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Utilization of Pili Nutshells (Canarium Ovatum) as Aggregates

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Abstract: This study explored the use of pili nutshells as aggregates and the economic value compared to standard aggregates. It involved observation, experimentation, analysis, and interpretation of data to determine the most appropriate design mixture of pili nutshells in concrete and the compressive strength of concrete using shells to ascertain its suitability as a replacement to aggregates in the production of the concrete mixture. Findings revealed that standard mixture and concrete with 25% pili nutshells replacement as fine aggregates has high workability. However, concrete with 25% pili nutshells replacement as coarse aggregates had medium workability. Furthermore, standard concrete is more economical compared to concrete with pili nutshells as coarse and fine aggregates. Researchers concluded that pili nutshells are more effective as fine aggregates than as coarse aggregates. Further studies on the properties/components of pili nutshells shall be made to determine the necessary treatment before they can be used as aggregates.

Keywords: Concrete, materials, strength, mixture, pili

1. Introduction

The construction industry generally uses river sand and gravel for their construction. Sand quantity and cost-effectiveness are critical in remote regions, where essential problems include alternative finance of building sand mines, determining accessible quality, and managing production [1]. This automatically creates the demand for the same. Concrete is the material that is used most in the whole world after water. It has taken several million years to form sand by several agents of weathering. The qualifications were concentrated mostly on more extensive regulatory schemes [2]. The average rate of population growth was about 0.48 percent per year and the average consumption of aggregate was about 1.23 million tons per year [3]. The high demand for aggregates will also cause the increasing environmental effects of quarrying, therefore, using alternative aggregates is crucial in the construction industry. Using aggregates from recycled materials will give economic and environmental benefits to the community. The addition of steel fibers (SF) increased the global warming potential (GWP), while mixtures including industrial waste, slag, or nano-silica had a lower GWP [4]. Waste materials increase each and every year so the importance to prevent waste production must be pointed out. The use of RCA is likely a viable option for structural use [5]. Commercial and agricultural waste materials such as rice husk, palm husks, and coconut husks may be utilized as a concrete aggregate or partially substituted for standard resources in cement and brick manufacturing.

The Pili production and process in commercial quantity is exclusive in the Philippines [6]. There were about 256 entrepreneurs recorded in the industry [7]. Moreover, in 1998, there were 13,435 farmers, that have at least 10 Pili trees and were hired as harvesters in the Bicol Region which provides additional earnings that highly contribute to the economy [8]. In the Bicol Region, the shell is commonly used in making different handicrafts and furniture. As industrial and agricultural operations increase, lots of waste materials are dumped into the biosphere with no effective

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solid waste management or recovery. Certain of these sediments are resistant to decomposition, and their buildup poses harm to the environment and the general population. The researchers conducted a study on how to use the pili nutshell as aggregates in concrete to help the community in disposing of the shells.

The purpose of this research was to determine the optimal design mixture of Canarium Ovatum shells for compressive strength of concrete in order to determine its appropriateness as a substitute for aggregates in the creation of the concrete mixture. The shell's characteristics were identified and compared to those of ordinary aggregate. The aggregates utilized have a significant effect on the strength of concrete. This provided a source of information for the researchers to use in the future while practicing their profession.

2. Materials and Methods

2.1 Physical Characterization of Pili Nutshells

(a) Specific Gravity and Unit Weight

The "pili nutshells" were packed in a zip plastic bag before sun-drying to minimize moisture contact, and the weight variations were monitored daily. No changes of weight infer that the samples were in the driest state. The weight and volume were measured using a graduated cylinder filled with water, hence, the displaced water volume was equivalent to the submerged pili nutshells. The researchers converted the volume from milliliter to cubic meter, then, the weight of the solid "pili nutshells" was divided by the volume. The specific gravity was calculated by dividing unit weight by water.

