

Utilization of Shell Waste as Fine Aggregate in K225 Quality Concrete

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Abstract: Conventional concrete materials derived from natural resources cause environmental problems. This encourages the development of concrete using recycled materials for sustainability reasons. One such material is shellfish, which is used to replace aggregates with concrete, both fine and coarse aggregates. This study conducted an experimental study using shellfish waste as a fine aggregate in a concrete mixture. Utilization of shellfish waste not only reduces environmental problems but can also provide economic value to construction, as well as an effort to conserve natural resources. Shellfish waste was obtained from the coast of Mempawah Regency. The planned test specimens were 15x15x15 cm cubes with a target quality of K225 kg/cm². The test specimens were made with a composition of sand with shellfish sand in proportions of 0%, 5%, 7%, 9%, and 100%. Physical properties of shellfish sand were tested, slump tests were conducted to determine the effect of shellfish sand on concrete viscosity, and concrete compression tests were conducted at the age of 28 days to determine the effect of shellfish sand on concrete strength. The compressive strength test results with 0% substitution = 246.22 kg/cm² or 24.15 MPa. 5% substitution = 211.98 kg/cm² or 20.79 MPa, resulting in a 5.79% decrease in quality. 7% substitution = 195.10 kg/cm² or 19.3 MPa, resulting in a 13.29% decrease in quality. 9% substitution = 176.14 kg/cm² or 17.27 MPa, resulting in a 21.72% decrease in quality. 100% substitution = 155.56 kg/cm² or 15.25 MPa, resulting in a 30.86% decrease in quality. The greater the substitution of the shell sand mixture, the greater the decrease in quality.

Keywords: waste, shells, fine aggregate, concrete, environmentally friendly

1. Introduction

Shellfish shells are often considered useless waste because they cannot be recycled (Mo et al., 2018; Nguyen et al., 2013; Safrin Zuraidah et al., 2015). Shellfish waste is generally utilized for crafts. However, not all shells can be used for crafts. This depends on the unique shape, strength, and sturdiness of the shell. Shells that are not perfectly shaped will

be wasted and become waste, especially in coastal areas.

Concrete is the most widely produced and used construction material worldwide. Concrete is a composite essentially composed of cement, water, and aggregate. Aggregate is the main constituent in concrete, consisting of sand, gravel, or crushed stone. Cement and aggregate obtained from natural

exploration continuously cause environmental problems. Eco-friendly concrete is concrete composed of materials that do not harm the environment. Replacing natural aggregates in concrete with various types of recycled materials, including shells, can be an alternative solution to waste problems. Currently, the use of finely ground waste in concrete is becoming increasingly effective because its use can provide good results in terms of mechanical properties and material durability. Shells have characteristics that have the potential to produce high-quality concrete (Bamigboye et al., 2022; Barbachi et al., 2017; Eziefula et al., 2018; Oh et al., 2024).

Therefore, this research conducted an experimental study utilizing shellfish waste as aggregate in a concrete mixture. Utilizing shellfish waste not only reduces environmental problems but also provides economic value to construction and contributes to natural resource conservation.

1.1. Research Urgency

This research is crucial because all materials used in concrete mixes must undergo physical and mechanical property testing as required by SNI 03-1750-1990. Similarly, the use of shell sand as a fine aggregate requires physical and mechanical property testing. This testing is intended to determine the effectiveness of using shell sand as a concrete mix.

1.2. Novelty

This research utilizing shell sand is relatively new for coastal communities, especially in Mempawah Regency. Shell sand is often considered waste by coastal communities, so this research is expected to provide added value to it. The research results can be utilized by coastal communities in utilizing shell sand as a concrete mix. The composition of the shell sand used will be explained in the results of this research.

