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COMPARISON OF DIFFERENT DENSITY MATERIALS IN LIGHTWEIGHT CONCRETE

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Abstract

Concrete is a highly prevalent construction material in contemporary society. The quest to reduce the weight of this material has been the focus of research that has posed a challenge to both scientists and engineers. The primary difficulty in producing a lightweight concrete lies in reducing its density while preserving its strength and without negatively impacting its cost. Adding light aggregates to the mix design is a frequently used method to reduce the density of concrete. According to BS EN 206-1, lightweight concretes are characterized by an oven dry density ranging from 800kg/m3 to 2000kg/m3. This is achieved by substituting dense natural aggregates with lightweight aggregates, either completely or partially. The materials used in this study are available locally, these includes Cement, River sand, Granite, Coconut shells (CS), Sawdust (SD), Expanded polystyrene (EPS), Master Rheobuild 858, and potable water. The mixture was prepared using a ratio of 1part cement, 1.6 parts sand, and 3.2 parts aggregate, with a water-cement ratio of 0.5. There are three different mixtures which are the conventional concrete, sawdust concrete and polystyrene concrete. The conventional aggregates were replaced with SD, CS and EPS in same ratio of 0%, 10%, 20% and 30%. Master Rheobuild 858 Plasticiser 858 was then mixed with half of the water required. The concrete's performance was evaluated based on its compressive strength and hardened density. The sample underwent testing at intervals of 7, 14, and 28 days. The compressive strength of the control sample (C0) at 28 days was 34.8 N/mm2, which successfully met the desired goal strength. Additionally, the density of the sample was measured to be 2447 kg/m3. S10, S20, and S30 exhibit compressive strengths and densities of 28 N/mm2 and 2198 kg/m3, 24 N/mm2 and 2081 kg/m3, and 18.4 N/mm2 and 1980 kg/m3, respectively, after 28 days. E10, E20, and E30 have compressive strengths and densities of 25 N/mm2 and 1884 kg/m3, 18 N/mm2 and 1752 kg/m3, and 12N/mm2 and 1653 kg/m3, respectively. The study determined that there is a reduction in both compressive strength and density. Nevertheless, given the circumstances, as the replacement material increased, both the strength and density also reduced. Lightweight concrete was achieved with 10% of EPS at 1884 kg/m3. This resulted in strength of 25 N/mm2, making it appropriate for M25 concrete. While it was achieved with 30% of SD and CS which has a density of 1980 kg/m3 and strength of 18.4 N/mm2. Hydrophobic compounds can be included into sawdust to mitigate its high water absorption rate.

Keywords: Coconut shells; Expanded polystyrene; Lightweight concrete; Sawdust

INTRODUCTION

Concrete is a highly prevalent construction material in contemporary society. The pursuit of reducing the weight of this material has been the focus of research that has posed challenges for both scientists and engineers. The primary difficulty in producing a lightweight concrete lies in reducing its density while simultaneously preserving its strength and minimizing any negative impact on cost. A common method for reducing concrete density is to add light aggregates to the mix design. Typical concrete consists of four constituents: cement, crushed stone, river sand, and water. Lightweight aggregates typically replace crushed stone and sand as components. Lightweight concrete is often manufactured by using either natural or synthetic lightweight particles, or by introducing air into a concrete mixture through injection. The lightweight aggregates often used in lightweight concrete construction include pumice, perlite, expanded clay, vermiculite, coal slag, sintered fly ash, rice husk, straw, sawdust, cork granules, wheat husk, oil palm shell, and coconut shell. (Basri, Mannan, & Zain 1999), (Mannan & Ganapathy 2002).

As a result of the increasing costs of construction materials, including cement, crushed stone (coarse aggregate), and fine sand (fine aggregate), it is necessary to explore the utilization of locally accessible alternative building materials. Considering that a significant portion of building construction projects involves concrete work, it logically follows that a decrease in the production cost of concrete will lead to a corresponding decrease in the overall cost of building construction. Maduabum and Munonye, (2025) opined that reducing cement usage, accelerates construction, and lessens the need for skilled labour. The expensive expense of construction materials has had a negative influence on many individuals in Nigeria, prompting them to resort to unscrupulous practices in order to complete building projects. Consequently, this has resulted in structural failures in these buildings.

