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Experimental Study on Light Weight Concrete Bricks by Partial Replacement of Fine Aggregate with Styrofoam

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ABSTRACT: This study investigated into the effect of Styrofoam used as partial replacement for fine aggregate on properties of concrete bricks such as absorption, density and compressive strength. Furthermore, the optimum Styrofoam content in concrete bricks which meet minimum values specified by local codes was recommended afterwards. Styrofoam content at 0.2%, 0.4%, 0.6%, 0.8%, 1% and 2% were used in this research. Other constituents of the concrete bricks include: water, cement, sand and Bida Natural Gravel (BNG) in the ratio: 0.5:1:4:2 respectively. Absorption of concrete bricks were taking after 24 hours, 7 days and 28 days. Absorption increased with increasing Styrofoam content but decreased with increasing curing days. For density, there was a significant decrease in weight as the Styrofoam increased in the concrete bricks. Also, compressive strength was inversely proportional to Styrofoam content. At 28 days, absorption of concrete bricks was 2.5%, 5.6% and 8.5% for 0%, 0.2% and 0.4% Styrofoam content respectively. For compressive strength at 7 days, the values were 6.7, 2.9 and 2.0 N/mm^2 at 0%, 0.2% and 0.4% Styrofoam content respectively. Furthermore, at 28 days, compressive strength improved to 9.9, 3.8 and 2.1 N/mm^2 at 0%, 0.2% and 0.4% Styrofoam content respectively. In conclusion, this research recommended Styrofoam content ranging from 0.2% to 0.4% for use in concrete bricks production as the values for absorption and compressive strength were within minimum requirement as specified by local codes.

KEYWORDS: Lightweight concrete bricks; Polystyrene; Styrofoam; Water absorption; Compressive strength

I. INTRODUCTION

Brick is one of the oldest construction materials that were first found in Southern Turkey and around Jericho (a Palestinian city in the West Bank) back to 7000 BC. Several types of bricks have been evolved as human civilization grew with time by the innovative use of recyclable materials such as: waste plastic, polystyrene, waste glass, saw dust ash, etc. in concrete production. Different types of bricks are now available, such as burnt clay bricks, sand lime bricks, Concrete bricks and fly ash clay bricks (Rodriguez, 2019). Concrete brick is a type of brick- shaped building element made from Portland cement, water and aggregate to be used as wall partition in buildings. Lightweight concrete brick as a nonstructural component of a building becomes popular since it offers very low density compared to normal concrete brick or clay brick. Therefore, it has potential to reduce the dead load of structures in building (Mochamad *et al.,* 2019).

The weight of typical concrete bricks is one of their drawbacks. It is high enough to cause a significant increase in the dead load on a structure. The use of polystyrene is one of many methods that can be used to reduce the weight concrete bricks. These techniques will result in concrete that has a lighter specific gravity than a typical concrete brick, thus the name "light-weight concrete." Utilising lightweight components, such as polystyrene, is one way to create light-weight concrete. The weight of the unit becomes very small and only ranges from 1300 to 1600 kg/m^3 when using polystyrene or expanded polystyrene, which is granular in shape (Ginting, 2007).

Mochamad et al. (2019) reported densities between 720 kg/m^3 to 1286 kg/m^3 for Self-Compacting Concrete (SCC) lightweight concrete containing high content Styrofoam between 60 – 80%. Polystyrene is synthetic aromatic hydrocarbon polymer made from the monomer known as styrene (John and Duane, 2003). One of the most commonly used plastics is polystyrene, which several million tonnes is produced annually. Although polystyrene can be transparent by nature, it can also be coloured with colourants. Protective packaging, such as packing peanuts and jewel cases for optical discs like CDs and occasionally DVDs, containers, lids, bottles, trays, tumblers, disposable cutlery, model-making, and phonograph records as an alternative material are just a few uses for this material (Maul *et al.,* 2007).

Many researchers have proposed several materials for use as replacement for aggregates in the production of lightweight bricks. Syed *et al.* (2020) conducted an experimental study on lightweight bricks prepared by partially replacing clay with saw dust at 2.5%, 5% and 7.5% and cow dung at 2%. They suggested the manufacture of lightweight bricks prepared in proportion of 7.5% of saw dust and 2% of cow dung slurry. The protection of the environment and waste recycling are very important in today's world. Due to polystyrene's inability to degrade, its amount in waste is growing annually, which ultimately damages the ecosystem and causes environmental pollution. As a result, this research will support ongoing efforts by scientists around the globe to create green concrete bricks that will help create a safer and greener environment. Styrofoam content ranging from 0% - 2% was used as partial substitute for fine aggregate in the production of lightweight bricks for use as partition walls in buildings.

