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Split Tensile Strength of Palm Kernel Shell and Expanded Polystyrene Composite Coarse Aggregates Lightweight Concrete

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Abstract

The purpose of this study was to examine the bulk density and split tensile strength of concrete that was completely substituted with composite Palm Kernel Shell (PKS) and Expended Polystyrene (EPS) for regular weight coarse aggregate. In the majority of nations worldwide, the environmental effects of managing agricultural and industrial waste have been a major source of worry. Conventional aggregate concrete's high density and self-weight, together with the environmental issues associated with their extraction, have equally alarmed stakeholders in the construction sector. Contrary to the aforementioned problem claims, this study concludes that using these industrial and agricultural wastes in the manufacturing of concrete is essential for social, economic, and environmental reasons. Table 1 displays the findings of the different material parameters, Figure 1 shows the concrete bulk densities at 7, 21, and 28 days of curing, which are 1640 kg/m3, 1647 kg/m3, and 1647 kg/m3, respectively. Plotting 0.054Mpa, 0.062Mpa, and 0.08Mpa split tensile strengths versus curing ages of 7, 21, and 28 days is shown in Figure 2. This study's 28-day split tensile strength of 0.08 MPa is roughly 4% of the minimum split tensile strength of 2 MPa required by ASTM C496 for normal aggregate concrete, 9% of the minimum value of 0.95 MPa determined by Nur et al. for the use of plastic waste in concrete, and 3.2% of 2.5 MPa for oil palm shell replacement of 5% for coarse aggregate. This concrete should only be used for constructions without severe loads or traffic, and not for structural lightweight concrete.

Introduction

This study's primary goal is to assess the split tensile strength of concrete made with expanded polystyrene and palm kernel shell composite coarse aggregate using cylindrical concrete specimens. Additionally, the bulk density of the concrete at different curing ages and the status of the concrete (normal or lightweight concrete) are assessed. Innovative technology that uses industrial and agro-base waste is a way to modify and improve construction.

Nigerian palm oil-producing regions, such as Edo, Kogi, Enugu, Cross River, Akwa-Ibom, Benue, and parts of Osun State, produce large quantities of palm kernel shells as agricultural waste with related disposal problems. Dumping polystyrene electronic packaging material is another environmental hazard. Reusing these components in the production of concrete will promote green concrete, more building material improvements, and a high-quality environment. It is possible to address the self-weight, density, and stress problems of ordinary concrete by incorporating lightweight particles into it.

Examining the split tensile strength of expanded polystyrene composite coarse aggregate concrete and palm kernel shells will help to resolve the aforementioned concerns. It will also determine whether these materials may be used as lightweight building materials.

Activities related to the building industry around the world, such as the use of natural aggregates in the production of conventional concrete and the handling of industrial agro-base waste, especially through open-air incineration, have contributed significantly to environmental pollution. Palm kernel shells (PKS) are a byproduct of crushing palm nuts in palm oil mills to obtain palm oil. This waste product, which is primarily produced in South East Asia and Africa, is readily available in tropical regions of the world. Almost 1.5 million tons of waste PKS are produced as a result of Nigeria's high demand for palm kernel oil. The large volume of PKS waste generated raises issues with disposal and the environment. Construction industry activities around the world, such as the use of natural aggregates for traditional concrete production and the handling of industrial agro-base waste, especially through open-air incineration, have been a major source of environmental pollution. There are now a lot of researchers working on this subject. Since 1984, PKS has been investigated as lightweight aggregates (LWAs) for the construction of lightweight concrete (LWC) (Sundalian *et al.*, 2021; Kabir *et al*., 2017).

The high or increasing demand for palm oil generates large amounts of PKS waste products annually, and despite the many benefits of PKS waste, its reckless disposal or incineration without energy recovery still poses a threat to the economy and environment (Uchegbulam *et al.*, 2022).

Expanded Polystyrene (EPS) is a rigid, cellular plastic that is typically white in color and is made from pre-expanded polystyrene beads. Because of its excellent thermal insulation and strong impact resistance, it is a sensible choice in many industrial applications. Its remarkable features, such as its strong load-bearing capacity at a low weight, air tightness for controlled conditions, long-lasting, 100% water and vapour-proof capacity, ease of maintenance, speed, and economical design, are also well-known. Its lightweight yet sturdy structure further adds to its versatility in the construction industry. (Sanjeev and Ankesh 2021).