In a study conducted by Obakin (2018) that examined sustainable housing in Nigeria, it was discovered that corn cob ash is a feasible and environmentally friendly source of pozzolan. maize cob ash is generated by utilizing maize cob as fuel in operations, rather than being exclusively burned in a boiler. Furthermore, it has been established that in order to attain energy efficiency and sustainability, it is crucial to prioritize the implementation of nearly zero-energy passive building design prior to commencing construction, utilize low-energy building materials during the construction process, employ energy-efficient equipment to minimize operational energy needs, and incorporate renewable energy technologies into various applications.

In a study another study conducted by Olutoge and Obakin (2017), the effects of corn cob ash and kenaf fiber on the compressive strength of concrete were examined. The compressive strength of the composites made of kenaf fibers and corn cob ash was shown to rise with curing age from 7 to 28 days while decreasing with the amount of corn cob ash replacement for Portland limestone cement. At 7.5% fiber inclusion in the matrix and 5% corn cob ash replacement for cement, the ideal compressive strength was reached. This suggests that replacing cement with up to 10% maize cob ash would increase the material's strength for construction and other structural engineering projects, and including up to 7.5% of kenaf fiber would have a similar effect.

Fresh concrete can be shaped to different dimensions and shapes. Concrete is a cost-effective and readily available material that is extremely resistant to water (Mehta & Monteiro 2006). Nevertheless, the significant enthusiasm for utilizing normal weight concrete (NWC) has led to the over utilisation of aggregates such as granite and gravel. Consequently, this has greatly diminished the availability of natural stone deposits and caused lasting environmental damage (Alengaram, Muhit, & Jumaa. 2013.).

The rapid usage of natural aggregates raises worries about the preservation of these resources, therefore the need to replace them with other alternatives (Amarnaths & Ramachandrudu, 2012). Ries and Speck, (2010) observed that Lightweight aggregate plays important role in today's move towards sustainable concrete. Lightweight aggregates contribute to sustainable development by lowering transportation requirements, optimizing increasing the life of structural efficiency that results in a reduction in the amount of overall building material being used, conserving energy, reducing labor demand and concrete.

Coconut shells (CS) as a local material: Coconut shells are the hard, outermost layer of a coconut fruit. It is the rigid and tough protective covering that surrounds the coconut seed. Coconut shells are typically brown in color and are known for their durability and strength, they are used for various purposes such as crafting, fuel, source of activated carbon and as Substituent in lightweight concrete.

Sawdust (SD), a by-product in woodwork industries is a material used to produce particleboard. It can also serve as fuel for cooking in households. Most woodwork industries dump sawdust as waste at landfills without proper regulation causing a significant increase in landfills daily. Researches to promote an eco-friendly environment by replacing fine aggregates with sawdust in the concrete mix have been proposed. Using both the materials that are damaging the environment can be a good replacement to the traditional materials and can possibly reduce the pollution in the environment which the world is facing.

Polystyrene (EPS) is an aromatic polymer made from monomer styrene, a liquid hydrocarbon that is manufactured from petroleum by the chemical industry. Polystyrene is one of the most widely used plastics, the scale being several billion kilograms per year. Polystyrene can either be a thermoset or thermoplastic. Thermoplastics polystyrene is in a solid (glassy) state at room temperature of higher than 100^{o}C and becomes solid again when cooled.

Solid polystyrene is used for parking materials, insulation, and foam drink cups. The increasing oil prices have increased the value of polystyrene for recycling. No known microorganism has yet been shown to biodegrade polystyrene and it is often abundant as a form of pollution in the outdoor environment, particularly along shores and waterways especially on its low density cellular form (Franklin, 1999). Sand with a low fineness modulus necessitates a greater quantity of paste to achieve sufficient workability.

METHODOLOGY

The Experimental methods, physical properties, density, mixing process, curing, and assessment of the samples were discussed in this chapter.

This stage comprises of three (3) phases, (i) *The Pre- Experimental phas***e**: at this phase, all the materials and equipment needed in this research were sourced and the physical properties (density and water absorption) of material were conducted. (ii**)** *The Experimental Phase*: Conventional concrete and two types of Light Weight Concrete (EPS and CS concrete) were produced, compacted and cured at this stage. (iii) *The Post-Experimental Phase*: different assessments were carried out on the sample, these include Compressive strength and Hardened density on different days.

Materials

The material used in the course of this research are: Sawdust(SD), Expanded polystyrene(EPS), Coconuts shell(CS), Sand, Granite, Plasticisers (Master Rheobuild 858**)**, Cement and water, all materials are sourced locally within Ibadan city and are fully discussed below.

