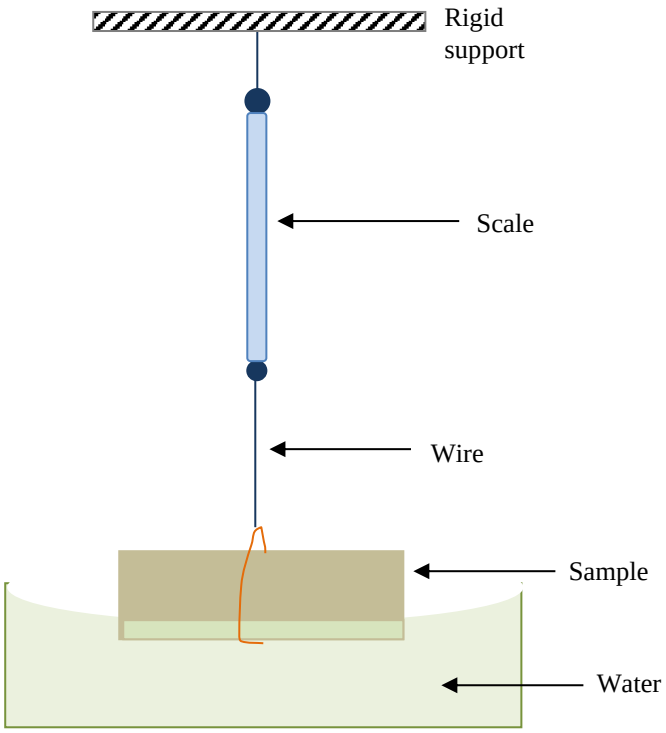


Fig. 3. View of the setup for water absorption coefficient measurement

For each triplicate group, the mean value was computed per property investigated. The mean values obtained for samples made with 10 % content of WPA were applied to formulate,

by means of Origin software (2019 version), a mathematical model describing the dependence of water absorption coefficient on density. Also, the mean values obtained for samples containing 5 % WPA content were used to validate the developed model. In doing so, the deviations between the measured and model-based values of water absorption coefficient were determined. One-way analysis of variance (ANOVA) was also employed to assess the values at 0.05 level of significance using SPSS Software. All the measurements were taken at (26 ± 1) ^{o}C.