Expanded Polystyrene (EPS), a 100% recyclable product of crude oil distillation, is one alternative building material. Because EPS material slows down the rate at which natural resources like wood and stones are removed from the environment, it promotes sustainable development. EPS buildings are quick to erect, affordable, and have thermal qualities suitable for areas with severe weather. EPS materials have been shown to be structurally sound for both low-rise and high-rise buildings up to ten stories. (Hannah *et al*., 2017)

Polystyrene is a popular plastic packaging material. While alternative disposal or treatment methods have negative effects on the ecosystem, land filling is nearly non-biodegradable and takes hundreds of years to decompose. However, this material is seen to be a fantastic complement to concrete because of its strong heat conductivity, lightweight nature, and sound insulation. Expanded polystyrene (EPS) waste is produced by both enterprises and post-consumer products. They are usually disposed of by burning or landfilling, which pollutes the environment even if they don't biodegrade. Depending on the amount of expanded polystyrene injected, the properties of fresh and cured concrete vary. (Ubi *et al*., 2022; Adeda and Soyemi, 2020).

The post-consumer disposal and management of polystyrene, which is widely utilized as packaging material in both large and smaller companies, presents numerous challenges. Due to its inability to biodegrade, expanded polystyrene poses a disposal issue and is hence an environmental annoyance. Non-structural uses for expanded polystyrene concrete include partition walls, wall panels, and more. Due to its massive production and lack of biodegradability, polystyrene wastes are becoming a significant environmental hazard.

Concrete made from unconventional aggregates, like leftover polystyrene foam, has been proposed as a way to recycle polymeric resources, improve concrete's qualities, and cut costs (Abah *et al*., 2018).

According to ACI Committee 318 requirements, lightweight concrete used for structural purposes needs to have a minimum compressive strength of 17.2 N/mm2 and a density of less than 1840 kg/m3. Concrete construction requires the use of lightweight aggregate (LWA) with a unit weight of no more than 1120 kg/m3. Structural lightweight concrete has a standing density (unit weight) between 1440 and 1840 kg/m3 (Dawood and Rami 2008).

The most widely used metric for assessing the quality and properties of concrete is the 28-day cube strength, which is the crushing strength of standard 150mm cubes 28 days after mixing. (Akinpelu, *et al.,* 2019)

One important criterion for describing the mechanical characteristics of concrete is splitting tensile strength. While pavement slabs and airport runways are made for bending strength and are consequently subject to tensile forces, plain concrete dams require tensile strength to withstand earthquakes. As a result, tensile strength is crucial while designing these structures. (Denneman *et al.,* 2011)

The density of concrete, which is a measurement of the material's weight, is a critical component in determining how a building behaves. The dead load on the structure rises with the concrete's density (Shafigh *et al*. 2010).

ASTM 330 defines lightweight concrete as a mixture in which the coarse aggregate (granite or ordinary gravel) is partially or completely substituted. In some cases, the fine aggregates could also be goods that are lightweight. By reducing the dead load of a concrete structure, structural lightweight concrete primarily allows the structural designer to reduce the size of footings, columns, and other load-bearing elements. Structural lightweight concrete more efficiently achieves the strength-to-weight ratio of structural components.

With an in-place density of 1440 to 1840 kg/m³ and a minimum characteristic strength of 17.0 MPa, structural lightweight concrete is superior to conventional weight concrete, which has an in-place density range of 2240 to 2400 kg/m³. The aim of this research work is to evaluate the split tensile strength of palm kernel shell and expanded polystyrene composites aggregates concrete.

Materials and Methods

Materials and Equipment

Materials required for this research which are sourced from different locations within Nigeria are;

Palm kernel shell: Palm kernel Shells an alternate coarse aggregate in concrete was collected from Utonkom in Ado local government area of Benue state. Utonkom is one of the palm oil producing districts in Benue state

Polystyrene: In Kaduna, Kaduna state, non-biodegradable material EPS is bought from electronic sellers as an alternative coarse aggregate. By hand, the EPS material was broken up into roughly equal pieces of natural coarse aggregate.

Cement: Commonly used as the binder in concrete, regular Portland cement (Dangote brand 3X) of grade 42.5R that complies with BS and ASTM requirements was bought locally from cement vendors in Kaura Namoda, Zamfara state.

River sand (fine aggregate): In Kaura Namoda town, Zamfara state, this river-sharp sand was bought locally from River Gagale

Water: Potable water from a borehole at the Federal Polytechnic's Civil Engineering department in Kaura Namoda, Zamfara state, is used for casting and curing concrete.

