Investigation of the Compressive Strengths of Coconut Shells as Partial Alternative of Coarse Aggregates in Concrete Mix

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Abstract

As the infrastructure development continues to thrive in the Philippines, the demand for concrete in the construction industry also grows. Aggregates, being one of the major components of concrete, plays a vital role in construction. The method of extracting these aggregates entails numerous environmental issues such as land degradation, water pollution, and air and dust pollution. The presence of these non-eco-friendly ways of acquiring raw materials of concrete calls for a need to explore and to find suitable material to substitute the natural stone. Alternative materials show increasing potential in concrete mix design strategies and provide new opportunities for a number of design conditions.

This paper introduces the usage of agricultural wastes namely the coconut shell as a substitute to coarse aggregates. Context of concrete mix and how standard design measures are enacted. The research incorporated the crushed coconut shell into the concrete mixture as an aggregate. The physical properties of coconut shells as well as the components of concrete were presented. The compressive strength, slump test, concrete density, and air content were also presented. The slump test and compressive strength test were conducted in accordance with ASTM C143 and ASTM C39 respectively. Results show that workability of concrete is slightly affected at increasing replacement of coconut shells. Integration of coconut shells caused a 24% concrete strength reduction for every 20% coconut shell replacement at 28 days strength.

Keywords: Coconut Shell, Agricultural Waste, Concrete Mix, Compressive Strength, Eco-friendly, Sustainable Material, Concrete Mix

I. Introduction

The high demand for concrete in the construction industry using normal weight aggregates such as gravel has drastically reduced the natural stone deposits in our country. The depletion of these stone deposits as well as the pollution it produces in the process of its extraction has greatly damaged the environment thereby causing ecological imbalance. The presence of these non-eco-friendly ways of acquiring raw materials of concrete calls for a need to explore and to find suitable material to substitute the natural stone.

Coconut, also known as the "tree of life", is one of the most important crops in the Philippines. It is considered a major export, contributing 3.6% of the country's gross value-added (GVA) in agriculture, next to banana, corn and rice. Coconut production plays an important role in the national economy of the Philippines. According to figures published in December 2009 by the Food & Agriculture Organization of the United Nations, it is the world's largest producer of coconuts, producing 19,500,000 tons in 2009. Production in the Philippines is generally concentrated in medium-sized farms.

Coconut shells as a partial substitute for coarse aggregates in concrete started gaining importance especially in terms of possible reduction of waste products in the environment and finding a sustainable alternative for non-renewable natural stone aggregates. The properties of concrete using crushed coconut shells as coarse aggregate were investigated in an experimental study. In this study, coarse aggregate was replaced at 2.5%, 5%, 7.5%, 10%, 15%, 20%, & 100% by crushed coconut shells. Workability, compressive strength, air content, and density of the above said mixes were compared with normal concrete properties. The results from the study is expected to promote the use of coconut shell as a partial substitute for conventional coarse aggregates

A. Background of the Study

1. Concrete

Concrete, one of the most used building materials in the world today, is known for its remarkable qualities: plastic and malleable when newly mixed and strong and durable when hardened. These qualities explain why one material, concrete, can create various building elements such as foundations, columns, beams, slabs, and other load bearing elements (The Constructor, 2018). Concrete, itself, can be used to build skyscrapers, bridges, sidewalks and superhighways, houses, and dams.

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2. Concrete Composition

Concrete is a material composed of cement, fine aggregates (sand), coarse aggregates, and water. Cement, usually Portland cement, is mixed with water to create a paste-like substance. This paste is then coated on the surface of the fine (small) and coarse (larger) aggregates in order for it to harden through the process of hydration and eventually gain strength to form the rock-like mass known as concrete (Portland Cement Association, 2018).

3. Concrete Aggregates

Aggregates are inert granular materials which are considered as base material for every construction. Concrete aggregates such as sand, gravel, or crushed stone, along with water and Portland cement, are regarded as essential ingredients in concrete.

a) Importance

Aggregates make up some 60 to 80% of the concrete mix. They determine the compressive strength and bulk of concrete (Greenspec, 2018).

More than just an inert filler within a concrete mix, aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Aggregates play an important role in concrete as they are responsible for the changes in gradation, maximum size, unit weight, and moisture, which can all alter the character and performance of the concrete mix.

The economical factor of concrete greatly lies on the inexpensive aggregate selection as well. Moreover, by selecting the maximum allowable aggregate size, the cement requirements, the costliest ingredient, can be reduced. Less cement (within reasonable limits for durability) will also mean less water if the water-cement (w/c) ratio is kept constant. A lower water content will reduce the potential for shrinkage and for cracking associated with restrained volume change (Concrete Network, 2018).

b) Sizes

Aggregates are divided into either ‘coarse’ or ‘fine’ categories depending on their sizes. Coarse aggregates are particulates greater than 4.75mm, while fine aggregates are usually sand or crushed stone that are less than 9.55mm in diameter (Greenspec, 2018). Larger sizes of well-graded aggregate and improved grading decrease the void content.

c) Aggregate Selection

Quality traits of aggregates which are considered for the selection process include their durability, strength, workability and ability to receive finishes. For a good concrete mix, it is recommended that aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete (Greenspec, 2018).

d) Examples of Traditional Aggregates

Aggregates may be natural, manufactured, or recycled. Common aggregates include crushed stone and manufactured sand, gravel, sand, lightweight aggregates (e.g., vermiculite and glass aggregate) and recycled concrete (Greenspec, 2018).

4. Issues with Traditional Aggregates

Small details about the traditional aggregate such as its size, quantity and quality cause large variations in performance. Because soil type is hardly consistent throughout the world, fine aggregate or rock can be hard to acquire. Moreover, the extraction of these aggregates may sometimes entail the need of rock quarries and extraction of marine aggregates, both of which result in the disturbance of the environment (Greenspec, 2018).

