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A Study on Properties of Concrete as a Potential Innovative of Coarse Aggregate with Coconut Shell

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Abstract: The excessive exploitation of natural aggregate in producing concrete seems like a significant problem that increases the chance of depleting natural resources. This paper presents coconut shell potential as a replacement for coarse aggregate and the strength of coconut shell concrete compared to conventional concrete in gradation replacement of 4.00 %, 8.00 %, and 12.00 %. A total of 24 cubes of 100 mm x 100 mm x 100 mm were cast and tested to determine the concrete's density, water absorption, and compressive strength. The coarse aggregate was replaced with a coconut shell size 10-14 mm for concrete grade M20. The test results showed the conventional concrete increase's compressive strength while the concrete coconut shell shows vice versa. Based on the result obtained, the concrete coconut shell resulted in high density where it meets the requirement for density of lightweight. However, the coconut shell only suitable as a substitution for lightweight aggregate as it did not meet the requirement compressive strength for lightweight concrete.

Keywords: Coconut shells , Replacement, Aggregate, Compressive strength

1. Introduction

Concrete consumes a large amount of natural material such as crushed rock and river sand used as fine or coarse aggregate. However, due to rapid growth in the construction industry, it leads to excessive depletion of natural aggregate and not the sustainability concept [1]. An investigation shows varying degrees of success in the implementation of agricultural waste in the construction industry [2][3]. The method that was suggested is by implementing the waste into the concrete.

The growing number of wastes has become a major environmental problem in a specific country [4]. Most waste is generated from various domestic, industrial, and commercial [5]. Besides, Malaysia's agricultural sector production is immensely worried since almost 998 million tons of waste were generated, and 1.2 million tons are disposed of into landfills annually. The problem of agricultural activities is the lack of a waste management system. There is no advance technology in disposed waste in Malaysia. The method that used to dispose of the waste is recycling, composting, incineration, inert

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landfill, sanitary landfill and other disposal sites [6]. To counter these problems, the agricultural waste, which is coconut shells, was chosen as a substitution for coarse aggregate to control environmental issues and achieve sustainability. The aim of this study is to analyses the potential of coconut shell as a partial replacement for coarse aggregate in concrete and evaluate the strength of coconut shell concrete compared to conventional concrete. The result of this study is expected to benefit the construction sector in reducing cost, balance the ecology of the environment, and achieve the sustainability of a product.

2. Concrete

Concrete is a composite material composed of binding mediums: cement, water, a mix of fine and coarse aggregates that provide high strength but low tensile strength [7]. The development of the construction industry is leading to make various types of concrete. Each classification of concrete can be rate according to the binding material and the design of concrete. In this study, the coarse aggregate was replaced with coconut shell to produce coconut shell concrete.

2.1 Coconut shell

Coconut tree, also known as the economic plant, where every single part of this plant are useful where foods and a soft trunk, water and oil are producing from the fruit. Meanwhile, the leaves are used for roofs and brooms, and bridges from its trunk. Husk, leaves, and coconut shell are being used as an agricultural waste product as it is low cost and flexible materials. Despite husk and leaves, the coconut shell is more effective in representing composites since it is a reliable waste product [8]. A coconut shell is an inner of a discarded outer hardcover of a coconut. The shell is considered an attractive biomass fuel and source of charcoal. It is also rich with lower ash content and volatile matter content and affordable cost [8]. Figure 1 show the coconut shell.

Figure 1: Coconut shell

2.2 Properties of coconut shell

Coconut is one of the potential materials for developing the new composites as it has high strength and modulus properties with the advantages of high lignin content [9]. The high lignin content made it more excellent in weather resistance and suitable for the application of construction materials. According to Rao, the coconut shell feature is high in durability, challenging, and strong abrasion resistance fitting for long-term use [10].

According to Monika, the coconut shell solid composite is immaculate, suitable in concrete, and has no pre-treatment necessity [11]. The specific gravity of coconut shell is 1.2 which twice density of hardwood. The coconut shell was also considered the most rigid organic material produced in nature due to aluminum alloys' lower strength. It stated that the shell could be ground into 50-micron chips to use as reinforcement for engineering plastic [9]. The shell properties that absorb less moisture due to its low cellulose content made it more unique compared to the other agricultural waste [12]. Kanojia also mentioned that the setting time and strength of the concrete do not change with sugar in the coconut shell [12].

2.3 Materials Used

The ingredient for concrete in this project is cement, fine aggregate, coarse aggregate, water and coconut shell. The constituent materials utilized for these studies was obtained from local sources.

