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Concrete Compressive Strength Evaluation: Coconut Shell Charcoal as Aggregate

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Abstract:
As the Philippines is a major producer of coconut products and goods, a lot of coconut shell is commonly turned coconut shells into charcoal. Because of this, the researchers evaluated the compressive strength of concrete mixed with coconut shell charcoal. With the objective of this study being focused on the coconut shell charcoal, the said material replaced the common fine aggregate component of concrete. Type I Portland cement, gravel, sand, and said aggregate were incorporated with a cement-sand ratio of 1:3 in a 150x300mm cylinder. 20% of the concrete mixture is composed of the powdered coconut shell charcoal. Consequently, 18 samples – 9 experimental samples and 9 control samples which is the common concrete mixture – were made for this study and was tested on their 7, 14, and 21 curing day counts. The statistical treatment ‘Paired t-Test: Two Sample Means’ was applied on the results gathered through the Universal Testing Machine (UTM) with the significance level of 95% or 0.05 as prescribed by ASTM International. Three samples were tested per curing day count and the mean of the individual results were taken. Through the results of this study, the 7, 14, and 21 curing day counts was rejected due to having 10.32 MPa, 13.76 MPa, 16.37 MPa respectively – failing to equal or surpass 65% of 25 MPa or 16.25 MPa for the 7 curing day count, 90% of 25 MPa or 22.50 MPa for the 14 curing day count, and 99% of 25 MPa or 24.75 to 25 MPa for the 21 curing day count. The researchers of this study recommend the lessening or modification of the coconut shell charcoal and the further testing of this experimental concrete through a trial-and-error method. The procedures used in this study are standards from ASTM C192/C192M and ASTM C39/C39M.

Keywords*: Concrete, Coconut Shell Charcoal, Aggregate, Compressive Strength.*

I. Background, Motivation and Objective

Concrete plays a major role in the construction field. Construction industries use concrete for its strength and for its affordability. However, its problem regarding sustainability is becoming a global concern due to the subsiding global limestone supply [1]. Nevertheless, there have been many successful attempts for improving concrete to lessen its environmental impacts by altering its properties using alternative aggregates [2]. Charcoal is a structureless carbon in the shape of an immensely permeable microcrystalline graphite. [3]. Coconut shell charcoal – a form of charcoal – can adsorb specific molecular matters making it an efficient raw material [4]. Consequently, a study in which coconut shell charcoal was added to cement with replacement percentages of 10, 15, 20, and 30% of its weight,

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concluded that the addition of coconut shell charcoal reduced the concrete in mortar samples' compressive strength after 10% addition. However, it enhanced the durability and abrasion resistance of the concrete [5]. On the other hand, results from another study wherein coconut shell charcoal was used as an aggregate with percentages of 10, 20, and 30% with trial periods of 7, 14, and 28 days showed that the increase in replacement is directly proportional to its workability and strength [6]. Coconut shell charcoal is then used as an alternative aggregate for making the experimental concrete of this study.

The principal objective of this study is to evaluate the concrete compressive strength with coconut shell charcoal utilized as an aggregate to concrete. This study has three sub-objectives, specifically (1) to know the contributions of coconut shell charcoal to the strength of the concrete and its capability as an aggregate to concrete; (2) to determine the accurate water-cement ratio of concrete to enhance its performance; and (3) to resolve concrete sources' sustainability issues. With these objectives in mind, the beneficiaries of this study are the construction industry and the environment. It will be advantageous for the construction industry to utilize an enhanced, eco-friendly, and a more affordable type of concrete. Correspondingly, there have been problems regarding the sustainability of normal concrete resources all over the world. In that case, with the use of coconut shell charcoal in concrete, the impact of a normal concrete to the environment will be lessened and there will be a more sustainable recipe for concrete.

As this study intends to experiment the compressive strength of a concrete with coconut shell charcoal, the original aggregate that is used for concrete will be replaced by the said type of charcoal. Furthermore, the weight of cement and sand are 1 kg and 4 kg respectively as stated from the American Concrete Institute (ACI) Method. This study will have three trials: the first trial will be in 7 days, the second will be in 14 days, and the last trial will be in 21 days with reference to ASTM C39. In addition, this study limits itself on the procedure that will be used for the manufacturing of this concrete and the compressive strength responses of concrete with coconut shell charcoal as an additive.

