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# Impact of Waste Foundry Sand as a Partial Substitute for Sharp Sand on Compressive Strength and Water Absorption of Hollow Sandcrete Block

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## Abstract

*The need for habitable and affordable shelter cannot be overemphasized but the high cost of components of shelter such as hollow sandcrete blocks, bricks etc. posed a challenge to our ability to access affordable and habitable shelter. Utilization of already discarded waste foundry sand (WFS) as eco-friendly construction material for production of hollow sandcrete blocks, will save cost and preserve our environment. In this study, impact of locally available waste foundry sand as partial substitute for sharp sand in production of hollow sandcrete blocks was investigated. Sharp sand was partially substituted with WFS at 0, 10, 20 and 30%. A mix ratio of 1:6 (ratio of cement to sharp sand) and a water-cement ratio of 0.5 were used. Hollow sandcrete blocks were subjected to compressive strength tests at 7$^{th}$ and 28$^{th}$ days as well as a water absorption test on the 28$^{th}$-day. Outcomes of the research showed that an increase in the amount of WFS led to the loss of compressive strength across all curing ages, and that all sandcrete block samples including control samples did not satisfy the minimum 28$^{th}$ day strength requirement of 3.5 MPa stipulated for load-bearing hollow sandcrete blocks. However, block samples containing 0 and 10% of WFS can satisfactorily be used for the construction of non-load bearing walls since they meet the required minimum strength of 1.5 MPa at 28$^{th}$ day. It was also observed that increasing the quantities of WFS from 0 – 30% caused a corresponding increase in the water absorption for all the block samples although the recorded values did not exceed the recommended maximum of 12% except for samples containing 30% WFS. Conclusively, WFS has a negative impact on both compressive strength and water absorption properties of sandcrete blocks and as such cannot serve as a good partial substitute for sharp sand.*

**Keywords:** Hollow sandcrete, Foundry sand, Sharp sand, Shelter, Eco-friendly

## Introduction

Rapid human growth and industrialization have made the management of humongous generated waste a challenge (Ravindran *et al.*, 2018; Salman *et al.*, 2021a). Some of these wastes which have been used for landfilling hitherto have now been considered for beneficial usages in concrete technology either as a partial substitute for cement or fine aggregate. Researchers in the field of concrete technology are now focussing on how to reuse these industrial and agricultural wastes as sources of raw materials in construction industries (Ganesan *et al.*, 2008). One of the major wastes that have been of interest to researchers is the Waste Foundry Sand (WFS). Demands for fabricated metallic materials has reached a level like never before due to rapid infrastructural development and urbanization, this has resulted in the generation of millions of ton of waste foundry sand in countries like China, the US, Australia, India, Taiwan, South Africa etc (Lin *et al.*, 2012). Foundry is an all-inclusive technique used in the production of non-ferrous (aluminium, bronze, copper, brass etc) and ferrous (steel, cast iron etc) metallic materials (Siddique and Singh, 2011). The processes include; metal melting, pouring of molten metal into moulds and solidification of molten metals to form desired shapes/features. After several usages of foundry sand, it becomes undesirable for use due to accruement of metal particles, resin and additives which will impact negatively on the moulds, and hence is termed as 'Waste Foundry Sand' (Singh and Siddique, 2012).

WFS is known for many nomenclatures such as spent foundry sand (SFS) and Used Foundry Sand (UFS) (Siddique, 2014; Siddique *et al.*, 2015).

The use of WFS as a partial substitute of fine aggregate was found to have positively influenced the mechanical and durability properties of concrete (Bhardwaj and Kumar, 2017; Bilal *et al.*, 2019; Coppio *et al.*, 2019; Gurumoorthy and Arunachalam, 2016; Khatib *et al*., 2013, 2010; Manoharan *et al*., 2018; Mavroulidou and Lawrence, 2019; Pathak and Siddique, 2012; Singh and Siddique, 2012). WFS was successfully used in the production of high-strength concretes, self-coMPacting concretes, high-performance concrete, ready-mixed concretes, geopolymer concretes and alkali-activated slag concretes, geopolymer bricks (Apithanyasai *et al*., 2020; Basar and Deveci Aksoy, 2012; Bhardwaj and Kumar, 2019; Guney *et al*., 2010; Pathak and Siddique, 2012; Smarzewski and Barnat-Hunek, 2016).