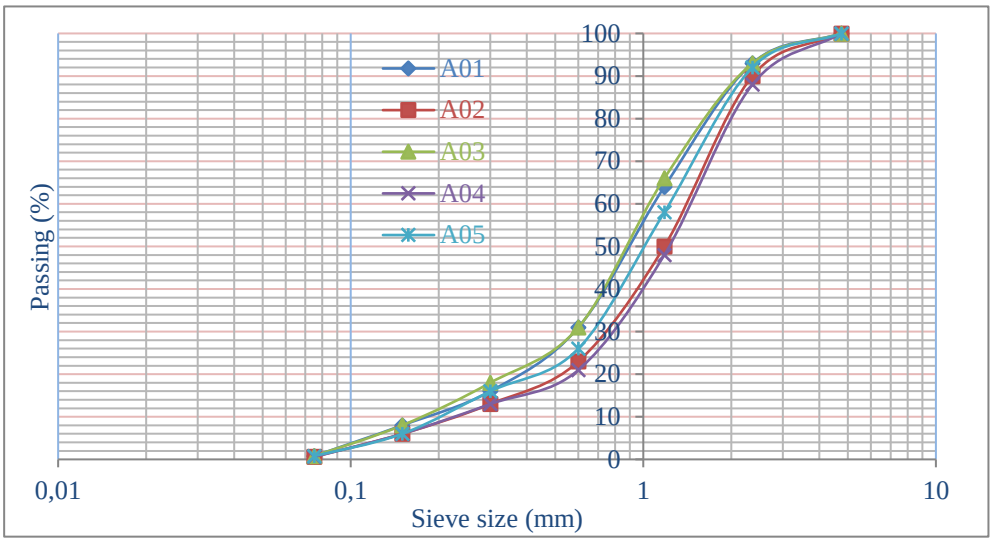
RESULTS AND DISCUSSION

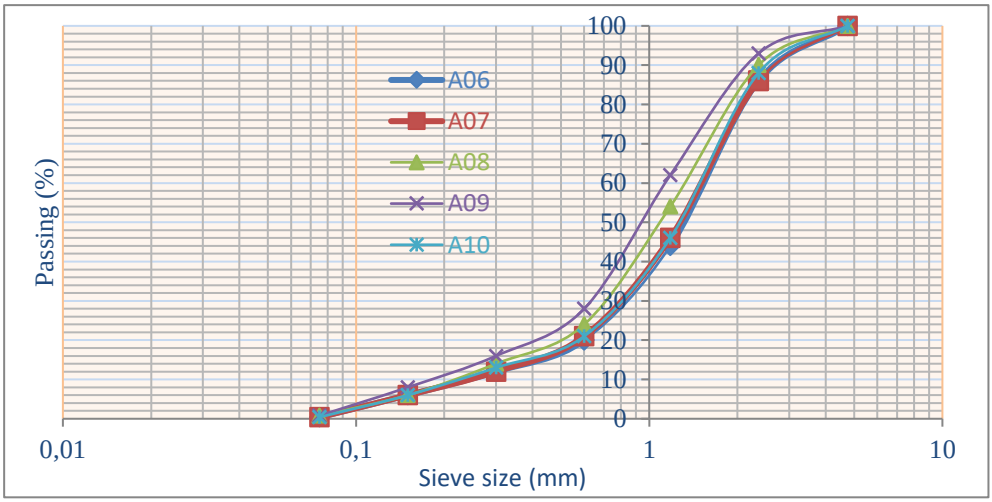
Table 2 shows the coefficients of uniformity and angles of repose obtained for the cement, WPA, and sand (fine aggregates) used in this work. The coefficients of uniformity are greater than 6, thus indicating that the sand materials are well graded [28]. Figure 4 reveals that the particles of each set of sand are of various sizes, thereby confirming that the aggregates are suitable for sandcrete blocks production. The observed differences in the coefficients of uniformity may be attributed to variations in the percentages of the aggregate particles that pass through a particular sieve opening.

Table 2. *Particulars of the materials*

Parameter	Value per material								
	Cement	WPA	Sand (fine aggregates)						
			A01	A02	A03	A04	A05	A06	A07
Coefficient of uniformity	-	-	6.54	7.48	6.37	7.54	6.87	7.70	7.68
Angle of repose	39.85^{o}	40.52^{o}	34.45^{o}	32.27^{o}	34.96^{o}	31.84^{o}	33.45^{o}	31.04^{o}	31.25^{o}
Parameter	Value per material								
	Cement	WPA	Sand (fine aggregates)						
			A08	A09	A10	A11	A12	A13	A14	A15
Coefficient of uniformity	-	-	7.36	6.76	7.59	7.76	7.42	6.84	7.89	7.13
Angle of repose	39.85^{o}	40.52^{o}	32.90^{o}	34.17^{o}	31.55^{o}	30.83^{o}	32.61^{o}	33.86^{o}	30.51^{o}	33.18^{o}

It can be inferred from the results that, approximately, the angles of repose of the materials range between 31^{o} and 41^{o}. Based on the fact that a value from 31^{o} to 35^{o}, 36^{o} to 40^{o}, and 41^{o} to 45^{o} indicates good, fair, and passable flow property respectively [35], it is appropriate to posit that all the aggregates (A01 to A15) possess good flow property while the cement and WPA exhibit, respectively, fair and passable flowability. However, all of them can be used for manufacturing purposes. Since angle of repose relates inversely with particle size of a material [36], it can be adjudged in this case that particles of the WPA are finer compared to those of the cement. Though the aggregates are made up of particles having the largest size on comparative basis, they differ in their proportions of particles for a particular size. This brings about variations in their coefficients of uniformity (ranging from 6.39 to 7.89).





