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Effects of Incorporating Expanded Polystyrene in Concrete Construction

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Abstract

Polystyrene is a highly popular plastic packaging material. It is essentially non-biodegradable and takes hundreds of years to decompose in case of land filling while other disposal methods or treatments methods create hazardous effects on the environment. However, this material is known to possess properties such as sound insulation, high thermal conductivity, and lightweight, thereby making it a great additive in concrete. Haven incorporated this material into a concrete matrix; in various percentages which served as partial replacement for coarse aggregates, the concretes' properties were tested and compared with the properties of the conventional concrete. The experimental data was obtained based on the replacement coarse aggregate by EPS volume ratio of 0%, 4%, 8%, 12% and 16%. The concretes' properties such as its slump, density, compressive strength, flexural strength and split tensile strength were experimentally determined. These results were then used to determine the influence of polystyrene as partial replacement for coarse aggregate was analyzed and the results compared with that of a concrete mix containing no polystyrene. The results obtained from this analysis indicate that the addition of polystyrene in a concrete mix implies smaller densities as the densities of concrete containing 0%, 4%, 8%, 12% and 16% are 2536, 2443, 2363, 2339 and 2316 Kg/m^3 respectively. It was also observed that the compressive strength of the concrete decreased with an increase in the percentage of polystyrene incorporated. This is clearly shown using in the 28th day strength of the concrete samples (21.68, 17.25, 15.87, 14.53 and 13.92 mpa for replacements at 0%, 4%, 8%, 12% and 16% respectively). Similarly, the flexural strength of the concrete decreased with an increase in the percentage of polystyrene incorporated. Whereas, the variations in the split tensile strengths were inconsistent as they were notable increments and decrease in the 28th day strength of the various concrete matrixes.

Keywords

Batching, Curing, Slump Test, Flexural Strength, Split Tensile, Modulus of Elasticity and Density

1. Introduction

In third world (developing) countries like Nigeria and most countries in Africa where it becomes harder each passing day to leave the traditional ways of doing things and embrace change, there is great need to intimate the people on the need to adopt certain new practices as these practices may bring about the much-needed change both economically and otherwise [1]. The construction industry not been left out of the rapid change occurring throughout the world constantly seeks ways to improve its systems and processes by incorporating new materials into its production processes while also modifying already existing processes to meet with the concept of quality improvement and cost efficiency; one of which is the incorporation of expanded polystyrene aggregate in concrete construction [2]. Expanded polystyrene; a rigid cellular plastic found in various shapes, sizes and with various applications is a common household waste as it is used for fish boxes, packaging of electrical appliances and insulation panels, packaging of fragile goods for delivery, etc. In recent times, research has shown that this material is capable of enhancing the properties of concrete when used as a partial substitute for coarse aggregate at certain percentages [3] [4]. This can serve as a major breakthrough in the construction industry as it not only enhances the property of the concrete but manages environmental degradation, reduces the cost of production of the concrete and also manages the issue of waste disposal [5] [6]. This modification proven to be worthwhile, has not still been incorporated in Nigeria, hence the need to enlighten the people on the possible benefits of embracing it and provide detailed information on the effect of this modification as already existing data (since not gotten directly from experiments in this geographical location) may vary with the actual data for this location due to the effects of certain factors that may cause variations in experimental results [7] [8]. Factors such as temperature differences, sources of materials used for experimental analysis, variance in composition of the materials etc. may cause variations in results and this must be put into consideration [9] [10]. There has been a notable increase in demand for construction materials, hence the need to utilize alternative materials for sustainable development [11]. There are many waste materials generated from construction processes and other processes. The wastes which can be reused in construction are instead left as rubble carted away to be discarded; one of such wastes is the expanded polystyrene bead. This did not go unnoticed by construction and structural engineers', thus making the use of expanded polystyrene in the production of lightweight concrete a rapidly growing trend. Expanded Polystyrene (EPS) was discovered in

Germany over 50 years ago and today is used extensively in construction around the world as it has been discovered to be capable of enhancing the design and structural integrity of buildings. It is a lightweight cellular plastic consisting of small spherical shaped particles containing about 98% air. This micro cellular cell structure provides the Expanded Polystyrene bead with excellent insulating and shock absorbing characteristic which makes it an excellent choice material in construction [12] [13]. This research therefore goes to analyze the properties of lightweight concrete containing expanded polystyrene as partial replacement for coarse aggregates, evaluating the effectiveness of expanded polystyrene in enhancing the properties of concrete and determining if it is a better partial replacement for coarse aggregate, with analysis been made in relation to the quality of the concrete, cost of production, availability, safety, variety of design, structural strength, ease of usage in construction, and maintenance amongst others. Research has shown that lack of effective assessment of construction materials has caused and imposed a lot of risk on so many lives and properties [14]. This error haven occurred in the past due to either carelessness on the designers' part or lack of adequate research information on some construction materials must be curbed to the barest minimum. The effect of incorporating expanded polystyrene aggregate in concrete construction has only been partially analyzed with only little experimental results to back up the study, hence there is a need to reanalyze and reevaluate these results and carry out a more detailed analysis. [15] studied the engineering properties of polystyrene lightweight concrete by partially replacing coarse aggregate with equal volume of expanded polystyrene then finding the compressive strength, unit weight, modulus of elasticity, drying shrinkage and creep increase and results showed that the higher the percentage incorporated, the lower the compressive strength of the concrete. [16], all carried out an investigation to study the properties, such as compressive strength, and tensile strength and compared its properties with those of normal concrete (without polystyrene beads). The results gotten showed that the number of polystyrene beads incorporated in concrete influences the properties of the hardened concrete. It was then concluded due to the observation that, the larger the quantity of polystyrene beads added, the lower the compressive strength of the concrete. [17] conducted an experiment involving concrete made from different compositions of waste EPS, cement and tragacanth resin. They concluded that concrete with high ratio of EPS to cement and resin exhibits high porosity and low density, thermal conductivity, compressive, and tensile stress. [18] also confirmed that the particle size of the polystyrene beads has an effect on the compressive strength of the concrete, since it was observed that concrete of equal mix containing smaller particle sizes had greater compressive strength. [19] investigated on the particle size effect of the EPS on the compressive strength and tensile strength and this showed that the particle sizes also have a role to play in the strength characteristics of the concrete. [18] also confirmed that the particle size of the polystyrene beads has an effect on the compressive strength of the concrete, since it was observed that concrete of equal mix containing smaller particle sizes had greater compressive strength. [20] [21] [22], also reported similar findings after using ultrasonic testing to check the effect of particle size on the mechanical properties; that is the flexural strength. Most research on expanded polystyrene concrete as shown above have shown a decrease in the durability performance and the engineering properties of concrete with increasing amount of polystyrene incorporated. On the economic side, the expanded polystyrene material technology appears to be very enticing for the key players in the construction industry. Most often, clients, designers, contractors and end users are always at logger heads over terms of establishing acceptable equilibrium on the major building industry of quality, cost and time as every client would want to construct a high-quality structure at the lowest possible cost. The use of expanded polystyrene offers considerable cost and environment advantages since it contributes positively towards a better environment. This research therefore goes to outline the effect of the particle sizes, volumes and densities of the Expanded Polystyrene beads on the concrete properties to determine the best possible particle size, volume and density to be incorporated into the production of lightweight concrete and exterminate all possible loopholes which may have been overlooked in past research papers.