2. Literature Review

2.1. Materials

Approximately 33% of the weight of shellfish is their shells. This has the potential to become waste if not recycled. Meanwhile, in the construction world, development continues, especially using reinforced concrete materials. Conventional concrete materials derived from natural resources cause environmental problems. This encourages the development of concrete that uses recycled materials for sustainability reasons. One such material is shellfish, which is used to replace aggregates with concrete, both fine and coarse aggregates. Several studies have examined the use of different types of shellfish and mollusks, such as periwinkle clams, mussels, and oysters as fine aggregates in concrete (Bunyamin & Mukhlis, 2020; Safi et al., 2015; Ammari & Fowler, 2017; Kurniawan et al., 2021). The results show that the higher the content of shellfish shells that replace fine aggregates, the lower the concrete's compressive strength.

In general, shells consist of almost 90% calcium carbonate (CaCO3) (Olivia et al., 2017) which are also found in large quantities in rocks and sand. Other elements found in shells include sulfur, sodium, magnesium, aluminum, silicon, strontium, iron, etc. The physical properties of mollusk shells vary depending on the size of the shell (Table 1).



Figure 1. Mollusk shells: (a) Stone Clam; (b) Oyster; (c) Mussel; (d) Scallops; (e) Snail.

Table 1. Physical properties of various mollusk shells

Properties	Stone Clam	Oyster	Mussel Clam	Scallops	Snail	
Bulk density	kg/m ³	-	-	1015	514	
compacted bulk density	kg/m ³	1408 - 1420	-	1224	515 - 1353	
Moisture content	%	-	-	0.3	1.1 - 8.32	
Water absorption	%	0.1 - 2.5	2.9 - 9.2	2.17 - 4.12	1.88 - 3.65	9.03 - 12.99

Source : Eziefula et al., 2018

Clam shells used in concrete must be cleaned of dirt, salt, and other harmful organic matter by washing them and then drying them in the sun until their moisture content is reduced. The shells are then crushed with a hammer and ground with a grinder until they are sufficiently fine. In this study, the shells used were a mixture of various shellfish species, randomly mixed naturally. These shells are abundant along gently sloping coastlines, such as in Mempawah Regency.

Fine aggregate should consist of particles with varying sizes, and when sieved using a series of standard sieves, it shall conform the following requirements: (1) the residue on the 4 mm sieve must have a minimum weight of 2%; (2) the residue on the 1 mm sieve must have a minimum weight of 10%; and (3) the residue on the 0.075 mm sieve should range between 80% and 95%. The grain size distribution or gradation requirements for fine aggregates are categorized into several zones, namely Zone 1, Zone 2, Zone 3, and Zone 4. Fine aggregates are considered to meet the quality standards of gradation if their particle distribution falls within one of these zones. The distribution of particle sizes within the fine aggregate can be seen in Table 2.

Table 2. Fine aggregate grain composition

Sieve hole size (mm)	Percentage of Granular Material Passing the Sieve			
	Zone 1	Zone 2	Zone 3	Zone 4
10	100	100	100	100
4.8	90 - 100	90 - 100	90 - 100	95 - 100
2.4	60 - 95	75 - 100	85 - 100	95 - 100
1.2	30 - 70	55 - 90	75 - 100	90 - 100
0.6	15 - 34	35 - 59	60 - 79	80 - 100
0.3	5 - 20	8 - 30	12 - 40	15 - 50
0.15	0-10	0 - 10	0 - 10	0 - 15

2.2. Concrete Compressive Strength

The characteristic compressive strength is determined by dividing the maximum load recorded during testing by the cross-sectional area of the specimen, which has a square geometry measuring 15 × 15 cm. According to SNI 03-2384-2020, the compressive strength of concrete can be calculated using the following formula:

$$\sigma_{bi} = P/A \dots\dots\dots (1)$$

Where σ_{bi} denotes the compressive strength (kg/cm^2), P represents the maximum load applied by the compression testing machine (kgf), and A is the cross-sectional area subjected to loading.

Formula for average concrete compressive strength:

$$\sigma_{bm} = \sum \sigma_{bi} / N \dots\dots\dots (2)$$

Where σ_{bm} represents the average concrete compressive strength (kg/cm^2), and N denotes the total number of test specimens.

