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Implications of Palm Kernel Shell-Filled Plastic Bottles on the Structural Behavior of Concrete Slab

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Abstract

The implications of palm kernel shell (PKS)-filled plastic bottles on the structural behaviour of concrete slabs were carried out by comparing the flexural performance of conventional solid concrete slabs to concrete slabs incorporated with plastic bottles filled with palm kernel shells and placed vertically, horizontally, and diagonally at the neutral axis of the slab as per Bubble Deck Slab technology. One-way slab specimens of size 700 × 300 × 150 mm thick were produced and subjected to a four-point flexural load test. Findings from the study indicated that: (1) The PKS-filled bottle slabs deflected more than the conventional solid slab, hence making them more flexible than the conventional slabs and, as such, giving the occupants enough time to evacuate. (2) The flexural strengths of the PKS-filled bottle slabs exceeded those of conventional slabs by 18.3% and 10.9%, respectively, for five and ten percentages of the volume of slab concrete occupied. (3) The condition of the PKS, either dry or saturated, coupled with the bottle arrangement (either vertical, horizontal, or diagonal), does not, however, cause any significant change to the performance of the PKS filled bottle slabs in terms of load carrying capacity, deflection, and strength.

Keywords: Concrete Slab; Plastic Bottles; Environment; Flexural Strength; Deflection.

1. Introduction

The present study investigates the implications of palm kernel shell-filled plastic bottles on the structural behaviour of concrete slabs. According to Sandanayake et al. (2020) [1], countries all over the world are seeing a steady rise in various sorts of waste as a result of the exponential growth in population (2020). To reduce waste generation, effective management, disposal, and reuse are required. According to studies, one of the major businesses that uses a lot of resources and has an impact on the environment is building. Unquestionably, concrete has been designated as the main building construction material that requires a significant quantity of energy and uses the majority of virgin materials. As a result, it was carefully examined if recycling waste into building materials like concrete might help the environment. Every year, a sizable amount of agricultural waste is produced, including shells, discarded palm fibre, and empty fruit bunches. The annual increase in the disposal of palm oil and kernel shells not only consumes a lot of land but also results in serious problems, including air pollution and substantial risks to human health and safety after combustion. Many studies have focused on using agricultural waste, including PKS, as an ingredient in building materials. Additionally, academics in the construction spheres have recently developed a keen interest in the use of used plastic bottles as building materials. According to UNEP (2018) [2], research indicates that if current consumption patterns and waste management practices are not changed, there will be a tremendous rise in the amount of plastic litter in landfills and the environment by 2050, totaling nearly 12 billion tonnes. According to Abergel et al. (2017) [3], the building sector is now dealing with the following two major challenges: (a) To promote the use of eco-friendly building materials in place of natural

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resources, particularly sand and crushed rock. (b) To reduce CO_2 emissions into the atmosphere by employing eco-friendly materials in building components and products. The aforementioned inputs serve to reinforce the necessity of conducting thorough academic and experimental research into the viability of using waste plastic (plastic bottles) and agro-waste (PKS) as sustainable building materials and components. Hence, the need to ascertain the impact of palm kernel shell-filled plastic bottles on the structural behaviour of concrete slabs.

Palm kernel shell is an agricultural waste that has achieved success in the manufacturing of concrete. Scientists have been using palm kernel shell (PKS) as light weight aggregate (LWA) to replace traditional normal weight aggregate (NWA) in building and road construction throughout Africa and Southeast Asia for the past three decades. PKS has the advantage of having greater impact resistance than NWA, which is one of its benefits, as observed by Okpala (1990) [4]. Numerous studies have been written about the structural, functional, mechanical, and physical characteristics of PKS as a lightweight aggregate. PKS is taken as a waste product from the oil palm tree Okpala (1990) [4]. Its scientific name is Elaeis guineensis, and it is primarily found in Eastern and Western Africa, as buttressed by Pantzaris & Mohd Jaafar (2002) [5]. In the past, the cultivation of palm oil trees was restricted to the Eastern part of Africa because it was believed that they were first cultivated in the time of the Pharaohs, some 5000 years ago. However, in recent years, Southeast Asian nations like Indonesia and Malaysia have made palm oil tree cultivation a top priority. Large numbers of palm oil trees can be found in Asia, America, and some parts of Africa, notably Ghana and Nigeria, according to a report by Olanipekun et al. (2006) [6]. About 90% of the world's palm oil exports originate from Malaysia and Indonesia, and the total production of palm oil in just Malaysia is 52.8% [5]. The palm oil nut contains two types of oil: palm oil and palm kernel oil. Palm oil is derived from the mesocarp, a fleshy and oily layer, while palm kernel oil is extracted from the inner core, also known as the palm kernel (endosperm). Palm kernel shell refers to an endocarp layer that surrounds the Palm kernel [5, 6]. In the exposition of Okpala (1990) [4], buttressed by Teo et al. (2006) [7], Malaysia produces more than 4 million tonnes of PKS annually, and according to research by Ramlee et al. (2019) [8], 5 million hectares (ha) of palm oil trees are anticipated to exist by the year 2020. Malaysia is likely to have a significant amount of palm kernel shell waste because it is the second-largest producer of palm oil in the world. Scientists have chosen to investigate the inventiveness of PKS as a light-weight aggregate as part of steps to facilitate and increase the preservation of the environment [9, 10].

On multiple occasions, it was suggested that PKS be used as a substitute for asphalt as a base material for roads [6, 9]. In a study by Teo et al. (2006) [7], PKS was used as the lightweight aggregate (LWA) to design a structure with a footbridge and one suspended floor, and the structural behaviour was closely observed on both accounts. PKS is also employed as a road base material, a granular filter material for water treatment, and a roofing material for floors [6]. According to Okpala (1990) [4]. PKS has a thermal conductivity of 0.19 Wm1 K1, which is significantly less than the value of 1.4 Wm1 K1 for typical coarse aggregate. Because of the excellent insulating capacity and low thermal conductivity of lightweight concrete built with PKS, a more favourable environment and reduced energy consumption can be achieved. PKS has recently been used in tests as a stand-in for poor lateritic soil.

However, data analysis from Amu et al. (2008) [11] shows that the composite PKS and asphalt mix is insufficient for the base course, subgrade, and subbase in highway construction. The suitability of palm kernel shells as a partial replacement for coarse particles in asphaltic concrete was examined by Ndoke (2006) [12]. Olutoge (2010) [13] looked into whether sawdust and palm kernel shells might be used in place of fine and coarse aggregate while making reinforced concrete slabs. He came to the conclusion that a substitution of 25% sawdust and palm kernels decreased the cost of producing concrete by 7.45%. Additionally, he suggested that sawdust and palm kernel shell might be used in place of some of the sand and granite used in the production of lightweight concrete slabs. When coconut shells and palm kernel shells were used as a substitute for coarse aggregates in concrete, Olanipekun et al. (2006) [6] found that coconut shells outperformed palm kernel shells in terms of performance. This study was carried out to ascertain how to effectively utilise such resources that are readily available locally (PKS, plastic wastes), and by so doing, to investigate the implications of palm kernel shell-filled plastic bottles on the structural behaviour of concrete slabs.

According to the United Nations Human Settlements Programme's research, it is projected that 1.6 billion people live in housing that is subpar or unfit for human habitation (2020). Therefore, it is necessary to address the housing crisis by utilising regional, affordable materials and processes, as Danso has pledged (2013) [14]. In order to improve housing stock, replace naturally resource-depleting building materials like sand and stone, and lessen environmentally harmful deforestation, the United Nations Commission on Human Settlement has also required the building and construction industries to seek out Alternative Building Materials (ABM). In comparison to conventional materials, agricultural wastes are advantageous for low-cost building [15]. Utilizing waste materials in building helps safeguard the environment and conserve natural resources [16]. In order to replace cement in the manufacturing of concrete, Nimityongskul & Daladar (1995) [17] looked into the usage of coconut husk ash, maize cob ash, and peanut shell ash. Clay brick production using water works effluent was studied by Slim & Wakefield (1991) [18]. It cannot be stressed enough how plastic has influenced every facet of modern culture. Plastic packaging is commonly discarded as waste since it is frequently used for a single purpose and is mass produced at a low cost. Depending on its characteristics, non-biodegradable waste may persist on Earth for more than 300 years. The UNEP (2018) [2], issued a warning, predicting that unless the current pattern of plastic consumption and disposal practises are improved, there will be a significant increase in plastic litter in landfills and the environment by 2050, amounting to about 12 billion tonnes. Recycling plastic items by reusing them for different purposes, such as using them in building slabs, was highlighted by Ghansah et al. (2015) [19] as one of the sustainable options for avoiding the UNEP report's warning. Due to various studies that have proven its feasibility as a construction material and as a method of getting rid of plastic waste, plastic bottles have been widely embraced in the building and construction industries. The foregoing submissions provide more grounds for advancing this present study so as to create awareness about the implications of palm kernel shell-filled plastic bottles on the structural behaviour of concrete slabs. The findings thereof would go a long way toward advising the construction industry on the effectiveness of using ABM such as PKS and plastic bottles in concrete slabs.