Equipment and Tools The necessary tools and equipment are available in the lab where the research experiment is being conducted and include a digital weigh balance, a set of sieves, a sieve brush, cylindrical cube molds that are 300 mm long by 150 mm in diameter, concrete compaction tapping rods, a set of slump testing apparatus, a precise compression and tensile testing machine, shovels, hand trowels, head-pans, and wheelbarrows.

Research Experiment:

Test for Material Properties: The specific gravity and bulk densities of cement, sand, palm kernel shell, and EPS, as well as the cement's setting time, PKS's water absorption, and the particle size distribution of sand and PKS, were among the common properties of the materials used in this study that were tested in accordance with the specified standard code of practice. The results are shown in table 1 below.

Table 1: Summary of Material properties

Materials	**properties**				
	Specific gravity	Bulk density (Kg/m^3)	Water Absorption (%)	Particle size distribution (FM)	Setting time (min)
Cement	3.11	1470	-	-	Initial - 48 Final - 237
Sand	2.58	1604	-	2.6	
PKS	1.301	692.4	1hr. - 13.1% 24hrs. - 21.02%	4.16	
EPS	0.103	15	-	-	-

Batching and Mixing:

For a mix ratio of 1: 2: 4 and a water/cement ratio of 0.55, the components were batch by weight. In order to get an appropriate and cohesive mix density, the components were initially dry mixed before being physically combined in the laboratory. In order to create the wet concrete paste that will eventually solidify and harden into a material resembling rock, wet mixing is then carried out with the addition of the water amount determined by the mixture design. Concrete was completely submerged in water in a curing tank at a standard temperature to cure it after 24 hours of casting and de-molding.

Sample Testing:

Nine cylindrical cubes with dimensions of 300 mm in length and 150 mm in diameter were cast, three for each of the seven, twenty-one, and twenty-eight-day curing ages. Using a precise testing machine, laboratory experiments were carried out in compliance with the project's specifications to measure the concrete's split tensile strength. The density of the concrete at the recommended curing ages was also ascertained. The mean strength was recorded as the attained strength at each curing age. The specimen's measured splitting tensile strength (Ft) was calculated using the following formula, which was accurate to within 0.05N/mm^2.

Tensile strength Ft.= $\frac{2P}{\pi ld}$

Ft. = Split tensile strength (Mpa.)

P = load at concrete failure (N)

L = length of specimen (mm)

D = diameter of specimen (mm)

Concrete Mix Design Calculation

The aggregate composition of concrete is estimated using this method, and in this instance, the aggregates are cement, water, fine aggregate, and coarse aggregates (palm kernel shell and expanded polystyrene composite). Based on the concrete grade (M15), the mix design uses a 1:2:4 specifications, a cylindrical concrete cube that is 300 mm long and 150 mm in diameter, and a water-to-cement ratio (w/c) of 0.55. The materials composition from this calculation is contained in table 2

Table 2: components of materials by weight and volume.

Components	Weight (kg)	Volume (m^3)
Cement	10	0.0056
Fine Aggregate	55	0.03429
Palm Kernel Shell (PKS)	25.85	0.03733
Expanded Polystyrene (EPS)	0.55	0.03667
Water	5.5	0.0055