II. MATERIALS AND METHOD

A. Materials

Materials used for this research work are; sand, cement, Bida gravel, water and styrofaom. Ordinary Portland Cement grade 42.5N (Normal hardening and 28-day compressive strength of 42.5 N/mm^2) was used for this research. The cement used conforms with BS EN 197-1 (2000). Fine aggregate was sourced from Minna area of Niger state. Bida gravel was gotten from Bida area in Niger state. The gravel was washed in 5 mm British Standard sieve to remove clay impurities which may affect concrete production and dried. Portable water was gotten from the civil engineering laboratory. The water used was colourless, odourless and free from visible impurities in accordance with BS EN 1008:2002. Styrofoam was sourced from an electronic shop in Kure market in Minna.

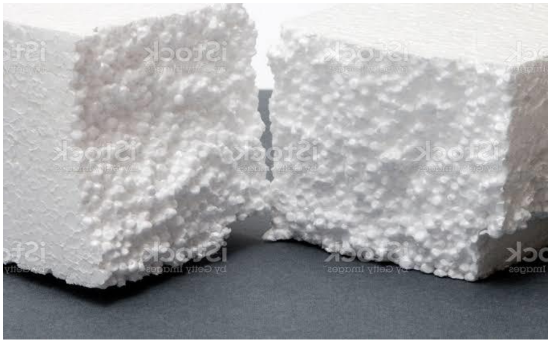

Figure I: Sample of Styrofoam

Figure II: Sample of Bida Natural Gravel (BNG)

B. Tests on Aggregates

Aggregates were characterized by determining their physical and mechanical properties through series of tests. The tests for physical parameters include those for bulk density, sieve analysis, specific gravity, absorption, and aggregate crushing value. Dry density test and compressive strength test were carried on hardened concrete, respectively to determine the mechanical properties of concrete.

Specific gravity test: This test was carried out according to BS EN 12620 (2008). The specific gravity is the ratio of the density of a material to the density of water. A dry pycnometer was initially weighed (M1). An air-dried sample was added to the pycnometer, and the combined weight was recorded as (M2). Water was introduced to the sample, and the resulting weight was noted as (M3). After emptying, rinsing, and drying the pycnometer, water was added to the marked level, and the weight was recorded as (M4). Three trials were conducted simultaneously, and the average specific gravity was calculated from the recorded values.

***Sieve analysis test*:** This test was carried out to determine the particle gradation of the aggregates. The tests were done in accordance to BS 822: part 1: (1973) and BS 812 Part 103:1: (1985). Sieves were cleaned, weighed, and arranged in descending order of aperture size. An air-dried sample of 300 g for fine aggregate and 10 kg for coarse aggregate was poured onto the sieves, covered, and placed on an electric sieve shaker. The shaker was operated for 5 minutes, and the weight of each sieve and the retained material were recorded. Percentage retained and percentage passing were then calculated from the recorded data.

***Bulk density test*:** The density of an aggregate is useful in the quantification of materials. Uncompacted and compacted bulk density tests were performed in line with BS 812 part 2 of 1975. A dry and empty mould was initially weighed and recorded as (M1). The dimensions (length, breadth, height) of the mould were measured and recorded. An air-dried sample was poured into the mould to the brim, excess material was trimmed, and the top was levelled. The weight of the sample and mould was recorded as (M2). This procedure was repeated for two additional trials, and the average bulk density was calculated from the recorded weights.

Aggregate impact value test: The test was carried out on the coarse aggregate to determine its resistance to load due to impact. The test sample, passing through a 12.5 mm sieve and retained on 10mm sieve was dried at 100 to 110^{o}C for 4 hours. After cooling, the sample was placed in the mould in three layers, compacted by tamping 25 times for each layer. The weight of the sample and mould was recorded. The impact machine was securely fixed on a stable surface and used to compact the test sample in the mould by dropping a hammer, 15 times from a height of 380 mm. The crushed aggregate was sieved with a 2.36 mm sieve, and the fractions passing through the sieve were weighed.

Table I: Physical Properties of the Aggregates

Physical Properties	Materials	
	Sand	BNG
Fineness Modulus	2.7	6.4
Absorption (%)	2.68	2.37
Specific gravity	2.6	2.68
Bulk density (kg/m^3)	1515	1663
AIV	-	16.56

Note: BNG – Bida Natural Gravel; AIV: Aggregate Impact Value

C. Concrete mix

Styrofoam content at 0, 0.2, 0.4, 0.6, 0.8, 1 and 2% by weight of fine aggregate were used as partial replacement for this research work. Other constituents of the mix include: Bida Natural Gravel of maximum size of 10 mm, water and cement. The absorption of concrete bricks was measured after 24 hours, 7 days and 28 days which was the average of two trial bricks for each mix. The compressive strength at the curing days; 7 and 28 days for each mix was the average of three trial bricks. Therefore, a total of 42 (225 mm ×112.5 mm × 90 mm) bricks were moulded using a mix ratio of 1: 4:2 (cement: fine aggregate: coarse aggregate) and water-cement ratio: 0.5. Mix design was carried out using the absolute volume method of mix design. The control mix was made of cement, sand, BNG and water while other experimental mixes will contain a certain percentage of Styrofoam by weight of fine aggregate used a partial replacement. Table 2 shows the batch per each mix used in moulding the bricks.