Hence, numerous researches have been done to approach this issue. Criteria for a solution for the issues shall have the following traits: Low tech, widely available, and be an improvement. Some of the alternatives for aggregates include expanded polystyrene (EPS), crush rubber, glass, high density polyethylene (HDPE), paper pulp, and the recently discovered local alternative- coconut shells. However, for the purpose of this research, only the effectivity of coconut shells will be studied among the many alternatives.

5. Coconut Shell as Concrete Aggregate

Coconut shells satisfy the mentioned criteria above for alternative aggregates well. It is low technology and easily acquired as an agricultural waste. It is widely available as it is locally sourced in the country. The Philippines, a tropical country, is abundant with coconut trees. In fact, it has a 59% share in world coconut exports (Choose Philippines, 2013). Coconut shells are also expected to produce an improvement in concrete in various aspects.

The question now is how effective it is as an alternative aggregate of concrete. This shall be determined through accomplishing this research.

II. Problem Setting

A. Statement of the Problem

In light of the government’s infrastructure program as well as the other construction projects of the private sectors, the flourishing of the construction industry in our country also requires a great demand on its construction materials like concrete. The growing rate on the demand of concrete causes problems in the extraction of its raw materials. Depletion of its main components like aggregates not only requires an innovative solution but also a sustainable one.

In this study, the researcher will conduct a qualitative analysis between the effects of the typical aggregate and that of coconut shells as an alternative aggregate on the concrete design in terms of shape, texture, density, air content, and compressive strength.

B. Objectives

This study aims to determine the possibility of substituting coarse aggregates with coconut shells in concrete mix.

This study aims to provide the following information:

1. To understand the effects of coconut shells in concrete mix.
2. To compare the performance of typical/common aggregates with the coconut shell as an alternative.
3. To identify the different properties of coconut shells that affect concrete mix design.
4. To evaluate the potential usage of coconut shell as partial replacement to stone aggregates in the production of conventional concrete.

C. Significance of the study

Environmental and economic crises have paved the way to the use of alternative materials such as the use of agricultural waste to lessen social and environmental issues. The recycling of coconut shells helps the industry in saving the environment and provides knowledge to contractors and developers on how to improve the construction industry methods and services that sustain good product performance and recycling goals.

D. Scope and Limitation

1. The species of coconut shells here in the Philippines may differ in terms of its physical properties and that results may vary for every experiment conducted.
2. Concrete mix practices/formulae may also vary in a local setting and that adjustments must be taken into account when testing the material.
3. The study involves an experiment that will help the researchers in determining the compressive strength of the materials to be tested using a controlled specimen.
4. The study focused on the compressive strength determination in accordance with ASTM C39.

E. Definition of Terms

1. Concrete Grade

Grade of concrete denotes its strength required for construction. This is presented in mix proportions based on various lab tests. For example, for M30 grade, the mix proportion can be 1:1:2, where 1 is the ratio of cement, 1 is the ratio of sand and 2 is the ratio of coarse aggregate based on volume or weight of materials. The first letter in grade "M" is the mix and 30 is the required strength in MPa.

Common grades of concrete include M15 for plain cement concrete works, M20 for reinforced concrete construction and M25 etc. (The Constructor, 2018).

2. Curing of Concrete

Curing of concrete refers to the provision of adequate moisture, temperature, and time for the concrete to achieve the desired properties for its intended use (Portland Cement Association, 2018).

III. Review of Related Literature

This chapter deals with the study of concrete and coconut shells, and their performance in a concrete mixture as per review of previous studies. At the end of this chapter, a short summary related to this literature review is presented.

A. Design of Concrete Mix

Concrete is a multifaceted substance containing numerous components in various compositions and ratios (Kosmatka et. al, 2002). Plain concrete possesses very low tensile strength, partial ductility and modest opposition to cracking. This flaw has been eradicated by using fibers into the concrete. Coarse aggregates constitute the volume and capacity of concrete and the material used remains to be an important factor that affects the mixture (Chakravarthy, 2017). It will help in safeguarding and repairing concrete structures. The process of determining required and specifiable characteristics of a concrete mixture is called mix design.

1. Components of Concrete Mix

Regular concrete mixture contains four components, cement, crushed stone, river sand and water. The components, crushed stone and sand are typically substituted with lightweight aggregates. Lightweight concrete is usually made by integrating natural or synthetic lightweight aggregates.

The composition of a concrete mix, cement, crushed stone, fine aggregate, steel fiber and water, were described by Kalyana Chakravarthy (2017) in a similar study as follows:

a. Cement

The cement used is Ordinary Portland Cement (OPC) and is conforming to IS: 12269-1987. The cement properties are listed in Table 1.

Table 1 Properties of cement

Description	Test Results	As per IS: 12269-1987
Fineness, %	4.12	Maximum 10%
Normal consistency, %	31	27 – 33
Initial setting time, min.	76	Not less than 30
Final setting time, min.	430	Not more than 600
Specific gravity	3.1	3.10 – 3.15

b. Crushed Stone

The stone aggregate of size around 12.5mm is chosen as coarse aggregate for control concrete chosen by shape as per IS: 2386 (Part 1)-1963 and surface quality description of the aggregate are classified as per IS: 383-1970. The properties of crushed granite stone were shown in Table 2.

Table 2 Properties of crushed granite stone

Description	Test Results	As per IS: 383-1970
Fineness modulus	6.94	5.00 – 7.00
Specific gravity	2.82	2.60 – 2.90

c. Fine Aggregate

The sand from Chakravarthy's study was taken from nearby river sand and conformed to grading II as IS: 383-1970. The sand was passed in 4.75mm sieve to eliminate any particles larger than 4.75mm. The properties of fine aggregate were shown in Table 3.

