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EXPERIMENTAL STUDY AND TEST ON LIGHT WEIGHT FOAMED CONCRETE SOLID BLOCK

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ABSTRACT

Foamed concrete, is classified as a light weight concrete, it is produced in this study by the mixing of Portland cement, sand, water and preformed stable foam. The foam is produced with the use of a foam generator, using protein foaming agent. Hardened foam concrete contains a lot of pore, which reduces the density and makes it lighter than conventional concrete solid block. This paper investigates the dry density, water absorption and compressive strength test of Foamed Concrete Solid Block (FCSB) by various cement-sand ratio of 1:2, 1:4, and 1:6, measured at ages of 7, 14 and 28 days, the consistency and stability of fresh foamed concrete are also examined. The experimental results show that the optimum compressive strength was achieved with cement-sand proportion of 1:2 at the age of 28 days with a value of 3.42 N/mm^2. As for the cement-sand ration of 1:6, at the age of 7 days, the compressive strength was 2.37 N/mm, while the strength is 3.31 N/mm^2 at 28 days age, Both have satisfied the minimum compressive strength of 1.8 N/mm2 at age 7 days, and 2.5 N/mm^2 at the age of 28 days of commonly used conventional hollow sandcrete block for building wall unit as allowed by Nigerian Industrial Standard (N.I.S). The result also shows an appreciable decrease in density of FCSB with 1185 kg/mm^3, as compared to dense concrete solid block with average of 1,950 kg/mm^3, which will significantly reduce the overall dead load of the building structure. The consistency and stability fresh foam concrete in this study was affected by water-cement ratio, thus caused the internal segregation of hardened foam concrete, FCSB also showed much improved water absorption capacity compared to Normal concrete solid block.

Keywords: *Compressive Strength, Consistency, Dry Density, Foamed Concrete, Solid block, Water Absorption.*

INTRODUCTION

Cement concrete blocks are versatile masonry materials which can be used in a wide variety of applications. The concrete blocks are generally made using concrete which is a mixture of Portland cement, sand and water in different specified ratios. Blocks and bricks are widely used in Nigeria as walling units and over 90% of houses in Nigeria are being constructed of blocks, this makes blocks a very important unit in building construction (John and ban, 2003). Blocks have been manufactured to meet the needs of the building industry; this was done without putting into consideration the strength and durability of the blocks (Dhir and Jones, 2009). In building construction, different types of bricks and blocks are used in Nigeria and also in other countries. Structural performances are the most important factors, when using these masonry blocks in constructing walls. However, due to the high cost of materials, the blocks available in the market have fallen below acceptable structural performances by the regulatory body; Nigerian Industrial Standard (N.I.S), and by the minimum standard recommended according to BS6073- Part 1and BS6073- Part 2 for precast concrete masonry unit. Therefore, it is very important to use innovative materials to reduce cost at least in masonry blocks. Also light-weight materials are becoming much popular nowadays, because of its easy handling and low dead loads (Lim *et al*, 2013). Light-weight masonry blocks with sufficient compressive strength will be a major benefit in building construction. Sand cement blocks are extensively used in Nigeria, because the cement block has benefit in fast assembling the blocks into wall. These blocks are mainly constructed with the cement and fine aggregate in a standard composition. Concrete blocks are used extensively for both load bearing and non-load bearing walls, externally and internally. This brings about the need for a light weight concrete block that reduces the accumulated loads on structural elements in building and still fulfills an acceptable compressive strength.

Concrete block is a commonly used building construction material for many centuries. It is a compound material that is essentially obtained by mixing the binder (cement), aggregate and water in a certain designed proportion. Conventional normal weight concrete block is dense, hard, strong and durable. Dense aggregate blocks have a density in the range of 1800 to 2100 kg/m^3, while lightweight aggregate blocks have a density in the range of 650 to 1500 kg/m^3. Aerated blocks have a density in the range 400 to 900 kg/m^3 (Hamza and Yusuf, 2009).