By incorporating PKS-filled plastic bottles into concrete slabs based on the Bubble Deck Slab (BDS) idea, this project intends to raise awareness about the exploitation of wastes (PKS and plastic bottles) in construction by presenting proof on its performance. Specific objective to investigate and compare the structural performance under load by undertaking flexural tests on the slab specimens with respect to: Load Carrying Capacity, Deflection Behaviour, Flexural Strength, Crack Pattern and Mode of Failure.

The assumptions are that:

- There is high increase in the world's population
- More people (about 1.6 billion) are thought to be residing in unfit and uninhabitable homes worldwide.
- In order to improve the housing stock and substitute building materials made of dwindling natural resources like sand, stone, and wood, there is the possibility of looking into Alternative Building Materials (ABM).
- Plastics and PKS wastes are reported to be more sustainable in solving the global challenges confronting the construction industries.
- By presenting data on its effectiveness, it may be possible to raise awareness about using plastic and PKS waste in buildings.

2. Literature Evidence

2.1. Studies on Palm Kernel Shell (PKS) Employed in Construction

A variety of empirical evidences support the use of PKS in construction. Thus, Alengaram et al. (2010) [20], Osei and Jackson (2012) [21], Olusola & Babafemi (2013) [22], Yew et al. (2014) [23], Foong et al. (2015) [24], Mo et al. (2015) [25], Aslam et al. (2016) [26], Adewuyi & Adegoke (2008) [27], Agbede & Manasseh (2009) [28], Osadebe & Ibearugbulem (2009) [29]. It is imperative to note to highlight that the majority of these research' findings point to the acceptability of employing both palm kernel shell as coarse particles in lightweight concrete. This is why this present seeks to accentuate the exact implications of PKS-filled plastic bottles on the structural behaviour of concrete slabs. PKS can be used to create concrete with a normal strength of between 20 and 30 MPa [30] with the right mix design. Since 1984 [31], research has been done on PKS as a lightweight aggregate to create lightweight concrete, which has caused significant changes in the concrete industry. Imam and Usman [32] found that palm nut shell can be used as a building material for inexpensive structures since it has a compressive strength of 18 N/mm². This may help with trash reduction indirectly.

Gibigaye et al., (2017) [33] investigated the proportioning of mixture for oil palm kernel shell lightweight concrete with batches of 1:1.6:0.96 and 1:1.53:0.99 for C:S:OPKS ratio with cement content of 450kg/m³, which produced a minimum slump of 20 mm, density between 1800 and 1900kg/m³, and minimum compressive strength of 15N/mm². Yusuf et al. (2018) [34] carried out an experiment on the structural application of lightweight concrete incorporated with palm kernel shells adopting a mix ratio of 1:1:2 and w/c of 0.5. PKSC beam at 28 days showed flexural strength of 2.883 N/mm² and deflection of 0.947 mm indicating resistance to load of 3981N.

The impacts of coconut and palm kernel shells on pervious concrete pavement were compared by Khankhaje et al. (2017) [35] in their study. In their study, thirteen distinct mixtures were created using 6.3 mm natural gravel and replacements of 4.75 mm and 6.3 mm CS and PKS, respectively, at various percentages. The compressive strength decreased when CS and PKS were used to replace natural gravel, although there was a significant correlation between the mechanical and durability parameters. According to the compressive strength value, pervious concrete pavement's field qualities can be predicted by using it as a quality control test.

In an effort to create a sustainably produced OPS lightweight concrete with improved mechanical properties, Islam et al. (2016) [36] substituted agricultural solid wastes of oil palm shell (OPS) and oil palm fuel ash (OPFA) at 10-15% for nominal concrete elements. The flexural and split tensile strengths of OPSC decreased as the proportion of POFA was increased, although 10% provided the best sustainability performance. Khankhaje et al. (2016) [37] created an affordable, lightweight pervious concrete by substituting palm kernel shell (PKS) with gravel with sizes ranging from

4.75 to 6.3 mm, and from 6.3 to 9.5 mm. Similar to this, PKS was utilised to substitute limestone from 25% to 75% of the time to cut costs. Results revealed a maximum compressive strength of 12 N/mm² and greater permeability values between 4 and 6 mm/s, which can be used in parking lots and moderately trafficked roadways.

By using a mix ratio of 1:2:4 and a w/c of 0.63, Oyedepo et al. (2015) [38] investigated the effectiveness of both coconut and palm kernel shell ashes (CSA and PKSA) as cement substitutes in concrete. Maximum compressive strengths of 15.4 N/mm² and 17.26 N/mm² were attained at 20% cement replacement with PKSA and CSA, respectively, and a compressive strength of 20.58 N/mm² at 28 days when 10% cement replacement with CSA was used. According to the mechanical characteristics, it can be used with both heavy and light concrete. The impact of palm kernel shell aggregate as a partial replacement for coarse aggregate on the physical characteristics of concrete was examined by Oti et al. (2017) [39]. The concrete cubes' densities and compressive strengths ranged from 1562 to 2042 kg/m³ and 12.71 to 16.63 N/mm² at age 28. Results of water absorption at 6, 11, and 21.5% were noted to be 1 hour and 24 hour, respectively.

Many observers have examined the mechanical and structural qualities of palm kernel shell lightweight concrete (PKSC) and Normal Weight Concrete to demonstrate the effectiveness of PKSC [7, 9]. Experimental studies and reports on the structural behaviour in terms of bond, flexure, and shear have all been made [7, 40]. Additionally, PKSC's durability characteristics, such as creep [40] and shrinkage [41] were contrasted with NWC. Achieving the minimal level concrete grade requirement and defining the areas where PKSC can be used will encourage the use of palm kernel shell in many civil works, eradicating the biological and environmental risks brought on by improper palm kernel shell disposal, while also lowering construction costs. In remote villages where they are easily accessible and when natural aggregates are pricey, palm kernel shells could be used for construction. The engineering characteristics of concrete built with varied amounts of palm kernel shell-filled plastic bottles as aggregate are determined in this paper. Thus, this paper aims to evaluate the performance characteristics of palm kernel shell-filled plastic bottles on the structural behaviour of concrete slabs.

2.2. Use of Plastics in Construction

Recycling waste PET was employed as a binder in polymer concrete, which, in comparison to traditional concrete made simply of cement, has higher compressive and flexural strengths [42, 43]. The compressive strength over seven days for samples with 9% resin was roughly 60 MPa [44]. According to the study Rebeiz (1995) [45], the compressive strength even reached 80 MPa when the samples contained 10% resin. An unusually rapid increase in strength that has been seen in Tawfik & Eskander (2009) [46]. After 24 hours, the compressive strength had reached 75% of its maximum. After 4 days, it had reached 83% of its maximum strength. Ordinary concrete's compressive strength reached 20% of its maximum compressive strength after 24 hours. This concrete's ability to develop its strength quickly makes it ideal for the creation of precast pieces because it expedites production.

In certain studies (like Reis, (2011) [47]), a distinct failure mode of concrete containing plastic aggregate was found. The samples lacked the typical brittle failure and two-part separation of normal concrete. Polymer concrete has a higher tensile to compressive strength ratio than regular concrete. Tensile to compressive strength ratios for conventional concrete range from 10 to 15%. In the case of plastic-based concrete, this ratio ranges from 30 to 50% [44]. Another way polymer concrete varies from conventional concrete is through its creep behaviour. According to the study, creep stresses develop relatively rapidly in new concrete compared to ordinary concrete. The polymer concrete displays more than 20% of its long-term creep within the first two days, and about 50% within the first 20 days.

Concrete made of plastic has the advantage of being less porous and absorbing less water. Ge et al. (2014) [48] found that the water absorption is barely 0.47%. This concrete was more resistant to chemical attack than conventional concrete due to these features. Therefore, plastic-based/polymer concrete is suitable for sewage pipe surfaces as well as flooring in chemical facilities. This substance is less heat resistant because of the polymer's comparatively low melting point (260 °C). As a result, the mechanical properties change as the temperature rises. Rebeiz (1995) [45], found that temperature increases from 25°C to 60°C cause a 40% decrease in compressive strength and a 35–40% decrease in elastic modulus. Polymer concrete has a higher tensile to compressive strength ratio than regular concrete. Tensile to compressive strength ratios for conventional concrete range from 10 to 15%. For plastic-based concrete, this ratio ranges from 30 to 50 percent [49]. Polymer concrete has a higher tensile to compressive strength ratio than regular concrete. Tensile to compressive strength ratios for conventional concrete range from 10 to 15% For polymer concrete, this ratio ranges from 30 to 50 percent [49].