Cement

This is a cohesive substance utilized in building to unite or secure various components together typically sand and gravel, to create concrete. It is a fine powder made primarily from limestone, clay, shells, and silica which are heated to high temperatures in kiln and then ground to powder. In addition, cement hydrates when water is added to it producing a gel that hardens quickly. When cement is added to the soil and hydrated, it makes the soil water resistant by reducing swelling and increasing its compressive strength (Maduabum & Munonye, 2020). The cement used was Lafarge Cement, purchased from a cement depot located at Bodija market, Ibadan.

Sand

The fine aggregate for this project was sharp sand obtained from local sand deposit. The sand was stored in a shaded area and sheltered to ensure that the surface of the sand was dry.

Sawdust (SD)

The sawdust for this project was sourced from discarded sawdust piles near sawmills in the city of Ibadan. The substance referred to as "Aayin wood" is a finely ground powder obtained by chopping hardwoods in a sawmill (Plate 1).

Granite

The granite employed as the coarse material in this study had the highest possible amount crushed size of 20 mm. The item was acquired from a nearby vendor.

Coconut shells (CS)

The coconut shell was generated from coconut seller in Gbagi market, Ibadan, which was later crushed in small size with hammer in the Laboratory as represented in Plate 2. The high water adsorption of the CS is a result of its porosity. To mitigate this issue, the CS was immersed in water for duration of 24 hours and subsequently dried under sunshine for 60 minutes before casting. To prevent issues with the water-to- cement ratios.

Expanded polystyrene (EPS)

The EPS was sourced from Iwo road Ibadan, which was later crushed in to fine aggregate and coarse aggregates by manual grater and plier respectively. The EPS was replaced at 10%, 20% and 30% for both fine and coarse aggregates (Plates 3 and 4)

Master Rheobuild 858 plasticiser

Master Rheobuild 858 plasticiser is a pre-made, powerful water-reducing substance that is used to create concrete with a high level of fluidity while maintaining its flexibility to be worked with. The product is devoid of chloride. The recommended dosage ranges from 0.8 to 2.0 litres per 100 kg of cementitious material. The water content for the combination was diluted by half.

Plate 1 : Sawdust
Source: Field study (2025)

Plate 2 : Coconut Shells
Source: Field study (2025)

Plate 3: EPS Coarse aggregates
Source: Field study (2025)

Plate 4: EPS Fine aggregates
Source: Field study (2025)

Methods

Fineness Modulus
The fineness modulus is a measure used to determine the overall coarseness or fineness of an aggregate. Calculating the fineness modulus of fine aggregates is essential for determining the mixture proportion, since the gradation of sand has the most substantial influence on workability. Sand with a low fineness modulus necessitates a greater quantity of paste to achieve sufficient workability.

Water Absorption Test
1 Kg of each samples was weighed and recorded. The samples were immersed in water for duration of 24 hours. The test sample was extracted from the water and then thoroughly dried with a towel until it reached a state of saturation and surface dryness. Then the SSD weight was recorded.

Concrete Mix

There were three different concrete mix: OPC concrete, Expanded Polystyrene concrete, Coconut and Sawdust concrete

Preparation of OPC concrete

OPC concrete was prepared using a standard manner, all aggregates was poured in an electric concrete mixer and was mixed thoroughly, the mixed concrete was poured into cast iron moulds with interior dimensions of 150mm x 150mm x 150mm. These moulds were prepared by cleaning and applying oil to prevent the concrete from sticking. The concrete was poured into the mould in three layers, with each layer being compacted using 25 strokes of a rod. This process ensured that the concrete was thoroughly compacted and completely filled the mould, preventing any defects such as honeycombs or air traps. These defects can ultimately weaken the concrete and reduce its strength. Excess material was removed and the surface was levelled and labelled with hand trowel for easy identification. The samples were labelled as C0, After 24 hours of casting, the specimens were removed from the moulds and put in a curing tank until the day of testing, which occurred at 7, 14, and 28 days.

Preparation of Expanded Polystyrene (EPS) concrete

EPS concrete was prepared by mixing all aggregates, sand, granite, EPS (fine and coarse aggregate) thoroughly to achieve homogeneous mixture before the solution of plasticiser was added, followed by the remaining water content. The fine and coarse aggregate was replaced with EPS at 10%, 20% and 30%. The concrete was compacted and removed from the mould same as the OPC concrete. The concrete was labelled E1, E2 and E3 respectively and cured for 7, 14 and 28 days before the test could be carried out.

