Experimental Study Compressive Strength of Concrete With Palm Shells as a Partial Replacement for Coarse Aggregate

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Abstract

This experimental study aims to evaluate the compressive strength of concrete using palm kernel shells as a substitution for coarse aggregates. The utilization of locally available materials in abundance, such as palm kernel shells, can serve as a sustainable alternative in construction. This research is conducted to measure the influence of palm kernel shell usage on the mechanical properties of concrete, particularly its compressive strength. The research methodology involves the preparation of concrete mixtures with various levels of substitution of coarse aggregates with palm kernel shells. Test specimens were prepared with substitution percentages of 0%, 25%, and 60% with planned ages of 7 days, 21 days, and 28 days. Three cube specimens were cast for each planned age. The test results were used to compare the compressive strength of concrete with and without palm kernel shells and to evaluate the potential of palm kernel shells as a substitute for coarse aggregates in structural concrete applications. The research findings indicate that the highest compressive strength was obtained in the concrete without any palm kernel shell mixture (0%), measuring 379.86 kg/cm^2. The highest compressive strength with the substitution of coarse aggregates using palm kernel shells was found in the 25% mixture, with a value of 362.57 kg/cm^2, while the lowest percentage was recorded in the 60% mixture, with a value of 270.65 kg/cm^2. Palm kernel shells have the potential to be used as a substitute for coarse aggregates in concrete. However, their utilization needs to be carefully analyzed and tailored to the specific conditions and requirements of construction projects. This research provides initial insights into the use of palm kernel shells in concrete and can serve as a foundation for further research in the development of environmentally friendly concrete using sustainable local raw materials

Keywords: Concrete, Agregat Substitusi, Palm Shell, Experimental, Coarse Aggregates.

I. INTRODUCTION

The construction industry is one of the key sectors in infrastructure development and sustainable construction. One of the main materials in the construction industry is concrete, which consists of Portland cement, fine aggregate, coarse aggregate, and water. Coarse aggregate in concrete typically comes from natural rocks, such as gravel or crushed stone, using natural aggregates can lead to the degradation of natural resources with adverse environmental impacts. Currently, the main challenge in the construction world is to find sustainable and environmentally friendly alternatives to conventional materials. One alternative material can be used by utilizing agricultural or industrial waste, such as palm kernel shells, as a replacement for coarse aggregate in concrete. The palm kernel shells depicted in Figure 1, are abundant waste from the palm oil industry's production process, and their use in construction can provide significant benefits, namely reducing environmental impact and reducing waste in the palm oil industry.

This study holds great relevance in the context of sustainable development in industrial waste management. If palm kernel shells are proven effective as a substitute for coarse aggregate in concrete, it can help reduce reliance on natural aggregates and mitigate their environmental impacts. Additionally, the utilization of palm kernel shell waste can provide added value to the palm oil industry by creating new opportunities in the circular economy. This research aims to conduct experimental tests on concrete mixing using palm kernel shells as a substitute for coarse aggregate. It seeks to identify the potential advantages and drawbacks of using palm kernel shells in concrete, including their influence on concrete strength. Thus, this study will provide a better understanding of the potential utilization of palm kernel shells in the construction industry.

The proportions of the concrete mix must meet strength requirements and produce concrete of suitable quality, including workability that allows ease of concrete placement, compaction, and leveling to fill molds and achieve uniformity. Additionally, concrete must meet durability and compressive strength requirements while remaining cost-effective [1]. Casting methods also affect concrete strength. If casting requirements are not met, the planned compressive strength of concrete is likely to be compromised [2].

Figure 1. Palm shell

When designing a structural component, it is assumed that concrete carries compressive stress rather than tensile stress. Therefore, the compressive strength of concrete is typically used as a reference to determine the quality and grade of concrete material. The compressive strength of concrete can be determined through compressive strength testing, following the ASTM C39/C39M-12a "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." Typically, test specimens are cylindrical with a diameter of 150 mm and a height of 300 mm. The compressive strength of concrete can be calculated using Equation (1) [3].

$$\text{Compressive Strength } (\sigma) = \frac{P}{A} \qquad (1)$$

The concrete compressive strength (σ) with cylindrical test specimens is expressed in MPa. The axial compressive force (P) is expressed in Newtons (N), and the cross-sectional area of the test specimen (A) is expressed in square millimeters (mm2).