Results and Discussion

Results

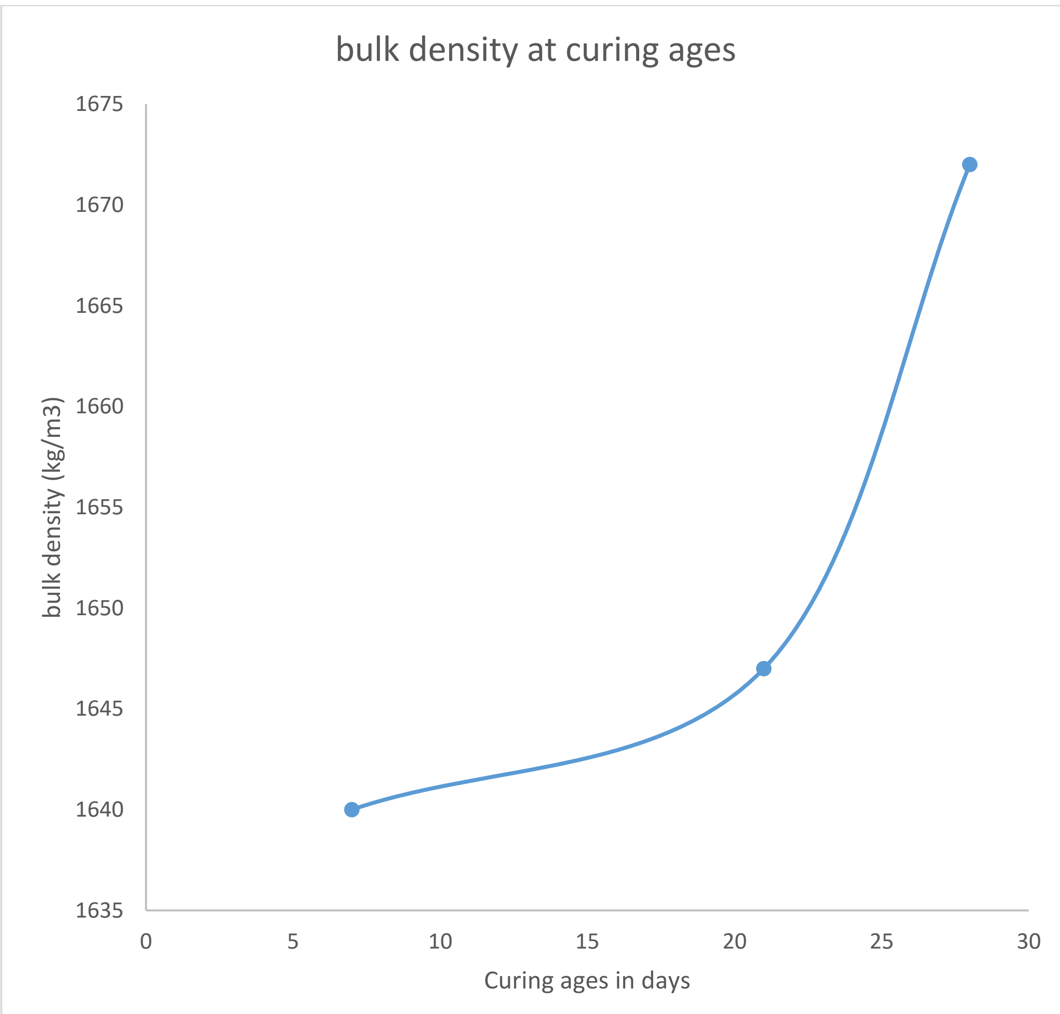

Figure 1: Bulk density against curing ages in days

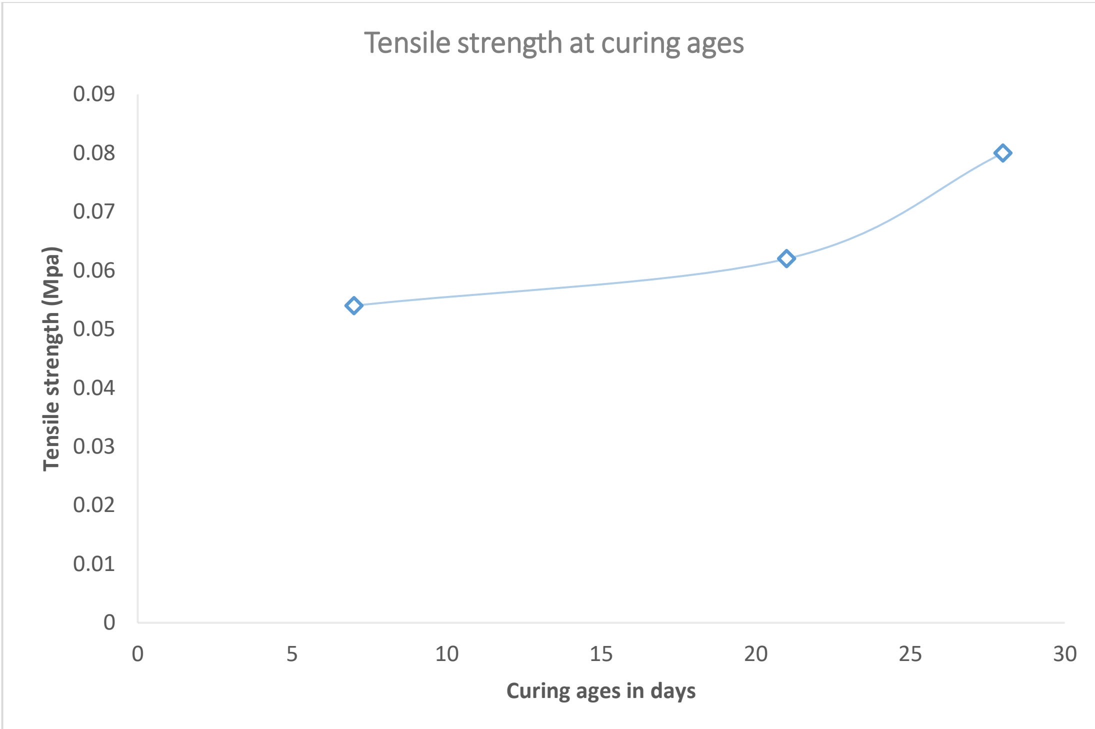

Figure 2: Split tensile strength against curing ages in days

Discussion of Results

The total replacement of the coarse aggregate with palm kernel shell and polystyrene aggregate increases the surface area of the aggregates and as such reduced the workability of the concrete mixtures. As shown in Figure 1, the concrete bulk densities measured at 7, 21, and 28 days of curing were 1640 kg/m3, 1647 kg/m3, and 1647 kg/m3, respectively. The bulk density of lightweight structural concrete, as defined by ACI 318, Dawood & Rami (2008), is between 1440 kg/m3 and 1840 kg/m3. The lightweight nature of the expanded polystyrene and palm kernel shell composite coarse aggregate materials was also suggested by this. Figure 2 displays the concrete's split tensile strengths at 7, 21, and 28 days, which are 0.054 MPa, 0.062 MPa, and 0.08 MPa, respectively.

According to ASTM C496 - 2021, the split tensile strength of standard aggregate concrete ranged from roughly 2 to 5 MPa at 28 days, which is typically 8 to 12% of the compressive strength. In contrast to his control value of 2.26 MPa, (Nur *et al*., 2021) obtained 28-day split tensile strength values of 0.95 MPa to 1.82 MPa by replacing aggregate with plastic trash. The split tensile strength values ranged from 2.5 MPa to 4.5 MPa, as oil palm shell was utilized as an aggregate substitute in percentages of 5, 10, 15, and 20%. About 4% of the minimum split tensile strength of 2 MPa required by ASTM C496 for regular aggregate concrete and almost 9% of the minimum value of 0.95 MPa determined by Nur *et al*. for the use of plastic trash in concrete are represented by the 28-day split tensile strength of 0.08 MPa found in this study. Approximately 3.2% of 2.5Mpa is used to replace 5% of coarse aggregate concrete with oil palm shell. It is clear that, in comparison to the other materials mentioned above, the composite coarse aggregates of PKS and EPS have a very low tensile strength. These materials' characteristics, such as the pore voids of PKS, which cause excessive water absorption, and the water-repellent, incompressible, and compaction-difficulty of EPS, which create voids that the fine aggregate and cement may not sufficiently fill to enhance strength gaining, may be related to the concrete's low strength.