The amount of filler and resin, the kind of aggregate, and the admixtures used in polymer or plastic-based concrete all have a significant impact on the material's mechanical properties. Miranda et al. (2014) [50] claim that as compressive strength rises, resin content also rises. Specifically, samples with 5% resin had compressive strengths of 5 MPa. For 10% resin content and even 20% resin content, the compressive strength increased to 12 MPa and 20 MPa, respectively. The maximum size of the aggregate particle has an effect on the compressive strength as well, claims the study (Yao et al. (2015) [51]). The compressive strength rose up to a particle size of 10 mm; when the particle size was raised, the compressive strength declined.

The relationship between mechanical properties and the quantity and kind of accelerator and initiator used to generate polymer concrete has been studied in a number of studies [50, 52]. Miranda et al. (2014) [50] found that the characteristics of polymer concrete are significantly influenced by the amount ratio of accelerator, initiator, and resin. Therefore, it is crucial to determine the optimal dosage ratio for these substances. The ideal initiator and accelerator contents, according to this study (Miranda et al. (2014) [50]), are 2% and 5%, respectively. In this work, cobalt naphthenate served as the accelerator and methyl ethyl ketone peroxide (MEKP) as the initiator. Methyl ethyl ketone peroxide (MEKP) and benzoyl peroxide were used in the study Mahdi et al., 2010 [52]; to make polymer concrete, and their compressive strengths were compared. This study demonstrates that using MEKP as an initiator result in an increase in compressive strength.

2.3. Studies on Bubble Deck Slabs Employed in Construction

According to reports, the slab is the crucial structural component using the most energy in a building. By removing the concrete from the middle portion of the slab, which is noted as serving no structural purpose, the BDS, or voided slab system, is used to prevent the disadvantages associated with conventional slabs regarding increased self-weight, CO_2 emissions, and huge energy consumption during the manufacturing process.

Al-Ahmed et al. (2022) [53] performed experimental and numerical investigations on seven one-way, reinforced concrete (RC) slabs with a new technique of slab weight reduction using polystyrene-embedded arched blocks (PEABs). Findings indicate that inserting the polystyrene arched blocks into the slab core significantly reduced the self-weight of the slab. On the other hand, this reduced the slab stiffness and led to strength degradation.

A study of the flexural behaviour of a BDS strengthened with FRP was conducted by Abishek & Iyappan (2021) [54]. In the study, a 75-mm plastic ball was placed between the bottom and top reinforcements within the neutral zone of a slab specimen measuring 700×300×125 mm thick. The flexural test report indicates that the load carrying capacity, flexural strength, and deflection of the bubble deck slab reinforced with FRP were 18% greater than those of the conventional slab. Orientilize et al. (2021) [55] studied experimentally a Hollow-core slab (HCS) containing waste PET bottles as an effort to reduce urban waste problems. The specimen had a length, width, and thickness of 1750 mm, 600 mm, and 150 mm, respectively. The waste PET bottles had a capacity of 1500 ml with an 80 mm diameter. The specimens were tested under a four-point loading scheme. Findings based on the results indicated that the strengths of the HCS specimens were about 12 to 16% less than those of the solid slab. However, the bending capacity of HCS specimens still met the design criteria of a RC slab. In general, the HCSs tended to behave more ductile than the solid slab.

Flexural behaviour and sustainability analysis of hollow-core R.C. one-way slabs were conducted by Mahdi & Ismael (2020) [56]. They used recycled plastic pipes to make longitudinal voids in the hollow-core slab (HCS). It was revealed that reducing the concrete volume of the hollow-core slabs by about 16.25%, 24.37%, and 32.5%, results in the first crack load being reduced by about 6.06%, 11.36%, and 16.67%, and the ultimate deflection being increased by about 8.72%, 21.57%, and 28.31% when compared with the solid slab. Also, the use of hollow-core slabs causes an increase in crack width and decrease in the number of cracks. Yaagoob & Harba (2020) [57], investigated the behaviour of a self-compacting, one-way BDS made of reinforced concrete. A flexural loading test was performed on a 1200×700×60 mm plastic ball. The deflection at cracking load and ultimate load of the BDSs were greater than those of the typical solid slab, according to study findings. In comparison to a slab with 60 mm diameter bottles, the flexural load and ultimate load are reduced when 73 mm diameter balls are used. The first crack loads in all the bubble deck slabs were lower than in the traditional slab. Ali & Babu (2019) [58] conducted a structural study on BDS, using polyethylene bubbles with a diameter of 120 mm. It was observed that a BDS has greater flexural strength and shear force capacity compared to a normal solid slab with the same properties.

The flexural strength of the BDS was the subject of research carried out by Thomas et al. (2019) [59]. Plastic balls with a diameter of 60 mm were inserted into a 600×300×120 mm slab. For the study, three distinct types of slabs made up of 9-number balls, 12-number balls, and 24-number balls were created. The investigation showed that the BDS performed in terms of flexural strength somewhat similarly to the solid slab. For the 9-number slab, 7.2% for the 12-number slab, and 14.4% for the 24-number integrated slab, less concrete was needed than for a typical slab. In the study, a significant drop in self-weight was seen.

The flexural behaviour of BDS strengthened with fibre reinforced polymer was studied by Abishek & Iyappan (2018) [54]. Three types of slabs (1) conventional solid slab, (2) BDS formed with 75 mm diameter balls, and (3) BDS formed with 75 mm diameter balls and strengthen with carbon fibre reinforced polymer (CFRP) were produced and subjected to two-points loading conditions to assess its flexural behaviour [60]. Corresponding results show that the conventional BDS formed with 75 mm diameter balls had less load carrying capacity, flexural strength, and deflection compared to the conventional solid slab specimen.

The flexural behaviour of a 600×300×100 mm BDS with 60 mm and 75 mm diameter plastic balls was researched by Dheepan et al. (2017). [61] According to a report, a slab with 60 mm diameter balls integrated into it had a higher flexural strength than a slab with 75 mm diameter balls.

2.3.1. Failures Associated with Bubble Deck Slab

Al-Ahmed et al. (2022) identified three types of failures associated with BDS:

- *Shear-failure:* Shear cracks initially appears near supports. After successive application of load, the shear cracks propagate towards the loading line then few flexural cracks appear in the middle zone of the specimen.
- *Flexure failure:* Flexural cracks appear and propagate at different locations within the middle span region of the slab. The cracks length and width increase until the flexural failure occurs.
- *Shear-flexure failure:* Flexural cracks initially appear at different location within the middle zone of the slab, then after successive load application, the cracks propagate, and shear cracks appears near the support.

In conclusion, past research has discussed the effectiveness of BDS, where voids are created using a variety of materials, including waste pipes, plastic balls, and PET bottles. In several experiments, BDS performed better than standard solid slab in terms of decreased self-weight, enhanced flexural strength, greater load carrying capacity and deflection, and decreased number of cracks. On the other hand, other studies' data suggested that BDS increased crack width and decreased slab rigidity and strength. The current study proposes a low-cost method of BDS construction that involves the integration of waste plastic bottles filled with PKS to occupy the voided area of the slab. The filling of the bottles with PKS eliminates the void created in the slab and helps improve the BDS reported problems, such as a reduction in stiffness and strength.

3. Research Methodology

The flowchart of the research methodology that was used to achieve the study's aims is shown in Figure 1.

