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Study on density and water absorption properties of timbercrete block

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ABSTRACT

The demand for sand as natural aggregates has recently increased in building and construction, resulting in a significant decrease in resources and a rise in prices. At the same time, developing countries are concerned about managing sawdust waste. This experiment investigates the density and water absorption properties of timbercrete block (cement-sand-sawdust). This study partially substituted natural sand with sawdust to create lightweight material. The demand for sand as natural aggregates has recently increased in building and construction, resulting in a significant decrease in resources and a rise in prices. At the same time, developing countries are concerned about managing sawdust waste. The sand replacement with sawdust was at four (4) levels (0, 5, 10, and 15%) at two (2) levels of mix proportions: 1:4 and 1:6, and curing age at five (5) levels (7, 14, 21, 28 and 56 days). A total of one hundred and twenty (120) cubes were used to measure the density of the material at five different levels (7, 14, 21, 28, and 56 days). In comparison, 16 cubes were explicitly used for the water absorption test after seven days of curing. "Full immersion" was employed as a method of choice for curing. The results revealed that the water absorption rate increases for the two mix proportions as the replacement percentage with sawdust increases from 5 to 15%. In comparison, density declines as the percentage of sawdust replacement increases from 5 to 15%. The study concluded that for mix ratios 1:4 and 1:6, a maximum of 5% sawdust should be utilised to avoid excessive loss of mortar physical properties, which will also contribute to the reduction of sawdust waste generated in society. However, the best mix proportions at a maximum of 5% substitution of natural sand with sawdust is 1:4.

1. Introduction

Sustainable development is an essential pillar in this century. Therefore, the world needs to balance the use of resources and energy while resolving environmental problems; by eradicating environmental pollution through the utilisation of wastes for good benefits and also by solving economic problems through the reduction of costly conventional building materials [1]. As well known that plenty of materials are used up during the process and operation of building construction and throughout the building service life cycle. In addition, the material is a very crucial component in building construction. The construction industry is the second-largest consumer of raw materials after the food processing industry [2]. Materials are needed and used for building construction to be possible. Safa et al. [3] observed that the cost of construction materials is 50–60 % of the project cost. Various construction materials used in the construction industry, such as bricks, blocks, stone, gravel, granite, timber, reinforcement, and others, have contributed significantly to the construction cost.

The high worldwide consumption of sand for concrete production has led several developing countries to encounter difficulties supplying natural sand to meet the increasing demand for infrastructural development in recent years [4]. Therefore, there is a need to incorporate underutilised wastes into construction. Charis et al. [5] reported that wood wastes such as sawdust and wood shavings are still the most underutilised wastes; when these wastes are not properly disposed of, they negatively affect the aesthetic appeal of the environment along with various ecological threats.

There are over 1000 active sawmills in Nigeria [1]. Sawmilling industries produce many wood wastes such as sawdust, cut slabs, tree barks, plain shavings, and strips annually. Disposing of wood waste has been a significant problem for the sawmilling industries since the more prominent the wood and industries, the larger the waste generated. Therefore, there is a need to know how locally available waste or materials can be effectively used for a positive impact.

Therefore, in resolving these problems, underutilised wastes should be incorporated into concrete for construction purposes, producing

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environmentally friendly materials that will reduce the negative impacts of wood waste on the environment. Olanipekun et al.; Osei and Jackson; Sasah and Kankam [6–8] suggested that one of the solutions for reducing the cost of conventional building materials is by investigating and developing non-conventional local sources of materials such as agricultural and industrial wastes as construction materials to be used for civil engineering construction. Sawdust can be mixed with clay or fine aggregates or admixtures to generate blocks, bricks, pavers, mortar, and other products that reduce weight and cost and boost insulating capacity [9].

One of the sustainable ways of building is using sustainable materials such as bamboo, wood, rammed earth, and timbercrete. Timbercrete is a sustainable building material that offers several benefits over traditional blocks. Timbercrete comprises a blend of carefully selected sand, a cementitious binder (cement), water, and cellulose materials such as sawmill waste (sawdust). Timbercrete has various advantages: aesthetic, low cost, thermal efficiency, user friendly, low carbon product, fire-resistant, and low capital equipment cost [10]. It provides a light-weight alternative [9], helps reduce pollution by utilising sawdust [1,11], and can be used to compensate for the lack of fine aggregates, such as sand.