After food and water, shelter comes second as an important part of human lives and the role played by walling units can never be overemphasised (Afolayan *et al.*, 2017). Sandcrete blocks are the most widely used masonry and walling units in the construction industries today, especially in residential, commercial and industrial buildings. It accounts for about 90% of houses built in Nigeria (Mohammed and Anwar, 2017; Anosike and Oyebade, 2012). Sandcrete block is a composite material containing a mixture of fine aggregate, cement and potable water moulded into different sizes (NIS 978:2017; Akinpelu and Adekanmbi, 2017; Oyekan and Kamiyo, 2011; Rasheed and Akinleye, 2016). Sandcrete blocks could either be used as external and load-bearing wall units in the case of 225 mm thick (or 9”) blocks or for partitioning and non-load bearing wall units in the case of 150mm thick (or 6”) blocks (Mohammed and Anwar, 2017). Sandcrete blocks are also used for fencing, barriers, cladding etc (Abdullahi, 2005; Oyekan and Kamiyo, 2011). They are either manufactured as solid, hollow, or cellular (Abdulrahman, 2015). It is called a hollow sandcrete block when holes which appear from the top of the block run through to the bottom of the block while solid blocks refer to those blocks without holes (Rimintsiwa *et al.*, 2019). Factors that determine the choice of walling units include compressive strength, durability, water absorption, density, cost, availability of materials, etc (NIS 978:2017; Raheem *et al.*, 2012; Wasiu and Makoji, 2017). The quality and compressive strength of sandcrete blocks are determined by factors such as characteristics of constituent materials, time of mixing, production method adopted, curing durations, and size and form of sandcrete blocks (Abdullahi, 2005; Sholanke *et al.*, 2015; Usman and Gidado, 2013). Methods of coMPacting sandcrete blocks also have an impact on their compressive strength and water absorption properties (Rasheed and Akinleye, 2016).

Naik *et al*. (2003) assessed the influence of fly ash (FA) as a partial substitute for cement as well as coal combustion bottom ash (BA) or Used foundry sand (UFS) as a partial substitute for sand on mechanical and durability properties of bricks and sandcrete blocks. They concluded that bricks and blocks containing cement partially replaced with FA perform better in terms of strength and durability than bricks and blocks without FA while bricks and blocks containing sand partially replaced with BA have their strength and durability lowered. Omoregie (2013) blended varied percentages of steel chips at 1, 2, 3, 4, 5, 10 and 15% of cement with sand, so as to improve sand grading parameters and compressive strength of the cube samples and blocks. It was observed that the grading parameters and compressive strength of cube samples and blocks improved as more steel chips are added. A significantly higher compressive strength was recorded at 4% steel chips (Omoregie, 2013). In research carried out by Akinyele and Toriola (2018), 0, 5, 10, 15, 20 and 100% of shredded waste plastic was used as a partial substitute for fine aggregate. It was discovered that sandcrete blocks containing 5% shredded waste plastic have the highest compressive strength while the control samples have the best outcome as regards density and water absorption properties. Sawdust was also used in order of 10, 20, 30 and 40% of fine aggregate and sandcrete blocks containing various percentages of sawdust as a partial substitute of sand experienced an increase in water absorption while at 10%, maximum strength was attained. In another research by Guendouz *et al.* (2016), sandcrete blocks were produced using 10 – 40% of plastic powder as a partial replacement for fine aggregate. The outcome of this research shows that as the percent of plastic powder increases in the mix proportions, so thus the bulk density and air content decrease while sandcrete blocks containing 10 – 20% of plastic powder recorded an increase in their compressive and flexural strengths. Abdulrahman (2015) also utilized iron ore tailing (IOT) as a partial replacement for sand in order to improve the compressive strength. WFS as a partial replacement for sand had also been used for the production of masonry units such as bricks, wet-cast concrete bricks, ceramic bricks, masonry blocks, paving blocks and paving stones (Alonso-Santurde *et al*., 2012; Mastella *et al.*, 2014; Naik. *et al.*, 2004).

The main objectives of this research are to evaluate the compressive strength and water absorption properties of hollow sandcrete block produced from the partial replacement of sharp sand with locally sourced WFS and its compliance to NIS 978:2017. The use of waste foundry sand as construction materials will serve as safe disposal of industrial wastes, protection of the environment from hazardous wastes, conservation of natural resources and utilization of WFS in hollow sandcrete blocks.

There might have been numerous research articles from the US, Canada, Europe, China, Turkey, Brazil etc on the utilization of WFS as a partial replacement of sand in various types of engineering/construction work, there existed few or none from Africa and nay, from Nigeria.

## Materials and Methods

### Materials

Materials used for this research are Portland limestone cement (PLC), Sharp Sand, Waste Foundry Sand (WFS), and pottable water.