II. II.LITERATURE REVIEW

A.Charcoal

Charcoal is highly permeable and a delicate material, usually collected from wood burning, peat, bones, cellulose, or any carbonic matter with an inadequate amount of air. It is a structureless carbon in the shape of an immensely permeable microcrystalline graphite [7].The physical property of charcoal is dependent on the charring material and temperature, the various amounts of hydrogen and oxygen, the ash, the impurities, and also the structure determine the charcoal's property. Additionally, immense permeability, low density, and poor conductivity for electricity and heat are the most significant characteristics of charcoal. On the other hand, greater amount of fixed carbon and lesser amounts of ash and volatile matter comes with finer charcoal chemical properties [8][9]. The state of the carbonization process and the raw materials that were used decides its physical and chemical properties. Table 1 shows the different properties of charcoal.

TABLE I: THE MAIN CHEMICAL AND PHYSICAL PROPERTIES OF CHARCOAL

BET surface area (m^2 g^{-1})	500-1400
Internal surface area (µm)	2-50
Density (t/m^3)	0.2-0.6
Bulk density (kg/m^3)	180-220
Moisture content (% db)	5-15
Ash content (% db)	0.5-5
Fixed carbon (% db)	50-95
Volatile matter (%db)	5-40
pHPZC	9.6

B.Coconut Shell

In the Philippines, the fourth largest contributor to gross value-added to agriculture is coconut. It has a

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total production of 14 million tons imparting 24% of global production making it the prime agricultural crop and export product of the Philippines. In line with this, 26% of the country's total agricultural land is comprised by coconut with 329.9 million bearing trees [10]. Because of these statistics, the researchers investigated the chemical properties of coconut shell charcoal for this study. The chemical properties of charcoal specifically produced from coconut shell are shown in Table 2 [11].

TABLE II: THE MAIN CHEMICAL AND PHYSICAL PROPERTIES OF COCONUT

A. SHELL CHARCOAL EXPRESSED IN %

Volatile matter	48.25
Fixed carbon	50.55
Ash content	1.20
Moisture content	10
Carbon	61.87
Hydrogen	4.66
Nitrogen	0.84
Sulphur	0.09
Oxygen	29.54

B. C.Utilization of Coconut Waste Materials in Concrete

Coconut shell waste is widely used as a concrete material replacement for it is cost-effective, nature-friendly, and can resolve problems regarding shortage. It is confirmed from an experiment that it is possible to use coconut shell as a building material for it appeases the requirements as per ASTM C330 [12]. However, one experiment proposed that coconut shell waste aggregate can only pass for lightweight concrete. Results from the study showed that the replacement of coconut shell waste lessened the concrete compressive strength as the amount of replacement increased [13]. Concrete with coconut shell increased the strength of concrete but only up to 20% replacement and decreased its workability and density [14]. Moreover, another study examined the compressive strength of coconut shell concrete wherein the coconut shell ash was mixed in concrete which varied depending on the concrete weight at 0, 5, and 10 percent. Results shown that the compressive strength reduces at 5% and 10% aggregate replacement of coconut shell [15]. Additionally, for the tensile strength, the workability of the concrete also reduces as the coconut shell replacement percentage increases [16].

On the other hand, one study produced a viable coconut shell concrete with enhanced strength [17]. The study concluded that the concrete compressive strength with 15% and 30% addition of crushed coconut shell significantly increases in comparison with conventional concretes [18]. Moreover, another study which also used coconut shell to concrete as an aggregate showed that the concrete compressive strength is higher in 16mm aggregate size compared to that of 10mm and 12mm [19].

Several previous researchers made use of charcoal as an addition or replacement to different materials of concrete. One of these studies ascertained that coconut shell charcoal as a sand replacement to lightweight foamed concrete decreases its compressive strength as the concrete age increases. In addition, cracks were observed which may remarkably affect the concrete's compressive strength [20]. One experiment showed the same results indicating that the compressive strength deduces the higher the replacement percentage [21]. Furthermore, a study in which coconut shell charcoal was added in 10, 15, 20, and 30 percent in accordance with the cement weight concluded that coconut shell charcoal reduced the concrete in mortar samples' compressive strength after 10% addition. However, it enhanced the durability and abrasion resistance of the concrete [5]. On the other hand, results from another study wherein coconut shell charcoal was used as an aggregate with percentages of 10, 20, and 30 percent with trial periods at 7, 14, and 28 days showed that the increase in replacement is directly proportional to its workability and strength [6].