Preparation of Coconut and Sawdust (CS) concrete

CS concrete was prepared by mixing all aggregates, sand, granite, Sawdust (as fine aggregates replacement) and Coconut shell (as coarse aggregate replacement) thoroughly to achieve homogeneous mixture before the solution of plasticiser was added, follow by the remaining water content. Coconut shell and sawdust was substituted at 10%, 20% and 30%. The concrete was compacted and removed from the mould same as the OPC concrete, The concrete was labelled S , S2 and S3 respectively and was cured for 7, 14 and 28 days before the test could be carried out.

Slump Test

According to Li (2011), the method of managing fresh concrete is heavily influenced by its qualities. The consolidation of concrete is also influenced by these factors, which might subsequently affect the properties of hardened concrete. To prevent the fresh concrete from sticking, the inner surface of the slump cone was thoroughly cleaned and coated with oil. Subsequently, a moist and rigid base of the plate was constructed, and the cone was placed on top of it and firmly secured in position by the foot. The newly mixed concrete was deposited into the cone in three distinct phases, with each layer being compressed using a rod for twenty-five strokes. This test was done in accordance with BS EN 12350-2 (2019). Subsequently, excess material was smoothed out and the cone was cautiously extracted.

Hardened Density

To ascertain the density of the concrete patterns, the samples were taken out of the water and let to sit for a few minutes to eliminate any surface water. The samples were subsequently weighed on an electronic balance. The average weight was determined by utilizing three test specimens, and these weights were then divided by the volume of each specimen. The repetition occurred at intervals of 7, 14, and 28 days. This test was done in accordance with BS EN 12390-1996-7.

Compressive Strength Test

Concrete compressive strength is the ability of concrete to resist compression or external forces that cause it to decrease in size. A compressive strength test was conducted to ascertain this capacity. The test in the present study was conducted according to the IS 4031-1988 standard. A mechanical test was conducted on the concrete cubes in the laboratory using a compression testing machine known as a Universal Testing Machine (UTM) (see Plate 5). The machine is specifically engineered to ascertain the strength and deformation characteristics of the cubes when subjected to compressive force. The concrete cubes were subjected to testing in order to determine their maximum load capacity prior to fracturing. This test has been performed in accordance with BS EN 12390-1996-3. For each testing age, three specimens were crushed for each replacement percentage of sawdust, coconut shell, and expanded polystyrene. The average compressive strength was then calculated for each percentage.

On the day of testing, the specimens were taken out of the curing tank and left on the laboratory floor for a few hours before being crushed. The test was conducted on the concrete cubes after 7, 14, and 28 days of cure. During each testing session, a grand total of twenty-one cubes were examined, with three cubes being selected from each of the categories C0, E1, E2, E3, S1, S2, and S3. Prior to the test, the weights of the cubes were measured. The cubes were carefully positioned in a horizontal and central manner within the compression platen of the machine. Plate 3.2.7 depicts the compression testing machine utilized for conducting the test. The load was steadily applied until the cubes reached their breaking point. The cubes' maximum load capacity before crushing was measured in kilo newtons (KN), and their compressive strength was measured in mega Pascal (MPa).

Mathematically, the compressive strength can be calculated as;

$$\text{Compressive Strength} = \frac{load}{Cross-Sectional\ Area}$$

Plate 5: Compressive Strength Test with UTM

Source: Field study (2025)

RESULTS AND DISCUSSION

The fine aggregates utilized in the current investigation, were well graded and conformed to grading zone II with fineness modulus of 2.74. Concrete's compressive strength with such sand grade was expected not to be affected according to the Indian Standard (383, 1970). This grading zone is characterized by a somewhat coarse texture. The addition of this grade of sand was anticipated to have no adverse impact on the compressive strength of the concrete. Figure 1 shows the grading curve of the sand used.