An evaluation of compressive strength with the addition of palm kernel shells at 7% and 12% revealed concrete compressive strength values exceeding those of normal concrete. In the 7% palm kernel shell mixture, the compressive strength of concrete was found to be 0.08 MPa greater than that of normal concrete, while for the 12% mixture, the compressive strength was 0.1 MPa higher than that of normal concrete [4]. Considering the limitations of natural resources, alternative lightweight aggregate materials must be sought from industrial waste. Palm kernel shells and palm kernel boiler clinker are two solid wastes from the palm oil industry that are abundant in tropical regions. The use of palm kernel shells alone as lightweight coarse aggregate in concrete has some drawbacks. However, when palm kernel shells are replaced with palm kernel boiler clinker, there is a significant increase in compressive strength, tensile strength, and flexural strength. Additionally, the initial and final water absorption, as well as drying shrinkage strain of concrete with coarse lightweight aggregate mixture are much smaller compared to concrete with palm kernel shells [5].

Palm shells are solid waste from agricultural production in the palm oil extraction process. Replacing conventional coarse aggregate with palm kernel shell aggregate is an environmentally friendly option offering several advantages, such as lightweight properties, renewability, and domestic availability. The hybrid lightweight concrete mixture with 0.4% palm kernel shells (OPSLWC-HYB-0.4%) achieved the highest compressive strength of 29 MPa at 28 days. The addition of palm shell fibers at 0.3% showed significant results with the lowest thermal conductivity at 0.55 W/m °C. The research results indicate that the inclusion of a palm shell enhances the thermal conductivity test performance compared to the addition of palm shell fibers. Therefore, OPS LWC has proven to be an environmentally friendly aggregate and is highly recommended as an alternative solution to replace conventional aggregates used in concrete mix compositions [6].

Results from various tests on palm kernel shells indicate that, for sieve analysis, specific gravity, and absorption, they meet SNI (Indonesian National Standards) standards, allowing their use as aggregate substitutes, not exceeding 10% for palm kernel boiler ash and not exceeding 30% for palm kernel shells. The average compressive strength on days 7 and 28 was obtained at 21 MPa, which did not meet the planned compressive strength of 25 MPa [7]. The average compressive strength results for each variation of palm kernel shell mixture, starting from 0%, 15%, 20%, and 25%, were 20.18 MPa, 17.20 MPa, 16.27 MPa, and 15.34 MPa, respectively. The decrease in compressive strength for each successive percentage increase of palm kernel shells (15%, 20%, and 25%) was 14.77%, 19.38%, and 23.98%, respectively. The higher the percentage of palm kernel shell mixture used in the concrete, the lower the compressive strength achieved. Conversely, a higher percentage of palm kernel shell mixture leads to a lighter test specimen [8]."

When adding 5% palm kernel shells, the compressive strength of the concrete increased. However, with the addition of 15% and 25% palm kernel shells in the concrete mix, the compressive strength deviated from the planned compressive strength [9]. The test results of the CKS-5% concrete mixture (f'c;23.33 MPa, fcf;3.6 MPa) can be used for rigid pavement in low-traffic roads compared to the CKS-2.5% mixture (f'c;14.43 MPa, fcf;2.85 MPa), CKS-7.5% (f'c;17.70 MPa, fcf;3.16 MPa), and CKS-10% (f'c;12.86 MPa, fcf;2.69 MPa). When compared to the CKS-0% concrete mixture (f'c;23.97 MPa, fcf;3.7 MPa), the CKS-5% mixture (f'c;23.33 MPa, fcf;3.6 MPa) experienced a decrease in f'c and fcf by 2.7% and 1.4%. The use of 5% palm kernel shells (CKS-5%) can reduce the use of coarse aggregate sized 1-2 by 69 Kg/m3 [10]. The availability of 2 million tons/year of palm kernel shell waste in the Riau province represents a potential source for the production of structural lightweight concrete and can also serve as an alternative to natural coarse aggregates. Compressive strength test results indicate that the average compressive strength at 7 days is 14.29 MPa, at 14 days is 17.04 MPa, at 21 days is 18.85 MPa, while the maximum compressive strength is achieved at 28 days, with an average of 20.79 MPa. The overall tested compressive strength of lightweight concrete is approaching the planned concrete compressive strength of 21 MPa [11]."