Findings:

1. The bulk density of the concrete produced with these composite materials fall within the range specified for structural lightweight concrete.
2. The split tensile strength at 28 days is very low compared with the specification of ASTM C496 and results of other researchers when other lightweight aggregates are utilised.
3. The result of the workability of the concrete based on slump test signified that the concrete has very poor workability and low strength.
4. The nature and characteristics of the composite materials PKS and EPS can influence the concrete strength.

Conclusion and Recommendations

Conclusion: Structural lightweight concrete can benefit from composite aggregate concrete that is based on bulk densities at different curing ages and other characteristics like sound insulation. In terms of strength, the concrete is not appropriate for structural lightweight concrete, but it may be used in buildings as non-load-bearing components like window hoods and partitions. Additionally, it is more appropriate for constructions where large loads or traffic are not anticipated. Concrete's strength can be affected by the water-to-cement ratio and the properties of the composite elements.

Recommendations:

1. This concrete should not be used as structural lightweight concrete
2. The use of this concrete should be limited to non-load bearing structural elements, and structures without heavy loads or traffic.
3. A higher water to cement ratio should be tried by other researchers based on water absorption characteristic of PKS.
4. To enhance the strength, concrete additives/ plasticizer may be employed during production of concrete with these coarse aggregate combinations.

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Plates

PLATE 1. EPS

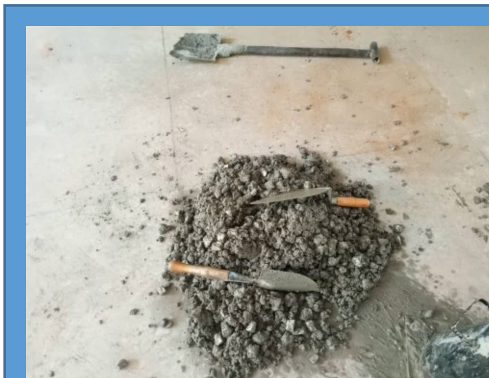

PLATE 2. COMPOSITES MIX

PLATE 3. CYLINDRICAL CONCRETE.

PLATE 4. TENSILE TEST

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