The main ingredient of Timbercrete is sawdust. Sawdust is a type of wood waste; wood wastes are the residue of processed wood left behind. Five types of wood wastes were obtained during sawmilling activities: tree barks, cut slabs, sawdust, plain shavings, and strips [12]. Maharani et al. [13] conducted a study on the physical properties of sawdust, which contributed to the development of knowledge on the subject. The study analysed the physical properties of sawdust from five tropical wood species prepared using different mill types and found that particle size and density were essential factors influencing the physical properties of sawdust.

Owoyemi et al. [14] estimated that in 2010, sawmills in Nigeria generated about 1.8 million tons of sawdust annually and 5.2 million tons of wood waste. Due to the vast amount of wood waste generated, mainly sawdust, proper disposal has been an excellent problem for sawmilling industries. Most sawmilling industries resort to publicly burning sawdust which is highly dangerous to human health and the environment.

Considering all of the above, the objective of this study is to; determine the density and water absorption of the timbercrete blocks at different percentages of replacement of sand with sawdust for mix ratios 1:4 & 1:6; and determine the optimal replacement percentage from this study at 1:4 and 1:6.

2. Literature review

Nigeria is an African country blessed with more than enough forest reserves, especially in the Southwestern region like Osun, Ondo, Oyo, Lagos, and Ekiti state [15]. The Southwestern part of Nigeria, especially the Ondo state vegetation, is dominated by thick forests with economic trees. There are several species of forest products. Even though Nigeria is well endowed with wood products, there is still high demand for wood for building and construction purposes.

Sawmill is a wood processing industry. The sawmill has contributed to the economic development of Nigeria [16]. According to Ogunwusi [17], in Nigeria, in 2010, 1325 sawmills were in operation. About 300 were located in the swamp forests of Lagos and River states, and about 945 sawmills were in the rainforest zones of Edo, Delta, Ondo, Ogun, Oyo, Osun, and Cross River States. While in the savannah zone, were about 80 sawmills located mainly in Taraba, Adamawa, Benue, Kwara, Kogi, Kaduna, and the Niger States. Akinbani [18] reported that Ondo state has more than 238 timber industries, and most sawmill industries in most parts of Nigeria operate on a small scale in scope and structure. Elehinafe et al. [15] pointed out that trees from forests were taken to sawmills to produce materials for building constructions and furniture. The residue of processing is left behind as sawdust.

Huge sawdust and other wastes are generated annually, like wood offcuts, plain shavings, wood barks, and wood rejects. Due to the high demand for wood and its products, the volume of waste being generated cannot but increase. The study conducted by Olawuni and Okunola [12] disclosed that five different types of wood wastes were obtained during sawmilling activities: tree barks, cut slabs, sawdust, plain shavings, and strips. From that study, those identified wood waste materials were produced in two sawmill sites in the study area, shown in Table 1.

One of the wood wastes left behind is sawdust. Olutoge [19] defined sawdust as loose particles or wood chippings from sawing timber into standard useable sizes. Paulrud, Mattson [20] noted that in milling operations, about 10–13% of sawdust was obtained from the total volume of the wood log and that the average width and the thickness of sawdust determine the sawdust. Owoyemi et al. [14] estimated that in 2010 sawmills in Nigeria generated about 1.8 million tons of sawdust annually and 5.2 million tons of wood waste.

Sawdust is a by-product of wood from sawmilling activities and the wood-based industry. Due to the more significant number of sawmills in Nigeria, enormous quantities of sawdust have been produced annually. Tiough [21] noted that sawdust accounted for about 10–20% of the wood waste. The volume of sawdust generated increases annually in Nigeria, and this has led to the creation of disposal problems.

Sawdust is obtained from wood. The sawdust will sometimes consist of chippings from one wood or wood. According to Sawant, Sharma [22], the chemical properties of sawdust that were sieved through 1.18 mm are shown in Table 2 below;

3. Materials and methods

The physical properties (water absorption and density) of cement-sand-sawdust blocks were carried out as experimental laboratory work at the Building department laboratory of the Federal University of Technology, Akure, Ondo State, Nigeria. The materials and equipment used, collection and sourcing of the materials, basic laboratory tests carried out on the materials sourced, and experimental procedures are discussed here. The physical properties studied were water absorption and density of the cement-sawdust-sand blocks (see Tables 3 and 4).

3.1. Materials used and their properties

The materials to make the timbercrete were first tested as per BS code recommendations or specifications. The essential components of the materials utilised in the production of lightweight cement-sand-sawdust (timbercrete) block consist of the following;

1) Cement (Ordinary portland cement (OPC))

Dangote Cement was procured from a cement distribution store, Akure, in Ondo State, Nigeria, with properties conforming to BS EN 197–1 [23].