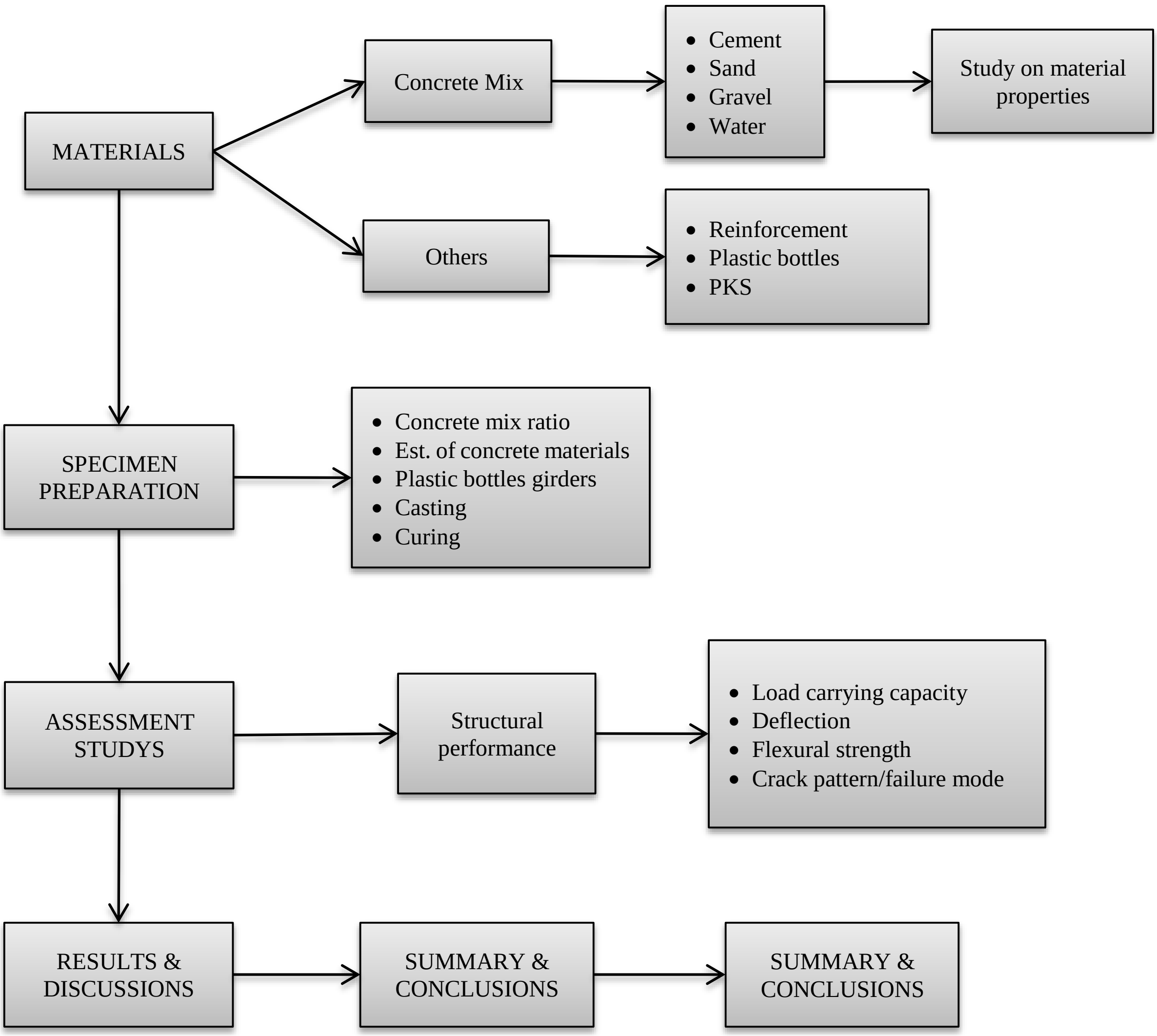

Figure 1. Methodology flowchart

3.1. Materials and Properties

3.1.1. Cement

The research made use of GHACEM (Heidelberg Cement Group) class 42.5 Ordinary Portland Cement made in Ghana. This cement is readily available in almost every part of the country, and as such, its properties conform to IS 8112:2013 requirements.

3.1.2. Fine and Coarse Aggregates

The sand used was clean, sharp river sand, whereas 10 mm of granite chippings was considered coarse aggregate for the study. Both aggregates were sourced from Cape Coast, the study area in Ghana. Tested properties with respect to particle size distribution (Tables 1 and 2, and Figures 2 and 3), specific gravity, water absorption, void percentage, and bulk density are presented in Table 3 following IS 383-2016 and IS 2386 (Part III) – 1963 protocols.

Table 1. Particle Size Distribution of Sand

Is Sieve Size	Weight Retained (Gm)	Cumulative Weight Retained (Gm)	Cumulative % Weight Retained	Cumulative % Weight Passing
10MM	0	0	0.00	100.00
4.75MM	28	28	1.87	98.13
2.36MM	57	85	5.67	94.33
1.18MM	380	465	31.00	69.00
600µ	452	917	61.13	38.87
300µ	391	1308	87.20	12.80
150µ	192	1500	100.00	0.00
Pan	0	1500		
Total	**1500**		**286.66**	

Table 2. Particle Size Distribution of Coarse Aggregate

Is Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative % Weight Retained	Cumulative % Weight Passing
40MM	0	0	0	100
20MM	0	0	0	100
16MM	0	0	0	100
12.5MM	22	22	1.47	98.5
10MM	128	150	10	90
4.75MM	1350	1500	100	0
2.36MM			100	0
1.18MM			100	0
600µ			100	0
300µ			100	0
150µ			100	0
Pan				0
Total	1500		611.47	

$$Finesness\ Modulus = \frac{286.66}{100} = 2.87$$

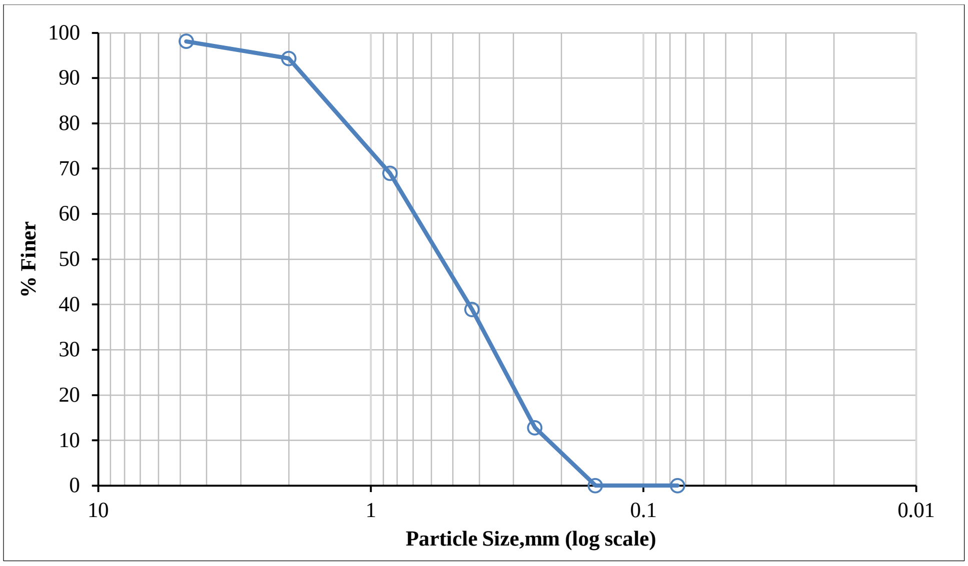

Figure 2. Graph of Particle Distribution of Sand

$$Finesness\ Modulus = \frac{611.47}{100} = 6.11$$

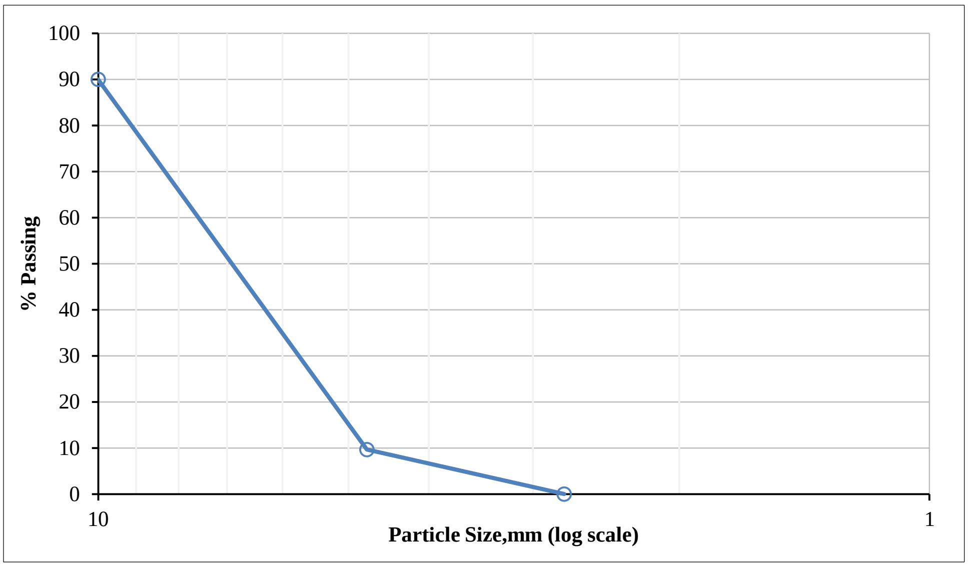

Figure 3. Graph of Particle Distribution of Coarse Aggregate

Table 3. Test Results on Fine and Coarse Aggregates

Sl. No.	Property	Value	
		Fine aggregate	Coarse aggregate
1.	Specific Gravity	2.61	2.54
2.	Fineness modulus/ Grade	2.87/Zone II	6.11
3.	Silt Content	2.1%	-
4.	Water Absorption	1.23%	0.89%
5.	Percentage of voids	33.7%	21.4%
6.	Bulk density	1.601kg/L	1.51kg/L

3.1.3. Plastic Bottle

PET water bottles with a 500 mL capacity that had been discarded and collected by trash haulers near Cape Coast Technical University were used in the study (Figure 4). The bottles' labels were first taken off. The labels on the bottles were first removed with a gentle detergent soap, and any adhesive residue was then removed with washing. Table 4 provides a list of the physical properties of the plastic water bottles used in the study.