- Coconut shell

For the purpose of this research, the coconut shell was collected from a local market in Pekan Pagoh, Johor. The inner surface (concave) of the coconut shell is smooth and rough on the other face. These coconuts shells were drying into the drying oven for 24 hours for better wrecking. The coconut was crushed manually using a hammer. Then, the different shapes of crushed coconut shell were sieved using the size of 10 mm and 14 mm. Figure 2 show the coconut shell.

Figure 2: The crushed coconut shells

Coarse aggregate

Aggregate is essential in giving volume to the concrete, reducing shrinkage, and affecting the economy. In this experiment, the combination of crushed gravel with the size of 10,14 and 20 mm was used complying to BS 5328: 1991 [13]. The coarse aggregate had been clean from dust or dry crushed granite before used for mixing.

Fine aggregate

The fine aggregate (typically natural sand) is a material that passed a No. 4 sieve; the sieve with four openings per linear inch. It used as a filler and known as the sand that complies with coarse, medium or fine grading requirement. In this project, the combination of size from 2.36 mm to 300 μm was used to combine with coarse aggregate, coconut shell, cement and water.

Cement

Cement is comprised in the concrete about 7 to 14 percent. Cement is an essential material and the costliest ingredient to bind the aggregates. There is numerous type of cement to produce concrete. The standard purpose cement which is ordinary Portland cement type 1 was used to prepare the specimen.

Water

Water is the main ingredient in mixed with the Portland cement, forms a paste in binding the aggregate together. Water that fit for drinking might be utilized for blending concrete [14]. It gives hydration for the chemical reaction between cement and water in creating a cementitious product and harden the concrete. In these studies, the distilled or de-ionized water that complies to EN1008 is used as a binding element to mix the mixtures.

3. Methodology

The innovation studies are conducted in testing and produce concrete with partial replacement of coarse aggregate with a coconut shell. In the beginning, the data are collected through previous studies, mostly from articles, white papers, books, thesis books, and conferences. The material used in this project is Portland cement, fine grinding stone, coarse aggregate, and coconut shell. In achieving the objective of the innovation studies, Figure 3 below shows the flow for the process of these studies.