(b) Void Contents and Water Absorption

The "pili nutshells" were submerged in water for 24 hours to fill the voids. The submerged "pili nutshells" were weighed and used the formula $1g/m^3$ to determine the volume of water. The amount of water that fills the void spaces was equal to the volume of void spaces. To determine the void ratio, divide the volume of voids with the volume of submerged pili nutshells, then, water absorption was equal to the computed weight of water after immersion.

2.2 Concrete Mixing Content

(a) Determination of the Water Cement Ratio

The concrete proportions were based on water-cement ratio limits. When trail mixers are unavailable, the permissible limits water-cement ratios for concrete may be determined using ACI Code Requirements Table 1. By knowing the desired compressive strength of the concrete, the water-cement ratio was determined directly from the table. If the desired compressive strength was not specified, use linear interpolation instead to approximate the ratio. The water-cement ratio based on the code requirements was used for the standard concrete mixture. To compensate for the particles' water absorption, more water was added to the mixes depending on the "pili nutshells" substitution; hence, the water-cement ratio of the mixtures differs from the standard mixture.

Table 1 – Maximum Permissible water-cement ratios for concrete

Specified compressive strength (psi)	Water-cement ratio
2465.92	0.66
2901.08	0.60
3626.35	0.50
4351.62	0.40

(b) Quantity of Materials to be Used in Making Concrete

The formulas used in making concrete as follow:

$$Cement\ (kg) = C.F \times V_C \times 360\ kg \tag{1}$$

$$Sand\ (m^3) = S.F. \times V_C \tag{2}$$

$$Gravel\ (m^3) = G.F. \times V_C \tag{3}$$

$$Water_D\ (kg) = W.C. \times 360 \times V_C \tag{4}$$

$$COS_F\ (m^3) = P \times Sand \tag{5}$$

$$COS_C\ (m^3) \quad = P \times Gravel \tag{6}$$

$$Water_{to\ be\ added}(kg)_F = Water_D + W.A\%(COS_F) \tag{7}$$

$$Water_{to\ be\ added}(kg)_C = Water_D + W.A\%(COS_C) \tag{8}$$

$$Water\ cement\ ratio_F = \frac{Water_{to\ be\ added}(kg)_F}{Cement\ (kg)} \tag{9}$$

Where:

C.F is a cement factor which was 0.9,
S.F is a sand factor which was 0.5,
G.F is a gravel factor which was 1.0,
V_c is a volume of concrete,
P is a percentage replacement,
W.A% is water absorption in terms of percentage,
$Water_D$ is a designed water of the mixture,
$Water_{to\ be\ added\ F}$ is water to be added when there's a percentage replacement for fine aggregates, and
$Water_{to\ be\ added\ C}$ is water to be added when there's a percentage replacement for coarse aggregates.

(c) Prototyping

The first phase of the study was to gather the needed materials in concrete samples which include cement, gravel sand, water, pili nutshells, and the tools used to pulverize the shells. In accordance with AASHTO M 205 Standard Specifications for Molds for Vertically Forming Concrete Test Cylinders, cylinder molds with a length equal to twice the diameter were prepared for concrete pouring by coating with used oil to simplify mold removal. This study used molders with 6 inches diameter and 12 inches in length. The mixing procedure was crucial in the production of concrete samples in order to attain the desired result. The analysis includes basic analysis of stress (σ), percentage of Canarium Ovatum shell to the total amount of sand mixture ($\%_{shell}$), percentage of Canarium Ovatum shell to the total amount of gravel mixture ($\%_{shell}$), and price comparison – economic aspect using strength to price ratio (S). The formula for the analysis as follows:

$$\sigma = \frac{\text{Force (P)}}{\text{Area (A)}} \tag{10}$$

$$\%_{shell}(\text{sand mixture}) = \frac{\text{Volume of crushed shell}}{\text{Volume of Canarium Ovatum shell} + \text{Volume of sand}} \tag{11}$$

$$\%_{shell}(\text{gravel mixture}) = \frac{\text{Volume of crushed shell}}{\text{Volume of Canarium Ovatum shell} + \text{Volume of gravel}} \tag{12}$$

$$\text{Price economical} - \text{strength ratio} = \frac{\text{Strength}}{\text{Price of cylindrical concrete}} \tag{13}$$