Figure 4. Sourcing of 500ml Plastic Bottles from Waste Collection Vendors

Table 4. Observations of Bottles Used for the Study

Sl. No.	Property	Value
1.	Cross-section shape	Circular
2.	Volume	0.5L
3.	Height	215mm
4.	Diameter (bottom)	60mm
5.	Weight	14g

3.1.4. Water

The water used for the entire experiment was potable water, supplied by Ghana Water Company Limited (GWCL), whose quality satisfied the IS 456:2000 and IS 10500:2012 standards requirements.

3.1.5. Reinforcement

The slab specimens were reinforced in the compression and tensile zones with 8 mm diameter mild steel reinforcement in accordance with IS 432:1982.

3.1.6. Chicken Mesh

hexagonal galvanised (20×20×1.8 mm) steel chicken mesh measuring 900×15240 mm (30 kg) was used to enclose the bottles in order to ensure bonding of the bottles to the concrete. The meshed bottles were later caged with the 8 mm diameter mild steel reinforcement before being incorporated into the concrete casting, as shown in Figure 5.

Figure 5. Meshed PKS Plastic Bottles Caged With 8 mm Dia. Steel Reinforcement

3.1.7. Palm Kernel Shells

The PKS used in this study was industrial waste stockpiled by the country's palm kernel oil producing firms. These palm kernel oil production sites served as the source for the PKS used. The shells were put in a basket in batches and thoroughly flushed with water to remove impurities that could contaminate or affect the block properties, and later spread in an open space for them to dry thoroughly.

3.2. Concrete Mix Proportions

Material proportions for M20 nominal mix concrete were determined using Table 9 of IS 456:2000 (included here in the Appendix I). For a grade M20 concrete mix, the total quantity of dry aggregate by mass per 50kg of cement was taken as the sum of the masses of the fine and coarse aggregate, as directed by IS 456:2000 (i.e., 250kg). The required mix proportion for the concrete indicated on Table 5 was determined based on the proportion of Zone II of fine aggregate to 10 mm size of coarse aggregates for a ratio of 1:112 (IS 456:2000).

Table 5. Computed Mix Proportion for Concrete Mix

Grade M20 Concrete (Mix ratio)	Materials and Quantity			
	Cement	**Fine aggregate**	**Coarse aggregate (10 mm size)**	**Water**
Mass	50kg	100kg	150kg	30L
Volume	1	2	3	w/c = 0.6

3.2.1. Estimate of Concrete Mix Materials

Table 6 from the Building Estimating Manual for West Africa by Amoa-Mensah (2016) [62] was used to create the concrete mix used in this study. Table 7 displays the proportional quantities of materials needed per cubic metre of concrete using the 1:2:3 mix ratio used in the study

Table 6. Quantities of Materials/M3 of Concrete (Amoa-Mensah, 2016) [62]

Nominal mix	Cement (1442 kg/m^3)		Sand (1602 kg/m^3)		Aggregate (1442 kg/m^3)	
	kg	m^3	kg	m^3	kg	m^3
1:1:2	520	0.36	580	0.36	1050	0.73
1:1½:3	390	0.27	640	0.40	1150	0.80
1:2:4	300	0.21	690	0.45	1230	0.85

Table 7. Quantities of Materials/M3 of Concrete for the Study

Nominal mix	Cement (1442 kg/m^3)		Sand (1602 kg/m^3)		Aggregate (1442 kg/m^3)	
	kg	m^3	kg	m^3	kg	m^3
1:2:3	360	0.25	673	0.42	1203	0.82

3.3. Details of Slab Specimen for the Study

A total of 26 slab specimens measuring 700×300×150 mm thick were prepared for the analysis of the flexural behaviour of the slab specimens, which included thirteen (13) different types of slabs. Additionally, Figure 6 shows the pattern of bottle arrangement in the slab specimens.

1. Conventional slab: Traditional solid slab without plastic bottles.
2. 5% Vertical dry PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in vertical direction.
3. 5% Horizontal dry PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in horizontal direction.
4. 5% Diagonal dry PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in Diagonal direction.
5. 5% Vertical saturated PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in vertical direction.
6. 5% Horizontal saturated PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in horizontal direction.
7. 5% Diagonal saturated PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in Diagonal direction.
8. 10% Vertical dry PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in vertical direction.

9. 10% Horizontal dry PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in horizontal direction.
10. 10% Diagonal dry PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in Diagonal direction.
11. 10% Vertical saturated PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in vertical direction.
12. 10% Horizontal saturated PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in horizontal direction.
13. 10% Diagonal saturated PKS filled bottle slab: Concrete slab incorporated with 5% PKS filled plastic bottles arranged in Diagonal direction.

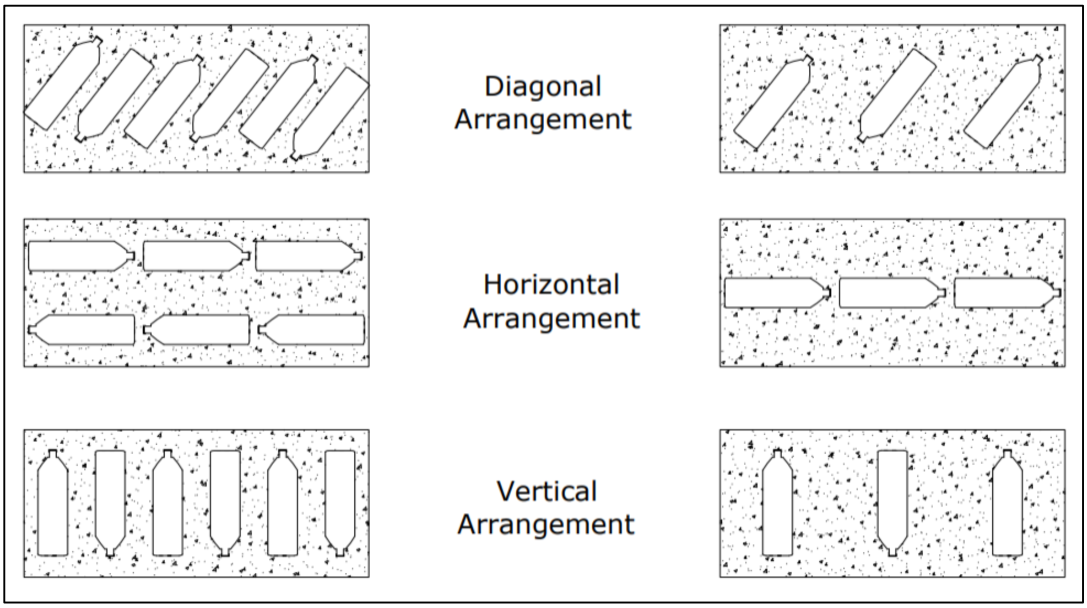

Figure 6. Arrangement of Plastic Bottles in Slab Specimen

3.4. Casting of Specimen

The specimens were poured using oiled wooden moulds. To prevent the specimens from adhering to the concrete platform, the formwork was set up on a concrete platform that was covered in cement paper. Placing the plastic bottles in the formwork with the 8 mm diameter reinforcement and chicken mesh ensures a 25 mm cover thickness. The concrete was mixed mechanically using an electric mixer in accordance with the guidelines provided in IS 456:2000. Three (3) different pours of concrete were created for each specimen. After each pour, the concrete was compacted with an electrically powered poker vibrator.

3.5. Curing of Specimens

After a day, the specimens' formwork was taken down. Jute sacks were placed over the specimens, and the specimens were wet every morning for 28 days before being subjected to the structural performance assessment.

4. Experimental Study

4.1. Flexural Test Setup and Testing Procedure

The slab specimens were subjected to a four-point loading test (see Figure 7) to ascertain their load/deflection behaviour in addition to their flexural strength and crack patterns. The tests were carried out in accordance with BIS 516:1959 concrete strength test methods. A loading frame of 23ton capacity was used to apply loads using a hydraulic jack of 10ton capacity. The support conditions of the slabs were roller support at both ends. The loads were applied at a 2 ton increment. Deflections were measured and recorded using a deflectometer as test specimens were subjected to loads up to the ultimate (load at failure) and load at first crack. Figure 8 depicts the testing procedure for a slab specimen.

$$f = \frac{PL}{bd^2} \quad (1)$$

where f is flexural strength, P is ultimate load, L is length of slab, and b is breadth or width of slab.