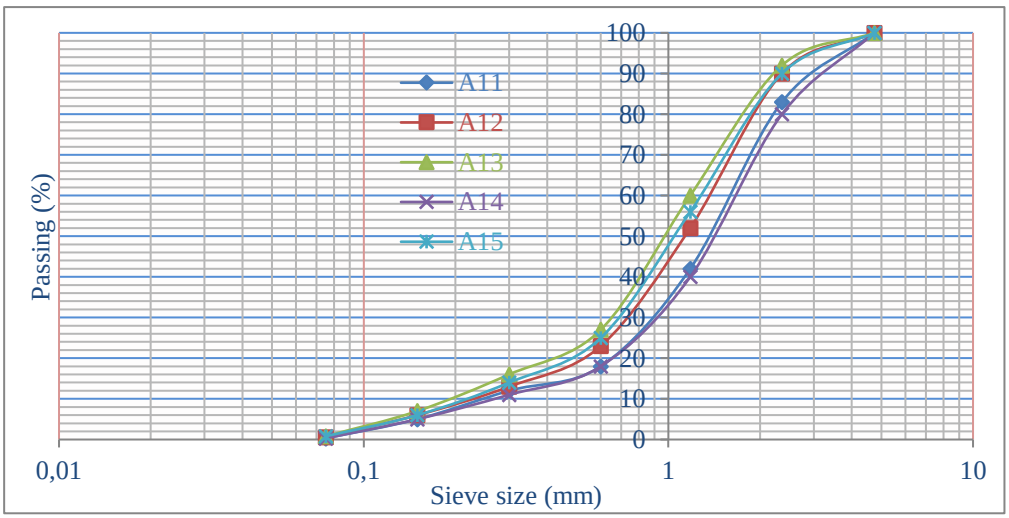


Fig. 4. Grading curves of the sand (fine aggregates) used in this study

The results of chemical composition analysis (Table 3) show that the first three prominent constituents (CaO, SiO_2, and Al_2O_3) of the cement and WPA have similar rankings. Between the cement and WPA, the respective difference in the proportions of CaO, SiO_2, and Al_2O_3 is 7.44 %, 12.65 %, and 1.00 %. For loss on ignition, cement has a value that is 64.49 % lower than that of the WPA. This portrays that, apart from having finer particles (which consequently ensures exposure of greater surface areas for decomposition), the WPA contains more carbon compared to the cement. The WPA utilized in this study is non-pozzolanic because the proportions of SiO_2 (28.97 %), Al_2O_3 (2.62 %), and Fe_2O_3 (1.74 %) in it sum up to 33.33 % instead of at least 70 % as stipulated [37] for a material to be a pozzolan.

Table 3. *Chemical composition of the cement and WPA*

Material	Proportion of oxides (%)						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
Cement	16.32	3.62	2.81	58.23	0.91	3.18	4.46
WPA	28.97	2.62	1.74	50.79	0.85	0.50	12.56

LOI = Loss on ignition

Table 4 shows the measured values of density and water absorption coefficient for samples produced with 10 % proportion of the WPA. Since the same process variables were maintained, variations in the density and, in turn, water absorption coefficient of the samples are as a result of different gradations exhibited by the aggregates used. There is no doubt that particle size distribution affects particles packing [38] such that larger particles pack less efficiently thereby creating bigger voids compared to smaller ones. According to the report of Kang and Weibin [39], bigger particle size has greater density and gives rise to less water absorption than smaller particle size. A careful consideration of the mean values of density and water absorption coefficient obtained for the samples (with respect to the gradation of the aggregates utilized) shows applicability of this trend in the present study. With a large number of small particles, a large number of pores is present in the sample. Values of water absorption coefficient obtained for the samples are greater than about 2.27 to 2.88 $kg/m^2h^{0.5}$ reported for cement mortar containing brick powder and glass powder as fine aggregates [40].

Table 4.*Data obtained for model formulation*

Sample code (Based on aggregate used)	Density, $D\ (kg/m^3)$				Water absorption coefficient, w $(kg/m^2h^{0.5})$			
	1	2	3	Mean	1	2	3	Mean
SA01	1692	1690	1694	1692	26.88	26.90	26.87	26.88
SA02	1795	1796	1793	1795	25.50	25.50	25.52	25.51
SA03	1684	1680	1682	1682	27.01	27.07	27.04	27.04
SA04	1808	1810	1810	1809	25.24	25.21	25.22	25.22
SA05	1730	1733	1732	1732	26.31	26.29	26.29	26.30
SA06	1844	1842	1843	1843	24.73	24.71	24.70	24.71
SA07	1831	1834	1832	1832	24.92	24.89	24.90	24.86
SA08	1768	1769	1766	1768	25.80	25.80	25.82	25.81
SA09	1698	1701	1699	1699	26.78	25.75	26.77	26.77
SA10	1825	1823	1825	1824	24.99	25.01	24.98	24.99

This could be due to the fact that the mortar contains more cement quantity than the sample, thus having tighter microstructure and less amount of capillary pores. Egenti et al [41] observed

in their studies that increase in cement content decreased water absorption coefficient of compressed earth blocks. The least mean density value (1682 kgm^{-3}) obtained for the block samples in this study exceeds the minimum value of 1500 kgm^{-3} recommended [29] for type A blocks.

Figure 5 reveals that though water absorption coefficient decreases as density increases, the relationship is not perfectly linear. For the studied samples, the mathematical representation showing the dependence of water absorption coefficient (w) on density (D) herein referred to as ($\mathrm{w} - D$) model is found to be such that

$$\mathrm{w} = 30.90 + 8.63\ (10^{-3})D - 6.50\ (10^{-6})D^2 \qquad (3)$$

with coefficient of determination of 99.9 % (which indicates a very strong agreement between the variables in the model).