The aim of this study is to determine the thermal properties, workability, specific gravity, flexural strength, split tensile strength, shear strength, modulus of elasticity and compressive strength (through crushing) of concrete containing Expanded Polystyrene as partial replacement for coarse aggregate in relation to the particle size and percentage of the Polystyrene incorporated.

2. Material and Methods

The individual materials, their composition, mix, manufacturing processes, curing, etc. are important factors that determine the structural and engineering properties of the concrete mix. This makes them of outmost importance during the course of this analysis. It must be ensured that each individual material or component is properly analyzed to ensure that they conform to standard (as stated in the standard codes for building materials and general construction works).

2.1. Expanded Polystyrene Bead

As explained earlier, expanded polystyrene bead is a rigid, tough and lightweight thermoplastic product ideal for the packaging and construction industries due to its lightweight, strong and excellent thermal insulation properties and high resistance to biological corrosion.

2.2. Portland Cement

Cement is a binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together (*Wikipedia*). It is by far the most important constituent of concrete. Cement is mixed with fine aggregate, coarse aggregate and water produce concrete. Portland cement is the most common type of cement in general use around the world as a basic ingredient of concrete. It was developed in England in the early 19th century by Joseph Aspdin and usually originates from limestone. The major chemical components of Portland cement include calcium, silica, alumina and iron. It is necessary to run quality tests on cement to check the strength and quality of the cement to be used. This helps to check the durability and performance of the cement. UNICEM Portland cement was used for this research.

2.3. Tests on Portland-Cement

The following tests were carried out on the cement;

- **Fineness test**; the cement was passed through sieve size 150 mic to ensure that the particles were fine and did not contain big particles. The particles retained on the sieve formed 3% of the total material used for the test. This shows that the cement passed this test as the standards stated that the particles retained must not exceed 10%.
- **Color test**; the color of the cement was observed to ensure that it was even and not uneven. The cement passed this test as it had a homogenous color.
- **Check for lumps**; the cement was checked to ensure that it did not contain any hard lumps as this may have been caused by absorption of moisture from the atmosphere.
- **Cement adulteration test**; the cement was rubbed between the fingers to ensure that it was smooth and not adulterated with materials like sand as that will have an effect on the concrete mix.
- **Float test**; the cement particles were tossed in water. It was observed that they flowed freely in water for some time before sinking. This then shows that the cement is of good quality as cement is in colloidal form of powder which should ideally float due to the surface tension of water.

2.4. Fine Aggregate (Sand)

These are granular materials composed of finely divided rock and mineral particles. It is mainly made of silicate minerals and silicate rock granular particles. Although it is an inert material in the concrete mix, it is a vital ingredient of concrete and its role cannot be neglected as it offers the requisite surface area for the film of the binding material to adhere and spread. Normal river sand was used for this research.

2.5. Test on Fine Aggregates (Sand)

The tests carried out on the fine aggregate include:

Sieve analysis

Research has shown that the finer the composition of sand granules present in the sand used for a concrete mix, the lower the compressive strength the concrete is likely to produce. The particle size distribution also aid in the determination of the size of aggregate to be used.

Apparatus;

- Sieve shaker
- Sieves
- Weigh balance

Procedures;

- One kilogram (1000 g) of the fine aggregate to be used was weighed.
- The sieves were arranged according to their numbers (in a descending order) and placed on the sieve shaker and the sieve shaker turned on.
- After ten (10 minutes) the sieve was turned off and the weight retained on each sieve weighed and recorded.
- The cumulative weight retained on each sieve was calculated by adding all weights retained on the sieves above each sieve under consideration to the weight retained on the sieve under consideration.
- The percentage retained was then calculated by multiplying the weight retained on each sieve by 100 and dividing the answer by the total weight of the sample (1000 g).
- The percentage cumulative was calculated by multiplying the cumulative weight retained on each sieve by 100 and dividing the answer by the total weight of the sample (1000 g).
- The percentage passing was then calculated by subtracting the percentage cumulative of each sieve from the percentage passing of the previous sieve.

2.6. Density Test

The density of the constituent materials of concrete grossly affects the density of the concrete. This in turn affects the strength property of the concrete. It is therefore necessary to analyze this property of each material to ascertain the effects of each on the properties of the concrete.

Apparatus;

- Weigh balance
- Container of known volume

Procedure;

- A container of known volume; V is filled with the fine aggregate in such a way that voids are eliminated.
- The sample is then levelled, weighed and recorded as W_2.
- The container is emptied, the weight of the container taken and recorded as W_1.
- The density of the material is then calculated using the formula;

$$\text{Density} = \frac{W_2 - W_1}{V}$$

2.7. Specific Gravity Test

The specific gravity of a material is the ratio of the weight of a given volume of aggregate maintained for 24 hours at a temperature of 100˚C to the weight of an equal volume of water displaced by saturated surface dry aggregates. It is used in calculating the air voids present in a given material and the solid volume of aggregates.