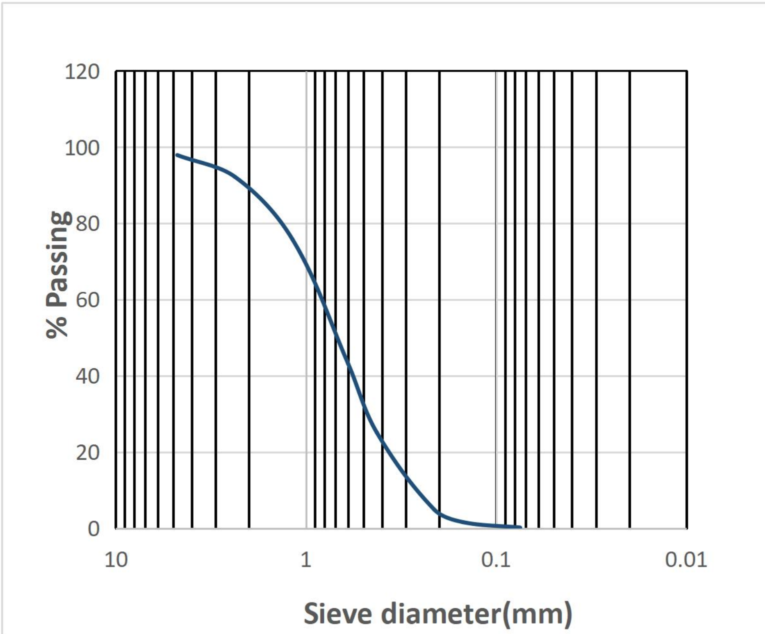

Figure 1: Particle Size Distribution Curve of Sand
Source: Field study (2025)

Density of Materials Used

It was observed that sand has a density of 1627kg/m^3 which is 6 times denser than sawdust with density of 275kg/m^3 while polystyrene have a density of 28kg/m^3 (see Figure 2,3,4,5). This indicates that the use of sawdust and polystyrene as partial substitutes for sand might result in a lighter concrete mixture. However, this also indicates that polystyrene will produce lighter concrete compared to sawdust.

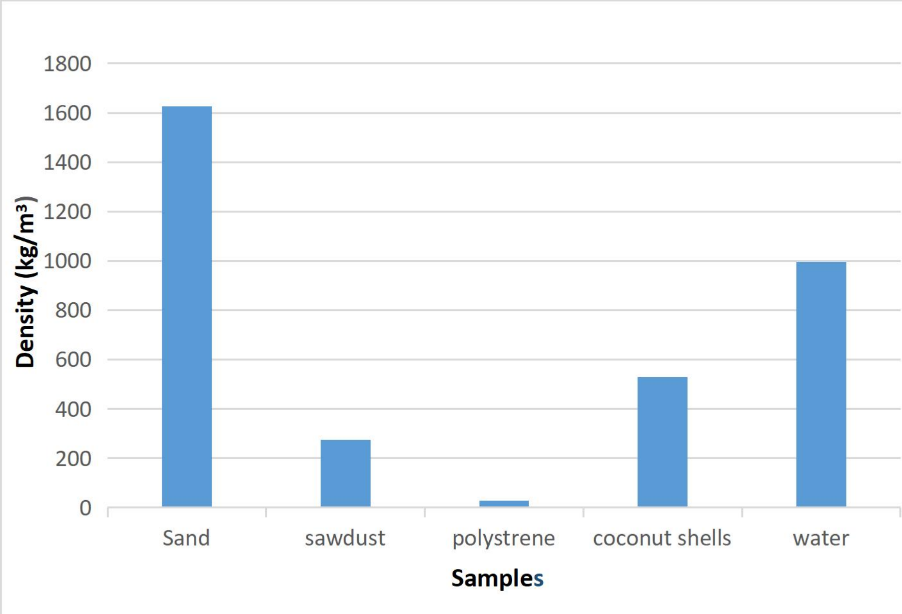

Figure 2: Density against Samples
Source: Field study (2025)

Water Absorption

The results of water absorption test are presented. It was observed that granite, CS, and EPS exhibited average water absorption rates of 0.16%, 12.61%, and 0.00% correspondingly. Due to their wood-based and organic nature, coconut shells have a higher moisture holding ability compared to crushed stone aggregates. In order to prevent the absorption of mixing water, the aggregates were pre-soaked in potable water for 24 hours before mixing. This ensured that they were in a saturated surface dry (SSD) condition during mixing, due to the high water absorption of CS.