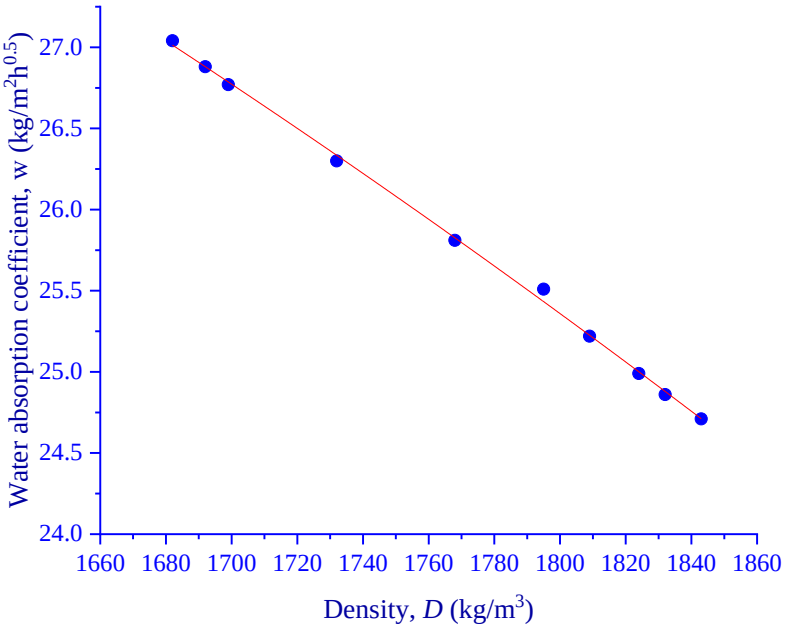


Fig. 5. Dependence of water absorption coefficient on density of the block samples

Table 5 shows the results of validation test for the model. As shown, the deviation of model-based data from the experimentally-measured values of water absorption coefficient ranges from -0.08 % to 3.36 %. The very low maximum deviation observed in this case signifies a very high correlation between the two sets of values. It is also indicative of the fact that the model developed can give a reliable prediction (a situation that is confirmed by the coefficient of determination value associated with the model fitting).

Table 5. *Validation results for the* (w – *D*) *model*

Sample code	Mean density, $D\ (kg/m^3)$	Mean water absorption coefficient, w $(kg/m^2h^{0.5})$		Deviation (%)	F - value	
		Measured value	Model-based value		Calculated	Critical
SA11	1861	23.85	24.45	2.52	0.1486	4.414
SA12	1780	25.64	25.67	0.12		
SA13	1715	26.60	26.58	-0.08		
SA14	1872	23.49	24.28	3.36		
SA15	1759	25.92	25.97	0.19		

More so, since the critical F-value (4.414) is greater than the calculated one (0.1486), it implies that the values of water absorption coefficient obtained by computation using the model are not significantly different from those determined experimentally. All the water absorption coefficients obtained in this study fall within the range (20 to 30 $kg/m^2h^{0.5}$) for solid bricks. In this research, each of SA01 to SA10 contains 10 % of the WPA whereas in the cases of SA11 to SA15, the proportion of the WPA utilized is 5 %. According to the report of Christopher et al [25], increase in the level of cement replacement with coconut shell ash lowered density of sandcrete blocks. Also, Alkamu et al [23] noticed that by replacing cement with guinea corn husk ash at 0, 5, 10, 15, and 20 % levels, the density of the resulting sandcrete blocks was 1943.3, 1922, 1886.5, 1865.3, and 1844 (all in kgm^{-3}) respectively at curing age of 14 days. However, it is observed in this study that even with 10 % content of the WPA, the mean density values obtained for some of the block samples (SA 04, SA06, SA07, SA 10) are greater than those of samples like SA12, SA13, and SA15 similarly produced but with 5 % content of the WPA. This is possible because blocks properties are influenced by fine aggregates used. In this case, the fine aggregates utilized vary in their gradation and hence, quality. This gives credence to the submission of Baiden and Tuuli [42] that the quality of aggregates depends on gradation.

SUMMARY

Sandcrete blocks produced with partial replacement of cement using 5 % and 10 % fractions of waste paper ash (WPA) were found to vary in density as a result of differences in gradation of the fine aggregates (sand) utilized. The same reason accounted for variations in their water absorption coefficient. It was observed that bigger sand particles yielded block samples having less water absorption coefficient but greater density. Water absorption coefficients of the studied samples were within the range for solid bricks. A non-linear inverse relationship was observed between water absorption coefficient and density of the samples. Statistically, the water absorption coefficients determined experimentally and those obtained based on the developed model were found to differ insignificantly. Thus, since it is very easy to determine density, using the model showing how water absorption coefficient depends on it could serve as a quick way of predicting the durability of solid core sandcrete blocks intended for application in building construction in moisture-prone environments.

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