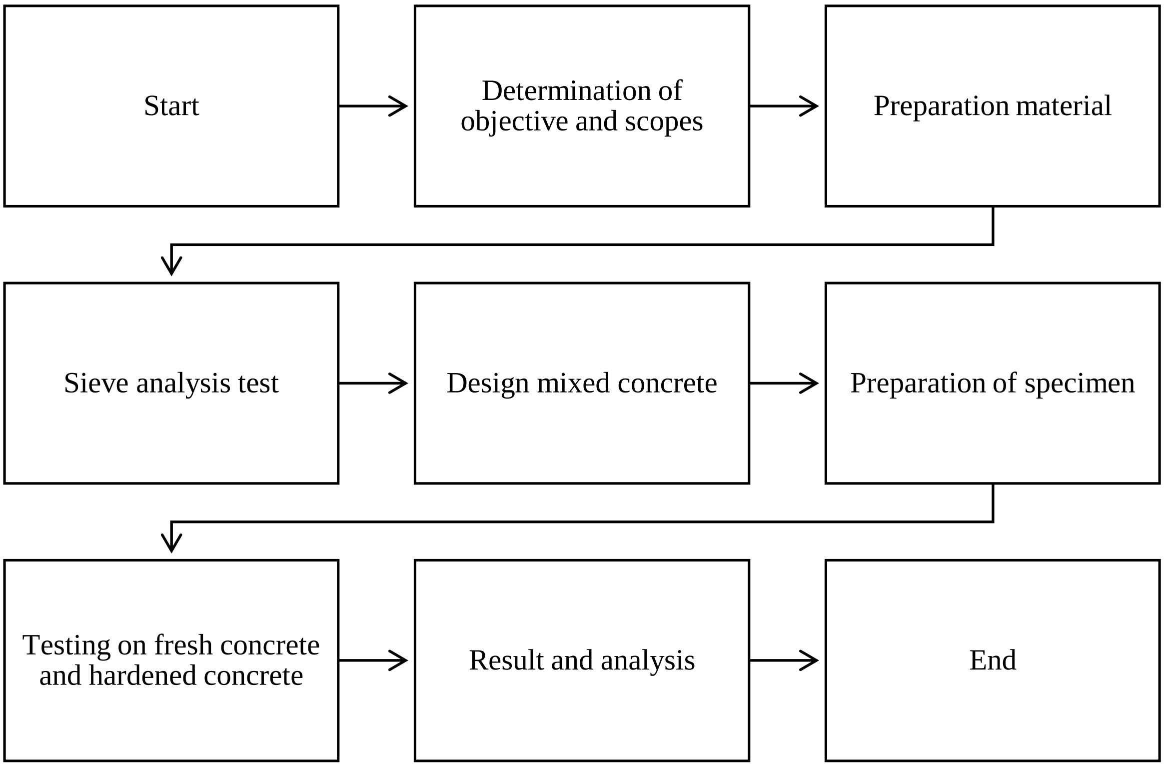

Figure 3: The flow of methodology study

3.1 Mix design

The mix design method for this project is comprehended based on the Department of Environmental (DOE). The mix proportion for these studies is complying with the appropriate requirement, as stated in BS 5328: Part 3 and 4. The coconut shell was used to replace the natural aggregate. For the mixture design, the water-cement ratio is constant (0.55). The mixes are restoring the natural aggregate in 4,8 and 12.00 % by weight of the coarse aggregate. The determination quantities of percentage that used are based on the allowable percentage range from previous studies. The cement aggregate/ aggregates (c/a) ratio are 1:2.1:2.20. Table 4 shows the mix proportions of the design method.

Table 4: The concrete mixture proportion

Specimen	Properties					Cube Sample	
	Water (l)	Fine aggregate (kg)	Cement (kg)	Coarse aggregate (kg)	Crushed Coconut Shell (kg)	7 days	28 days
0% C	1.50	5.76	2.70	6.00	NA	3	3
4% CS	1.50	5.76	2.70	5.76	0.24	3	3
8% CS	1.50	5.76	2.70	5.52	0.48	3	3
12% CS	1.50	5.76	2.70	5.28	0.72	3	3

Note: C = Control, CS = Coconut Shell, W/C= water/cement, NA= No added

3.2 Preparation of specimen

The cube size of 100 mm x 100 mm x 100 mm was prepared to conduct the hardened concrete test. The mixture proportion of the concrete consists of different percentages (4.00 %, 8.00 %, and 12.00 %) and is compacted in three-layer after mixing by hand. The sample was let harden for 24 hours, and then the cube is cured in a curing tank for 7 and 28 days.

3.3 Laboratory test

There are two types of tests conducted to test the specimen, a test on fresh concrete and hardened concrete. The laboratory test for fresh concrete is a slump test. The test was carried out to identify the workability of the concrete to resist internal and external friction. The workability is expressing by the consistency of concrete but more confined to the parameters of water content. Meanwhile, the laboratory test on hardened concrete is a test where the curing sample after 7 and 28 days is used to test for water absorption test and compressive strength test. All the test that is being conducted is referring to British Standard specification. The procedures for each test are as below:

- Slump test is a method used to measure the consistency of fresh concrete, obtained from the laboratory or site of work. This test not suitable for too wet or dry concrete. It is utilized as a control test and indicates the consistency of concrete from batch to batch. The procedure is based on BS EN 12350-2:2019 [15]:

    i. The cone and base plate was cleaned using a moist cloth to remove any excess moisture and dirt before place the cone on the horizontal base plate.

    ii. After the apparatus was set up, and the cone was clamped by standing on the two-foot pieces for the pouring process. The concrete was poured into three-layer with 25 strokes for each layer using the tamping rod. The strokes were uniformly distributed over the cross-section of each layer.

    iii. For the first layer, the position of rod is inclined and positioned approximately half the strokes spirally toward the center and not touch the base plate. The same steps are repeated for the second and third layer.

    iv. After the top layer had been compacted, the surface of the concrete was struck off using the trowel. Then, the spilt concrete was removed from the base plate.

    v. The cone was raised carefully in 2 s to 5 s in a vertical direction without no lateral or torsional motion.

vi. After the removal of the cone, the slump h was measured and recorded by calculating the difference between the height of the cone and the highest point of the slumped test specimen.

- Water Absorption is used to determine the amount of water absorbed by material under specified test conditions. The concrete cube at the ages of 28 days was tested to determine the amount of water absorbed under a specific condition. The procedure of the absorption test is based on BS 1881-122:2011 [16].

  i. Firstly, the specimen was put into the drying oven at 105 °C for 72 hours by distancing each cube in 25 mm from any heating surface from each other for better air access to all cube's surface.

  ii. After drying for 72 hours, the specimen was cooled on room temperature for 24 hours.

  iii. The mass of specimen is weighted after the cooling process

  iv. Then, the specimen was immersed in the water for 30 minutes.

  v. After 30 minutes, the specimen was removed and dry with a cloth as rapidly to remove free water from the surface

  vi. Then, the saturated concrete samples are reweighted and recorded to determine the mass of water absorption. This method can evaluate the pores present inside the specimen, according to ASTM C1585.