Dry weight (D_W) = 1.00kg

Saturated Surface Dry weight (SSD_w) =1.0016kg

$$\text{Water absorption} = \frac{SSD_w - D_w}{D_w} * 100$$

$$\text{Water absorption} = \frac{1.0016 - 1.00}{1.00} * 100$$

$$\text{Water absorption} = 0.16\%$$

Water absorption for coconut shells

Dry weight (D_W) = 1.00kg

Saturated Surface Dry weight (SSD_w) = 1.1261kg

$$\text{Water absorption} = \frac{SSD_w - D_w}{D_w} * 100$$

$$\text{Water absorption} = \frac{1.1261 - 1.00}{1.00} * 100$$

$$\text{Water absorption} = 12.61\%$$

Water absorption for expanded polystyrene

Dry weight (D_W) = 100 g

Saturated Surface Dry weight (SSD_w) = 100 g

$$\text{Water absorption} = \frac{SSD_w - D_w}{D_w} * 100$$

$$\text{Water absorption} = \frac{100 - 100}{100} * 100$$

$$\text{Water absorption} = 0\ \%$$

Slump Test

The slump test was conducted to assess the workability of concrete with varying fractions of sawdust and coconut shells, which were used as partial replacements for sand and granite. The test was performed at a water cement ratio of 0.5. The result shows that the workability of concrete was found to diminish as the proportion of SD, CS, and EPS used as substitutes for sand and granite in the mixture increased.

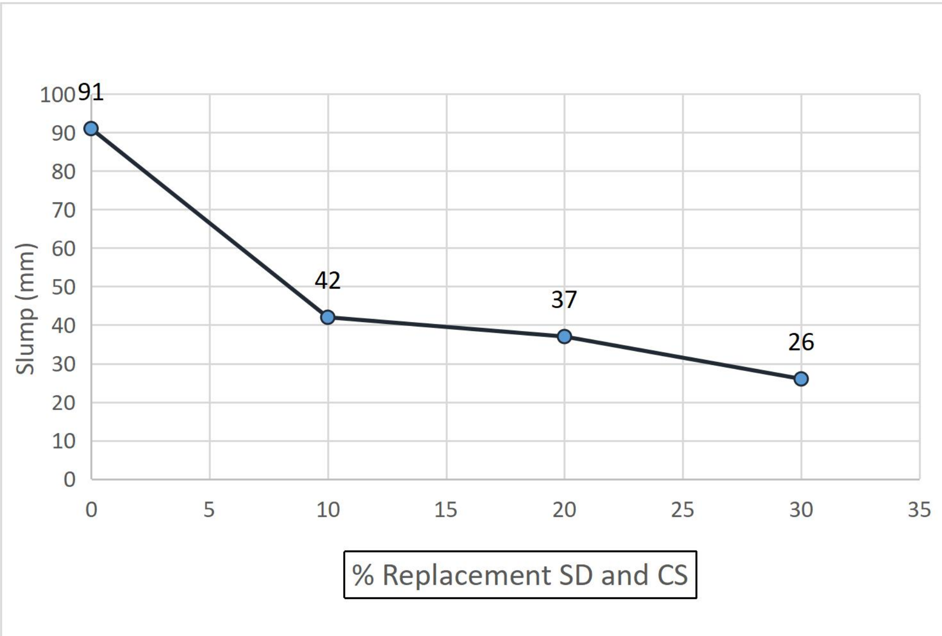

Figure 3: Density against Samples
Source: Field study (2025)

Hardened Density

Figure 3 displayed the outcomes of the average density of concrete specimens acquired from the hardened density test on SD and CS replacement. It was observed that the densities of sawdust replacements at 0%, 10%, 20%, and 30% after 28 days of curing are 2447 kg/m3, 2198 kg/m3, 2081 kg/m3, and 1980 kg/m3, respectively, this indicated that as the sawdust content increases there is decrease in concrete density. However, 30% replacement falls within the lightweight density requirement.

Figure 3 displays the density of EPS replacement at different percentages (0%, 10%, 20%, and 30%) after 28 days of curing. The corresponding densities are 2447 kg/m3, 1884 kg/m3, 1752 kg/m3, and 1653 kg/m3, respectively. The density of concrete decreases as the EPS content increases. However, all the cube densities met the minimum requirement for light weight concrete density i.e. 800 to 2000 kg/m^3.