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III.Methodology

In this study, the ingredients are mixed with a cement -sand ratio of 1:3 in a 150x300 mm cylinder by 25 times circularly. There are 18 samples, wherein half of those are experimental and the other half are controlled, and three trials with test ages of 7, 14, and 21 days. The preparation of materials and procedures that this study undergo is based on the standards of ASTM International specifically C 192/C 192M - Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory and C 39/C 39M - Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. With C 192/C 192M as the standard basis for this study, the main materials that are used are Type I Portland cement, sand, gravel, and the additive coconut shell charcoal. To start, all the materials must be mixed except for water using a trowel in a metal pan until the mixture is uniformly formed. Then, the concrete mixture will be placed into a mold also with the use of a trowel and at the same time the mixture should be remixed to hinder segregation. While setting the concrete, use a tamping rod to allocate the mixture inside the mold. The next part of the procedure is consolidation using rodding method wherein for each layer, the external side of the mold is struck 10 to 15 times with the tamping rod to clear out the holes and bubbles formed inside. Lastly, lid the top of the concrete with Portland cement paste to solidify the concrete. Additionally, only initial curing is required for this experiment.

As for the testing of the concrete compressive strength, C 39/C 39M is used as the standard method. The Universal Testing Machine (UTM) was used to evaluate the compressive strength of the concrete samples produced in this experimentation. The specimen batch should be tested as quickly as possible after being removed from the storage. In the testing machine attach the specimen in the lower bearing block placed on the table or platen then carefully adjust the specimen's axis with the upper block's center of thrust. Before starting the test, check if the load indicator is set to zero. During the test, load will be applied by the machine, the classified movement rate should be prolonged at least during the near half of the expected loading phase of the testing process. The loading rate will begin to increase once the first half of the expected loading phase is reached. Load should be continuously applied until failure of the specimen. Once it fails, conduct the maximum load that the specimen bore and record the failure type and concrete appearance. Lastly, to calculate for the compressive strength, divide the maximum load bore by the specimen by its average cross-sectional area and express the quotient to the nearest 0.1 MPa. Above all that, the statistical treatment used in this study is one-tailed t-test for independent samples which determines whether there are any differences between the means of the two samples. In this study's case, the null and alternative hypothesis are expressed as indicated below. Granted that the null hypothesis is rejected, the workability of the coconut shell charcoal as an aggregate to concrete and its ability to contribute to the compressive strength will be accumulated.

$$H_o: \bar{X}_1 \leq \bar{X}_2 \qquad (1)$$

and

$$H_a: \bar{X}_1 > \bar{X}_2. \qquad (2)$$

IV.RESULTS AND DISCUSSION

As for the compressive strength test results, the maximum stress that Specimen Unit A was able to withstand was approximately 12.74 MPa to 8 MPa for 7 days, 15.12 MPa to 11.53 MPa for 14 days, and 18.32 MPa to 14.89 MPa for 21 days. Table 3 shows the specified results of the test.

For the hypothesis testing, Tables 4, 5, and 6 show the results of the one-tailed t-test of two independent sample means and Figures 1, 2, 3 demonstrates the t-distribution graphs for 7, 14, and 21-day curing period, respectively.

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The null hypothesis states that the average compressive strength of experimental concrete specimens, denoted as $\bar{X}_1$, is less than or equal to the average compressive strength of controlled concrete specimens, denoted as $\bar{X}_2$. Conversely, the alternative hypothesis states that the average compressive strength of experimental concrete specimens is greater than of the controlled specimens. In addition to that, the confidence level used in the t-test is 95%.

In accordance to American Society for Testing and Materials (ASTM C39/C39M), the concrete is required to gain strength of at least 65%, 90%, and 99% for 7, 14, and 21 days, respectively. For this reason, the experimental concrete specimens failed to conform with the standard compressive strength of concrete, 25 MPa, used in structural foundations due to its insufficient maximum stress; which are 10.32 MPa out of 16.37 MPa for 7 days, 13.76 MPa out of 22.50 MPa for 14 days, 16.37 MPa out of 24.75 MPa for 21 days. And as for the hypothesis testing, the researchers rejected the null hypothesis for both 14 and 21-day curing age but accepted the null hypothesis for the 7-day curing age. Hence, resulting for the specimens to have a greater compressive strength than the controlled concrete specimen of the certain trial.