2.3 Production Cost

Pili nutshells were collected from a food company that specialized in pili nut products. The shells were then manually crushed into tiny fragments using a hammer and sieved through a 4.75 mm mesh. The calculation for unit labor cost of pulverizing Pili nutshells were as follow:

$$\text{Production rate} = \frac{\text{Weight of shells broken into small chips}}{\text{Time required to pulverize the shells}} \tag{14}$$

$$\text{Total time} = \frac{\text{Required weight of pulverize the shells}}{\text{Production rate}} \tag{15}$$

$$\text{Total cost} = \text{Total time X Cost of laborer per hour} \quad (16)$$

$$\text{Unit cost} = \frac{\text{Total cost}}{\text{Required weight of pulverized shells}} \quad (17)$$

$$\text{Materials cost} = \text{Quantity used x Unit cost} \quad (18)$$

$$\text{Labor cost} = 30\% \text{ x Total cost of materials} \quad (19)$$

$$\text{Cost of product} = \text{Labor cost x Total cost of materials} \quad (20)$$

2.4 Compressive Strength Determination

This stage involved the final testing of the concrete samples. Testing machines from Provincial Engineering Office (PEO) was used. ASTM C39 (Compressive strength of cylindrical concrete specimens) was a test method for determining the compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. Compressive strength was determined by preparing cylinders. The specimens were cast and cured for 7 and 14 days, since mixed and cured for up to 14 days, the compressive strength of concrete was increased [9]. The cured specimens were subjected to testing and the results were obtained. Compressive strength is inversely proportional to all other qualities of concrete. The field testing was intended to find out the maximum load-carrying capacity of the test sample.

2.5 Pre-Design

The researchers were fully aware of the materials utilized to construct the concrete samples. The proponents figured out the mixture class as the basis in mixing proportion. The details of mixture proportions were included to analyze the effect of shells on concrete in terms of strength. Each proportion had a different percentage replacement of aggregates.

2.6 Materials

The study's elements were sourced locally. Appo Blue Cement was used in the mixture. Normal aggregate was used as coarse aggregate passing through 9.75 mm. As a fine aggregate, well-graded river sand with a particle size of less than 4.75 mm was employed. For 9.75 mm and 4.75 mm aggregates, the particular gravities were 2.65 and 2.63, respectively. The shells were manually crushed into tiny fragments and sieved using a 4.75 mm sieve. The material was sieved to a 4.75 mm mesh size and utilized in lieu of fine aggregates. Additionally, coarse particles were substituted with shells that were 9.75 mm in diameter. We rejected the material retained on a 4.75 mm sieve. The primary purpose of this experiment was to determine the strength of concrete reinforced with a “pili nutshell”. Before the shells were used as aggregates in the concrete, the properties were determined through laboratory tests. The properties of the shells used to arrive at the appropriate mixture design of the concrete. Compressive strength was used to determine the performance of concrete. Compression strengths were determined on the specimens after 7 and 14 days. The indicators should be used such as for 7 days, 65 % of strength, and 90 % for 14 days, 94 %. The compressive strength varied depending on the curing method [10]. Laboratory tests would give results that were used to attain the objectives of the study.

3. Results and Discussion

3.1 Desired Proportions

Table 2 shows the mixed proportions of concrete for varying pili nutshells replacement as fine aggregates. Nine mixtures were used to determine the compressive strength of concrete. The control mix (E) represents without pili nutshells. To determine the impact of aggregate substitution, fine aggregates were substituted with “pili nutshells” in 25 % (AF), 50 % (BF), 75 % (CF), and 100 % (CF) (DF).