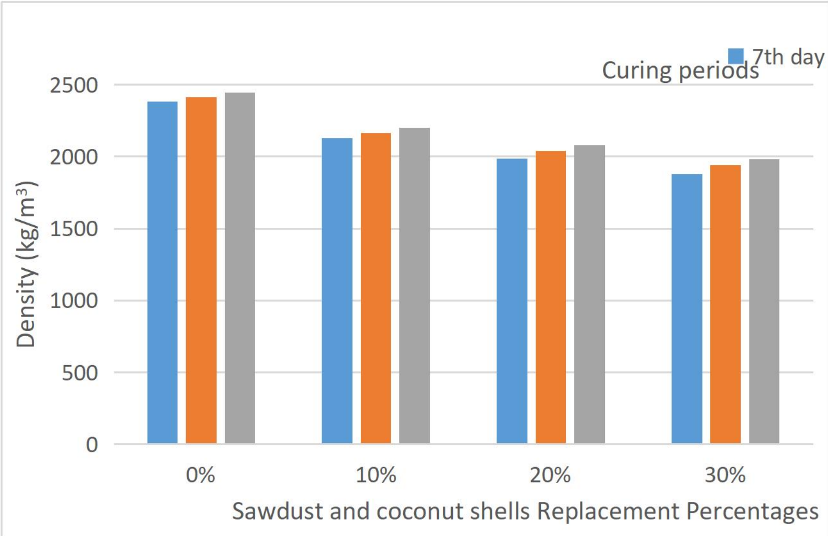

Figure 4: Hardened Density (kg/m3) with SD and CS Replacement
Source: Field study (2025)

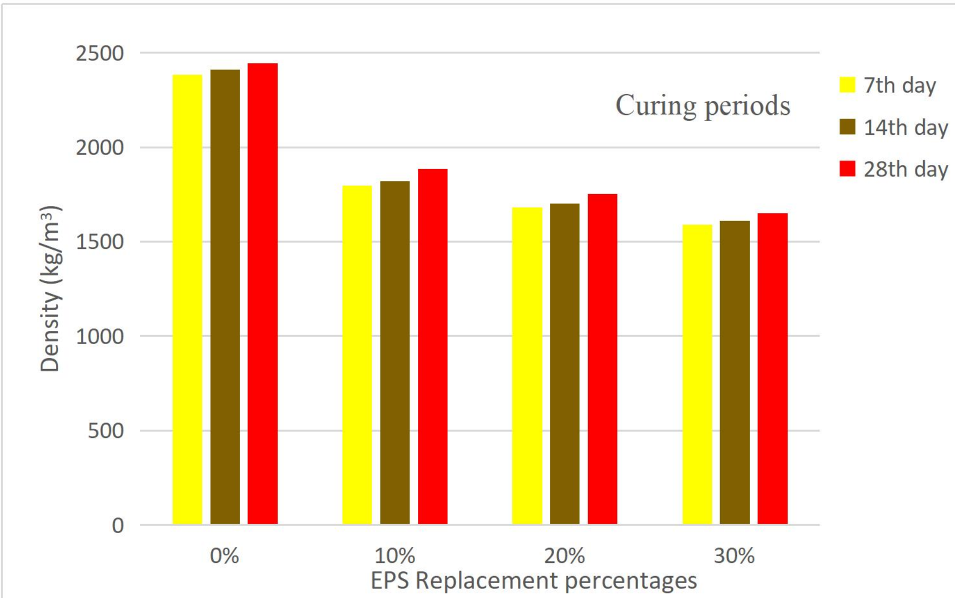

Figure 5: Hardened density (kg/m3) with EPS replacement
Source: Field study (2025)

Compressive Strength

It was observed that at 28 days, the control concrete C0 had an average compressive strength 34.8 N/mm which met the target strength, also it was deduced that control concrete has the highest strength compare to EPS concrete and SD concrete.

It was demonstrated in Fig. 7, that the compressive strength with 10% replacement of SD and CS had the highest strength compared to other replacement with 28 N/mm^2 at 28days. This shows that as the SD and CS content increases, compressive strength reduced.

For the EPS concrete, the results shows that the compressive strength slightly reduced from 25 N/mm^2 to 18 N/mm^2, the reduction in the compressive strength of the concrete is due to the rise in the EPS content.