Formula for standard deviation:

$$S = \sqrt{\frac{1}{N} \frac{(\sigma_{bi} - \sigma_{bm})^2}{N}} \dots\dots\dots (3)$$

Where S is the standard deviation (kg/cm^2), N is the number of test objects of 4 pieces.

Concrete compressive strength characteristics:

$$\sigma_{bk} = \sigma_{bm} - 1.63 \times S \dots\dots\dots (4)$$

Where σ_{bk} denotes the compressive strength characteristics (kg/cm^2), σ_{bm} represents the average compressive strength of concrete (kg/cm^2), 1.63 is a constant, and S is the standard deviation (kg/cm^2).

3. Methodology

This study employed a substitution method using shell waste of various compositions as a partial replacement for fine aggregate in concrete. The shell waste used was in the form of powder obtained from crushed shells. The physical properties of the shell waste tested included water content, absorption capacity, specific gravity, bulk density, and particle size distribution. Concrete mixtures were then prepared by substituting shell waste for fine aggregate at variation levels of 0%, 5%, 7%, 9%, and 100% of the fine aggregate composition. The concrete mix was designed to achieve a target compressive strength of K-225 kg/cm^2 .

3.1. Research Tools and Materials

The research utilized various equipment for testing the physical properties and compressive strength of concrete at the Materials Testing Laboratory of the Civil Engineering Department Pontianak State Polytechnic. The equipment used included small scales; a large-scale capacity of approximately 100 kg; a set of analysis sieves; a sand tank; a concrete cube soaking tank; a measuring cup; a ruler; an oven; and a concrete compressive strength tester. The materials used in this study consisted of shell sand; natural sand; crushed stone with a size range of 1–2 cm; Portland cement; paint; and water.

3.2. Collecting Data Methods

The data in this study used primary data, namely direct testing of samples. The data and data collection methods in this study are explained in Table 3 below.

Table 3. Test Data and Data Collection Method

No.	Test Data	Data Collection Method
1.	Water Rate	water content testing is conducted in the materials laboratory
2.	Absorption Capacity	absorption testing conducted in materials laboratory
3.	Type Weight	specific gravity testing is conducted in the materials laboratory
4.	Content Weight	bulk density testing is conducted in the materials laboratory
5.	Grain Arrangement	sieve analysis testing is conducted in the materials laboratory

3.3. Data Analysis Methods

The testing and analysis methods in this study refer to the Indonesian National Standard (SNI) issued by the Indonesian National Standards Agency. The analysis methods in this study

are divided into 2, namely Physical Properties Analysis in Material Testing and Compressive Strength Analysis in the form of 15x15 cm cubes. Physical properties testing such as water content, absorption capacity, specific gravity and bulk weight and grain arrangement refer to SNI 03-1750-1990. Concrete compressive strength testing refers to SNI 03-2834:2000.

3.4. Research Stages

The research phase began with sampling shell sand from a coastal location in Mempawah Regency, followed by physical property testing. The shells used were a mixture of various types of shells. These shells were first washed to remove any residue that could affect the testing. They were then dried in the sun and then crushed into small granules (Figure 2). The aggregate was then subjected to sieve analysis, absorption capacity, water content, specific gravity, and bulk density tests to ensure that the shell sand met the requirements of SNI 03-1750-1990.



Figure 2. Crushed Mussel Shells

The target quality of the job mix for this test specimens was K225 kg/cm^2 with slump of 30-60 mm (Table 4). The test specimens were made by substituting sand with shell sand in proportions of 0%, 5%, 7%, 9% and 100%. The test specimens were prepared in the form of cubes with dimensions of 15 x 15 x 15 cm. Following the preparation of fresh concrete, a slump test was conducted to evaluate the influence of shell sand on the workability of concrete. The specimens were cured by water immersion. Compressive strength tests were performed at curing ages of 7, 14, and 28 days to assess the effect of shell sand on the concrete's strength development. Then an analysis was carried out from the test results to the conclusion stage.