Table 3 Properties of fine aggregate

Description	Test Results
Fineness modulus	2.56
Specific gravity	2.57

d. Steel Fiber

Steel fibers are supplemented at different proportions from 0.5 % to 2.0 % in order to find the optimum level in control concrete and coconut shell aggregate concrete by volume fraction. The properties of steel fiber used were shown in Table 4.

Table 4 Properties of steel fiber

Parameters	Value
Length, mm	50
Diameter, mm	1
Aspect ratio (l/d)	50
Tensile strength, N/mm2	1225

e. Water

Potable water is mostly initiated in fresh concrete and curing of specimens which remain free of charge from all impurities.

2. Characteristics and Proportioning of Concrete Mix

Characteristics of a concrete mix may include fresh concrete properties, mechanical properties that are required in order to harden concrete such as strength and durability requirements and the inclusion, exclusion, or limits on specific ingredients (Gunasekaran et al, 2008). The researchers also pointed out that the mixture proportioning refers to the process of determining the quantities of concrete components and the usage of local materials, to achieve specified characteristics of the concrete.

According to Abrams (1918), Hover (1998), and Shilstone (1990), a properly proportioned concrete mix should have the following qualities: (1) acceptable workability of the freshly mixed concrete; (2) durability, strength, and uniform appearance of the hardened concrete; and (3) economical. The qualities mentioned above will be obtained in concrete mixing with proper selection of materials. The basis for selection and proportioning of materials are its structural requirements, environmental conditions, job site conditions, such as the methods of concrete production, transport, placement, compaction and finishing, and the characteristics of the available raw materials.

B. Factors Affecting Concrete Mix Design

According to The Constructor (2018), the various factors affecting the choice of concrete mix design are as follows:

1. Compressive Strength of Concrete

The compressive strength of concrete is considered as the most essential concrete property as it influences other properties of the hardened concrete. The mean compressive strength required at a specific age, which is usually 28 days, determines the nominal water-cement ratio of the mix. One factor that influences the compressive strength of concrete is its compaction degree (The Constructor, 2018). Also, it is demonstrated that concrete compressive strength of a fully compacted concrete is inversely proportional to the water-cement ratio.

2. Workability of Concrete

Table 5. Maximum Water-Cementitious Material Ratios and Minimum Design Strengths for Various Exposure Conditions.

Exposure condition	Maximum water-cementitious material ratio by mass for concrete	Minimum design compressive strength, f'_c, MPa (psi)
Concrete protected from exposure to freezing and thawing, application of deicing chemicals, or aggressive substances	Select water-cementitious material ratio on basis of strength, workability, and finishing needs	Select strength based on structural requirements
Concrete intended to have low permeability when exposed to water	0.50	28 (4000)
Concrete exposed to freezing and thawing in a moist condition or deicers	0.45	31 (4500)
For corrosion protection for reinforced concrete exposed to chlorides from deicing salts, salt water, brackish water, seawater, or spray from these sources	0.40	35 (5000)

Adapted from ACI 318 (2002).

Concrete workability is a broad term describing how easily freshly mixed concrete can be mixed, placed, consolidated and finished with minimal loss of homogeneity (Gilson Company, Inc., 2018). Workability is a property that directly impacts strength, quality, appearance, and even the cost of labor for placement and finishing operations.
The workability of concrete may be satisfied depending on the size and shape of the section to be concreted, the amount and spacing of reinforcement and concrete transportation, placement and compaction technique (The Constructor, 2018).

3. Durability of Concrete

Durability refers to the ability of concrete to withstand certain environmental conditions that are detrimental to the material. High strength concrete is generally more durable than low strength concrete. Concrete durability depends on the water-cement ratio (The Constructor, 2018).

4. Maximum Nominal Site of Aggregate

Aggregate size is inversely proportional to cement requirement for water-cement ratio. This occurs because the workability of concrete is directly proportional to the size of aggregate to be used. Also, the compressive strength tends to increase with the decrease in size of aggregate. Smaller aggregate size offers greater surface area for bonding with mortar mix that give higher strength (The Constructor, 2018).

Table 6. Compressive Strength of Different Concrete Mixes (Cement: Fine Aggregate: Coarse Aggregate).

Nominal Mix	Minimum cube strength required (in psi)			
	Laboratory Tests		Work Tests	
	7 days	28 days	7 days	28 days
1:1:2	4000	6000	3000	4500
1:1½:3	3350	5000	25000	3750
1:2:4	2700	4000	2000	3000
1:3:6	---	2500	---	2000
1:4:8	---	2000	---	1500

5. Grading and Type of Aggregate

Aggregate grading influences the mix proportions for a specified workability and water-cement ratio. The relative proportions between coarse and fine aggregate in concrete mix influence concrete strength (Abrams, 1918). Well graded fine and coarse aggregate produce a dense concrete because of the achievement of ultimate packing density (The Constructor, 2018).

6. Quality Control at Site

The degree of control could be evaluated by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients, in addition to lack of control of accuracy in batching, mixing, placing, curing, and testing (The Constructor, 2018).

C. Coconut Production in the Philippines

Coconut has been widely available and one of the most important crops in our country. It is considered a major export, contributing 3.6% of the country's gross value-added (GVA) in agriculture, next to banana, corn and rice. The country remains to be a top producer and exporter of coconut worldwide (PSA 2019, Lapina & Andal, 2017).

Coconut production was estimated at 3.31 million metric tons this quarter (April–June 2019), slightly lower by 0.8 percent than the 2018 same quarter level of 3.34 million metric tons (Philippine Statistics Authority, 2019).