Apparatus;

- Weigh balance
- Oven
- Pycnometer
- Tray
- Air tight container
- Filter paper and funnel

Procedures;

- A sample of 400 g (0.4 kg); was weighed and placed in the pycnometer.
- The mass of the pycnometer and sample was weighed and recorded as W_2.
- Distilled water was then poured into it until it was full.
- The entrapped air was then eliminated by rotating the pycnometer on its side, the hole in the apex being covered by a finger.
- The outer surface of the pycnometer was then wiped, weighed and recorded as W_3.
- The contents of the pycnometer were then transferred into a tray in such a way that no aggregate was lost.
- The pycnometer was then filled with distilled water to the same level, weighed and recorded as W_4.
- The pycnometer was then dried, weighed and recorded as W_1.
- The specific gravity of the aggregate was then calculated using the formula;

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1)(W_3 - W_2)}$$

2.8. Coarse Aggregates (Granite)

Coarse aggregates are particulates that are greater than 4.75 mm in diameter but not larger than 37.5 mm. It is very important in concrete construction as it improves the strength, dimensional stability, thermal and elastic properties, and volume of concrete whilst managing the cost. The properties of the coarse aggregates used also have effects on the properties of the concrete produced.

Test on coarse aggregate (granite)

The tests carried out on the granite used include;

Particle size distribution (**Sieve analysis**)

Research has shown that the smaller the maximum sized aggregate used, the higher the compressive strength. Concrete with smaller maximum sizes of aggregate, known to develop greater strength than concrete with larger sizes of aggregates. This experiment is therefore needed as all the factors which may influence the strength of the concrete in one way or the other must be properly analyzed.

Apparatus;

- Sieve shaker
- Sieves
- Weigh balance

Procedures;

- One kilogram (1000 g) of the coarse aggregate to be used was weighed.
- The sieves were arranged according to their numbers (in a descending order) and placed on the sieve shaker and the sieve shaker turned on.
- After ten (10 minutes) the sieve was turned off and the weight retained on each sieve weighed and recorded.
- The cumulative weight retained on each sieve was calculated by adding all weights retained on the sieves above each sieve under consideration to the weight retained on the sieve under consideration.
- The percentage retained was then calculated by multiplying the weight retained on each sieve by 100 and dividing the answer by the total weight of the sample (1000 g).
- The percentage cumulative was calculated by multiplying the cumulative weight retained on each sieve by 100 and dividing the answer by the total weight of the sample (1000 g).
- The percentage passing was then calculated by subtracting the percentage cumulative of each sieve from the percentage passing of the previous sieve.

2.9. Specific Gravity Test

The specific gravity of a material is the ratio of the weight of a given volume of aggregate maintained for 24 hours at a temperature of 100˚C to the weight of an equal volume of water displaced by saturated surface dry aggregates. It is used in calculating the air voids present in a given material and the solid volume of aggregates.

Apparatus;

- Weigh balance
- Oven
- Pycnometer
- Tray
- Air tight container
- Filter paper and funnel

Procedures;

- A sample of 400 g (0.4 kg); was weighed and placed in the pycnometer.
- The mass of the pycnometer and sample was weighed and recorded as W_2.
- Distilled water was then poured into it until it was full.
- The entrapped air was then eliminated by rotating the pycnometer on its side, the hole in the apex being covered by a finger.
- The outer surface of the pycnometer was then wiped, weighed and recorded as W_3.

- The contents of the pycnometer were then transferred into a tray in such a way that no aggregate was lost.
- The pycnometer was then filled with distilled water to the same level, weighed and recorded as W_4.
- The pycnometer was then dried, weighed and recorded as W_1.
- The specific gravity of the aggregate was then calculated using the formula;

$$\text{Specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1)(W_3 - W_2)}$$

Aggregate Impact value test

This is the measure of the ability of the aggregate to resist impact or shock. It is a measure of the toughness of the aggregate.

Apparatus

- Aggregate impact testing machine; with a weight of 60 kg and having a metal base plane concrete floor of 45 cm thickness with provisions for fixing its base.
- Cylindrical steel cup of internal diameter 102 mm, depth 50 mm, and minimum thickness 6.3 mm.
- A metal hammer weighing 13.5 kg, with cylindrical lower end, 50 mm long, 100 mm in diameter, with a 2 mm chamfer at the lower edge and case-hardened hammer which could slide freely between its vertical guides and the concentric with the cup. The fall of the hammer was about 380 mm.
- A cylindrical metal measure with an internal diameter of 75 mm and depth of 50 mm for measuring the aggregates.
- A tamping rod of 10 mm diameter and length 230 mm, rounded at one end.
- Weigh balance.

Procedure

- The aggregates were then sieved through 12.5 mm and 10 mm sieves. The aggregates passing through the 12.5 mm sieves and retained on the 10 mm sieves were the ones used for the test.
- The aggregates were poured to fill about 1/3 depth of the measuring cylinder.
- It was then compacted by giving 25 gentle blows with the end of the tamping rod.
- Two more layers were added in such a way that the cylinder was full and compacted in that manner and the excess material removed with a straight edge. The material in the cylinder then constituted the test material.
- The net weight was then determined and recorded as W_1.
- The impact machine was then brought to rest without wedging or packing upon the level plate, block or floor, so that it was rigid and the hammer guide columns vertical.
- The cup was fixed firmly in position on the base of the machine, the whole sample placed in it then compacted by giving 25 gentle strokes with a tamping rod.
- The hammer was then raised until its lower face was 380 mm above the sur-

face of the aggregate sample in the cup and allowed a free fall on the aggregate sample. 15 of such blows were given at an interval of one second each.