Table 4. Test Data and Data Collection Method

Type of Material	Proportion for 1 m ³ (kg)	Model 1 0% Shell Sand (kg)	Model 2 5% Shell Sand (kg)	Model 3 7% Shell Sand (kg)	Model 4 9% Shell Sand (kg)	Model 5 100% Shell Sand (kg)
Cement	380.00	6.16	6.16	6.16	6.16	6.16
Natural Sand	623.90	10.11	9.60	9.40	9.20	—
Shell Sand	—	—	0.51	0.71	0.91	10.11
Coarse Aggregate	1,237.29	20.04	20.04	20.04	20.04	20.04
Water	190.00	3.08	3.08	3.08	3.08	3.08

*All proportion is for 4 cubes specimen

4. Result And Discussion

The testing of the physical properties model 4 showed the highest results compared to model 1, 2, and 3, but it still fell within the grain size distribution standard of Zone 1 (Figure 3).

Table 5. Results of Physical Properties Testing of Sand with Shell Sand Substitution

Type of Test	Moisture Content (%)	Specific Gravity	Absorption (%)	Bulk Density (kg/m ³)	Sieve Analysis
Test Result	1.25	2.52	1.10	1200	Grain distributi falls within Zon

Table 6. Results of Gradation Analysis of 9% Shell Sand Substitution

Sieve Diameter	Weight Retained	Cumulative Weight Retained	Weight Passing Sample	Percentage Passi
mm	gram	gram	gram	%
9.5	3.88	3.88	798.15	99.52
4.75	25.20	29.08	772.95	96.37
2.36	82.60	111.68	690.35	86.08
1.18	201.11	312.79	489.24	61.00
0.6	243.87	556.66	245.37	30.59
0.3	160.61	717.27	84.76	10.57
0.15	57.45	774.72	27.31	3.41
Pan	27.31	802.03	0.00	0.00
Sieve Diameter	Weight Retained	Cumulative Weight Retained	Weight Passing Sample	Percentage Passi

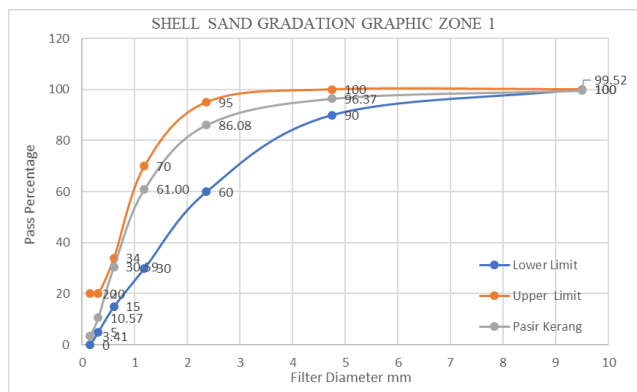


Figure 3. Shell sand substitution gradation

Another result obtained from this study was the compressive strength test conducted to obtain the quality of the resulting concrete. The target concrete strength was set at K-225 or equivalent to $f'c = 22.06$ MPa. Cube specimens measuring 15×15 cm were prepared and cured using the standard curing method. The results showed that only Model 1 meets the target of concrete strength with compressive strength $f'c = 24.15$ MPa (Table 7). However, other models did not meet the concrete compressive strength target, Model 2 with 20.79 MPa (Table 8), Model 3 with 19.13 MPa (Table 9), Model 4 with 17.27 MPa (Table 10) and Model 5 with 15.25 MPa (Table 11). These results indicate that increasing the proportion of shell material in the concrete mixture tends to decrease the overall concrete strength.

Table 7. Analysis of compressive strength characteristics of model 1 with shell sand proportion 0%

No	Test Time Data Weight (Kg)	Age (Days)	Load (Kgf)	Strength 28 days (Kg/cm2)	($\sigma_b - \sigma_{bm}$)	($\sigma_i - \sigma_{bm}$) ²
1	9,0	28	56.000	248,88	-3,34	11,15
2	8,9	28	57.000	253,33	1,11	1,23
3	9,0	28	58.000	257,77	5,55	30,80
4	8,9	28	56.000	248,88	-3,34	11,15
			Σ	1.008,86	Σ	54,33
obm	252,22			kg/cm ²		
d	3,68					
obk	246,22			kg/cm ²		
Fc	24,15			Mpa		