2) Sawdust

Sawdust (from hardwood) was obtained manually from Babatunde sawmills at Roadblock, Akure, Ondo State, Nigeria. After collecting, it

Table 1
Wood waste components produced during sawmilling activities. (Source; Olawuni and Okunola [12].

Wood waste	Ondo road Frequency (%)	Orisunbare Frequency (%)
Sawdust	27.6	29.0
Cut slabs	25.0	25.8
Tree barks	19.7	19.4
Strips	15.8	16.1
Plain shavings	11.8	9.7
TOTAL	100	100

Table 2
Chemical properties of sawdust.

S/N	Constituents	Percentage (by weight)
1	SiO_2	87
2	Al_2O_3	2.5
3	Fe_2O_3	2.0
4	MgO	0.24
5	CaO	3.75
6	Loss of ignition (LOI)	4.76

Table 3
Grain size distribution of sawdust.

Materials	Sawdust	Sand
Weight of empty specific gravity bottle = W1 (g)	365.40	365.25
Weight of specific gravity bottle + oven dried sample = W2 (g)	415.40	416.6
Weight of specific gravity bottle + oven dried sample + water = W3 (g)	768.80	806.6
Weight of specific gravity bottle + water = W4 (g)	782.05	779.05
Specific gravity	0.80	2.18

Table 4
Grain size distribution of sawdust.

Materials	Sawdust	Sand
Weight of moisture content can = W0 (g)	12.20	12.17
Weight of moisture content can + wet sample = W1 (g)	17.20	35.17
Weight of moisture content can + dry sample = W2 (g)	15.50	33.27
Moisture content	51.5%	9.01%

was sun-dried and kept in waterproof bags. To maintain standards, the sawdust was passed through a 4.76 mm BS test sieve, allowing the sawdust to be readily and uniformly mixed during usage.

3) Sand

The sand was clean, sharp river sand free of clay, loam, dirt, and organic or chemical matter. The sand was sourced from Akure in Ondo State, Nigeria. The sand was checked and tested to conform to BS EN 12620:2002 + A1 [24]. The fine aggregate, which is locally available sand, was tested as per the requirements of the BS code. The preliminary tests were carried out on the sand.

4) Water

Rainwater was collected and used (for the production of timbercrete and curing) for this research, and it met the standard for drinking.

3.2. Procedures for preliminary test on materials

The aggregates (sand and sawdust) were tested before usage to determine their physical properties regarding moisture content, specific gravity, and grain size distribution.

i) Specific gravity of sawdust and sand

It is defined as the ratio of the weight of the sample to that of an equal volume of distilled water. An empty specific gravity bottle with its lid was first weighed and noted (W1). Then the specific gravity bottle with about 50g of oven sample was weighed and noted (W2). The bottle with the sample was filled with water, and after 24 h, it was weighed and noted (W3). Then the content of the specific gravity bottle was emptied and filled with clean water to the brim and covered with its lid; the weight was noted (W4). In accordance with BS EN 12620:2002 + A1 [24]. The specific gravity is calculated using Eq. (1) below;

$$Specificgravity(SG) = \frac{\text{dry weight of the aggregate}}{\text{weight of an equal volume of water}} = \frac{W2 - W1}{(W2 - W1) - (W3 - W4)} \quad (1)$$

ii) The moisture content of sawdust and sand

This test was conducted on the sample in order to determine the moisture content of the sample. The apparatus used was a moisture content can, oven and digital weighing balance. The weight of the moisture content can was first determined and noted (W0). Then the weight of the can with the wet sample was determined and noted (W1), and it was placed inside the oven for 24 h at a one-degree temperature. After the specified hours, the can was brought out, weighed, and noted (W2). In accordance with BS EN 12620:2002 + A1 [24]. Moisture content is calculated using Eq. (2) below;

$$\text{Moisture content} = \frac{\text{Weight of moisture}}{\text{Weight of dry sample}} X100 = \frac{W1 - W2}{W2 - W0} X100 \quad (2)$$

iii) Grain size distribution of sawdust and sand

Sieve analysis is used for grading. It is the process of splitting a sample of aggregate into fractions, each containing particles of the same size. A stack of sieves containing nine sieves of progressively smaller openings with a catching pan at the lowest base to collect ash samples passing through a sieve 75 mm was employed for the experiment. The various sieve sizes used were 4.75 mm, 2.36 mm, 1.70 mm, 0.600 mm, 0.500 mm, 0.425 mm, 0.212 mm, 0.150 mm and 0.075 mm per American Association of State Highway and Transportation Officials (AASHTO) [25].