- The crushed aggregates were then removed from the cup and sieved through 2.36 mm sieve and the sum of the weights of the fractions retained and passing through the sieve weighed and recorded. The weight passing through the sieve recorded as W_2 and the weight retained W_3.
- The aggregate impact value was then calculated using the formula;

$$\text{Aggregate Impact Value} = \frac{W_2}{W_1} \times 100$$

2.10. Aggregate Crushing Value Test

This gives the relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. It is the percentage by weight of the crushed material obtained when the test aggregates are subjected to a specific load under standardized conditions.

Apparatus

- The test mould; a 15.2 cm diameter open-ended steel cylinder with a square base plate; plunger having a piston of diameter 15 cm, with a hole provided across the stem of the plunger so that a rod could be inserted for lifting or placing the plunger in the cylinder.
- The straight metal stamping rod of circular cross section 16 mm in diameter and 45 mm long, rounded at one end.
- A weigh balance
- IS sieves of sizes 12.5 mm, 10 mm and 2.36 mm
- Compression testing machine
- Cylindrical measure with an internal diameter of 11.5 cm and height of 18 cm.

Procedures

- The aggregate was dried at 100˚C for 4 hours and cooled to room temperature.
- The aggregates were then sieved through 12.5 mm and 10 mm sieves. The aggregates passing through the 12.5 mm sieves and retained on the 10 mm sieves were the ones used for the test.
- 3.2 kg of the material was weighed.
- The aggregates were poured to fill about 1/3 depth of the measuring cylinder.
- It was then compacted by giving 25 gentle blows with the end of the tamping rod.
- Two more layers were added in such a way that the cylinder was full and compacted in that manner and the excess material removed with a straight edge. The material in the cylinder then constituted the test material.
- The cylinder was then emptied and the weight of the aggregate taken and recorded as W_1.
- The whole weighed quantity was then transferred to the test mould by filling

it in three layers as earlier done for the measuring cylinder.

- The total depth of the aggregate was then about 10 cm and the surface a little below the top of the mould.
- The surface was levelled and the plunger placed over it in such a way that it rests horizontally on the surface of the aggregates.
- This assembly was then placed on the pedestal of the compression testing machine.
- The load was then applied at a rate of 4 tonnes (39.2 KN) per minute until a total load of 40 tonnes (392 KN) was applied.
- The load was then released and the aggregate taken out of the cylinder.
- The aggregate was then sieved through sieve size 2.36 mm and the fraction passing weighed and recorded as W_2. This fraction then becomes the measure of loss of material due to crushing.
- The aggregate crushing value was then calculated using the formula;

$$\text{A.C.V} = \frac{W_2}{W_1} \times 100$$

2.11. Aggregate Abrasion Test

Apparatus:

- Los Angeles Abrasion testing machine.
- Abrasive charges (12N)
- Oven
- Sieves (sizes 12.5 mm, 10 mm and 1.7 mm).
- Weigh balance

Procedures:

- The material to be used for the test (coarse aggregate - granite) was thoroughly washed, cleaned and oven dried at 105 to 110˚C to a substantially constant weight.
- 5 kg of the prepared sample was weighed, recorded (A) and placed in the Los Angeles abrasion testing machine together with 10 abrasive charges.
- The machine was then rotated at a speed of 20 to 33 revolutions/minute for 1000 revolutions.
- The material was then discharged from the machine and passed through 1.70 mm IS sieve.
- The material retained on the sieve was then washed, and oven dried at a temperature of 100˚C to 110˚C to a constant weight and weighed (B).
- The Aggregate Abrasion Value was then calculated as;

$$\text{Aggregate Abrasion value} = \frac{A - B}{A} \times \ 100\%$$

3. Processes/Methods Involved in Concrete Production

They are several processes involved in the preparation of the specimen for the needed experimental research. The tests to be carried out are on both fresh and hard samples, and the processes are needed to prepare the samples for testing are as shown below;

- Batching (Measurement of individual materials according to standard quantities)
- Mixing of concrete
- Casting of specimen
- Compaction
- De-molding
- Curing
- Age of test

3.1. Batching

This involves the measurement of individual constituents and materials according to the mix ratio. Batching can either be done by weight or by volume. Although batching by weight is generally more recommended and professionally preferable as it eliminates errors due to the variations contained in a specific volume, for this experiment batching by volume was used as the one of the aims of this experiment is the production of lightweight concrete using polystyrene as a partial replacement for coarse aggregate. Replacing coarse aggregate (granite) by weight with polystyrene is also nearly impossible as polystyrene is a lightweight material composed of about 98% air.

3.2. Mixing of Concrete

Since hand mixing was used, the various quantities of the components were measured (excluding water) and mixed until there is an even distribution of the materials. Water was then measured (with reference to the cement content and water/cement ratio) and added in batches to ensure that a homogenous mix was achieved.

3.3. Casting of Specimen/Moulds

Square, cylindrical and beam casting mould made of cast iron were used. Grease was used to oil the inner part of the mould to aid in easy removal of the concrete specimen. The specimens were then cast in 3 equal layers and properly compacted in order to avoid honeycombs and the presence of voids.

3.4. Compaction

In compacting, a tamping rod of 16mm diameter must was used to compact the specimen. 25 strokes were used to compact each layer in all parts of the mould to ensure proper compacting.

3.5. De-Molding

Outmost care was taking during the de-molding of the specimen to prevent fractures and breakage.

3.6. Curing

The specimens were placed in a curing tank after de-molding till the day they were needed for testing. They were cured with portable water to prevent unwanted reactions from occurring.

3.7. Age of Test

The specimens were immersed completely in water (curing) for the recommended time for a test and brought out only when the test was to be carried out. The time frame range varied from 3 days to 28 days.

4. Experimental Analysis

To determine the suitability of concrete for construction purposes, tests must be carried out on the concrete sample to determine its properties (engineering properties). This test can be broadly divided into two categories, they are;

- Test on fresh concrete (workability and density test)
- Test on hardened concrete (strength properties)

Therefore, to determine the suitability of concrete containing expanded polystyrene (as partial replacement for coarse aggregate) for concrete works, the following laboratory tests and experiments must be performed on the concrete and the results compared to the results gotten from similar tests carried out on natural concrete.