Table 8. Analysis of compressive strength characteristics of model 2 with 5% shell sand proportion

No	Test Time Data Weight (Kg)	Age (Days)	Load (Kgf)	Strength 28 days (Kg/cm2)	($\sigma_b - \sigma_{bm}$)	($\sigma_i - \sigma_{bm}$) ²
1	8,6	28	52.000	231.11	8.89	79.01
2	8,7	28	50.000	222.22	0.00	0.00
3	8,6	28	48.000	213.33	-8.89	79.01
4	8,6	28	50.000	222.22	0.00	0.00
			Σ	888.89	Σ	158.02
obm	222.22			kg/cm ²		
d	6.29					
obk	211.98			kg/cm ²		
Fc	20,79			Mpa		

Table 9. Analysis of Compressive Strength Characteristics of Model 4 with Shell Sand Proportion of 7%

No	Test Time Data Weight (Kg)	Age (Days)	Load (Kgf)	Strength 28 days (Kg/cm2)	($\sigma_b - \sigma_{bm}$)	($\sigma_i - \sigma_{bm}$) ²
1	8,5	28	45.000	200.00	-1.11	1.23
2	8,4	28	46.000	200.00	3.33	11.11
3	8,3	28	46.000	204.44	3.33	11.11
4	8,4	28	44.000	195.56	-5.56	30.86
			Σ	800.00	Σ	54.32
obm	201.11			kg/cm ²		
d	3.69					
obk	195.10			kg/cm ²		
Fc	19,13			Mpa		

Table 10. Analysis of Compressive Strength Characteristics of Model 3 with Shell Sand Proportion of 9%

No	Test Time Data Weight (Kg)	Age (Days)	Load (Kgf)	Strength 28 days (Kg/cm2)	($\sigma_b - \sigma_{bm}$)	($\sigma_i - \sigma_{bm}$) ²
1	8.1	28	40000	177.78	-7.78	60.49
2	8.2	28	41000	182.22	-3.33	11.11
3	8.2	28	43000	191.11	5.56	30.86
4	8.3	28	43000	191.11	5.56	30.86
			Σ	742.22	Σ	133.33
obm	185.56			kg/cm ²		
d	5.77					
obk	176.14			kg/cm ²		
Fc	17,27			Mpa		

Table 11. Analysis of Compressive Strength Characteristics of Model 5 with 100% Shell Sand Proportion

No	Test Time Data Weight (Kg)	Age (Days)	Load (Kgf)	Strength 28 days (Kg/cm2)	($\sigma_b - \sigma_{bm}$)	($\sigma_i - \sigma_{bm}$) ²
1	7.9	28	35000	155.56	0.00	0.00
2	7.7	28	35000	155.56	0.00	0.00
3	7.8	28	35000	155.56	0.00	0.00
4	7.8	28	35000	155.56	0.00	0.00
			Σ	622.22	Σ	0.00
obm	155.56			kg/cm ²		
d	0.00					
obk	155.56			kg/cm ²		
Fc	15,25			Mpa		

5. Conclusion

Based on the discussion above, it can be concluded that the substitution of shell sand with compositions of 5%, 7%, and 9% falls within the grain size distribution of Zone 1. The compressive strength test results indicated that the concrete with 0% substitution achieved a strength of 246.22 kg/cm² (24.15 MPa), 5% substitution achieved 211.98 kg/cm² (20.79 MPa), 7% substitution achieved 195.10 kg/cm² (19.3 MPa), 9% substitution achieved 176.14 kg/cm² (17.27 MPa), and 100% substitution achieved 155.56 kg/cm² (15.25 MPa). A decrease in concrete strength was observed compared to the planned target of K-225 kg/cm², with reductions of 5.79%, 13.29%, 21.72%, and 30.86% for 5%, 7%, 9%, and 100% substitutions, respectively. These results demonstrate that an increase in the proportion of shell sand in the concrete mixture results in a corresponding reduction in compressive strength.

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