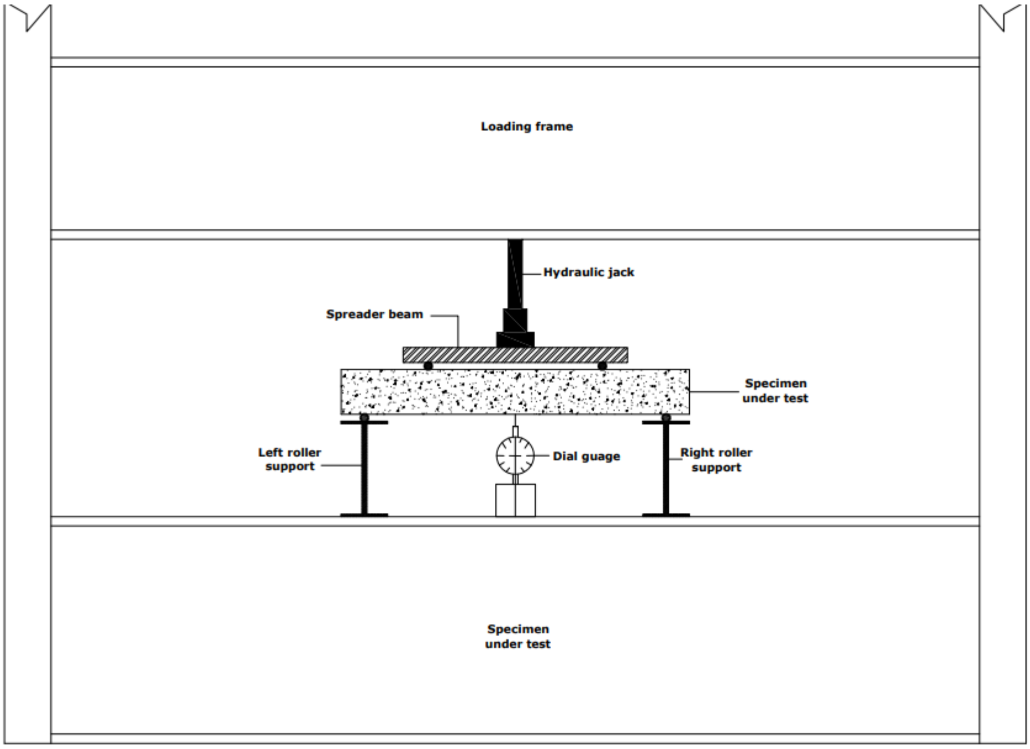

Figure 7. Schematic View of Flexural Strength Test Setup

Figure 8. View of Flexural Strength Test in Progress

5. Results and Discussion

5.1. Load vs. Deflection Behaviour of Slab Specimens

Table 8 shows the results of the slab specimens when subjected to flexural tests. It indicated the ultimate loads and their corresponding deflections for 5% and 10% dry and saturated PKS filled plastic bottle slabs as compared to conventional solid slabs. The load versus deflection behaviour of vertically, horizontally, and diagonally placed slab specimens filled with 5% and 10% dry and saturated PKS filled plastic bottles is also shown in Figures 9 to 12. This is in contrast to the traditional slab specimen. In contrast to the PKS filled bottle slabs, which all had deflection values greater than 2 mm, observations from the graph show that conventional slab failure occurs at an early stage of loading with a maximum deflection not exceeding 2 mm. This makes PKS filled bottle slabs more flexible than conventional slabs. The graphs also demonstrate that, up until the point of complete failure, deflection rises as the slab's loading increases. Comparing the load carrying capacity of the bottle slabs to the conventional, it can be deduced that the load carrying capacity of all the bottle slabs (53 kN-58.9 kN for 5% bottles and 46 kN-54 kN for slabs with 10% bottles), irrespective of their bottle arrangement, exceeds the conventional slabs in the percentages of 20% to 33.4% and 4.2% to 22.2% for both percentages of bottle incorporation in the slabs. According to the researchers' own assessment, these percentage differences are not significant. Because of this, the load behaviour of plastic bottle slabs and traditional solid slabs is almost identical. Based on the findings of this study, both slab types can therefore be used in combination. Additionally, because the corresponding results are nearly identical, the PKS filling material's state-dry or saturated-has no bearing on how well the slab performs under load. Moreover, the arrangement of the bottles in the slabs, either vertical, horizontal, or diagonal, does not have any control on the load/deflection capacity of the slab, hence any type of arrangement is acceptable. The deflection behaviour of the slab specimens was further analysed based on the results from Table 8 and Figures 9 to 12. Compared to comparing the observations of the bottle slabs to the conventional slabs, the bottle incorporated slabs gave better deflection results in the range of 3 mm to 8.7 mm considering both 5% and 10% bottle slabs, as against their conventional slab counterpart of 1.9 mm. In terms of percentages, the PKS bottle slab deflection exceeds the conventional slab by 57%–356% when the plastic incorporation in the slab does not exceed 10%. The PKS condition, whether dry or saturated, combined with the bottle arrangement, however, has no significant effect on the deflection behaviour of the PKS-filled bottle slabs.

Table 8. Observation of Load vs. Deflection

Type of slab specimen	Analysis on load				Analysis on Deflection			
	Ultimate Load (kN)	% Diff.	Ultimate Load (kN)	% Diff.	Max. Deflection (mm)	Deflection diff.	Max. Deflection (mm)	Deflection diff.
Conventional slab (No bottles)	44.1	-	44.1	-	1.9	-	1.9	-
PKS Plastic Bottles slabs	5% incorporated		10% incorporated		5% incorporated		10% incorporated	
Vertical dry PKS filled bottle slab	54.9	24.5%	54.0	22.2%	4.8	153%	8.7	356%
Horizontal dry PKS filled bottle slab	58.9	33.4%	50.0	13.3%	4.7	145%	5.3	180%
Diagonal dry PKS filled bottle slab	54.0	22.2%	47.1	6.7%	5.2	171%	5.3	180%
Vertical saturated PKS filled bottle slab	53.0	20.0%	46.0	4.2%	4.4	130%	6.1	221%
Horizontal saturated PKS filled bottle slab	54.0	22.2%	54.0	22.2%	3.0	57%	3.0	58%
Diagonal saturated PKS filled bottle slab	54.0	22.2%	48.1	8.9%	6.1	219%	7.4	291%

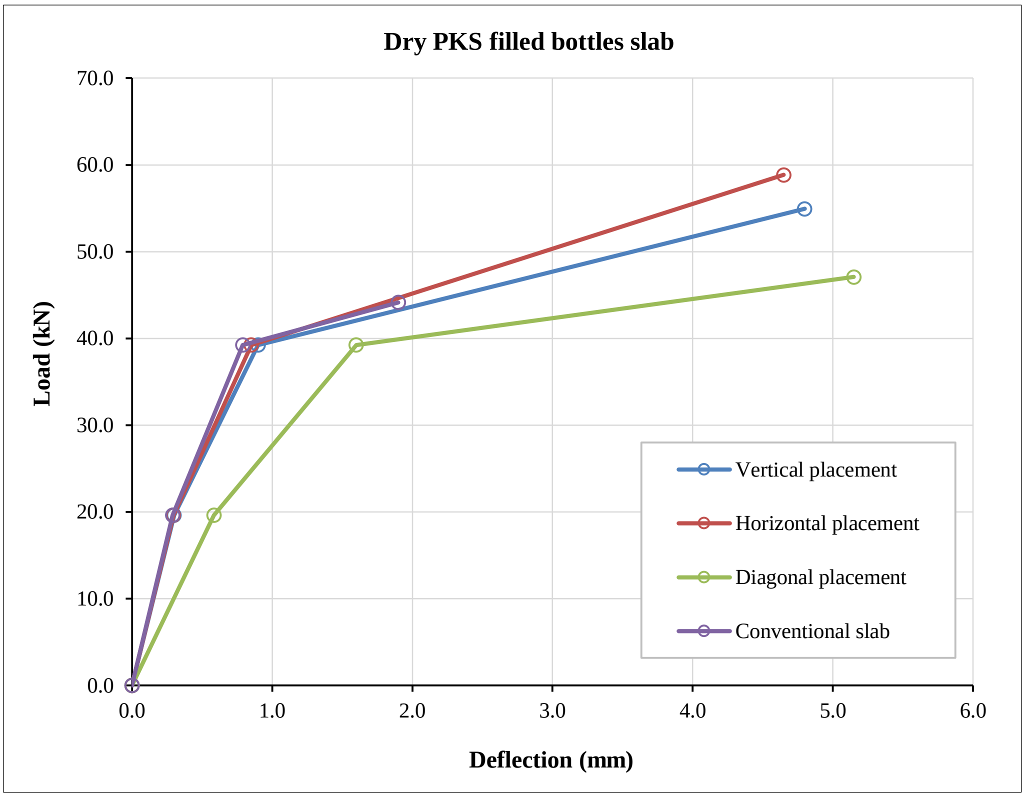

Figure 9. Load Vs. Deflection Behaviour of Conventional Vs. 5% Dry PKS Filled Bottles Slabs