The top coconut-producer from April to June 2019 was Davao Region, with a contribution of 453.67 thousand metric tons or 13.7 percent. This was followed by Zamboanga Peninsula and Northern Mindanao with 12.8 and 12.7 percent shares, respectively (Philippine Statistics Authority, 2019).

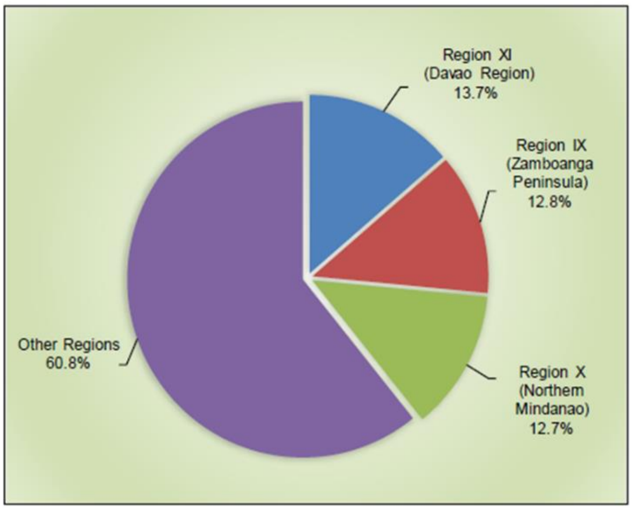

Figure 1. Distribution of Coconut Production by Region April–June: 2019
Source: Tepora et al. (2019).

From the table below, it is noticeable that Coconut is one of the most produced agricultural products in the Philippines with sugarcane being the top agricultural product.

Table 7. Volume of Production in Agriculture, Philippines, 2017–2019 (in thousand metric tons).

SUBSECTOR	April-June			January-June		
	2017	2018	2019	2017	2018	2019
CROPS						
Palay	4,149.92	4,090.24	3,852.39	8,569.18	8,713.22	8,269.24
Corn	1,329.82	1,284.30	1,172.19	3,696.11	3,760.87	3,597.41
Coconut	3,207.09	3,339.61	3,314.30	6,280.88	6,645.16	6,622.71
Sugarcane	8,733.01	6,460.63	2,608.98	21,309.10	16,687.12	14,325.41
Banana	2,272.84	2,358.79	2,260.97	4,373.47	4,502.67	4,375.46
Pineapple	675.20	697.45	702.25	1,288.73	1,319.09	1,323.62
Coffee	6.77	6.48	6.07	26.95	24.91	23.24
Mango	546.28	528.49	556.88	654.10	626.19	651.79
Tobacco	35.89	34.91	36.41	48.92	48.13	49.19
Abaca	18.84	18.89	18.91	33.96	34.39	34.77
Peanut	8.49	8.46	8.26	20.54	20.76	20.51
Mongo	23.39	24.18	23.56	30.76	32.11	31.70
Cassava	817.09	809.88	751.46	1,407.75	1,354.63	1,265.69
Sweet Potato	158.82	153.99	150.09	271.06	264.88	262.38
Tomato	72.19	73.50	71.95	163.45	165.19	167.25
Garlic	0.72	0.72	0.76	7.75	7.56	7.26
Onion	45.69	39.08	60.08	175.10	163.25	212.56
Cabbage	23.16	22.51	22.50	55.07	53.28	53.43
Eggplant	99.49	103.08	106.33	178.25	182.10	186.86
Calamansi	18.95	18.39	18.02	33.94	33.24	32.97
Rubber	117.68	120.33	125.37	163.05	167.69	171.10
Other Crops	986.88	999.82	994.47	1,834.72	1,845.52	1,830.60

Source: Tepora et al. (2019).

D. Properties of Concrete by Using Coconut Shell as Concrete Aggregate Composite Materials

Major reference taken from 'Water Absorption and Compressive Properties of Coconut Shell Particle Reinforced-Epoxy Composite' by Bhaskar and Singh.

1. Coconut Shell Consistency and Density

a. The coconut shell particle, as determined by Bhaskar and Singh, has an approximate density of 1.60 g/cm³.
b. Shell Particles, of what looks like the desired consistency similar to a sample of wood shavings, range from sizes of 200–800μm. This is a workable range for the grinding up of coconut shells as it is easily introduced into the mix and evenly distributable.
c. In their experiment, composite specimens were crafted out of the coconut shell particles and sent through a furnace to harden. The mixes of resin were 20 wt%, 25 wt%, 30 wt%, and 35 wt%.

2. Water Absorption Properties

Upon testing, Bhaskar and Singh uncovered that the particles of coconut shell, after epoxied and produced into specimens of size 15mm x 10mm x 10mm, absorbed as much as 0.5% for filling voids with water. This is plotted in their Figure 6 as shown. It shows that the sample with 30 wt% resin absorbs most water.

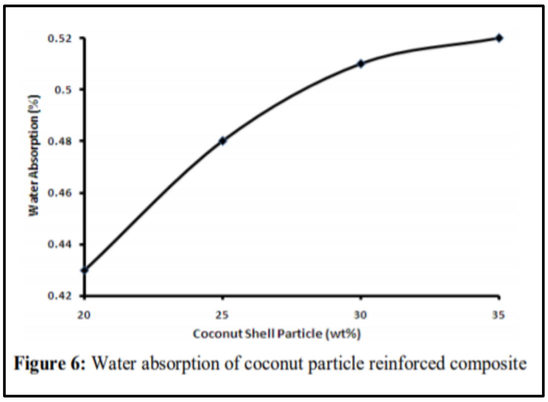

Figure 2. Water absorption of coconut particle reinforced composite.
Source: Bhaskar and Singh (2012).