Concrete blocks are generally defined as a mixture of sand, cement and water formed in a block making mould. The blocks are supposed to have adequate compaction pressure so that they can be confidently used in building of walls and other structures at various levels during construction (Nambiar and Ramamurthy, 2008). Concrete blocks must satisfy building specification byelaws with respect to the compressive strength. The thickness of the blocks ranges from 50 mm to 255 mm. British standard BS2028, BS1364 defines blocks as a walling unit with dimensions greater than brick specified in BS3921 (Hamza and Yusuf, 2009). The British standard gives more of a performance specification for block rather than detailed description of mode of manufacture (Curtin, *et al.*, 1992). The most popular size recommended in accordance with the British Standard BS2028, BS1364 and Nigeria Industrial Standard (N1S) is 450 mm x 225 mm and are available in thickness of 75 mm, 100 mm, 150 mm, 200 mm and 225 mm. BS2028 and BS1364 also allows the size of 150 mm x 450 mm, 200 mm x 450 mm, 300 mm x 450 mm, 200 mm x 600 mm and 225 mm x 600 mm blocks (John and Ban, 2003). The range of strength for concrete blocks specified by N.I.S 74:1976 is between 1.8 N/mm^2 to 2.5 N/mm^2 as the minimum strength.

The blocks can cope in a wide range of thermal and moisture conditions, and the problem of algae growth on the face of block work during construction is unlikely to affect the strength of the block (Edward, 1995). The compressive strength of concrete block increases by adding optimum quantity of water, which will also have an impact on the mix and workability. This means that there is a limit to an increase of water in the mixture during which further increase in water percentage will result to decrease in the strength (George, 2000). Also considering the three main forms of concrete blocks (i.e solid, cellular and hollow) the hollow sandcrete block is more economical in terms of weight, density and compressive strength and is commonly used in construction works. Curtin, *et al*. (1992) showed that the compressive strength in concrete block increases sharply with the increase in the ratio of cement content and in the size of the fine aggregate.

Light weight foamed concrete has been used around the world since 1920 with the compressive strength not critical but limited application (Nayak and Jain, 2012). It is referred to a premixed cement paste or mortar containing a minimum volume of 20% air voids entrapped by using appropriate foaming agent (Awang *et al.*, 2012). Light weight foamed concrete has its advantages in high workability, low self-weight, minimal consumption of aggregate, self-compaction, controlled strength and excellent thermal insulation properties (Ramamurthy *et al.,* 2009). The density of lightweight foamed concrete is governed by the quantity of pre-formed foam. With proper control in amount of stable foam and methods of fabrication, a wide range of densities of light weight foamed concrete could be formed and hence providing load bearing and non-load bearing masonry wall units in building construction. Furthermore, light weight foamed concrete also facilitates the benefits of self-levelling, where compaction or vibration is not required during the concrete casting work.

These foam concrete materials basically consist of Portland cement, fine aggregate, water and stable foam. By adding materials such as stable foam, small cells or air bubbles form inside the concrete and makes it lighter (Lim *et al*, 2013). The entrapped air bubbles increase the volume and thereby reduce the densities of the concrete (Dhir and Jones, 2009). The density of foam concrete is determined by the amount of foam and water that is added to the mixture.

MATERIAL AND METHODS

Materials

The following materials were used in producing the lightweight foam concrete solid block used in this research work:

Cement

Ordinary Portland cement (OPC) – Dangote Portland Cement brands which conformed to NIS 444 – 1: 2003 as evidenced by the certification mark ISO 9001: 2008 on the product bags were used. The cement is class 32.5, which is applicable where a high initial strength is not required and with construction of standard thickness (<50 mm).

Water

Portable water which is free from suspended particles, salts and oil contamination were used throughout this study as specified by (Nayak and Jain, 2012).

Foam

Stable foam was produced by using liquid pre-foamed method (Dhir and Jones, 2009). The foaming agent was diluted with water in a ratio by weight of 1:30, and thoroughly mix with machine operated stirrer to achieve a stable foam. The amount of added foam in the mortar mix depended on the designated density of foamed concrete.

Sand

Clean sand was used as fine aggregate, free from waste stone and impurities. The sand was taken directly from the bulk condition, which was exposed to natural weathering. Figure 1 shows the particle size distribution grading of sand used in this study.