Ordinary Portland Cement (CEM I): A locally produced Ordinary Portland cement with strength grade 43MPa was used for this research. It was purchased from a retail shop in Tanke area of Ilorin. To determine the chemical composition of the cement, a sample from the cement was taken to the department of chemical and petroleum engineering at Afe Babalola University, Ado Ekiti, Ekiti State where X-ray fluorescence spectrometer Shimadzu EDXRF-720 was used to analyze the cement.

Fine Aggregate (FA): Sharp sand was used as FA. The sharp sand was a clean naturally occurring sharp sand obtained from transported erosion soil deposited along a drainage path in Tanke Area, Ilorin. Kwara State.

Waste Foundry Sand (WFS): Used and discarded waste foundry sand was obtained from a local foundry workshop by the name *Hasbunallahi foundry* located off Asa Dam road, Ilorin. Kwara State. Lumps of WFS were manually broken into smaller pieces. Chemical/Oxides composition of the WFS was carried out with Shimadzu EDXRF-702HS spectrometer at the department of petroleum and chemical engineering, Afe Babalola University, Ado-Ekiti, Ekiti State. Chemical/oxides composition of WFS and CEM I are as presented in Table 4.

Potable Water: Pottable water obtained from the borehole at the concrete laboratory, department of civil engineering, University of Ilorin was used for this study.

### Methods

Procedures suggested by NIS 978:2017 (2017) were followed in the production of hollow sandcrete blocks. Mix proportion of 1:6 (ratio of cement to sharp sand) was adopted for batching while batching by weight was employed. Water-cement ratio of 0.5 was also adopted for all mix proportions. The sharp sand was partially replaced with WFS at 0,10, 20 and 30% as shown in Table 1.

**Table 1**: Mix Codes

| Mix Codes | % Replacement |
|---|---|
| CTL | 0 |
| SCB10 | 10 |
| SCB20 | 20 |
| SCB30 | 30 |

The sandcrete block of dimensions 450mm x 250mm x 250mm was moulded and manually vibrated. The sandcrete blocks were kept in an open space for 24 hours before demoulding. The blocks were water cured by action of water sprinkling in the morning and afternoon for 28 days.
CTL stands for control sandcrete blocks sample while SCB 10, SCB 20 and SCB 30 stands for sandcrete blocks containing 10, 20 and 30% partial substitute of F.A with waste foundry sand. Major tests suggested by NIS 978:2017 are compressive strength and water absorption;

**Compressive Strength test**

Compressive strength measures the resistance of sandcrete block to crushing load/force and it is calculated as crushing force/load per unit area. A manual compression testing machine with a maximum capacity of 1500kN available at the concrete laboratory of the department of civil and environmental engineering, university of Ilorin was used for this purpose. The compressive strength of the sandcrete blocks was determined on the 7$^{th}$ and 28$^{th}$-day as shown in equation 1.

$$\text{Compressive Strength} = \frac{Crushing\ load}{Net\ Area}\ (N/mm^2) \quad (1)$$

**Water absorption test**

Water absorption measures the amounts of transported liquids in a porous solid induced by surface tension through capillaries or due to the presence of voids or pores. The initial weight of dried sandcrete blocks was determined on the 28$^{th}$-days. Time taken for sandcrete blocks to be completely immersed in water was observed and noted. At about 24 hours after immersion, the weight of submerged sandcrete blocks was measured. Based on the measurement, $W_1$ and $W_2$ were determined accordingly and rate of water absorption was determined as shown in equation 2.

$$\text{Rate of Water absorption (\%)} = \frac{W2-W1}{W1} X\ 100 \quad (2)$$

Where $W_1$ = Weight of Dry Block and $W_2$ = Weight of the wet block after 24 hours in water.

## Results and Discussion

### Properties of Sharp sand, WFS and Cement

The physical properties of sharp sand and waste foundry sand used for this research are shown in Table 2. Visual inspection shows that Waste foundry sand is light black/dark brown in colour as collected from the foundry.

**Table 2**: Physical properties of Sharp sand and WFS

| Sand type | Specific gravity | Water Absorption | Fineness Modulus |
|---|---|---|---|
| Sharp sand | 2.52 | 2.5 | 3.13 |
| WFS | 2.21 | 3 | 3.15 |

Some physical properties of cement such as the strength on the 28$^{th}$ day, specific gravity, consistency and setting times are shown in Table 3.