Table 5 shows the grain size distribution of sawdust. It shows that 99.65% passed through the 4.76 mm sieve and 41.10% passed through the required 0.600 mm aperture sieve, and about 54.90 were retained.

Table 6 presents the sieve analysis for fine aggregate, with about 90.10% passing through the 0.600 mm aperture of the sieve, while only about 9.52% was retained.

Table 7 below shows all the physical properties of the aggregates used.

where; $Cu = D_{60} / D_{10}$

$C_C = (D_{30})^2 / (D_{60} \times D_{10})$

D_{10} is the soil diameter, of which 10 per cent of the soil weight is finer. It can be read directly from the graph.

D_{60} is the soil diameter, of which 60 per cent of the soil weight is finer. It can be read directly from the graph.

For:

a) Cu greater than 4.0, the soil is well-graded. It has a particle size distribution extending evenly over a wide range of particle sizes without excess or deficiency of any particle size.
b) Cu between 1 and 4, the soil is uniformly graded. That is, all soil particles are almost the exact sizes.
c) Cu < 1.0, the soil is poorly graded; the soil sample particle distribution contains an excess of some particle sizes and a deficiency of others.

3.3. Mix design and specimen production

The process involved in the production are as follows;

a) **Mixing:** The appropriate quantities of material were weighed according to proportions and then mixed according to BS specifications. The mixing was done manually.

Table 5
Grain size distribution of sawdust.

Sieve size(mm)	4.76	2.36	1.70	0.600	0.500	0.425	0.212	0.150	0.075	Pan
Percentage retained (%)	0.35	1.65	2.00	54.90	16.20	1.75	16.15	3.80	2.35	0.85
% passing	99.65	98.00	96.00	41.10	24.90	23.15	7.00	3.20	0.85	0

Mass of Sample = 200 g.

Table 6
Grain size distribution of sand.

Sieve size(mm)	4.76	2.36	1.70	0.600	0.500	0.425	0.212	0.150	0.075	Pan
Percentage retained (%)	0	0.32	0.06	9.52	16.86	1.62	33.60	8.66	4.58	24.78
% passing	100	99.68	99.62	90.10	73.24	71.62	38.02	29.36	24.78	0

Mass of Sample = 500 g.

Table 7
Physical properties of aggregates used.

Sample	Moisture content (%)	Specific gravity	Effective size (D_{10}) (mm)	Uniformity Coefficient (Cu)	Coefficient of Gradation (Cc)
Sand	9.01	2.18	0.06	5.42	1.57
Sawdust	51.5	0.80	0.25	2.80	1.73

b) **Casting of cubes:** The mould size adopted was 100 × 100 × 100 mm. The two mix proportions using (cement: fine aggregate (sand + sawdust); 1:4 and 1:6 (0, 5, 10 & 15% sawdust replacement). For each percentage replacement, 15 solid cube samples; 120 cube samples for density, while 1 cube sample for each percentage replacement; 16 cube samples for water absorption.
c) **Compaction:** The mortars were compacted immediately after mixing and placing. Compaction was done manually by tamping with the means of a tamping rod.
d) **Curing**: Cubes were cured under complete immersion technique and were affected for up to 6, 13, 27, and 55 days. Demolding was done after 24 h of casting.

3.4. Tests for timbercrete

1) Determination of density

Each cube sample from each composition was weighed in its dry state, during which their masses were determined by the digital weighing balance and recorded. The dimensions, which are each cube sample's length, breadth, and height, were determined using a measuring tape. Then, the volume and the bulk densities were calculated for 1:4 and 1:6 (0, 5, 10 & 15% sawdust replacement) at 7, 14, 28, and 56 days. According to EN 12390–7:2019/AC:2020 [26]. Density is calculated using Eq. (3) below;

$$\text{Density} = \frac{\text{Mass of sample}}{\text{Volume of the sample}}. \tag{3}$$