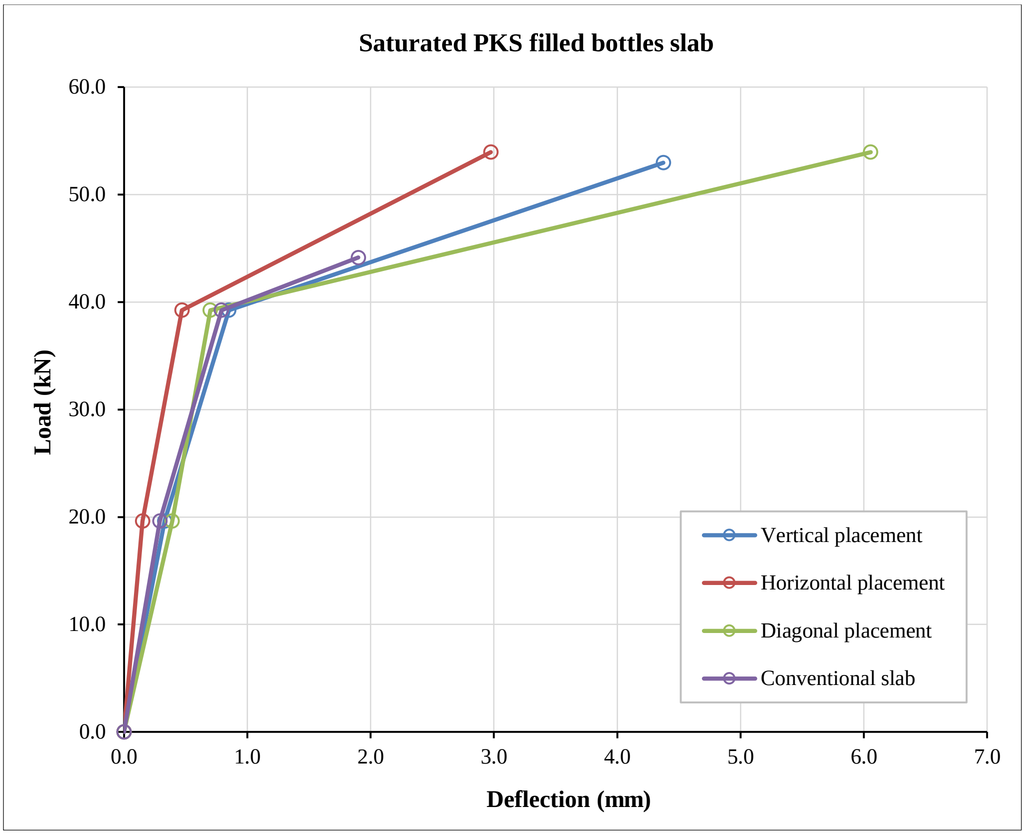

Figure 10. Load Vs. Deflection Behaviour of Conventional Vs. 5% Saturated PKS Filled Bottles Slabs

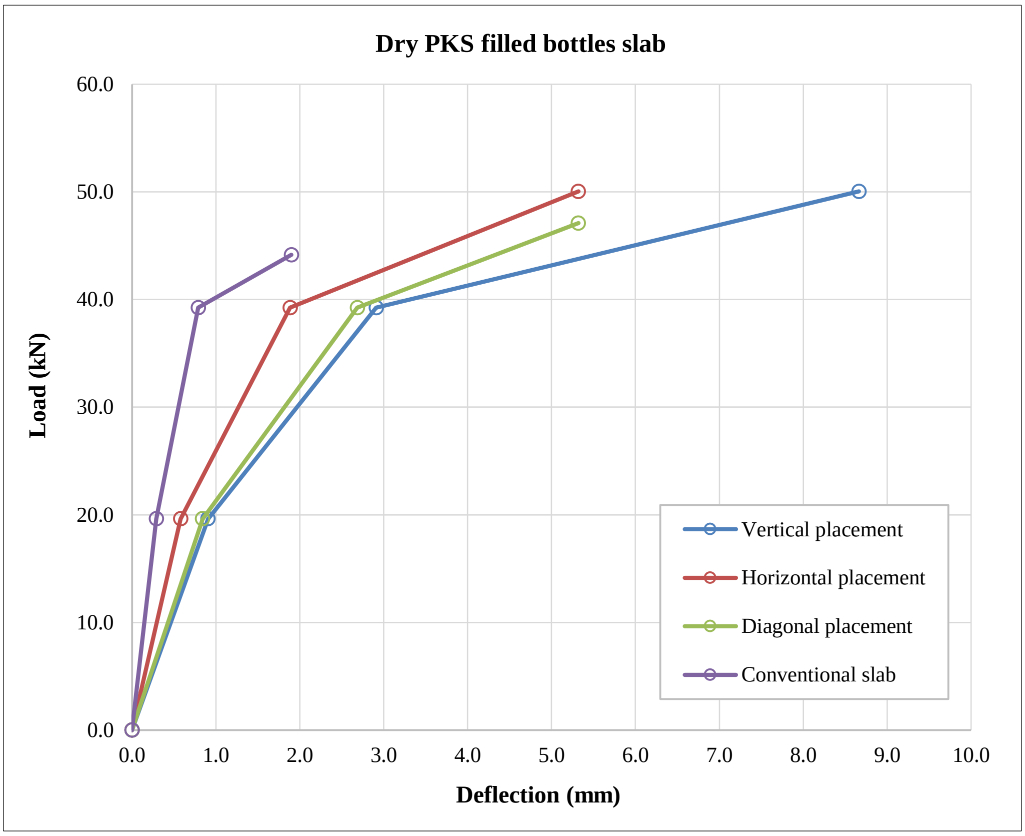

Figure 11. Load Vs. Deflection Behaviour of Conventional Vs. 10% Dry PKS Filled Bottles Slabs

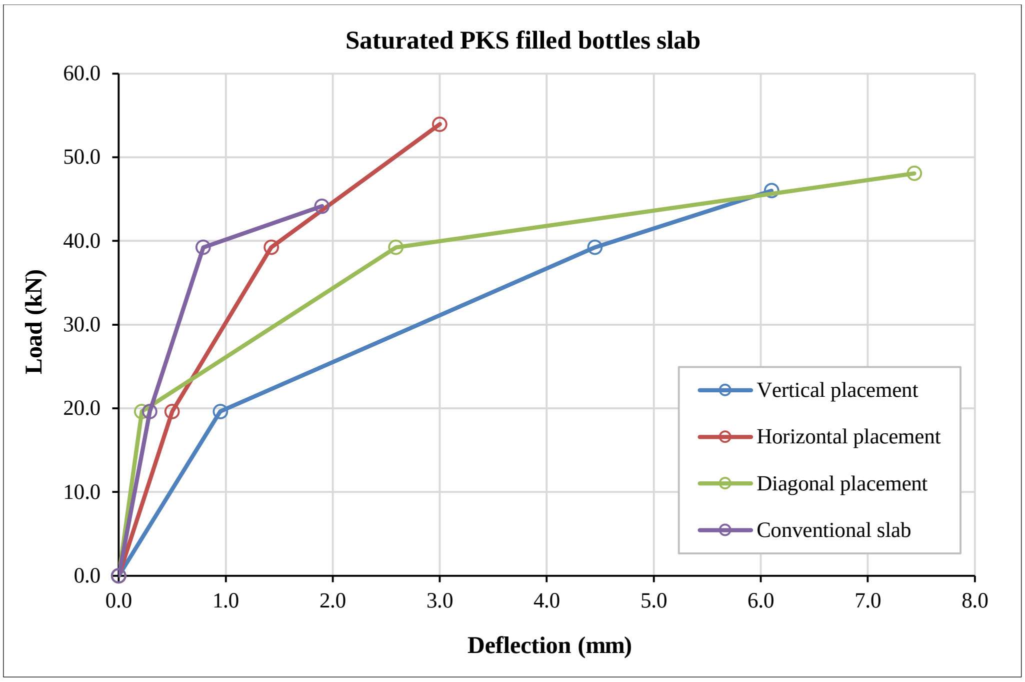

Figure 12. Load vs. deflection behaviour of conventional vs. 10% saturated PKS filled bottles slabs