Table II: Batch for Concrete Bricks

Styrofoam content (%)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	Styrofoam (g)
0	3.1	13.3	7.1	1.5	0
0.2	3.1	13.28	7.1	1.5	26.6
0.4	3.1	13.26	7.1	1.5	53.2
0.6	3.1	13.23	7.1	1.5	80.0
0.8	3.1	13.20	7.1	1.5	106.5
1.0	3.1	13.18	7.1	1.5	133.1
2.00	3.1	13.04	7.1	1.5	266.2

D. Curing of cubes

The cubes are often moistened using this method, which lowers their porosity to a point where the design strength and durability may be achieved. The cubes were immersed in water for a set age of 7 and 28 days after which they were removed from the moulds at the respective curing ages.

E. Tests on hardened concrete

Absorption test: The absorption test was carried out on concrete bricks in accordance to BS 1881-122:2011. The specimen was dried in a ventilated oven at 105 - 115°C until it achieved a substantially constant mass. After cooling to room temperature, the initial mass (M1) was measured and recorded. The cubes were then immersed in water for 24 hours, 7 days, and 28 days successively. After each designated time, the specimen was removed, excess water wiped off, and the final mass (M2) was measured and recorded.

Density test: The density test was carried out on concrete bricks in accordance to BS 1881-114:1983. The concrete bricks were removed from the curing tank on the designated curing day and allowed to drain before weighing. The density was calculated by dividing the weight measured in kilogram (kg) by volume of the cube in cubic meter (m^3).

Crushing test: The concrete bricks were removed from the curing tank on the designated curing day and allowed to drain before being centrally placed in the crushing machine. They were then subjected to a uniformly applied axial load, gradually increasing until the cube failed. The maximum load the cube could withstand before failure was recorded in accordance with (BS EN 12390, 2009).

III. RESULTS AND DISCUSSION

A. Water absorption of concrete bricks

To assess a brick's durability, including its degree of burning, quality, and behaviour under various weather conditions, a water absorption test is performed on the brick. During the rainy season, a brick with water absorption of less than 7% offers better protection against damage. Lower absorptions are a tool that structural engineers can use to reduce safety factors in their designs. The most applicable data of water absorption data is here. Brick and mortar bonds are higher when absorption is lower. As shown in Fig. 3., absorption increased with increasing Styrofoam content at 24 hours, 7 days and 28 days. After 24 hours absorption increased from 4.3% at 0% Styrofoam content to 13.1% at 2% Styrofoam content. At 7 days the same trend repeated itself but with slight lower values when compared to absorption values recorded at 24 hours - absorption increased from 3.3% at 0% Styrofoam content to 12.1% at 2% Styrofoam content. At 28 days, absorption values reduced from 2.5% at 0% Styrofoam content to 8.8% at 2% Styrofoam content. The result also indicates that as the curing duration increased, the absorption of concrete reduced significantly. This improvement in absorption values is due to further bonding between the components of the concrete bricks and reduction in voids in due to further densification as curing days increased.

The trend observed in this research has been reported by other researchers who have worked on similar studies as this. Syed *et al*. (2020) reported increasing absorption in clay bricks containing saw dust at 2.5%, 5% and 7.5% and cow dung at 2%. Furthermore, Mochamad *et al.* (2019) in their study on "High Content Styrofoam as Partial Substitution for Fine Aggregate in Self Compacting Concrete Lightweight

Concrete Brick" reported an increase in absorption with higher Styrofoam content.

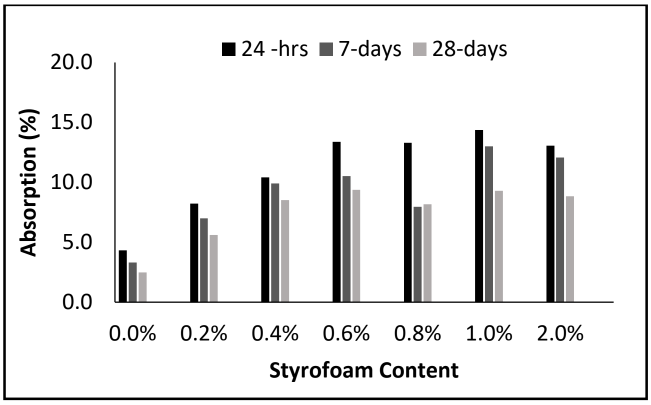

Figure III: Absorption of Concrete Bricks at Varying Percentages of Styrofoam Content