2) Determination of water absorption

A cube sample for each percentage replacement; 16 cube samples were used. This test was conducted on day 28 after curing for seven days to determine the rate at which timbercrete samples absorb water due to the presence of sawdust. The weights of the samples were first taken in the dry state (W_W) and noted. Then they were fully immersed in water, and the duration of complete immersion was noted. After 24 h, the wet cube samples were removed and weighed (W_D). The difference between each cube's dry and wet weights was obtained by subtracting the dry weight from the wet weight. According to BS 1881–122:2011 [27]. Water absorption is calculated using Eq. (4) below;

$$\text{Water absorption capacity} = \frac{(WW - WD)}{WD} X100\% \tag{4}$$

where W_W = Wet Weight in kg
W_D = Dry Weight in kg

4. Results and discussion

4.1. Density test

The sand-sawdust ratio determines the density. The density of timbercrete decreases as the ratio of sawdust to sand increases. Fig. 1 and Fig. 2 show the graphical representation of the variation in density for varying percentages of sawdust replacement. For zero percentage, replacement density ranges from 2300 to 2250 kg/m^3. That is, it was observed that density reduces as the % replacement with sawdust increases from 5 to 15%. Also, according to observations by Kumari et al. [28], the percentage of sawdust in the blocks increases, and the density decreases.

In Fig. 1, an average density of timbercrete for mix 1:4 made using sawdust aggregate for 28 days are 1970 kg/m^3, 1820 kg/m^3 and 1800 kg/m^3 for 5, 10 and 15% respectively and control of 2250 kg/m^3; for 56 days are 1930 kg/m^3, 1800 kg/m^3 and 1800 kg/m^3 for 5, 10 and 15% respectively and control of 2250 kg/m^3. While in Fig. 2, for mix 1:6; for 28 days are 1980 kg/m^3, 1850 kg/m^3 and 1720 kg/m^3 for 5, 10 and 15%, respectively and control of 2250 kg/m^3; for 56 days are 1970 kg/m^3, 1850 kg/m^3 and 1720 kg/m^3 for 5, 10 and 15% respectively and control of 2200 kg/m^3.

4.2. Water absorption test

Water absorption tests were carried out on each composition on the 28th day after casting and seven days of curing. Sawdust is more susceptible to moisture. The results provided in Fig. 3 depict the water absorption curve. The result shows that due to the varying percentage composition of sawdust in the sand-cement cubes, the rate of water absorption increases. That is, the water absorption rate increases as the percentage replacement with sawdust increases from 5 to 15%. Boob [11] also suggests that the percentage of sawdust directly affects water absorption potential. As the percentage of sawdust increases, there is an increase in water absorption, which, if excessive, can lead to a decrease in strength. However, it is possible to maintain an acceptable level of water absorption.

Also, Adebakin [29] suggests that the replacement percentage of sand should be at most 10% for optimal results in producing sandcrete blocks.

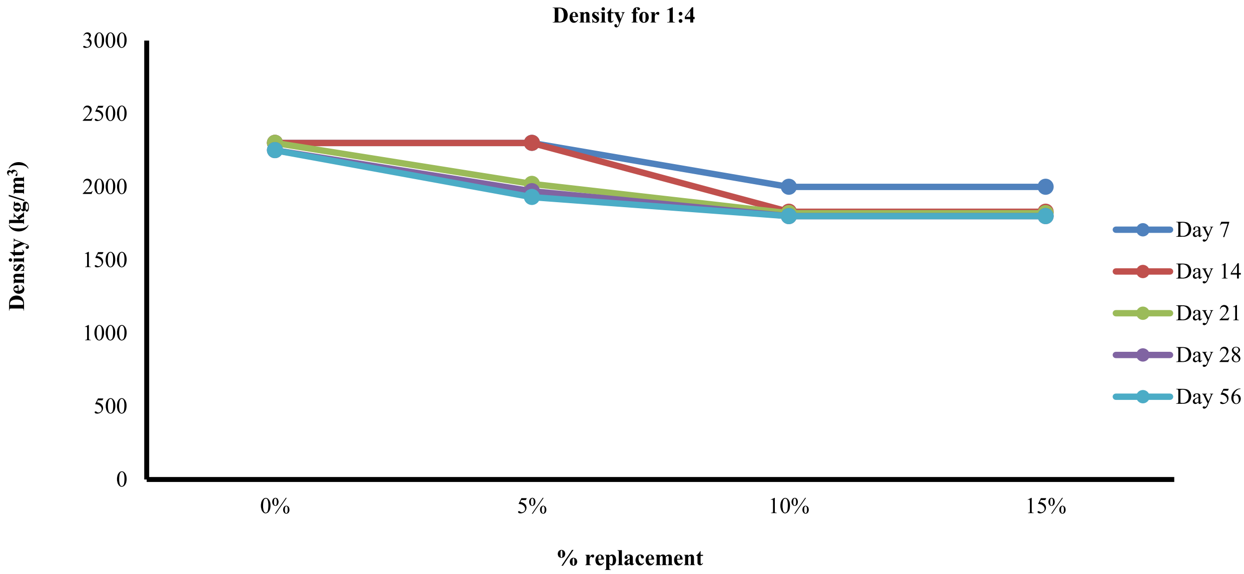

Fig. 1. Density of 1:4 for timbercrete.