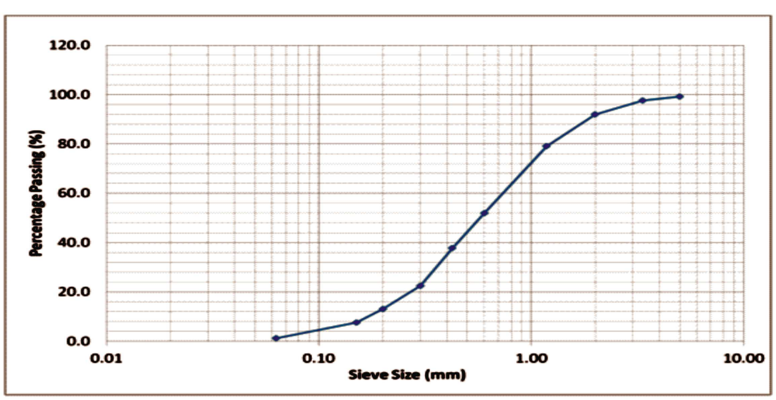

Figure 1: Particle size distribution grading of sand used

Methods

Mixing

In this study, the mixing was done by electric operated concrete mixer, for uniform and thorough mixing. The cement and sand were mixed in a dry form and water was added in moderate proportions to allow the cement to hydrate and excess of water was avoided that would have caused shrinkage and distortion of block on drying, prepared stable foam was added, to achieve a workable concrete.

Curing

Curing was employed to maintain satisfactory moisture content and allow proper hydration and hardening of the foamed concrete solid blocks. The blocks were cured for the whole period of the 28 days during which they were tested at interval of 7days, 14 days and 28 days for their compressive strengths.

Test specimens

The test specimens were investigated, three different cement-sand ratio for light weight foamed concrete solid block, i.e. 1:2, 1:4 and 1:6 (designated as FC12, FC14 and FC16 respectively) were prepared. Lightweight foamed concrete base mix proportion detail was obtained initially with the preparation of mortar as base mix, followed by foam preparation and finally mixing the foam with the mortar base mix. Prior to the introduction of foam, the density of mortar was determined to ensure accurate amount of foam that need to be added. Flow table test was performed to check the workability of the base mix mortar. Base mix with low water content will be too dry, causing the burst out of the bubble in foamed concrete and hence affect the density and strength of the lightweight foamed concrete (Gambhir, 2013).

The required amount of foam was then measured by weight and added into the base mix mortar. Afterwards the mix were blended uniformly, and the foamed concrete was measured for its bulk density by pouring the foamed concrete into a known volume container and weighed. When the lightweight foamed concrete has reached to the designated density, it was poured into mould with cube size of 125 × 200 × 400 mm for compressive test specimens. The casting work for each set of different cement-sand ratio was carried out in the same batch to ensure the homogeneity for both compressive strength test and water absorption capacity. The fresh lightweight foamed concrete was then left to set for 24 hours before de-moulding, and all specimens proceed to water curing process until the respective testing ages of 7 days, 14 days and 28 days.

Testing method

All the experiment tests were conducted in accordance with the methods describe in the methodology, and there are flow table test for stability and consistency of fresh foam concrete. Water absorption test and Compressive Strength Test were carried out for hardened foamed concrete solid block samples.

Fresh concrete properties

According to (Gambhir, 2013), The flow table test was conducted to determine the consistency of the freshly made foamed concrete in accordance with BS EN 12350-8:2010 (Bristish Standard Institution, 2010). After mixing of the mortar with stable foam, the produced lightweight foamed concrete was filled into the inverted slump flow cone without compaction and vibration. The cone is raised and allowed the foamed concrete to spread freely. The spread diameter values were measured with a measuring tape in orthogonal direction. An average value was taken to control the fluidity consistency of the fresh mixed lightweight foamed concrete. Foamed concrete was measured for its bulk density by pouring the foamed concrete into a known volume container and weighed to determine the density of fresh foamed concrete. The design of variety mix proportion and method of curing is done in this project to obtain the Compressive Strength test, whereas this will show the development of high strength of foam concrete solid block. According to (Gambhir, 2013), flow table test is performed to check the consistency of freshly made concrete, meanwhile the Compressive Strength Test is measured to determine the strength of hardened foam concrete solid block. The strength of foam concrete will be affected by the ages of curing process, cement content, water cement ratio and the properties of the sand (Khaw, 2010). High compressive strength is generally achieved by using high cement content with a low water cement ratio and sand.