Furthermore, Table 3 shows the mixed proportions of concrete for varying pili nutshells replacement as coarse aggregates. it was also replaced in 25 % (AC), 50 % (BC), 75 % (CC), and 100 % (DC). For all concrete mixes, the free water to cementitious ratio was kept constant at 0.5. To compensate for the particles' water absorption, more water was added to the mixtures depending on the pili nutshells replacement.

Table 2 - Mix proportions of concrete for varying pili nutshells replacement as fine aggregates

Sample	Water cement ratio	Cement (kg)	Gravel (m^3)	Sand (m^3)	Pili nutshells (m^3)	Ratio (sand to shells)
AF	0.63	2.0016	0.0056	0.002085	0.000695	3:1
BF	0.81	2.0016	0.0056	0.00139	0.00139	2:2
CF	0.95	2.0016	0.0056	0.000695	0.002085	1:3
DF	1.10	2.0016	0.0056	0	0.00278	0:4
E	0.52	2.0016	0.0056	0.00278	0	4:0

Table 3 - Mix proportions of concrete for varying pili nutshells replacement as coarse aggregates

Sample	Water cement ratio	Cement (kg)	Gravel (m^3)	Sand (m^3)	Pili nutshells (m^3)	Ratio (gravel to shells)
AC	0.58	2.0016	0.0042	0.00278	0.0014	3:1
BC	0.64	2.0016	0.0028	0.00278	0.0028	2:2
CC	0.70	2.0016	0.0014	0.00278	0.0042	1:3
DC	0.76	2.0016	0	0.00278	0.0056	0:4
E	0.52	2.0016	0.0056	0.00278	0	4:0

Since this study introduced a new material in the concrete, the mixture design was affected. The addition of fibers raised the flexural strength of concrete, whereas the substitution of waste sludge did not result in a significant improvement in compressive strength [11]. The water-cement ratio of mixes including pili nutshells as aggregates was found to be different from that of the reference mixture. According to laboratory studies, the shells absorbed more water than ordinary aggregates. To compensate for water absorption, more water was added to the mixes. Apart from affecting workability, more water in structural lightweight aggregate concrete impacts the degree of cement hydration [12]. Water was added in accordance with the number of aggregates replaced. The proponents undertook critical research to determine the proper combination design for the concrete. The control concrete without pili nutshells was also fabricated along with the mixes.

3.2 Slump Test

Fig. 1 illustrates the slump cone test in this study. The slump of the conventional mixture and the concrete containing 25 % pili nutshells as fine aggregates was 95 mm and 100 mm, respectively, indicating that the mixes were workable. The degree of compaction of concrete has a significant effect on its strength [13]. The combination might be utilized in concrete with sparsely spaced reinforcement. The concrete using 25 % pili nutshells as coarse aggregates had a workability of 76 mm, indicating that it may be utilized for conventional reinforced concrete set with vibration. Vibration is used to determine the capacity of concrete to reshape itself in response to applied vibration [14].

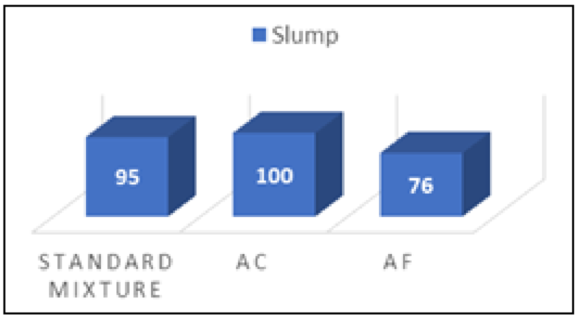

Fig. 1 - Slump cone test

3.3 Compressive Strength of Concrete Samples

Concretes were subjected to compressive load-testing. The standard mixture and concrete containing 25 % fine and coarse particles were evaluated after 7 and 14 days of curing. Table 4 illustrates that fine aggregates replaced with pili nutshells at 25 % in concrete were suitable for construction. The displaced volume values were exactly proportional to the applied load for the examined mixtures and at a predefined consistency level. The strength was about 89.75 % of the control mix at the 14 days curing period. Cement hydration can absolutely promote the performance of cement composites [15]. The process of strength development was expected to continue with curing time until the completion of hydration.