Palm shells are lightweight and have a hard shell, making them a potential aggregate for lightweight concrete. Non-sand concrete is a type of lightweight concrete obtained by eliminating fine aggregate from the normal concrete mix. In tests conducted at 28 days, non-sand concrete with a cement-to-gravel volume ratio of 1:3 achieved a compressive strength of 8.71 MPa. Meanwhile, for non-sand concrete with cement-to-palm kernel shell volume ratios of 1:3, 1:6, and 1:8, compressive strengths of 4.64 MPa, 3.62 MPa, and 3.06 MPa were obtained, respectively. Furthermore, for cement-to-palm kernel shell volume ratios of 1:10 and 1:12, compressive strengths were below 3 MPa. These results indicate that non-sand concrete with palm kernel shell aggregates at ratios of 1:3, 1:6, and 1:8 meet the criteria for non-sand concrete compressive strength, ranging from 2.8 MPa to 10 MPa. Thus, non-sand concrete made with palm kernel shell aggregates can be used as environmentally friendly non-structural lightweight concrete due to its water permeability [12]. Palm kernel shell waste has significant potential in the construction industry, considering the increasing extent of palm oil plantations each year. Compressive strength tests on paving blocks with mixing percentages of 0%, 5%, 10%, and 15% resulted in strengths of 8.08 MPa, 7.18 MPa, 6.46 MPa, and 5.94 MPa, respectively. The water absorption values of paving blocks with mixing percentages of 0%, 5%, 10%, and 15% were 9.88%, 10.25%, 12.27%, and 12.44%, respectively [13]. The workability and dry density of palm kernel shell concrete (OPSC) increase with the age category of OPS species. The compressive strength of CD3 specimens increased significantly compared to CT3 specimens by 21.8%. The maximum compressive strength achieved at 28 days and 90 days was 54 MPa and 56 MPa, respectively. Water absorption was found to be within the range suitable for good concrete performance for various OPSC species. Additionally, ultrasonic pulse velocity (UPV) results indicated that OPS HSLWC reached a favorable condition at 3 days of age [14].

Palm kernel shell concrete (OPSC) treated with full OPS (Wash-Dry-Sieve) exhibited the highest compressive strength values, increasing by 65% compared to untreated OPS (Wash-Dry-Sieve). The strength enhancement may be attributed to 1) the removal of residual oil on the OPS surface through washing with detergent, with a mass of 2% of the dry OPS mass, and 2) the elimination of sub-2mm particles in OPS through sieving, which includes soil and OPS fibers. OPSC can develop higher compressive strength levels with the washing, drying, and sieving treatment applied to OPS compared to concrete casting with untreated OPS [15]. Palm kernel shell in concrete mix undergoes shrinkage expansion during the hardening process, causing the bond between palm kernel shell and cement matrix to weaken, which is the main reason for the low compressive strength of concrete. Cost analysis was also conducted to compare the cost between palm kernel shells and normal concrete with the same quality. The cost of palm kernel shells was found to be 2% lower than the cost of normal concrete [16]. The addition of palm kernel shells to concrete is an innovation and breakthrough in the more productive utilization of palm waste. The compressive strength of concrete was obtained with the following data: For FAS 0.35, the average compressive strength of BTCS is 348.15 kg/cm2, BDCSA (7%) is 363.07 kg/cm2, and BDCSB (14%) is 302.90 kg/cm2. For FAS 0.45, the average compressive strength of BTCS is 292.59 kg/cm2, BDCSA (7%) is 303.20 kg/cm2, and BDCSB (14%) is 249.27 kg/cm2. For FAS 0.50, the average compressive strength of BTCS is 273.09 kg/cm2, BDCSA (7%) is 271.53 kg/cm2, and BDCSB (14%) is 219.47 kg/cm2. The test results show that the average compressive strength of concrete is influenced by the water-cement factor (FAS) and the percentage of palm kernel shell addition in the concrete mix [17]. Palm kernel shell material coated with nanomaterials exhibits comparative strength with regular cement. The mixture of regular cement with palm kernel shell concrete can address modern waste that can be utilized to create strong and durable concrete [18]. Palm kernel shells, as a biomaterial (renewable resource), can be used as a substitute for natural coarse aggregates. The optimum fly ash content is 10%, and SP 1% is used to reduce water content. The use of palm kernel shells as a substitute for aggregates means reducing waste from the palm kernel industry while also decreasing the use of natural materials. Additionally, in Indonesia, there are many areas where natural stone resources are scarce, while palm oil plantations are quite extensive [19]