Compressive strength

The compressive strength test was performed in accordance to BS EN 12390-3 (Bristish Standard Institution, 2009) by using a universal compression test machine with constant loading rate. 125 × 200 × 400 mm dimension were tested. The compressive strength was obtained based on the average of three crush FCSB specimens. The Compressive strength tests were carried out at 7, 14, and 28 days of moulding the foamed concrete solid blocks (FCSB) using ELE2000 kN compressive testing machine. The tests were carried out at the Concrete Laboratory of the Moshood Abiola Polytechnic, Abeokuta, Nigeria.

$$Compressive\ Strength\ (N/mm^2) = \frac{Load}{Area} \qquad (1)$$

$* (The\ average\ for\ 3\ units)$

Water absorption test

The test specimens were completely immersed in water at room temperature for 24 hours. The soak aggregates were taken out from the water and wiped it. The sample was allowed for surface drying and the weight was measured. The same sample was placed inside an oven under the 100°C of temperature for not less than 24 hours and until two successive weighing at intervals of two hours show an increments of loss not greater than 0.2 percent of the last previously determined mass of the specimen.

Fire resistance

Lightweight foamed concrete solid blockis a type which is resistant to heat and can reduce risk fire. It is building component that produced by process aeration and autoclave to produce high quality products, lightweight, strength, waterproof, fireproof, and soundproof. According to Aventi (2016), the fire resistance is put at 6 hours minimum and can resist heat up to 1200°C in accordance with BS 1364.

RESULTS AND DISCUSSION

Consistency and Stability

The consistency and stability check are needed to make sure the mixed was considered stable, where the density ratio was kept nearly to unity (Ramamurthy *et al.*, 2009). Table 1 shows the result of consistency and stability based on 28-day concrete cube.

$$\text{Water Absorption}(\%) = \frac{A - B}{B} \times 100 \qquad (2)$$

Where:

A = Wet mass of unit in kg

B = Dry mass of unit in kg

(Results as the average for the 3 units)

$$Consistency = \frac{\text{Measured Fresh Concrete Density}}{\text{Designated Densiry}\,(1200\,\text{kg/m}^3)} \qquad (3)$$

$$Stability = \frac{\text{Measured Fresh Concrete Density}}{\text{Measured H}\textit{ardened}\text{ Concrete Density}} \qquad (4)$$

$$\text{Performance Index} = \frac{\text{28-days Compressive Strength}}{\text{Unit Density }(1000\,\text{kg/m}^3)} \qquad (5)$$

Table 1: Mix proportion and summary work details at an average fresh concrete density unit at 1200 kg/m^3

FCSB Specimen	Consistency	Stability	Flow table spread (mm)	Performance Index
FC12	0.98	0.84	430	5.14
FC14	0.93	0.97	525	4.76
FC16	0.96	0.89	485	4.44

For consistency mix, the produced fresh density of foamed concrete are supposed to be ± 100 kg/m3 difference corresponding to designated density, the consistency is in the range of 0.97 to 1.03 (Jones and McCarthy, 2005). From the result shown in Table 1, the consistency was at the low margin, especially for sample FC14 as the additional of foam was too much during mix into the mortar. However, sample FC14 exhibit the stability nearest to unity among the samples. The low stability of sample FC12 and FC16 could be due to the mixture is a bit dry as compared to FC14, as the inverted slump cone flow table spread value is much lower than FC14. FC12 had the lowest value for inverted slump cone flow table spread value.

Dry mixture caused burst out of the bubble inside the light weight foamed concrete during the hardened process. It also caused the highest amount of foam added into the mix as shown in Table 1, in order to control the consistency in the range of 0.97 to 1.03. The burst out made the concrete denser after hardening and hence influence its stability. Besides that, the sand taken from bulk without sieve may leads to large variation size of sand. Large size variation of fine aggregate, could cause burst out of the bubble of stable foam. Furthermore, non-uniform size of aggregate would entrap large amount of foam bubble, which later create larger void in the lightweight foamed concrete.

Dry Density

The average dry density at 28 day of FCSB with varying mix ratio is shown in Table 2. The results shows appreciable decrease in weight as compared with conventional concrete solid block which gives 2000 kg/mm3. FC12 has heaviest density of 1292 kg/mm3, while FC16 has lowest density with 1185 kg/mm^3.