- Slump test
- Density test
- Compression test
- Flexural strength
- Split tensile strength
- Shear strength
- Modulus of elasticity
- Water permeability test
- Water absorption test

4.1. Concrete Slump Test

Slump tests measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which the concrete flows even to the remotest corner of the formwork or mould. It can also be used as an indicator of improperly mixed batch. Scientifically, it can be seen as the property of concrete which determines the amount of useful internal work necessary to produce full compaction; in other words, it is the property of concrete which allows and enables it to be compacted.

Apparatus:

- Slump cone
- Tamping rod
- Slump test base

- Slump cone filling funnel
- Measuring tape/steel rule
- Scrub brush
- Recording sheet

Procedures:

- The internal surface of the mould (cone) was cleaned thoroughly and freed from superfluous moisture and any set of concrete and placed on a smooth, horizontal, rigid and non-absorbent surface (slump test base). It was held firmly in place during the filling process.
- The mould was then filled in four layers, each approximately one-quarter of the height of the mould. Each layer shall be tamped with twenty-five strokes with the tamping rod; the strokes been distributed in a uniform manner over the cross section of the mould and the second and subsequent layers must penetrate into the underlying layers.
- The bottom layer was tamped throughout its depth. After the top layer had been tamped, the concrete was struck off level with a trowel so that the mould is exactly filled.
- After that, the surface of the concrete was compacted by means of screeding and rolling motion of the tamping rod.
- Any mortar which may have escaped out from between the mould and the base plate was cleaned out and the mould removed from the concrete by raising it slowly and carefully in a vertical direction.
- The concrete then subsides and the slump measured by determining the difference between the height of the mould and the height of the highest point of the specimen been tested.

It must be noted that the above operation be carried out at a place free from vibration or shock, and within a period of two minutes after sampling.

Interpretation of Results:

The slumped concrete taking various shapes and according to the profile of slumped concrete, the slump is termed as true slump (concrete simply subsides, keeping more or less to shape), shear slump (the top portion of the concrete shears off and slips sideways) or collapse slump (the concrete collapses completely). If a shear or collapse slump is achieved, a fresh sample should be taken and the test repeated.

Only a true slump is of any use in the test. A collapse slump will generally mean the mix is too wet or that it is a high workability mix, for which the slump test is not appropriate (**Table 1**).

The following values can be used to determine if the workability of the concrete is adequate;

Precautions:

1) The test was carried out at approximately 10 minutes after mixing to prevent moisture loss.

2) Slump tests were carried out in a place free from vibrations and shock.

3) Parallax error was avoided when taking readings.

Table 1. Workability/slump standards.

Workability	Compaction factor	Slump (mm)
Very low	0.78	0 - 25
Low	0.85	25 - 50
Medium	0.92	50 - 100
High	0.95	100 - 175

4.2. Density Test

Density is also known as unit weight. It must conform to ASTMC138 standards. This test is useful as the density of concrete has been proven to have a direct relationship with the concretes' strength; a denser concrete is known to generally provide higher strength and fewer amounts of voids and porosity hence the need for proper compaction.

Apparatus:

- Container of known volume
- Weighing balance

Procedures:

A container of known volume and weight was filled with concrete and then weighed. Subtract the empty container weight from the full container weight to get the weight of the concrete, then divide the weight of the concrete by the volume of container to get the density or fresh unit weight of the concrete. This was done to get the results.

$$\text{Density} = \frac{W_1 - W_2}{V}$$

where;

W_1 = weight of container with concrete.

W_2 = Weight of empty container.

V = Volume of container.

4.3. Compression Test

In actual construction, concrete is often used in compression and it has proven to be strong in compression. The compressive strength of concrete indicates the control exercised during construction as it serves as an indicator of how well the concreting was done. This test therefore provides an idea about all the characteristics of concrete as by this single test, it can be predicted whether the concreting was properly done or not, the durability of the concrete (the higher the compressive strength, the greater the durability) and also the suitability of the mix (both the individual materials and the mix ratio) for the construction processes to be undertaken can be predicted. The factors which affect the compressive strength of concrete include; air entrainment, water-cement ratio, etc. The test was carried out using 100 mm × 100 mm concrete cubes. The test was carried out according to 1S: 456.

Apparatus:

- Square concrete mold (100 mm × 100 mm)
- Trowel
- Weighing balance
- G.I. sheet for mixing
- Tamping rod
- Curing tank
- Compression testing machine

Procedures:

- The concrete molds were filled in three (3) layers of approximately 40 mm depth after mixing.
- Compaction was done hand using standard rod and tamping at 25 strokes per layer.
- The specimen was then removed after 24 hours (once it set) and cured in clean/drinkable water for the required number of days (3, 7, 14, 21, and 28 days).
- On the test day, on removal from water the specimen is left to air dry for about half an hour (till the surface is in a saturated dry condition).
- The weight of the specimen was observed and recorded and the specimen placed for crushing.
- The specimen was then placed in the machine in such a way that the load was applied to opposite sides of cubes cast and not the top and bottom and the specimen properly aligned.
- The load was applied slowly at the rate of 140 $kg/cm^2/min$ until the cube failed/broke.
- The maximum load at the appearance of the concretes' failure was noted and recorded.
- The compressive strength shall then be calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area, calculated from the mean dimensions of the section, and shall be expressed to the nearest kg per cm^2.

Compressive strength of concrete = maximum load carried by specimen/top surface area of specimen

$$\text{Compressive strength} = \frac{P}{A}$$

where;

P = Load at failure.

A = Cross sectional area of specimen.