3. Compression Properties

a. Compressive properties were tested on specimens of uniform geometry and conducted on hydraulic machines. 30mm diameter x 60mm height cylinders.
b. Bhaskar & Singh found that the 30 wt% resin sample was, again, the optimum combination for compressive strength. Sitting at 88.0 MPa.

E. Coconut Shells as Substitute for Aggregates in Mix Proportioning of Concrete Hollow Blocks

Ganiron's (2017) main focus in his study is the generation of products using agricultural waste as building materials in relation to the environment and the construction. His study also aimed at designing a technical specification of concrete hollow block (CHB) using coconut shells as aggregates that will meet the requirements set forth by ASTM. A conventional concrete hollow block was compared to concrete hollow blocks with coconut shells and fibers of the same proportions. The changes in the compressive strength, density, fire resistance, and thermal conductivity of concrete hollow block with coconut shell and fiber were discussed in this study, whether each requirement will be achieved by the composite material.

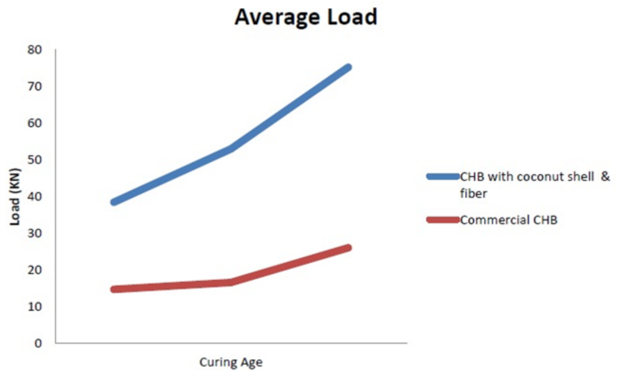

Figure 3. Average Loads of CHB w/ coconut & fiber and commercial CHB after 7th, 14th and 28th days of curing.
Source: Ganiron (2017).

From Figure 3, it is shown that samples from the commercial CHB, in 7 days of age reached a load capacity of 11.65 KN to 17.58 KN, and stress capacity of 0.57MPa to 0.8MPa. For 14 days of age it reached a load capacity of 14.71 KN to 20.24 KN and a stress capacity of 0.71 MPa to 0.98 MPa. For 28 days of age reached a load capacity 25.09 KN to 27.07 KN and a stress capacity 1.22 MPa to 1.31 MPa. This signifies that the number of aging requirements was achieved.

Table 8. Thermal Conductivity at Cold Temperature.

Specimen	Commercial CHB	CHB with coconut shell & fiber
Weight (Kg)	12.4	10.6
Load (KN)	12.87	96.69
Stress (MPa)	0.62	4.69

Table 8 shows that CHB with coconut shell and fiber can resist freezing and gain a large value of the load. In cold temperatures, CHB with coconut shell and fiber has a load capacity of 96.69 KN and stress capacity of 4.69 MPa.

Table 9. Thermal Conductivity at Warm Temperature.

Specimen	Weight (Kg)	Load (KN)	Stress (MPa)
1	6.8	50.47	2.97
2	9.4	59.98	2.97

Table 9 shows that even in high-temperature conditions, CHB with coconut shell and fiber can resist. It was subjected to the compressive test to determine if the strength will change. In warm temperature, CHB with coconut shell and fiber has a load capacity of 50.47 KN and stress capacity of 2.97MPa.

Table 10. Fire Resistance of CHB with Coconut Shell and Fiber.

Specimen	Weight (Kg)	Load (KN)	Stress (MPa)
1	9.8	68.32	3.38
2	9.4	59.98	2.97

Table 10 shows that the specimens are subjected to a high degree of temperature for a certain period of time. It was subjected to the compressive test to determine if the strength will change. Data gathered shows that CHB with coconut shell and fiber can resist high temperatures. The results at 28th days attained an average load capacity of 64.15 KN and 3.175 MPa for average stress.

Table 11. Good Indicators of Coconut Shell and Fiber as Aggregate.

Good indicators	Significance
1. Particle shape and texture	Affects workability of fresh concrete.
2. Resistance to crushing	In high strength concrete, an aggregate is low in crushing value. This will not give high strength even though cement strength is higher
3. Absorption and surface moisture	Affects the mix proportions and control water content to maintain the water-cement ratio
4. Grading	Economizes cement content and Improves workability.
5. Resistance to freezing and heating	Significant to cold countries where frost action deteriorates concrete due to alternate freezing and heating.
6. Lightweight	Reduce weight of structure

The addition of coconut shell and fiber to the concrete mix of CHB made a positive impact on the mechanical properties of concrete CHB. The compressive strength of CHB with coconut shell and fiber attained the highest average loads and stress and exceeded the strength attained by commercial CHB. Additionally, the thermal conductivity of CHB with coconut shell and fiber for cold and warm temperature resist freezing and heating gained a large value of the load. Lastly, the fire resistance of CHB with coconut shell and fiber affects its mechanical properties in terms of compressive strength.

IV. Methodology

The main objective of the research is to produce an efficient and eco-friendly building material available using coconut shells as partial replacement to stone aggregates in the production of conventional concrete.

A. Material Sample Preparation

The raw materials used in this experimentation were locally available and these included Ordinary Portland Cement (OPC) as binding agent, river sand as fine aggregate, basalt stone as coarse aggregate, and coconut shell as possible replacement to coarse aggregate. Potable tap water was used for mixing and curing throughout the entire investigation.

The coconut shell samples used for this study were cut into size 3/8 of an inch. No sieve grading was considered as sizes were almost 90% of 3/8 inch sizes. The cut coconut shells were soaked for 24 hours before drying for 2 days from 9:00 a.m. to 3:00 p.m.