Table 2: Average dry density of test specimen

Specimen	Mass of Block (kg)	Volume of Block (m^3)	Dry Density (kg/mm^3)	Average Dry Density (kg/mm^3)
	13.41	0.01	1341	
FC12	12.53	0.01	1253	1292
	12.82	0.01	1282	
	12.24	0.01	1224	
FC14	13.21	0.01	1321	1274
	12.77	0.01	1277	
	11.83	0.01	1183	
FC16	11.78	0.01	1178	1185
	11.94	0.01	1194	

*125 mm x 200 mm x 400 mm =0.01 m^3

Compressive Strength

The average compressive strength of 7, 14 and 28 day of FCSB with varying cement-sand mix ratio is shown in Table 3. Figure 2 shows the variation of average compressive strength of FCSB with varying cement-sand mix proportion. The optimum compressive strength was obtained at cement sand ratio of 1:2 and it complies with the minimum standard value of 2.5 N/mm^2 according. These values falls within the specified minimum compressive strength of 2.0 N/mm^2 and 3.45 N/mm^2 for sandcrete blocks prescribed by NIS 87: 2000 for load bearing and non-load bearing walls for the 28 days result.

Although compressive strength of FCSB of mix 1:6 have lower value when considering the compressive strength results of control samples, they have fulfilled the minimum requirement value of 2. N/mm^2, Addition of stable foam in FCSB lead to the fluctuation and inconsistency of the 7-day compressive strength as shown in Figure 1. Less fluctuation after 14 days, while 28-day compressive strength of lightweight foamed concrete is more consistent, and is increasing with the increment of cement content. Higher cement content in foamed concrete, resulted production of more C-S-H (Calcium-Silicate-Hydrate) gel that can imposed to additional load bearing.

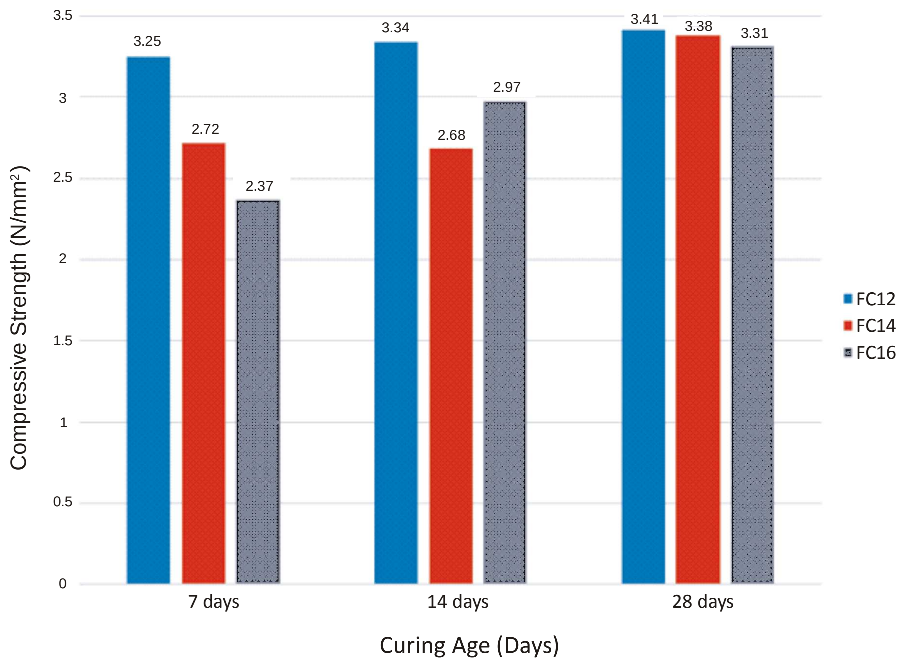

Figure 2: Result of compressive strength test with respective cement=sand mix proportion

Table 3: Average compressive strength of test specimen

Time (Days)	Foamed Concrete Solid Block Average Compressive Strength (N/mm^2)			Conventional Concrete Block Compressive Strength (N/mm^2)		
	FC12	FC14	FC16	C12	C14	C16
7	3.05	2.72	2.67			
14	3.11	2.78	2.82	3.42	3.27	3.19
28	3.39	3.04	2.91			

Water Absorption

The average water absorption of FCSB manufactured with varying mix proportion is shown in Table 4. It can be seen from Table 4 that the water absorption decreases with increase in cement content. However, all varying mix proportion of FCSB which were considered for the study has acceptable value of 12% for masonry blocks according to BS 5628: Part 1: 2005. The variation of water absorption with varying cement content is shown in Figure 3. It can be seen that the water absorption is also maximum at FC12. But there wasn't significant difference with other varying cement content. With the increasing of cement content, the water absorption decreases.