The compressive strength test results at 28 days of age show an increase in concrete compressive strength. However, as the percentage of palm kernel shell content increases, the compressive strength decreases. Normal concrete (0% palm kernel shell) has a compressive strength of 46.188 MPa, while substitutions of 15%, 30%, 45%, and 60% result in compressive strengths of 42.917 MPa, 23.287 MPa, 18.860 MPa, and 8.468 MPa, respectively. There is a decrease in compressive strength from 0% substitution to 60% substitution, and there is also a decrease in the weight of the concrete with palm kernel shell substitutions of 0%, 15%, 30%, 45%, and 60%, resulting in densities of 2528 kg/m3, 2359 kg/m3, 2053 kg/m3, 1990 kg/m3, and 1809 kg/m3, respectively. The test results show that concrete with 0% palm kernel shell substitution can be categorized as high-quality concrete, as 60% palm kernel shell substitution results in non-structural and lightweight concrete [20]. The addition of a 10% mixture of palm kernel shell (PKS) as a substitute for coarse aggregate in concrete is very beneficial without significantly reducing the concrete's strength [21]. The compressive strength and density of concrete continuously decrease with the addition of palm kernel shell into the concrete mix for all tested curing ages. The compressive strength of palm kernel shell concrete at 28 days ranges from 12.71 to 16.63 N/mm2, while its density ranges from 1562 to 2042 kg/m3. Physical property tests include sieve analysis, density, water content, and density analysis to describe the aggregates. The density of sharp sand, crushed granite, and palm kernel shell is found to be 2500 kg/m3, 2760 kg/m3, and 1,301 kg/m3, respectively, with respective water absorption capabilities of 6% in 1 hour and 24 hours for granite, and 11% in 1 hour and 21.5% in 24 hours for palm kernel shell. All aggregates examined are suitable for concrete production based on the observed physical properties [22].

II. RESEARCH METHOD

The first step is the collection of palm kernel shells. Palm kernel shells should be gathered from various sources and inspected to ensure consistent quality and size. Additionally, conventional coarse aggregates should also be collected for use as a comparison, and Portland cement should be gathered as the binding material. Afterward, prepare the materials as depicted in Figure 2.

Figure 2. Prepare the materials

Palm kernel shells must be cleaned of impurities and unwanted materials. Initial material testing involves conducting laboratory tests to determine the physical and chemical properties of palm kernel shells and conventional coarse aggregates, such as density, particle size, strength, and moisture content. After the materials are prepared, the next step is to design the concrete mix, with different mix variations using varying ratios of palm kernel shells and conventional coarse aggregates. These variations should encompass different substitution percentages of palm kernel shells, such as 0%, 25%, and 60%, using three cube test specimens per planned age. Maintain a consistent ratio of cement to aggregates for all mixtures. Conduct a concrete consistency test using the slump test method or other consistency tests to ensure that the mixture achieves the desired consistency, as shown in Figure 3.

Figure 3. Slump Test

The concrete samples should be prepared in the form of cubes, following the standard concrete strength testing procedures as depicted in Figure 4. Dry and cure the concrete samples, and then conduct concrete strength tests by testing the samples at different ages, such as 7, 14, and 28 days, using a concrete compression test.

Figure 4. Specimens

Compare the concrete strength of mixtures with palm kernel shells and conventional coarse aggregates at various substitution percentages. Perform statistical analysis to determine whether the differences between the concrete mixtures vary significantly.