**Table 3**: Physical and mechanical properties of CEM I*

| | |
|---|---|
| Strength grade | 43MPa |
| Fineness | 7.50% |
| Specific gravity | 2.9 |
| Initial setting time | 30mins |
| Final setting time | 600mins |
| Consistency | 30% |

* Salman *et al.* (2022)

Table 4 presented is the results of X-ray fluorescence which shows the oxides/chemical composition of cement and waste foundry sand. Waste foundry sand, just like ordinary sand consists mainly of silica oxide which is in form of quartz crystalline. Waste foundry sand are been classified as crystal materials (Alonso-Santurde *et al.*, 2012; Martins *et al.*, 2019; Sua-Iam & Makul, 2018).

**Table 4**: Chemical/Oxides compositions

| Parameter | $SiO_2$ | CaO | $Fe_2O_3$ | $Al_2O_3$ | MgO | $Na_2O$ | $TiO_2$ | MnO | LOI |
|---|---|---|---|---|---|---|---|---|---|
| WFS | 76.55 | 2.85 | 2.64 | 9.01 | 1.99 | 0.92 | <0.01 | 0.04 | 2.38 |
| *CEM I | 20.62 | 61.79 | 3.07 | 5.35 | 1.93 | 0.2 | 0.12 | 0.06 | 3.47 |

*Salman *et al.* (2021b)

## Compressive Strength

Figure 1 shows the compressive strength results of the sandcrete block for different curing ages. The CTL, SCB10, SCB20 and SCB30 are sandcrete blocks made with 0, 10, 20 and 30% of WFS. The compressive strength of sandcrete blocks increases with curing ages but reduces with increase in the amount of WFS being used as a partial replacement of sharp sand across all curing ages i.e the CTL has the highest compressive strength coMPares to others and the compressive strength reduces from CTL down to SCB30 across all curing ages. It is obvious from the result of this research that the replacement of sharp sand with WFS has led to a reduction in the compressive strength of sandcrete block and this may be due to accumulations of additives, resins and waste metals. Some of these wastes are known to have negative effects on hydration, and iMPaired bonding as such will lead to a reduction in compressive strength.

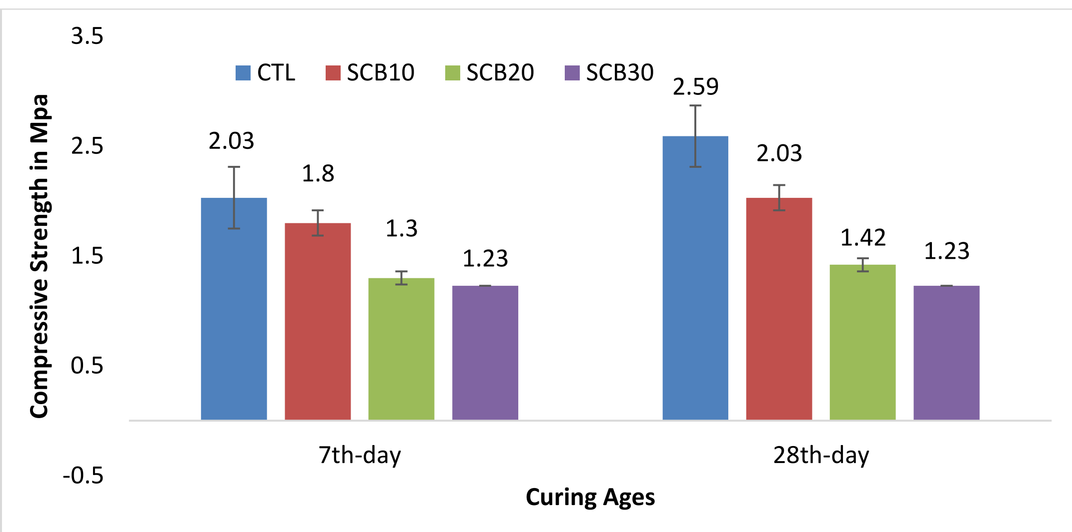


**Figure 1**: Compressive Strength of sandcrete block

Also, an increase in volume and amount of WFS present in the mix will weaken the interfacial zone between cement paste and sharp sand or paste as the case may be. The outcome of this research agrees with other works carried out by Coppio *et al.*, (2019), Khatib *et al.* (2010), Basar and Deveci Aksoy (2012) and Khatib *et al.* (2013) wherein WFS was used as a partial substitute for sand in concrete production and the outcomes of their research works showed that an increase in the WFS as a substitute for sharp sand caused decrease in compressive strength of the concrete. NIS 978:2017 specifies a minimum of 3.5MPa of compressive strength for a 9" hollow load-bearing sandcrete block and 1.5MPa for a 6" hollow non-load bearing sandcrete block on the $28^{th}$ day. As seen in Figure 1, none of these sandcrete block samples meets the minimum requirement, not even the control but both CTL and SCB10 can be utilized as non-load bearing sandcrete blocks.