TABLE III: SPECIMEN UNIT A AND SPECIMEN UNIT B – COMPRESSIVE STRENGTH

Curing Age	No. of Specimen	Specimen Unit A – Experimental			Specimen Unit B – Control		
		Max. Force	Max. Stress		Max. Force	Max. Stress	
		(kN)	(kN/mm^2)	(MPa)	(kN)	(kN/mm^2)	(MPa)
7 days	1	145.984	0.00800	8.00	127.690	0.00700	7.00
	2	186.484	0.01022	10.22	182.962	0.01003	10.03
	3	232.344	0.01274	12.74	197.738	0.01084	10.84
14 days	1	275.875	0.01512	15.12	491.243	0.02693	26.93
	2	210.391	0.01153	11.53	394.198	0.02161	21.61
	3	266.813	0.01463	14.63	440.896	0.02417	24.17
21 days	1	290.047	0.01590	15.90	376.281	0.02063	20.63
	2	334.266	0.01832	18.32	357.906	0.01962	19.62
	3	271.594	0.01489	14.89	345.156	0.01892	18.92

TABLE IV: ONE-TAILED T-TEST: TWO INDEPENDENT SAMPLE MEANS FOR 7-DAY CURING PERIOD

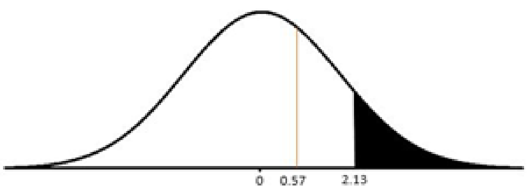

Fig. 1. Graph of t-distribution of the 7-day curing period

Variable	Mean (MPa)	Variance	t-value	t-critical	Decision
Experimental	10.32	5.62	0.57	2.13	Failed to reject H_0
Control	9.29	4.10			

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TABLE V: ONE-TAILED T-TEST: TWO INDEPENDENT SAMPLE MEANS FOR 14-DAY CURING PERIOD

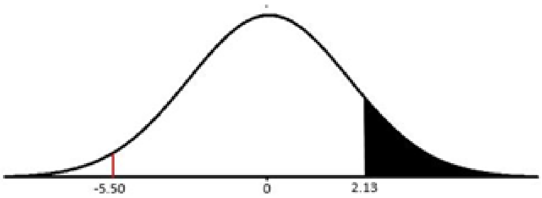

Fig. 2. Graph of t-distribution of the 14-day curing period

Variable	Mean (MPa)	Variance	t-value	t-critical	Decision
Experimental	13.76	3.79	-5.50	2.13	Failed to reject H_0
Control	24.24	7.08			

TABLE VI: ONE-TAILED T21-T-DAY EST: CTURING WO INDEPENDENT PERIOD SAMPLE MEANS FOR

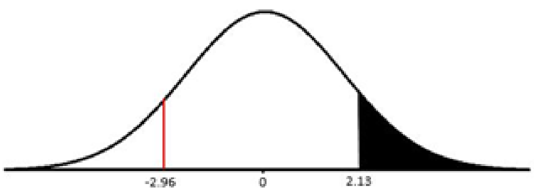

Fig. 3. Graph of t-distribution of the 21-day curing period

Variable	Mean (MPa)	Variance	t-value	t-critical	Decision
Experimental	16.37	3.11	-2.96	2.13	Failed to reject H_0
Control	19.72	0.74			

Conclusion

In this study, the compressive strength of nine experimental concrete specimens with their original aggregate being replaced by coconut shell charcoal were evaluated and compared with another 9 controlled concrete specimens with curing ages of 7, 14, and 21 days. For every curing age, three experimental concrete specimens were being tested. Based on the results of the evaluation, the experimental concrete specimens failed to abide by the qualifications of the structural concrete. Specifically, the compressive strengths of the concrete specimens were lower compared to the controlled concrete. Hence, it was concluded that the replacement of coconut shell charcoal to the original aggregate reduced the compressive strength of the concrete. However, according to the hypothesis testing done by the researchers, the experimental concrete specimens for the 7-day curing resulted higher than the controlled concrete specimens Regardless of that, it was concluded that the experimental concrete specimens successfully conformed to another concrete type which is the residential concrete requiring a lower strength compared to the structural one.

Because of the findings of this study, the researchers recommend to future researchers to modify or lessen the coconut shell charcoal replacement percentage as an aggregate to concrete which can possibly increase the efficiency and workability of the concrete, produce more concrete specimen samples to come up with a more precise results and be able to accurately use the statistical treatment, and utilize more effective machineries and equipment in producing the concrete mixture and materials to produce a more consistent and proper concrete. Furthermore, the researchers recommend a trial-and-error method in experimenting with the replacement percentage through testing the samples on its 3-day mark.

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