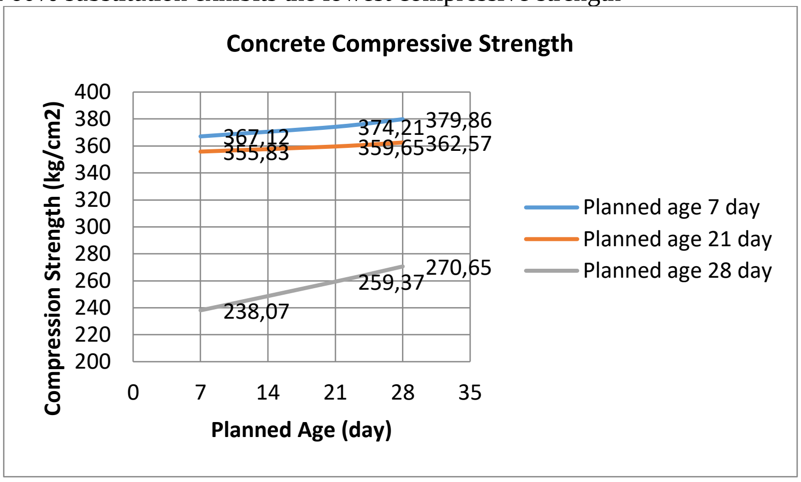
III. RESULT AND DISCUSIION

From the results presented in table 1, for the mixtures with aggregate substitution percentages of 0%, 25%, and 60% at the planned age of 7 days, the respective average compressive strengths are 367.12 kg/cm^2, 355.83 kg/m^2, and 238.07 kg/cm^2. This indicates that the composition with 0% substitution has the highest average compressive strength, while the mixtures with 25% and 60% substitution experience a decrease in compressive strength. Furthermore, at the planned age of 21 days, the respective average compressive strengths are 374.21 kg/cm^2, 359.65 kg/m^2, and 259.37 kg/cm^2. This condition is consistent with the 7-day age results, where the composition with 0% substitution has the highest average compressive strength, and the mixtures with 25% and 60% substitution experience a decrease in compressive strength. Lastly, at the planned age of 28 days, the results are not significantly different from those at 3 and 7 days. There is a decrease in compressive strength as the dominance of palm kernel shells in the concrete mixture increases.

TABLE 1. AVERAGE CONCRETE COMPRESSIVE STRENGTH TEST RESULTS

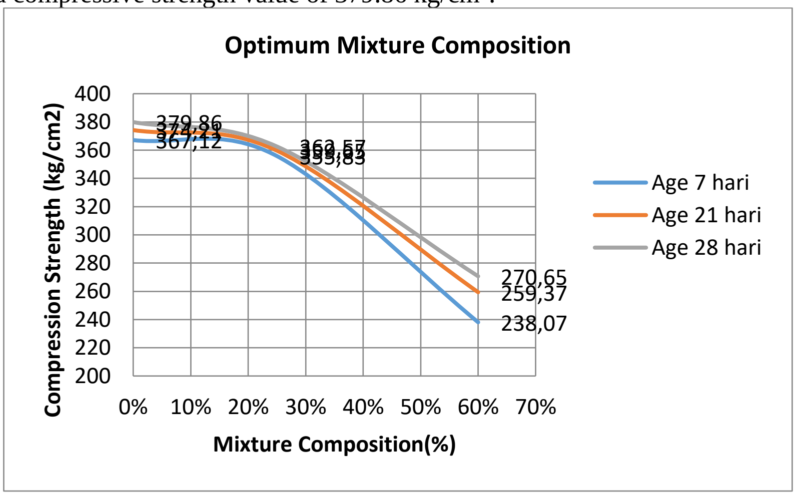
Percentage of Coarse Aggregate Substitution (%)	Planned Age (day)	Load (kN)			Area (cm²)	Compression Strength (MPa)			Average Compression Strength (MPa)	Compression Strength (kg/cm²)
		Sample 1	*Sample 2*	*Sample 3*		*Sample 1*	*Sample 2*	*Sample 3*		
0	7	679	663	675	225	30,18	29,47	30,00	29,88	367,12
	21	680	686	690	225	30,22	30,49	30,67	30,46	374,21
	28	680	712	695	225	30,22	31,64	30,89	30,92	379,86
25	7	654	648	653	225	29,07	28,80	29,02	28,96	355,83
	21	658	673	645	225	29,24	29,91	28,67	29,27	359,65
	28	647	675	670	225	28,76	30,00	29,78	29,51	362,57
60	7	440	438	430	225	19,56	19,47	19,11	19,38	238,07
	21	480	475	470	225	21,33	21,11	20,89	21,11	259,37
	28	480	520	487	225	21,33	23,11	21,64	22,03	270,65