4.4. Flexural Strength

The flexural strength is the ability to withstand bending. It is determined using beam specimens (100 × 100 × 400 mm). After casting and curing, the beam was then placed on the flexure test machine provided with a steel roller mounted at a specific distance away from each other. The load to be applied was then divided equally between the two sides and the roller placed at the mid-point in such a manner that the load is applied axially and without subjecting the specimen to any torsional stress or restraint. The flexural strength is then given by;

$$F_b = \frac{3Pa}{2bd^2} \text{ or } \frac{Pl}{bd^2}$$

where;

a = distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen

b = width of specimen (cm)

d = failure point depth (cm)

l = supported length (cm)

p = maximum load (kg)

Split tensile strength

This is another property that relates indirectly to the tensile strength of the concrete. It is measured with a compression testing machine. A cylindrical specimen of 10 mm diameter and 20 mm length was used for this test. After curing of the specimen, the water on the surface of the specimen is wiped out and diametrical lines are drawn on the two ends of the specimen using a marker. The dimension of the specimen is measured, a plywood strip is kept on the lower plate and the specimen placed on it. The specimen is then aligned so that the lines marked on the end are vertical and centered over the bottom plate. Another plywood strip is placed over the specimen and the upper plate brought down to touch the plywood strip. The load is then applied continuously without shock at a rate of approximately 14 - 21 kg/cm^2/minute (which corresponds to a total load of 9.9 ton/minute to 14.85 ton/minute). The breaking load of the specimen is then recorded.

The split tensile strength is then calculated using;

$$F_{st} = \frac{2F}{\pi Ld}$$

where;

F_{st} = split tensile strength.

F = Failure load.

L = Length of specimen.

d = diameter of the specimen.

Shear strength

This is the measure of the ability of the concrete to resist shearing. It can be determined from the test for the flexural strength. It can then be determined using;

$$F_s = \frac{F}{A}$$

where;

F_s = shear strength.

F = Shear load at failure.

A = cross sectional area of the test specimen.

Modulus of elasticity

This is the relationship between the applied stresses and the strains they may cause. It has a direct relationship with the compressive strength, increasing as the compressive strength increases. It can be determined using the formula below;

$$E_S = 1.7 \rho f_c 0.33 \times 10.6$$

where;

E = static modulus of elasticity.

ρ = density.

f_c = compressive strength.

The above mentioned tests were performed to determine the properties of the polystyrene mix concrete, the results analyzed and hypotheses and conclusions drawn.

5. Results and Discussion

Slump Test

The test was conducted by using a slump flow cone that was filled up with the fresh concrete and lifted up vertically to allow the fresh concrete flow on a flat surface. After 30 seconds, the slump was measured and the result is shown in Table 2

Based on Table 2 all test results of Slump flow indicates that the utilization of polystyrene affects the slump flow of concrete as the values of slump decreases with each increase in the percentage of Polystyrene added. It is as shown in Figure 1.

Density

The weight/volume was calculated by dividing the weight of specimen by its volume. The summary of weight/volume is presented in Table 3 as shown below.

Table 3 shows that the higher the percentage of the Polystyrene incorporated, the lower the weight of the concrete produced. The results obtained on the weight/volume in this research shows that Polystyrene is very effective in the production of lightweight concrete. Moreover, the observation after the flexural

Table 2. Slump test.

S/N	ADDITION OF POLYSTYRENE (%)	SLUMP (mm)
1	0	25
2	4	20
3	8	16
4	12	12
5	16	10

Table 3. Density test.

S/N	ADDITION OF POLYSTYRENE (%)	AVERAGE RESULTS (Kg/m^3)	REDUCTION (%)
1	0	2536	-
2	4	2443	3.77
3	8	2363	6.82
4	12	2339	7.77
5	16	2316	8.68

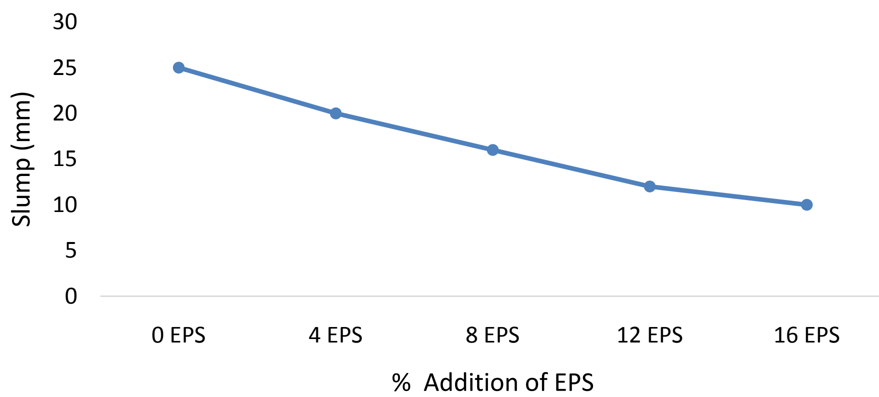

Figure 1. Slump at various % of addition.

test shows a relatively even distribution of Polystyrene on the surface of cross section. Hence, it confirms that Polystyrene is compatible in concrete. Figure 2 shows the reduction of weight of concrete as % addition of EPS increases.

Compressive Strength

The compressive strength test was conducted by testing specimen with dimension; 100 × 100 × 100 mm using the universal testing machine (UTM) and the maximum load (load at failure) was used to calculate the compressive strength of each specimen. The average results are presented in Table 4.

With the increase of polystyrene dosage as a replacement for the coarse aggregate, compressive strength decreases, in comparison with the control mix, as shown in Figure 3. The highest value of compressive strength for concrete with polystyrene is smaller than that of the control mix.

Table 4 and Figure 3 gave the average compressive strength of the EPS concrete in 7, 14, 21 and 28 days. It could be seen that the higher the dosage of EPS, the lower the strength. Also, as the days goes by, the EPS concrete gains more strength.

Flexural Strength

The flexural strength tests were carried out using a beam (100 × 100 × 400 mm) supported at 50 mm to the edge with 300 mm clear span. The result after 3, 7, 14, 21 and 28 days are presented in Table 5 and Figure 4. It also shows that as the EPS dosage increases, the flexural strength decreases.