## Water absorption

Figure 2 shows the water absorption properties of sandcrete blocks on the $28^{th}$ day for different sandcrete block samples; 0 – 30% of WFS. As can be seen in Figure 2, CTL, SCB10, SCB20 and SCB30 had water absorption of 6, 7.3, 7.9 and 12.3% respectively. Water absorption increases as the amount of WFS incorporated into sandcrete block increase from 0 to 30% of WFS. Higher water absorption indicates lower resistance to movement of water and lower water absorption signifies higher resistance to movement of water within the voids of sandcrete blocks (Naik. *et al.*, 2003). Compressive strength is inversely proportional to water absorption. Higher compressive indicates a strong interfacial transition zone and vice-versa. Higher water absorption indicated a weakened interfacial transition zone due to the presence of high connectivity of pores. A higher amount of water absorption showed presence of greater interconnectivity of voids and pores. It is a known fact that many properties of concrete/mortar are correlated to compressive strength.

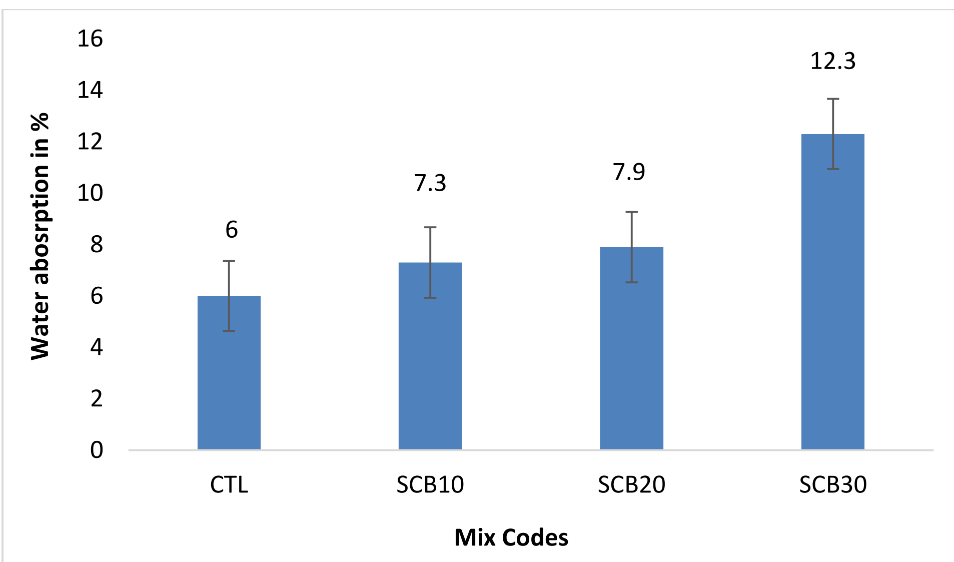


**Figure 2**: Water Absorption properties of Sandcrete blocks

NIS 978:2017 (2017) recommended that the water absorption should not exceed a maximum of 12% for all Sandcrete block types. A good look at Figure 2 shows that all Sandcrete block samples meet this requirement except SCB30 with a water absorption slightly above the recommended value. Results from the water absorption test show that an increase in the amount of WFS weakens existed interfacial zone which leads to a reduction in compressive strength and vice-versa. Thus, the addition of WFS results in increased water absorption and decrease in compressive strength of sandcrete block produced.

## Conclusion

In the light of the above results from compressive strength and water absorption properties of sandcrete block, the following are the major conclusion drawn out of this research work;

- Addition of WFS as a substitute for sharp sand reduces the compressive strength of hollow Sandcrete blocks. Control hollow sandcrete block has the highest compressive strength followed by hollow Sandcrete blocks with 10% of WFS, in that order and hollow sandcrete blocks containing 30% of WFS have the lowest compressive strength.
- Application of WFS as a partial substitute for sharp sand in the production of hollow sandcrete blocks lead to an increase in water absorption properties which is a sign of strength loss. Water absorption increases from hollow sandcrete blocks containing 0% of WFS to hollow sandcrete blocks containing 30% of WFS.
- Though constitutes nuisance, WFS cannot be used as a partial substitute for sharp sand due to its negative impacts on compressive strength and water absorption properties of hollow sandcrete blocks.

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