Figure 4. Cutting of Coconut Shells

Figure 5. 3/8" Coconut Shells

Figure 6. Soaking of Samples for 24 hours

Figure 7. Washing of Soaked Sample

Figure 8. Day 1 of Drying

Figure 9. Day 2 of Drying

B. Slump Test

In this study, the researchers used the ASTM standards and AASHTO specifications when referring to the concrete slump test. The American standards explicitly state that the slump cone should have a height of 12-in, a bottom diameter of 8-in and an upper diameter of 4-in. The ASTM standards also state in the procedure that when the cone is removed, it should be lifted up vertically, without any rotational movement at all. The concrete slump test is known as "Standard Test Method for Slump of Hydraulic-Cement Concrete" and carries the code (ASTM C 143) or (AASHTO T 119).

Figure 10. 0% Coconut Shell (0% Admix)

Figure 11. 0% Coconut Shell (1% Admix)

Figure 12. 100% Coconut Shell (0% Admix)

Figure 13. 100% Coconut Shell (1% Admix)

C. Finished Products

Figure 14. Wet and Dry Concrete with 100% Coconut Shell (0% Admix)

Figure 15. Wet and Dry Concrete with 100% Coconut Shell (1% Admix)

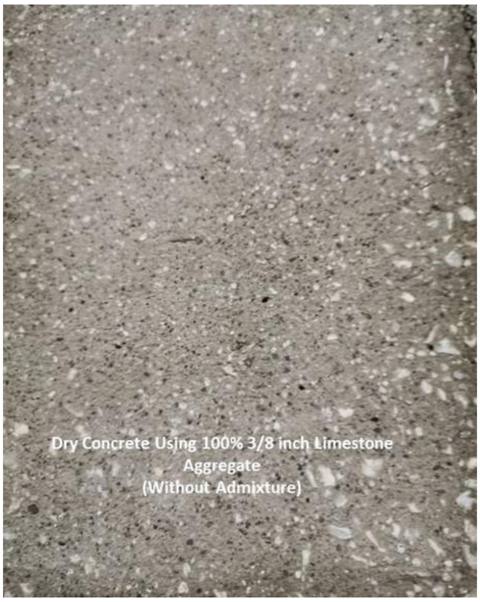

Figure 16. 0% Coconut Shell (0% Admix)

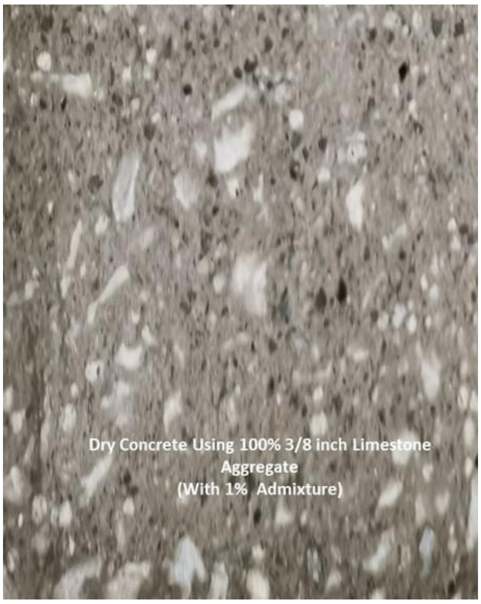

Figure 17. 0% Coconut Shell (1% Admix)

Concrete mix design using a maximum 340 kg of Portland Type I cement was used as the basis. Specific gravity of coco shell of 1.32 was determined using a water-displacement method of density calculation.

Limestone aggregates passing the specifications of 3/8 inch of ASTM C33 were used as ordinary gravel. A PCE (Ploy-carboxylate esters) admixture was also used as part of the study. The study also focused on the compressive strength determination only and did not include however the flexural concrete design. The study focuses only on 2.5%, 5.0%, 7.5%, 10%, 15%, 20%, & 100% replacement of coco shell to 3/8 inch limestone gravel. No further study was conducted on possible coco shell replacement between 20%–100%.

CEMENT: Ordinary Portland Cement Type I, conforming to ASTM C150 / PNS 07:2018 was used.

Table 12. Physical Properties of Ordinary Portland Cement.

	PHYSICAL PROPERTIES	RESULTS
1	Normal Consistency, %	26%
2	Specific Gravity	3.14
3	Fineness passing 325 mesh, %	92.5%
4	Initial Setting Time, minutes	145 minutes
5	Final Setting Time, minutes	265 minutes
6	3 days strength, MPa	22 MPa
7	7 days strength, MPa	30 MPa
8	28 days strength, MPa	38 MPa

FINE AGGREGATE: Vibro sand from Porac, Pampanga was used as fine aggregate, conforming to ASTM C33 specification.

Table 13. Physical Properties of Fine Aggregate.

	PHYSICAL PROPERTIES	RESULTS
1	Specific Gravity, SSD	2.55
2	Fineness Modulus	2.60
3	Compacted Bulk Density, kg/m3	1600
4	Absorption, %	2.8%
5	Passing 200 mesh, %	2.3%

COARSE AGGREGATE: Limestone aggregates, conforming to ASTM C33 specification was used.

Table 14. Physical Properties of Coarse Aggregate.

	PHYSICAL PROPERTIES	RESULTS
1	Specific Gravity, SSD	2.68
2	Abrasion Loss, %	23%
3	Compacted Bulk Density, kg/m3	1650
4	Absorption, %	0.8%
5	Passing 200 mesh, %	0.5%
6	Grading	Passing ASTM C33 specs

COCONUT SHELL: Locally available coconut shells were used in the study. These shells were dried and crushed to obtain sizes similar to normal aggregates.