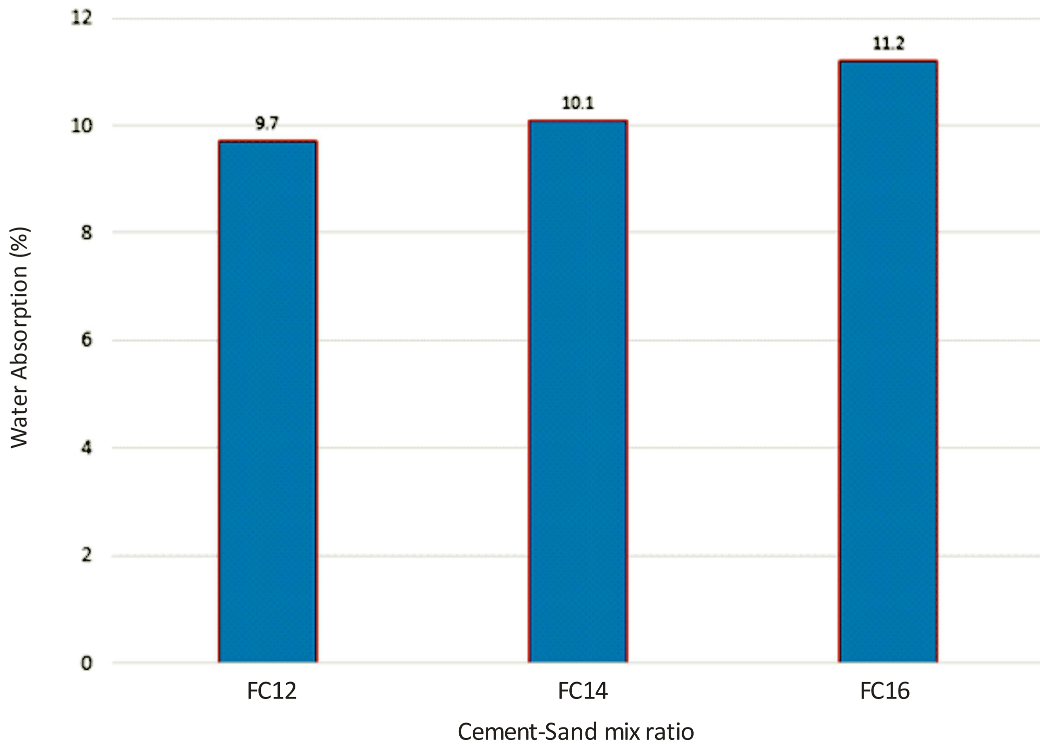

Figure 3: Average percentage of water absorption of FCSB

Table 4: Water absorption at varying mix proportion of FCSB

Mix proportion	Average water absorption (%)
FC12	9.7
FC14	10.1
FC16	11.2

CONCLUSIONS

The compressive strength of light weight foamed concrete with various cement-sand. Several conclusions can be drawn from the experimental study:

- Lightweight foamed concrete with cement-sand ratio of 1:2, 1:4 and 1:6 are investigated. The 28-day compressive strength increases in-line with the cement-sand ratio. Highest compressive strength occurred at samples with cement-sand ratio of 1:2 and thus it is taken as the optimum design within the scope of study.
- Varying amount of materials used influence the performance of foamed concrete solid block. The flow table test result of fresh foam concrete in this study was affected by water cement ratio and amount of cement, thus caused the internal segregation of hardened foam concrete.
- Lightweight foamed concrete solid block (FCSB) with density of less than 1200 kg/m^3 was achieved with FC16, and the compressive strength fall between 2.5 N/mm^2 and 3.45 N/mm^2 as recommended by Nigerian Industrial Standard (NIS).
- Lightweight foamed concrete solid block (FCSB) with density of less than 1200 kg/m^3 was achieved and minimum water absorption capacity of 12% as recommended by Nigerian Industrial Standard (NIS).
- As the curing age increased, there were increases in the compressive strength of the FCSB.

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