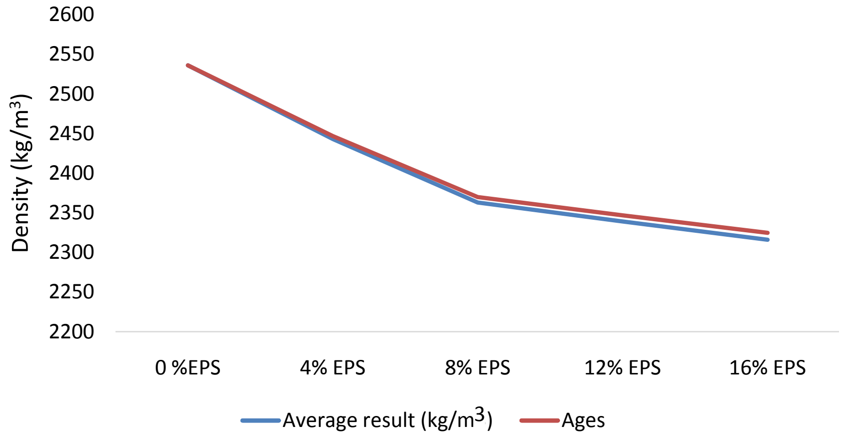

Figure 2. Density reduction with increase in EPS.

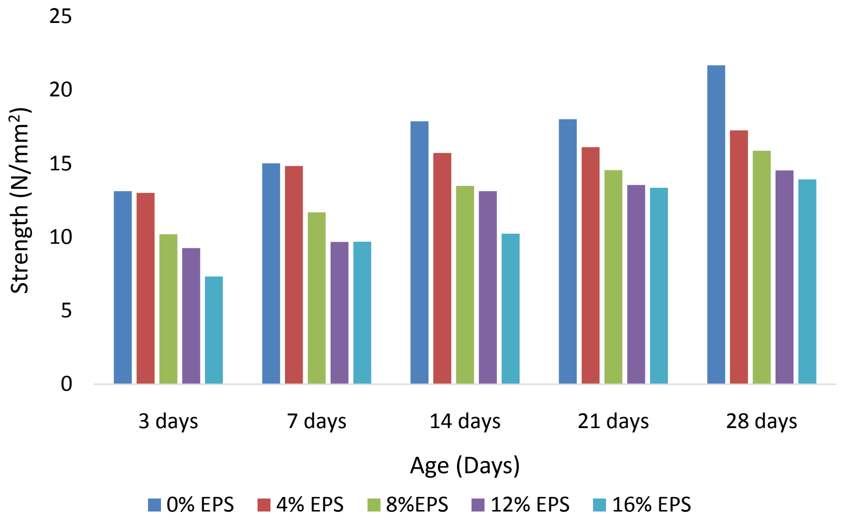

Figure 3. Average compressive strength of EPS concrete with percentage of dosage of EPS.

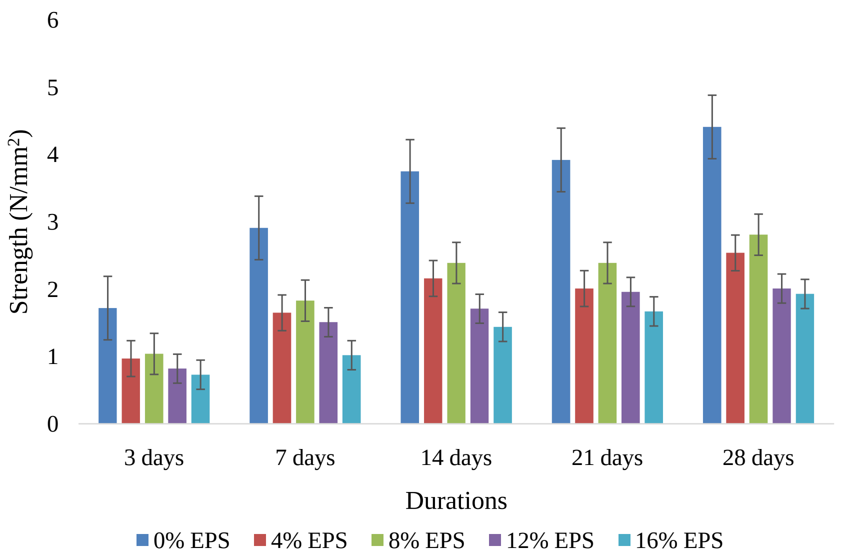

Figure 4. Flexural strength comparison.

Table 4. Compressive strength test (N/mm^2).

Days	0% EPS	4% EPS	8% EPS	12% EPS	16% EPS
3	13.12	13.00	10.19	9.25	7.32
7	15.01	14.83	11.68	9.67	9.69
14	17.87	15.72	13.48	13.12	10.23
21	18.01	16.11	14.55	13.54	13.35
28	21.68	17.25	15.87	14.53	13.92

Table 5. Flexural strength.

Days	0% EPS	4% EPS	8% EPS	12% EPS	16% EPS
3	1.72	0.97	1.04	0.82	0.73
7	2.91	1.65	1.83	1.51	1.02
14	3.75	2.16	2.39	1.71	1.44
21	3.92	2.01	2.39	1.96	1.67
28	4.41	2.54	2.81	2.01	1.93

Table 6. Split tensile strength.

Days	0% EPS	4% EPS	8% EPS	12% EPS	16% EPS
3	1.93	1.78	1.22	1.43	1.47
7	2.18	1.82	1.83	1.54	1.46
14	2.29	1.95	1.63	1.99	1.96
21	1.93	1.91	1.71	1.39	1.55
28	1.73	1.72	1.64	1.33	1.49

Split Tensile Strength

Likewise, the split tensile test was carried out to determine the tensile strength of the EPS concrete and result presented in Table 6. There was a rise in the value of the tensile strength from the control to the highest value at 10% EPS concrete (2.28 MPa) and then a fall in the value to least value of 1.25 MPa for 30% EPS concrete. This can be deduced to be because of the hydrophobic nature of the EPS. The larger the amount, the less the cohesiveness of the material, thus shearing of at high dosage.