Table 15. Physical Properties of Coconut Shell.

	PHYSICAL PROPERTIES	RESULTS
1	Specific Gravity, SSD	1.32
2	Water Absorption	18%
3	Compacted Bulk Density, kg/m3	850
4	Shell Thickness	2 – 6 mm
5	Particle Sizes	3/8 – ¾ inch

CONCRETE ADMIXTURE: Type G PCE (poly-carboxylate esters) concrete admixture, locally available, was used only when 100% replacement of coconut shell was studied.

Table 16. Physical Properties of Concrete Admixture.

	PHYSICAL PROPERTIES	RESULTS
1	Specific Gravity, SSD	1.05
2	Water Reduction, %	20–30%
3	Addition	1% based on cement weight
4	Color	Slightly brownish

Table 17. Concrete Mix Design: As per ACI 211

	0% CS (0 Admix)	0% CS (1% Admix)	2.5% CS	5.0% CS	7.5% CS	10% CS	15% CS	20% CS	100% CS (0 admix)	100% CS (1% admix)
Cement, kg	340	340	340	340	340	340	340	340	340	340
Fine Sand, kg	757	809	757	757	757	757	757	757	757	809
Coarse Aggregate, kg	961	1027	917	874	830	786	699	612	-	-
Coconut Shell, kg	-	-	22	43	65	87	130	173	477	510
Water, kg	220	175	220	220	220	220	220	220	220	175
Type G Admixture, L	-	3.4	-	-	-	-	-	-	-	3.4
Water-Cement Ratio	0.65	0.51	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.51
Density, kg/m3	2278	2352	2256	2234	2212	2190	2146	2102	1794	1838

NOTE:

The concretes were mixed in a half bagger mixer using a 0.03 m^3 batch volume. The mixing time kept to about 3 to 4 min. Mixing of the materials was done following the British Method as follows:

1. Portion of design water poured into a mixture drum together with coarse & fine aggregates.
2. Cement gently placed after 30 seconds together with remaining water.
3. Mixing to desired consistency. Total mixing time is around 3–5 minutes.
4. Specimens were then prepared and left for 24 hours. The specimens were demolded after 24 hours and immersed in normal water for curing until the test age. The specimens were cured for 3, 7, 14, and 28 days.

Compressive Strength of Cylindrical Composite Samples:

The determination of compressive strength of composite samples was done in accordance with ASTM C39 - Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Listed below is the procedure of the aforementioned testing.

1. Compression test of moist-cured specimen is made right after its removal from moist storage.
2. The specimen is tested in moist condition and is kept moist during the period between removal from moist storage and testing.
3. The specimen is then placed on the lower bearing block of the Compression Machine and is carefully aligned with the center of thrust of the spherically seated block. Prior to testing, the load indicator of the compression machine is set to zero.
4. The load is then applied on the specimen continuously without shock. The compressive load is applied until the load indicator shows that the load is decreasing steadily and the specimen displays a well-defined fracture pattern.
5. The maximum load read from the load indicator will now be used for the computation of the compressive strength.
6. The compressive strength of the specimen is determined by dividing the maximum load carried by the specimen during the test by the average cross-sectional area of the specimen.

Table 18. Compressive Strength Test Result

	0% CS (0 Admix)	0% CS (1% Admix)	2.5% CS	5.0% CS	7.5% CS	10% CS	15% CS	20% CS	100% CS (0 admix)	100% CS (1% admix)
Compressive Strength										
3 days, psi	1678	2512	1543	1511	1421	1411	1375	1250	719	1056
7 days, psi	2175	3372	2102	2059	2030	2001	1740	1667	799	1242
14 days, psi	2682	3780	2610	2581	2537	2465	2175	2030	994	1286
28 days, psi	3045	4544	3001	2914	2769	2682	2537	2320	1011	1402