Table III: Absorption of Concrete Bricks at Varying Percentages of Styrofoam

Styrofoam Content	Absorption at 24 hrs (%)	Absorption at 7 Days (%)	Absorption at 28 Days (%)
0.0%	4.3	3.3	2.5
0.2%	8.2	7.0	5.6
0.4%	10.4	9.9	8.5
0.6%	13.4	10.5	9.4
0.8%	13.3	8.0	8.2
1.0%	14.4	13.0	9.3
2.0%	13.1	12.1	8.8

B. Density

Table 4 presents the density of concrete bricks at 28-day curing as well the density of the hardened concrete bricks. The density of the concrete bricks is inversely proportional to Styrofoam content. Polystyrene, also known as polystyrene foam, is a material created from polystyrene by blowing hot air into the material to create a foam with an air content of up to 95%, resulting in a low unit weight of 15 to 22 kg/m3 (Rhami *et al.*, 2019). In granular form, there is a further reduction in unit weight in the range of 13 -16 kg/m^3 (Ginting, 2007). This property of this material explains the significant reduction in density from 2151 kg/m^3 at 0% Styrofoam content to 1405 kg/m^3 at 2% Styrofoam content.

Table IV: Density of Concrete Bricks at Varying Percentages of Styrofoam

Styrofoam Content	Weight (kg)	Density (kg/m^3)
0.0%	4.9	2151
0.2%	4.4	1931
0.4%	4.2	1844
0.6%	4.0	1756
0.8%	3.8	1668
1.0%	3.5	1536
2.0%	3.2	1405

C. Compressive strength

The compressive strengths of concrete bricks at 7 and 28-day curing are shown in Fig. 4. The compressive strength of a concrete bricks is the maximum axial compressive load it can withstand before failure. As shown in the figure, the strength of concrete bricks reduced significantly with increasing Styrofoam content. Comparing the strength at 7 days and 28 days curing, it shows that further hydration of cement through curing is significant in achieving optimum brick strength for all the mixes. This trend in decreasing strength as Styrofoam content increases has also been reported by other researchers. Ankur (2021) investigated the effect of polystyrene on the strength and durability of concrete and reported a decrease in compressive strength as volume of Styrofoam increased in concrete.

Table V: Compressive Strength of Concrete Bricks at Varying Percentages of Styrofoam

Styrofoam Content	Compressive Strength at 7 Days (N/mm^2)	Compressive Strength at 28 Days (N/mm^2)
0.0%	6.7	9.9
0.2%	2.9	3.8
0.4%	2.0	2.1
0.6%	1.8	2.0
0.8%	0.8	1.0
1.0%	0.8	0.9
2.0%	0.6	0.9

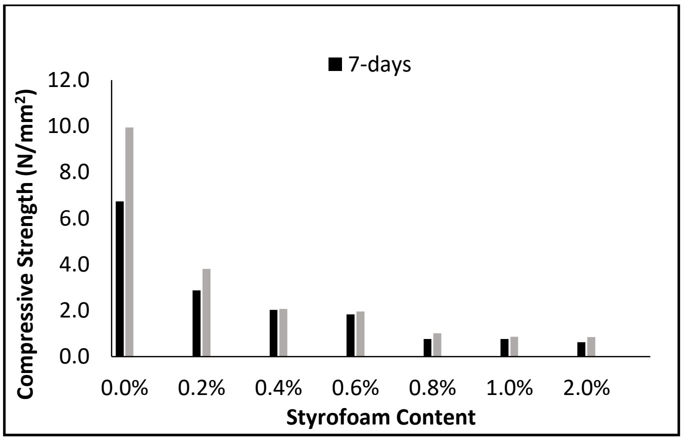

Figure IV: Compressive Strength of Concrete Bricks at Varying Percentages of Styrofoam Content.

IV. CONCLUSION

This research investigated the properties such as: density, absorption and compressive strength of lightweight concrete bricks produced with cement, Bida Natural Gravel (BNG), sand, water and polystyrene (Styrofoam). The conclusions drawn from this study are as follows:

1. Absorption of concrete bricks increased with increasing Styrofoam content from 0.2% to 2%. However, absorption

reduced with increasing curing day after 24 hours, 7 days and 28 days.

2. There was significant weight loss as Styrofoam content increased which in turn reduced the density of the concrete bricks making it suitable for use as partition walls in structures due to reduced dead weight load on structural components.

3. Despite a slight strength improvement with longer curing times, the compressive strength of the concrete bricks decreased as the polystyrene content increased.

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