6. Conclusion

The research investigated the effect of Expanded Polystyrene beads (EPS) on the mechanical properties of the concrete. From the results and analysis of this research, it was observed that as the volume of the EPS incorporated increased, the workability decreased, the compressive strength decreased, the flexural strength decreased while the tensile strength varied (was not consistent). This then shows that concrete produced with Expanded Polystyrene as partial replacements for coarse aggregates is weak and thus should be used for low-strength components of a structure (that is, the components of a structure with low strength requirements); this polystyrene-based concrete is best suitable for non-structural elements which do not require high compressive and flexural strength. EPS concrete has the advantages of small density and thermal insulation. So, it is of great significance on the study of modern structural materials and practical engineering to research new concrete materials. Lightweight concrete produced with Expanded Polystyrene beads can therefore be used for concrete walls in frame buildings as both the dead and live loads of the building will be borne by the frame. This then serves as a means of reducing cost, improving thermal insulation, reducing the dead load (weight) on/off the building amongst so many other benefits.

Recommendations

1) Lightweight concrete produced with Expanded Polystyrene can be used to solve problems of weight/density, durability, ease of handling and size of structural elements.

2) Further studies in this area should be of importance to add more values to the use of this material in concrete production and waste management.

3) This concrete type can serve as a major breakthrough in the construction industry as it can be used in the fabrication and optimization design of structural elements using computational approaches.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Aina and Wahab (2011) Construction Procurement Systems: Influencing Factors for Nigerian Indigenous Contractors Project Planning.

[2] Babu, K.G., Babu, D.S. and Tiong-Haun, W. (2005) Properties of Lightweight Expanded Polystyrene Aggregate Concretes Containing Fly Ash. *Cement and Concrete Research*, **35**, 1218-1223. https://doi.org/10.1016/j.cemconres.2004.11.015

[3] Cheng, B. and Liu, J. (2007) Mechanical Properties of Polymer-Modified Concrete Containing Expanded Polystyrene Beads. *Construction of Building Materials*, **21**, 7-11. https://doi.org/10.1016/j.conbuildmat.2005.08.001

[4] Ubi, S.E., Okafor, F.O., Mama, B.O. and Agbor, R.B. (2020) Prediction of Flexural Strength of Expanded Polystyrene Lightweight Concrete Using Scheffe's Model. *International Journal of Advanced Research in Engineering and Technology*, **11**, 492-503.

[5] Herki, B.A., Khatib, J.M. and Negim, E.M. (2013) Lightweight Concrete Made from Waste Polystyrene and Fly Ash. *World Applied Science Journal*, **21**, 1356-1360.

[6] Kageni (2014) Lighter Weight during Construction and Reduction of Self-Weight in Structures.

[7] Ravindrarajah, S. and Tuck, A.J. (1993) Lightweight Concrete with Expanded Polystyrene Beads. Civil Engineering Monograph No. C.E. 93/1 M.E., University of Technology, Sydney.

[8] Ubi, S.E., Nkra, P.O., Agbor, R.B., Thankgod, T. and Monday, A. (2020) Effect of Damp and Treatment Methods on Residential Buildings in Calabar Metropolis of Cross River State. *International Journal of Research*, **8**, 372-376. https://doi.org/10.29121/granthaalayah.v8.i8.2020.1206

[9] Nor, H.S. (2019) Application of Expanded Polystyrene (EPS) in Buildings and Construction: A Review. *Journal of Applied Polymer Science*, **136**, Article No. 47529.

[10] Omnexus (2020) Expanded Polystyrene (EPS): Ultimate Guide on Foam Insulation Material.

[11] Leite, F., Alcamete, A., Akinci, B., Atasoy, G. and Kiziltas, S. (2011) Analysis of Modeling Effort and Impact of Different Levels of Detail in Building Information Models. *Automation in Construction*, **20**, 601-609. https://doi.org/10.1016/j.autcon.2010.11.027

[12] Richfield, W.I. (2019) Polystyrene. https://dielectricmfg.com

[13] Ubi, S.E., Nkra, P.O., Agbor, R.B. and Okafor, F.O. (2020) Mathematical Model for Optimization of Modulus of Elasticity of Polystyrene Lightweight Concrete Using Scheffe's Model. *International Journal of Civil Engineering*, **7**, 16-30. https://doi.org/10.14445/23488352/IJCE-V7I10P103

[14] Tamut, T., Praghu, R., Venkatarmana, K. and Yaragal, S.C. (2014) Partial Replacement of Coarse Aggregate by Expanded Polystyrene Beads in Concrete. *International Journal of Research in Engineering and Technology*, **3**, 238-241.

[15] Sabha and Ravindrarajah (2004) Engineering Properties of Polystyrene Aggregate.

[16] Babu, K.G. and Babu, D.S. (2003) The Behavior of Lightweight Expanded Polystyrene Concrete Containing Silica Fume. *Cement and Concrete Research*, **33**, 755-762. https://doi.org/10.1016/S0008-8846(02)01055-4

[17] Babu, K.G., Babu, D.S. and Tiong-Haun, W. (2006) Effect of Expanded Polystyrene Size on Strength and Moisture Migration Characteristics of Lightweight Concrete. *Cement and Concrete Composite*, **28**, 520-527. https://doi.org/10.1016/j.cemconcomp.2006.02.018

[18] Miled, *et al.* (2004) Size Effects and Failure Mechanism of an Expanded Polystyrene Concrete.

[19] Miled, K., Sab, K. and Leroy, R. (2007) Particle Size Effect on EPS Lightweight Concrete Compressive Strength: Experimental Investigation and Modelling. *Mechanics of Materials*, **39**, 222-240. https://doi.org/10.1016/j.mechmat.2006.05.008

[20] Chen, M., Mao, S. and Liu, Y. (2014) Big Data: A Survey. *Mobile Networks and Applications*, **19**, 171-209. https://doi.org/10.1007/s11036-013-0489-0

[21] Ravindrarajah, S. and Tuck, A.J. (1994) Properties of Hardened Concrete Containing Treated Expanded Polystyrene Beads. *Cement and Concrete Composites*, **16**, 273-277. https://doi.org/10.1016/0958-9465(94)90039-6

[22] Kosmatka, S. (1985) Compressions vs. Flexural Strength for Quality Control of Pavements.