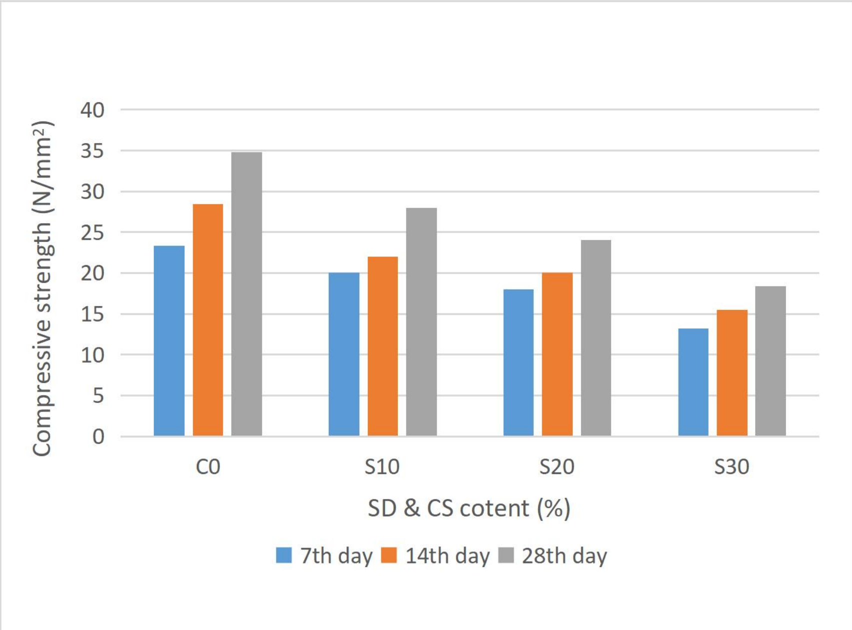

Figure 6: Compressive strength of SD and CS percentages replacement
Source: Field study (2025)

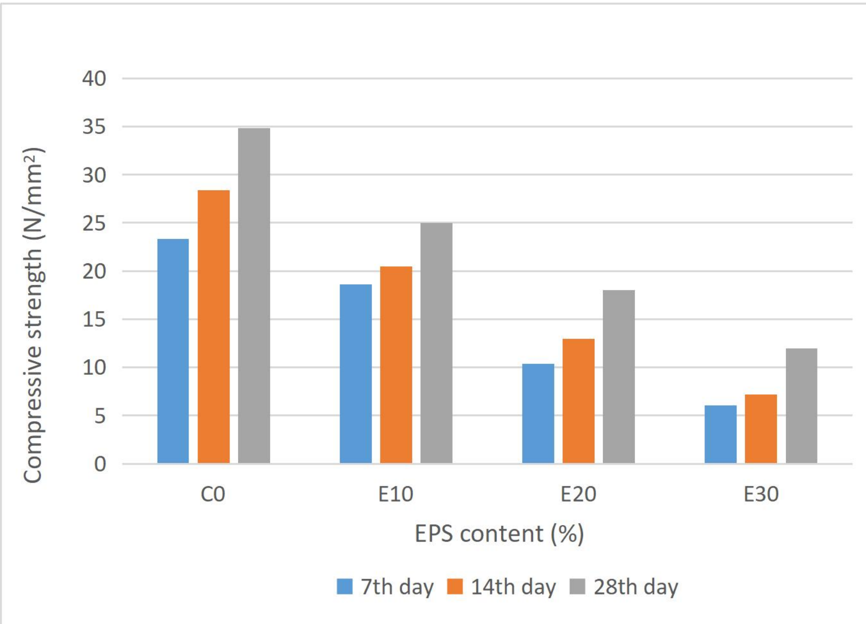

Figure 7: Compressive Strength of EPS Percentages Replacement
Source: Field study (2025)

CONCLUSION AND RECOMMENDATION

Conclusion

The present study examined the impact of substituting sand and granite with SD, CS, and EPS on density, workability, and strength. Based on the results, the following deductions were made:

i. Lightweight concrete density was achieved at 10% of EPS replacement with density of 1884 kg/m^3 while Lightweight concrete was achieved at 30% of SD and CS replacement with density of 1984 kg/m^3 , Fig. 5.
ii. The compressive strength of EPS at 10% replacement falls in M25 range and the compressive strength of control meet the target strength 31N/mm^2, Fig 7.
iii. This sawdust concrete is suitable for applications where high compressive strength is not a primary need, such as roadside curb construction, wall panels, partition walls, and similar uses. Additionally, it functions as a remedy for the disposal of SD, CS, and EPS.
iv. By substituting sand with sawdust (SD), crushed stone (CS), and expanded polystyrene (EPS) in concrete, the cost of concrete might theoretically be reduced since these materials can be produced at minimal or no cost.
v. As the proportion of EPS used in the concrete increases, the samples exhibit a higher degree of ductile failure. This indicates that concrete made with EPS has superior energy absorption capabilities compared to traditional concrete.

Recommendation

Waterproofing agents can be incorporated into sawdust to mitigate its high water absorption rate.

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