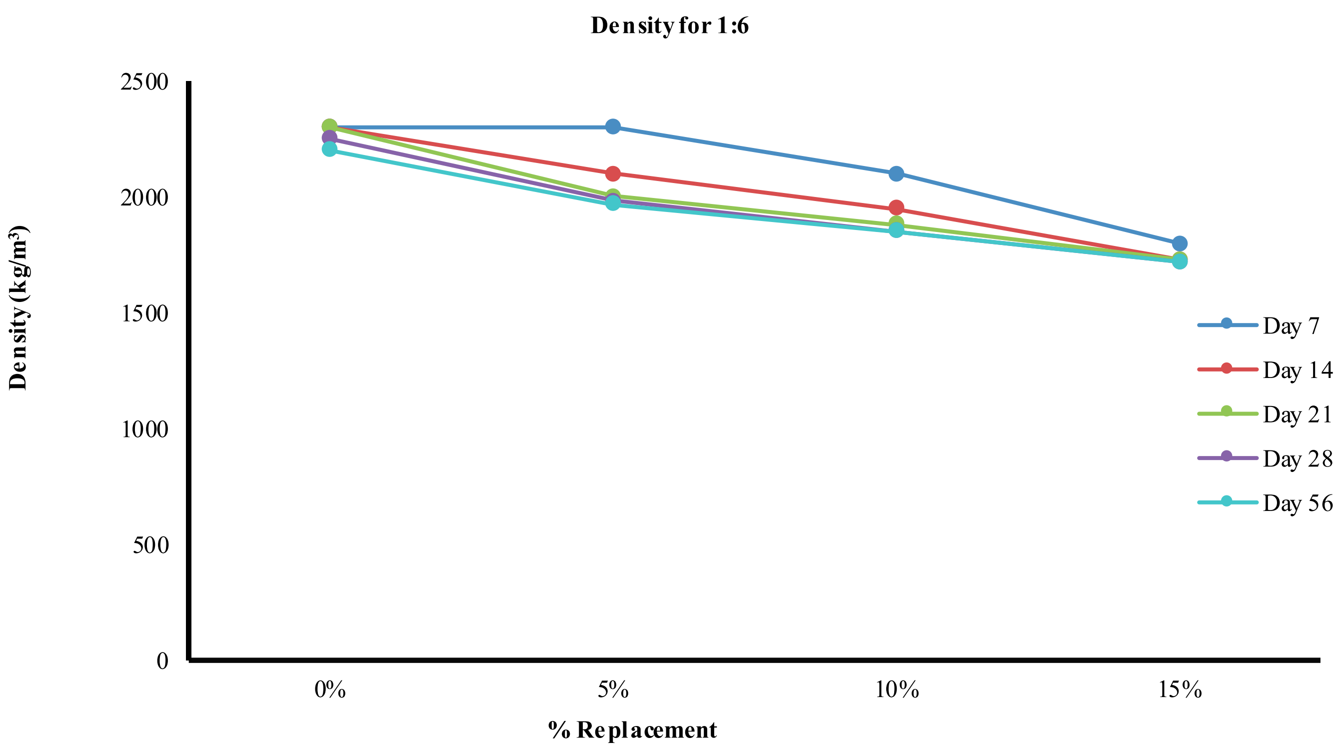

Fig. 2. Density of 1:6 for timbercrete.

5. Conclusions

This study focused on the construction density and water absorption properties of timbercrete blocks. The physical analysis was conducted explicitly on the sand and sawdust sample to ascertain its distinctive physical properties. The analysis yielded results that showed that the sand had a water content of 9.01% and specific gravity of 2.18. In contrast, sawdust's moisture content was 51.2%, and the specific gravity of 0.80 is shown in Table 5.