5.2. Flexural Strength

Tables 9 and 10 exhibit the findings about the flexural strength calculated using the slab's size parameters and the applied load. The comparison of the flexural strength of slab specimens with 5% plastic bottles filled with dry and saturated PKS to that of standard solid slabs is shown in Table 9. In addition, Table 10 presents the same data as Table 9, but it explicitly compares the flexural strength of a slab specimen filled with plastic bottles with 10% PKS to a regular, solid slab specimen. Observations from both tables indicate that the flexural strengths of the PKS-filled bottle slab specimens all exceeded those of the conventional slab specimen. The average flexural strength for the PKS-filled bottle slabs is 6 N/mm^2 for 5% PKS-filled slabs, and 5.5 N/mm^2 for slabs with 10% PKS-filled bottles, compared to the conventional slab of 4.9 N/mm^2. In terms of percentages, the flexural strength of PKS-filled bottle slabs exceeded the conventional slab by an average of 18.3% and 10.9% for five and ten percentages of PKS-filled bottle slabs, respectively. It can therefore be said that the incorporation of plastic bottles filled with PKS performed better in terms of flexural strength than conventional sod slabs of the same concrete properties. Previous research on bubble deck slabs has found that the plastic formers reduce the strength of the slabs [53, 55]. Furthermore, the increased flexural strength of the PKS-filled bottle slabs could be attributed to the PKS filling the voids created by the plastic bottles in the slab, thereby assisting in the load carrying capacities of the slabs. In a related development, the results back up claims made by previous researchers that slabs made using the Bubble Deck Slab technology had higher flexural strength than regular solid slabs [54, 58]. The study next evaluated how the bottle arrangement affected the plastic bottle slabs loaded with PKS's flexural strengths. When flexural strength results for specimens with 5% PKS-filled bottles and slabs with 10% PKS-filled bottles are compared, the differences between the corresponding results are not statistically significant, ranging from 5.9 to 6.5 N/mm^2 for the specimens with 5% PKS-filled bottles to 5.1-6 N/mm^2 for the slabs with 10% PKS-filled bottles (not statistically tested). On the contrary, it can be concluded based on the resulting observations that the arrangement of the bottles in the slab, either vertically, horizontally, or diagonally, does not significantly affect the strength performance of the plastic incorporated slab. Moreso, the examination of the effect of the PKS condition (dry or saturated) on the flexural strength performance was not different from the observations deduced from the bottles' arrangement in the slabs, hence, whether the PKS filling material is dry or saturated does not significantly affect the strength performance of the bottle slab.

Table 9. Flexural Strength of Conventional vs. 5% PKS Filled Slabs

Type of slab specimen	Flexural strength (N/mm^2)	%Diff.
Conventional slab (No bottles)	4.9	-
Vertical dry PKS filled bottle slab	6.1	19.7%
Horizontal dry PKS filled bottle slab	6.5	24.6%
Diagonal dry PKS filled bottle slab	6	18.3%
Vertical saturated PKS filled bottle slab	5.9	16.9%
Horizontal saturated PKS filled bottle slab	6	18.3%
Diagonal saturated PKS filled bottle slab	6	18.3%

Table 10. Flexural Strength of Conventional vs. 10% PKS Filled Slabs

Type of slab specimen	Flexural strength (N/mm^2)	%Diff.
Conventional slab (No bottles)	4.9	-
Vertical dry PKS filled bottle slab	6	18.3%
Horizontal dry PKS filled bottle slab	5.6	12.5%
Diagonal dry PKS filled bottle slab	5.2	5.8%
Vertical saturated PKS filled bottle slab	5.1	3.9%
Horizontal saturated PKS filled bottle slab	6	18.3%
Diagonal saturated PKS filled bottle slab	5.3	7.5%

5.3. Failure Mode and Pattern of Cracks

Table 11 shows the types of crack failures experienced during the flexural testing of the slab specimens. All the slab types exhibited different types of failures in terms of their bottle arrangement and the percentage of PKS-filled bottles incorporated. Nearly 62% (eight types) of the slabs experienced flexural crack failure; that is, cracks appeared and propagated at different locations within the middle span region of the slab [53]. Three (3) out of the total thirteen (13) slabs showed shear crack failure, representing 23%, whereas the remaining two types (15%) failed by shear-flexural crack pattern. As indicated by Al-Ahmed et al. (2022) [53], shear-flexural crack failure occurs when cracks initially appear at different locations within the middle zone of the slab, then after successive load applications, the cracks propagate, and shear cracks appear near the support. However, in a situation where shear cracks initially appear near the support, then, after successive applications of load, the shear cracks propagate towards the loading line, a few flexural cracks appear in the middle zone of the specimen. Such failure is known as "shear crack failure" [53]. The arrangement of PKS-filled plastic bottles in the slab can be seen to modify the cracking patterns of the PKS-filled bottle slabs, in addition to the observations made above on the specimens' fracture patterns. As a result, any configuration, whether vertical, horizontal, or diagonal, is appropriate for the crack failure mode. Furthermore, the majority (nearly 42%) of the slabs that contained plastic bottles filled with 5% PKS failed due to flexural cracks, which are comparable to failures from ordinary slabs. Therefore, in practise, the 5% PKS-filled plastic bottle slabs would be preferable to the traditional solid slabs.

Table 11. Observation of Cracks Pattern and Failure Mode

Type of slab specimen	Plate of Crack Pattern	Type of failure
Conventional slabs (No bottles)		Flexural cracks failure
5% Vertical Air-filled bottle slabs		Flexural cracks failure
5% Horizontal Air-filled bottle slabs		Shear-flexural cracks failure
5% Diagonal Air-filled bottle slabs		Flexural cracks failure
5% Vertical PKS filled bottle slabs		Flexural cracks failure
5% Horizontal PKS filled bottle slabs		Flexural cracks failure

5% Diagonal PKS filled bottle slabs		Flexural cracks failure
10% Vertical Air-filled bottle slabs		Flexural cracks failure
10% Horizontal Air-filled bottle slabs		Shear-flexural cracks failure
10% Diagonal Air-filled bottle slabs		shear cracks failure
10% Vertical PKS filled bottle slabs		Shear-flexural cracks failure
10% Horizontal PKS filled bottle slabs		Flexural cracks failure
10% Diagonal PKS filled bottle slabs		shear cracks failure

6. Conclusions

By contrasting the flexural performance of conventional solid concrete slab with concrete slab incorporated with 5% and 10% plastic bottles filled with dry and saturated PKS arranged in vertical, horizontal, and diagonal directions, respectively, the implications of palm kernel shell-filled plastic bottles on the structural behaviour of concrete slab have been studied. The following conclusions were drawn based on the findings of flexural tests performed on slab specimens constructed using Bubble Deck Slab technology.

- Failure of the conventional slab occurs at an early stage of loading, with maximum deflection not exceeding 2 mm as compared to the PKS filled bottle slabs, where all the deflection values exceeded 2 mm, thereby making them more flexible than the conventional slabs and, as such, giving the occupants enough time to evacuate;
- The flexural strengths of the PKS-filled bottle slabs exceeded the conventional slab specimen on average at 6 N/mm^2 for 5% PKS-filled slabs and 5.5 N/mm^2 for slabs with 10% PKS-filled bottles, compared to the conventional slab of 4.9 N/mm^2, representing 18.3% and 10.9% for five and ten percentages of PKS-filled bottle slabs, respectively;
- The condition of the PKS, either dry or saturated, coupled with the bottle arrangement (either vertical, horizontal, or diagonal), does not, however, cause any significant change to the performance of the PKS filled bottle slabs in terms of load carrying capacity, deflection, and strength;
- Finally, nearly 62% of all the slabs tested experienced flexural crack failure. However, the majority of the slabs incorporated with 5% PKS-filled plastic bottles resulted in flexural crack failures that are similar to those of conventional slab failures. Hence, the better option is to replace the conventional solid slabs in practice.

7. Declarations

7.1. Author Contributions

Conceptualisation, D.K.D.; methodology, D.K.D.; software, D.K.D.; validation, A.K.K.; formal analysis, D.K.D.; investigation, D.K.D.; resources, D.K.D.; data curation, D.K.D.; writing—original draft preparation, D.K.D.; writing—review and editing, D.K.D.; visualization, D.K.D.; supervision, A.K.K. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in the article.

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7.5. Conflicts of Interest

The authors declare no conflict of interest.

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Appendix I

Table I-1. Proportions for Nominal Mix Concrete (Table 9 of IS 456:2000)

Grade of Concrete	Total Quantity of Dry Aggregates by Mas per 50 kg of Cement, to be taken as the Sum of the Individual Masses of Fine and Coarse Aggregates, kg, Max	Proportion of Fine Aggregates to Coarse Aggregate (by Mass)	Quantity of Water per 50 kg of Cement, Max 1
(1)	(2)	(3)	(4)
$M5$	800	Generally, 1:2 but subject to an upper limit of $1:1\frac{1}{2}$ and a lower limit of $1:2\frac{1}{2}$	60
M 7.5	62.5		45
M 10	480		34
M 15	330		32
M 20	250		30

Note: The Proportion of the fine to coarse aggregates should be adjusted from upper limit to lower limit progressively as the grading of fine aggregates becomes finer and the maximum size of coarse aggregates become larger. Graded coarse aggregates shall be used.

Example: For an average grading of fine aggregate (that is, Zone II of table 4 of IS 383), the proportions shall be $1:1\frac{1}{2}$ and $1:2\frac{1}{2}$ for maximum size of aggregates 10 mm, 20 mm and 40 mm respectively.