Table 4 - Compressive strength of concrete with 25 % replacement of fine aggregates with pili nutshells

Sample identification	Compressive strength (psi)	
	7 days	14 days
AF	2541	3642
E	3073	4058

Table 5 shows that pili nutshells as coarse aggregate was not good for the mixture. Since the shells have a smooth surface, the strength was only about 51.3 % of the control mix. Whilst the clean surface may enhance workability, rougher surface results in a better binding between the paste and the aggregate, which results in increased strength.

Table 5 - Compressive strength of concrete with 25 % replacement of coarse aggregates with pili nutshells

Sample identification	Compressive strength (psi)	
	7 days	14 days
AC	1530	2082
E	3073	4058

Fig. 2 shows that the percentage difference during the seven-day curing time was 18.95 %, based on the data supplied. Compressive strength rises as the cure time lengthens. Mechanical strength improves linearly with an increasing degree of compaction across all gradations and cure times [16]. For the 14 days curing period, concrete containing 25 % pili nutshells was 10.81 % lighter than the usual mixture. Additionally, data indicate that the standard combination is larger by 67.04 % and 64.36 % for 7 days and 14 days curing periods, respectively.

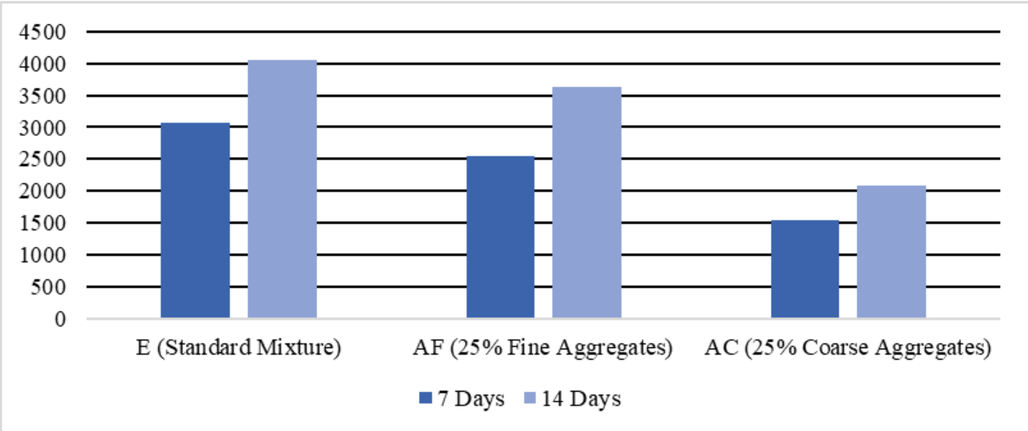

Fig. 1 - Compressive strength values

3.4 Economic Value

The raw materials used in cylindrical concrete samples were bought in the market. The researchers used an accurate quantity of materials to find the corresponding cost. The price per sample depends upon the cost of materials and labor.

The material used in creating concrete with pili nutshells as fine aggregates and coarse aggregates. The researchers considered labor cost which is 30 % of the total cost of the materials used. Proponents also computed the unit labor cost for making the shells into smaller chips that passed on U.S Sieve no.4. The price of the product would serve as a basis to determine its economic value. The volume of sand or gravel was less by 25 % resulting to a higher price compared to the standard concrete mixture.