The research results presented in Graph 1, Show a comparison of compressive strength. The blue line represents the composition with 0% substitution, indicating that it has the highest average compressive strength at both the planned ages of 7 days, 21 days, and 28 days. The red line on the graph represents the composition with 25% substitution, with the average compressive strength falling between 0% and 60% substitution. Meanwhile, the composition with 60% substitution exhibits the lowest compressive strength



Graph 1. Comparison of concrete compressive strength

The research results presented in Graph 2, show the optimum composition mixture percentage. The blue line represents the planned age of 7 days, indicating that the optimum composition mixture is at 0% substitution with a compressive strength value of 367.12 kg/cm^2. The red line, which represents the planned age of 21 days, also shows the optimum composition mixture at 0% substitution, with a compressive strength value of 374.21 kg/cm^2. Furthermore, at the planned age of 28 days, the results are the same, with the optimum composition mixture at 0% substitution and a compressive strength value of 379.86 kg/cm^2.



Graph 2. Optimum Mixture Composition

Based on the analysis of cube-shaped test specimens regarding the cracking behavior observed in concrete test specimens with 0% variation, after testing, the average failure type observed is parallel to the vertical axis (columnar). The fracture pattern occurs due to the placement of the test specimen at a pivot point centered in the middle of the sample, as shown in Figure 5.

Figure 5. Crack Pattern of Concrete in the 0% Mixture.

In the data presented in Figure 6, the crack pattern or fracture type observed in concrete test specimens with a 25% variation, after testing, on average, results in a cone-type failure. The fracture pattern occurs due to the placement of the test specimen at a pivot point centered on the surface of the specimen. Meanwhile, the crack pattern or fracture type observed in concrete test specimens with a 60% variation, after testing, on average, results in a shear-type failure. The fracture pattern occurs due to the excessive voids caused by palm kernel shell fragments, leading to numerous cracks, as depicted in Figure 7.

Figure 6. Crack Pattern of Concrete in the 25% Mixture.

Figure 7. Crack Pattern of Concrete in the 60% Mixture.

IV. CONCLUSION

The research results indicate that the highest compressive strength is achieved in concrete without palm kernel shell mixtures at 0%, which is 379.86 kg/cm2 at 28 days of age. In contrast, the percentage of palm kernel shell mixtures in concrete results in a decrease in compressive strength as the percentage of palm kernel shell mixtures in the concrete increases. It can be concluded that the more palm kernel shell mixtures are added, the lower the compressive strength of the concrete. For the highest compressive strength at the age of 28 days, a composition with 25% palm kernel shell mixtures yields a compressive strength of 362.57 kg/cm2, while the lowest compressive strength is found in the 60% mixture, which is 270.65 kg/cm2 at 28 days. The compressive strength test results for concrete with 0%, 25%, and 60% substitution of palm kernel shell waste as a coarse aggregate replacement do not exceed that of normal concrete. Based on the analysis of cube-shaped test specimens regarding the cracking behavior observed in concrete test specimens, it can be concluded that for the 0% variation, the fracture pattern results in columnar-type failure. The fracture pattern occurs due to the placement of the test specimen at a pivot point centered in the middle of the sample. In contrast, for the 25% variation, the fracture pattern results in cone-type failure. Finally, for the test specimens with a 60% mixture, the fracture pattern results in shear-type failure. The fracture pattern occurs due to the excessive voids caused by palm kernel shell fragments, leading to numerous cracks.

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