Note: CS – Coconut Shell

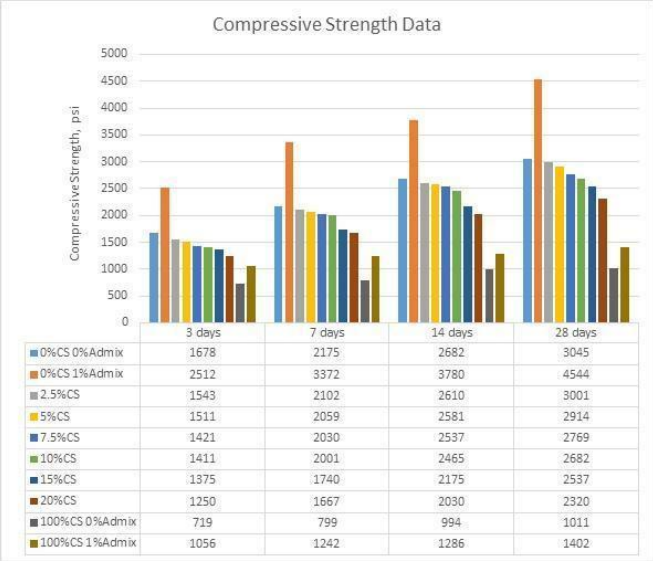

Figure 18. Bar Graph of Compressive Strength Data

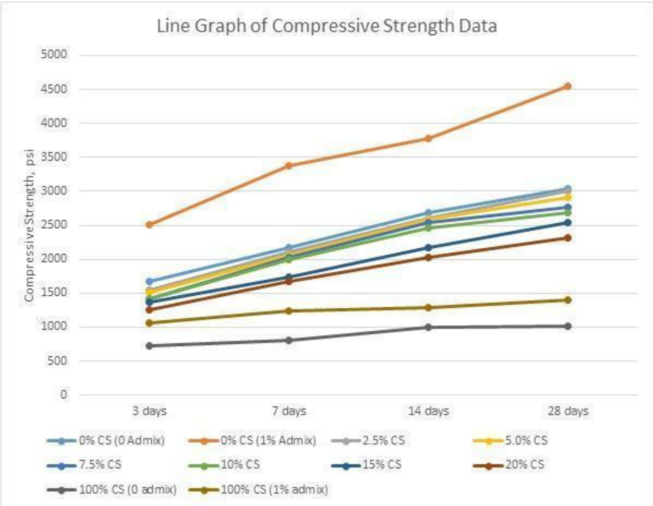

Figure 19. Line Graph of Compressive Strength Data

V. Evaluation of Results

From figures 18 and 19, it can be seen that a maximum compressive strength of 3,045.00 psi only was attained using a concrete mix design of 340 kg of cement using 100% 3/8 stone gravel and without a dose of concrete admixture. Same concrete mix design increases the concrete strength by 49.2% when 1% of concrete admixture was used. However, you can observe a decrease in concrete strength when part of 3/8 stone aggregates were being replaced by coco shells at a rate of 2.5%, 5%, 7.5%, 10%, 20%, and eventually 100%. Almost 24% reduction in concrete strength was observed when 20% of stone gravel was replaced by coco shell and about 67% of concrete strength was reduced at 100% replacement of 3/8 stone gravel by coco shell.

Table 19. Slump Test Result

	0% CS (0 Admix)	0% CS (1% Admix)	2.5% CS	5.0% CS	7.5% CS	10% CS	15% CS	20% CS	100% CS (0 admix)	100% CS (1% admix)
Initial Slump, inches	4.25	7.5	4.0	4.0	4.0	4.0	3.75	3.75	5.0	5.5

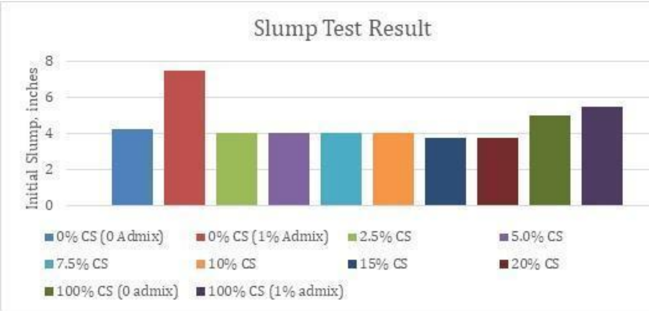

Figure 20. Bar Graph of Slump Test Result

It is observed in Figure 20 that there is a slight reduction in concrete workability during the trial. While this reduction in concrete workability is not noticeable at small replacement but more visible at 100% replacement. Most possible reason can be attributed to the size and granulometry of the coco shell. Coco shells are flat and thinner in size compared to stone aggregates which makes concrete harder to flow. The use of concrete admixture and adjusting the grading sizes of coco shell may help improve the workability of concrete.

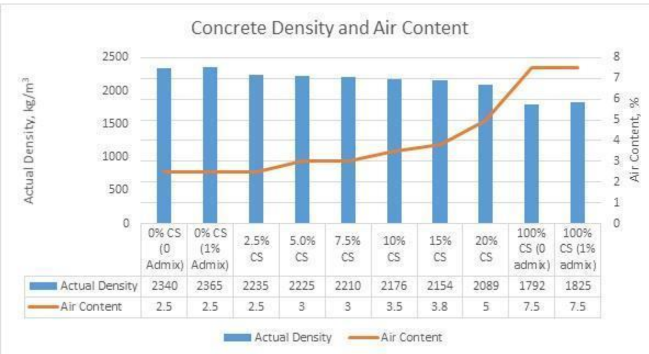

Figure 21. Concrete Density and Air Content

From the graph above, concrete density is indirectly proportional to the air content of concrete. The higher the concrete density, the lower is the air content of concrete. From the study, it was observed that concrete air content increased when coco shells were used. Its concrete density was also observed to be lowered by 11% at 20% addition and almost 24% at 100% replacement by coco shell. This only shows that more concrete voids are created when coco shells are being used as replacement to stone aggregates. Possible reason could be due to the almost single grading of coco shell (almost same sizes).

VI. Conclusions

1. An increase in the percentage replacement by coconut shells reduces compressive strength of concrete. This is due to the increase of the concrete air content. Possible culprit is the grading & granulometry of the coco shell which creates more concrete voids.
2. Workability of concrete is slightly affected by increasing replacement of coco shells. Although the effect is more visible at higher replacement.
3. Coco shell can be used as partial replacement of stone aggregates, however, sound concrete mix design should be considered and applied when using coco shell as partial replacement to aggregates. The following rule of thumb can be used in lieu of more detailed study. “For every 20% coco shell replacement, there is a 24% concrete strength reduction at 28 days strength.”
4. Improving the grading of the coco shell to pass ASTM C33 will improve its chances to replace more stone aggregates.

VII. Recommendations

1. It is recommended in the future study to use different kinds of additives that reduce the air content of concrete to improve its compressive strength.
2. Varying sizes of coconut shells must be used in order to improve the air content of the concrete.
3. In order to determine the other effects of coconut shells in the concrete mixture, additional tests must be conducted such as the ASTM C78 which determines the flexural strength of concrete as well as ASTM C496 which covers the determination of the splitting tensile strength of cylindrical concrete.

VIII. Acknowledgement

The author/researcher would like to thank Engr. Juan E. Necesario, for his assistance in the conduct of laboratory testing procedures. Engr. Marge Rea Erma C. Gonzaga for her help and untiring assistance in the preparation of the manuscript.

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