The density decreases as the percentage of sawdust replacement increase from 5 to 15%. The density of cement-sand-sawdust produced with mix 1:4 was higher than those of mix 1:6. The water absorption rate increases as the percentage replacement with sawdust increases from 5 to 15%. To achieve a better result when utilising sawdust to build timbercrete blocks, the sand replacement percentage should be at most 5% regarding density and water absorption.

The optimal replacement percentage from this study is 5% at 1:4 and 5% at 1:6. The one with a lower rate of density and water absorption out of the two mix proportions is at 1:4. The most suitable mix proportion at 5% sand replacement with sawdust is 1:4.

Declaration of Competing Interest

The authors declare that they have no known competing financial

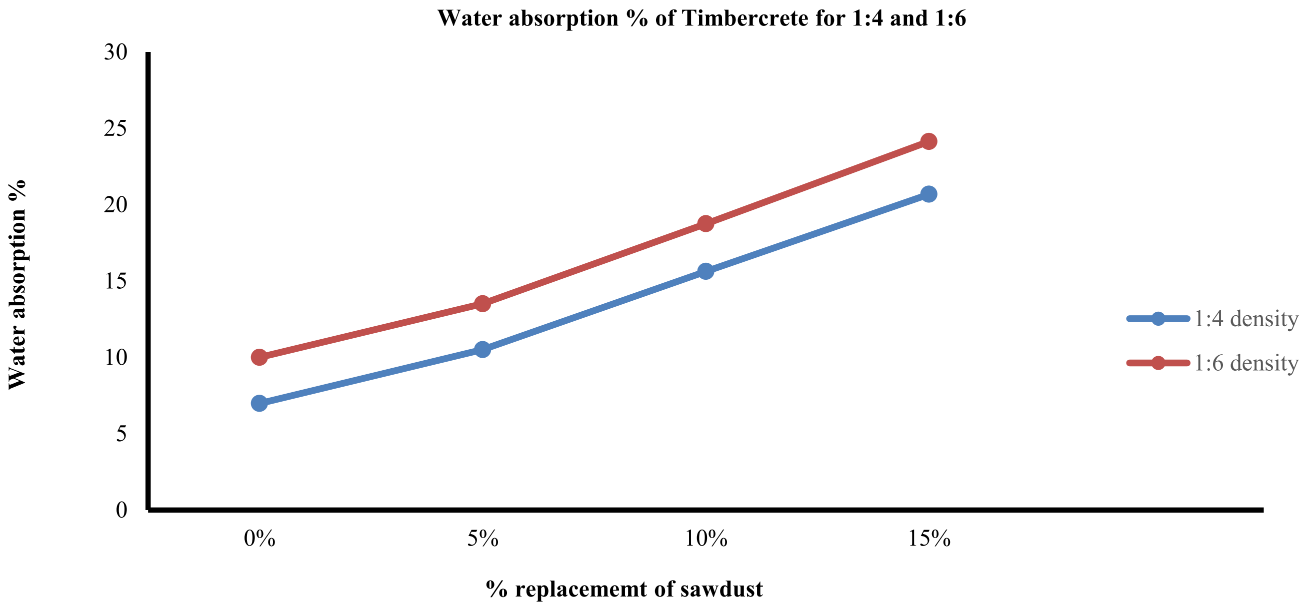

Fig. 3. Water absorption of timbercrete for mix ratio 1:4 and 1:6.

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

[1] IJ. Mogaji, Strength and Water Absorption Characteristics of Sawdust in Timbercrete Blocks. 2019, Federal University of Technology, Akure, Ondo State, Nigeria. p. 1-90.

[2] S. Halliday, Sustainable Construction, Butterworth-Heinemann, Oxford, 2008.

[3] M. Safa, A. Shahi, C.T. Haas, K.W. Hipel, Supplier selection process in an integrated construction materials management model, Auto. *Constr.* 48 (1) (2014) 64–73.

[4] Y. Divatar, S. Manjunath, M.U. Aswath, Experimental investigation on behaviour of concrete with the use of granite fines, Int. J. Adv. Eng. Res. Stud. 1 (4) (2012).

[5] G. Charis, G. Danha, E. Muzendaa, A review of timber waste utilization: Challenges and opportunities in Zimbabwe, Proc. Manuf. 2019 (35) (2019) 419–429.

[6] E.A. Olanipekun, K.O. Olusola, O.A. Ata, Comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates, Build. Environ. 41 (3) (2006) 297–301.