Table 6 - Price of standard concrete mixture

Material	Standard concrete mixture			
	Unit	Quantity	Unit cost	Amount
Fine aggregates	m^3	0.00278	450	1.251
Coarse aggregate	m^3	0.0056	550	3.08
Cement	kg	2.0016	6.25	12.51
Total material cost	16.841			
Labor cost (30% of material cost)	5.0523			
Price per sample	21.89			

Table 7 - Price of concrete with pili nutshells as fine aggregates

Material	Concrete with pili nutshells as fine aggregates			
	Unit	Quantity	Unit Cost	Amount
Fine aggregates	m^3	0.002085	450	0.93825
Coarse aggregate	m^3	0.0056	550	3.08
Cement	kg	2.0016	6.25	12.51
Pili nut shells	m^3	0.000695	3000	2.085
Total material cost	18.61			
Labor Cost (30% of mat. Cost)	5.58			
Unit labor cost of size reduction of pili nutshells	m^3	0.000695	8754.32	6.08
Price per sample	30.27			

Table 8 - Price of concrete with pili nutshells as coarse aggregates

Material	Concrete with pili nutshells as coarse aggregates			
	Unit	Quantity	Unit Cost	Amount
Fine aggregates	m^3	0.00278	450	1.251
Coarse aggregate	m^3	0.0042	550	2.31
Cement	kg	2.0016	6.25	12.51
Pili nut shells	m^3	0.0014	3000	4.2
Total material cost	20.271			
Labor cost (30% of mat. cost)	6.08			
Price per sample	26.35			

The data represents the strength to the price ratio of concrete with pili nutshells as a replacement of aggregates. After 7 days curing period, samples using pili nutshells as fine and coarse aggregates reduced load-bearing capacity by 18.95 % and 67.04 %, respectively, as compared to the conventional concrete mixture. Furthermore, the mixture with shells as fine and coarse aggregates is lesser by load-bearing capacity 10.81 % and 64.36 %, respectively. In terms of economic advantage, the data shows that the standard concrete is more economical compared to the concrete with pili nutshells as coarse and fine aggregates. Not only is cement more costly than the majority of other components in conventional concrete, but it also has a significant environmental effect [17].

Table 9 - Economical advantage of concrete with pili nutshells in 7 days curing period

Sample	Strength (psi)	Price (Php)	Strength to price ratio
Standard concrete	3073	21.89	140.38
Concrete with pili nutshells as fine aggregates	2541	30.27	83.94
Concrete with pili nutshells as coarse aggregates	1530	26.35	58.06

Table 10 - Economical advantage of concrete with pili nutshells in 14 days curing period

Sample	Strength (psi)	Price (Php)	Strength to price ratio
Standard concrete	4058	21.89	185.38
Concrete with pili nutshells as fine aggregates	3642	30.27	120.32
Concrete with pili nutshells as coarse aggregates	2082	26.35	79.01

4. Conclusion

The researchers concluded that pili nutshells are more effective as fine aggregates than coarse aggregates based on the outcomes of this investigation. The water-cement ratio drops as the percentage replacement of aggregates lowers. As a result, their connection is exactly proportionate to one another. Only the substituted aggregates and the water-cement ratio vary across samples, while the remainder of the mixture remains constant. Nutshells from Pili were unable to be utilized as coarse aggregates. Shell aggregate concrete has a lesser performance than standard aggregate concrete since it may be utilized as fine aggregates with a 25 % replacement rate. When compared to conventional concrete, crushed pili nutshell-containing concrete is not more cost-efficient. Mechanical equipment is required to readily crush pili nutshells. Further research on the properties/components of pili nutshells is needed to establish the treatment that is required before they can be used as aggregates. Other common tests, including soundness and abrasion, are carried out to further examine the raw material's quality (pili nutshells). It's also a good idea to look at the environmental benefits of concrete using pili nutshells. The potentials of pili nutshells as aggregates were discussed in the study, thus pili nutshell as a product may be utilized as a replacement for other commercial-based materials. The study also suggests that pili nutshells as recyclable waste can turn into industrial materials or components.

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