[7] D.Y. Osei, E.N. Jackson, Compressive strength of concrete using sawdust as aggregate, Int. J. Sci. Eng. Res. 7 (4) (2016) 1349–1353.

[8] J. Sasah, C.K. Kankam, Study of brick mortar using sawdust as partial replacement for sand, J. *Civ. Eng. Constr. Technol.* 8 (6) (2017) 59–66.

[9] Timbercrete Pty. Ltd Building with Timbercrete. Timbercrete, 2022. 1-67.

[10] Timbercrete Pty. Ltd Timbercrete: An Introduction. Timbercrete, 2015. 1-14.

[11] T.N. Boob, Performance of saw-dust in low cost sandcrete blocks, Am. J. Eng. Res. 3 (4) (2014) 197–206.

[12] P.O. Olawuni, O.H. Okunola, Socioeconomic impacts of sawmill industry on residents. A case study of ile-ife, Nigeria, J. Econ. Dev. Stud. 2 (3) (2014) 167–176.

[13] R. Maharani, T. Yutaka, T. Yajima, T. Minoru, Scrutiny on physical properties of sawdust from tropical commercial wood species: effect of different mills and sawdust's particle size, J. For. Res. 7 (1) (2010) 20–32.

[14] J.M. Owoyemi, H.O. Zakariya, I.O. Elegbede, Sustainable wood waste management in Nigeria, Environ. Socioecon. Stud. 4 (3) (2016) 1–9.

[15] F.B. Elehinafe, O.B. Okedere, M. Angela, Analysis of the properties of some Southeastern Nigeria sawdust of different wood species, Int. J. Civ. Eng. Technol. 10 (3) (2019) 51–59.

[16] T.J. Akinbode, A.B. Olujimi, Effects of sawmill wastes in residential areas of Ogbese and Akure townships, Ondo State, Nigeria. *Int. J. Innov. Sci. Res.* 9 (2) (2014) 399–409.

[17] A.A. Ogunwusi, The Forest Products Industry in Nigeria, Afr. Res. Rev. 6 (4) (2012) 191–205.

[18] A.S. Akinbani, Assessment of Timber Industry as a Means of Livelihood for the Timber, J. Agric. Vet. Sci. 8 (10) (2015) 60–62.

[19] F.A. Olutoge, Investigations on Sawdust and Palm Kernel Shells as Aggregate Replacement, J. Eng. Appl. Sci. 5 (4) (2010) 7–13.

[20] S. Paulrud, J.E. Mattson, C. Nelson, Particle and Handling Characteristic of Wood Fuel Powder: Effects of Different Mills, Fuel Process. Technol. 7 (6) (2002) 23–39.

[21] M.D. Tiough, Recycling Sawdust Waste for Construction Purposes- Solution for Disposal Problems, J. Resour. Distinct. 8 (1) (2014) 1–6.

[22] A.B. Sawant, A. Sharma, R. Rahate, N. Mayekar, M.D. Ghadge, Partial Replacement of Sand with Sawdust in Concrete, Int. Res. J. Eng. Technol. 5 (3) (2018) 3098–3101.

[23] BS EN 197-1, Cement composition, specification, and conformity criteria for common cement. BS EN 197-1. 2000, London: British Standard Institute.

[24] BS EN 12620:2002+A1, Specification for aggregates from natural sources for concrete. 2008, London: British Standard Institute.

[25] American Association of State Highway and Transportation Officials (AASHTO) Soil Classification. What Is the AASHTO Classification System | AASHTO Classification System Procedures. 2019; Available from: https://civiljungle.com/what-is-the-aashto-classification-system-aashto-classification-system-procedures/.

[26] EN 12390-7:2019/AC:2020, Testing hardened concrete - Part 7: Density of hardened concrete. 2020: European Committee for Standardization.

[27] BS 1881-122:2011, *Testing concrete.* Method for determination of water absorption. 2011, London: British Standards Institution.

[28] P. Kumari, M. Daniyal, S.A. Bhat, Y. Goyal, Effect of replacement of fine and coarse aggregate by sawdust in solid concrete blocks for different mix proportions, J. Emerg. Technol. Innov. Res. 7 (6) (2020) 595–623.

[29] I.H. Adebakin, A.A. Adeyemi, J.T. Adu, F.A. Ajayi, A.A. Lawal, O.B. Ogunrinola, Uses of sawdust as admixture in production of low cost and light-weight hollow sandcrete blocks, Am. J. Sci. Ind. Res. 3 (6) (2012) 458–463.