- Compressive strength is utilized to show the ideal strength concrete can reach in perfect conditions. It is also used to measure the capability of concrete to resist loads that tend to crush it. The strength of concrete is measured in Mega Pascal (MPa) and is usually tested 28 days after mixing. The procedure is:

  i. The bearing surface of machine was wiped to remove all loose grit from the surfaces of the specimen that in contact with the platens.

  ii. The cube was tested based on days 7 and 28 using the compression testing machine conforming to EN 12390-4.

  iii. The maximum load that indicated in kN was recorded.

4. Results and data analysis

This project's main objectives are to investigate coconut shells' potential as a partial replacement for coarse aggregate and evaluate the strength of coconut shell concrete compared to conventional concrete. The coarse aggregates were sieved through 14 mm and retained on 10mm to fulfill the project's objectives. The analysis result is based on the slump test, density test, water absorption test, and compressive strength test.

4.1 Slump test

The slump test was carried out to determine the consistency of fresh concrete, the concrete was poured with the correct amount of water. Figure 5 shows the result of the slump test that had been carried out from the experiment.

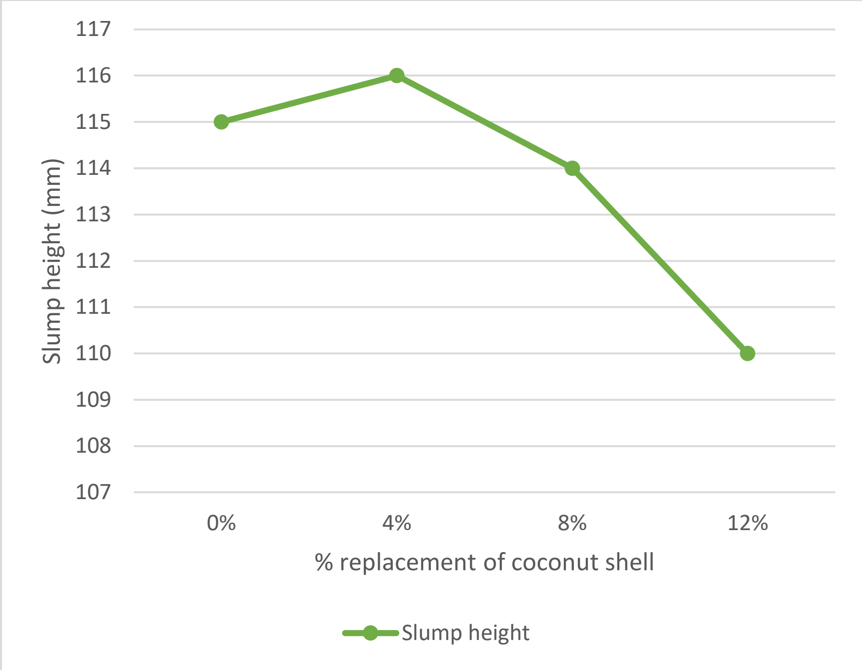

Figure 5: The graph of slump height vs % replacement

Based on the Figure 5, the slump height for concrete control is 115 mm. The highest recorded value of slump height is for concrete with 4.00 % of coconut shell which is 116 mm, and the lowest is 110 mm for 12.00 % of coarse replacement aggregate. The slump high for 8.00 % of replacement is 113 mm. Based on the JKR standard, the height of this slump is classified in class S3. This concrete is suitable for strip footings, mass concrete foundations, blinding, standard reinforced concrete in slabs, beams, walls, columns, sliding formwork construction, pumped concrete, and vacuum processed concrete.

The slump shapes for all concrete mixes are shear slumps. According to Eric et al [17], the shear slump could be happened due to insufficient cohesion, and it may undergo segregation and bleeding. Some factors could lead to a shear slump in this experiment. One of the reasons is the shape and surface textures of aggregates. Various shape of aggregate has been used in this experiment. The coconut shell's texture that rough at the outer and smooth in the inner has been crushed into different shapes such as rounded, flaky, crushed, and angular. As the surface area increases, more adhesive is needed to bind the paste and require more water to lubricate all materials. The different aggregate shapes bring difficulty in mixing them since the different surface area and frictional resistance.

4.2 Density test

Figure 6 present the data for the density of concrete with a variation of % replacement of coconut shells (CS). According to the Figure 6, the density of cube concrete reduces with an increasing replacement coconut shell. The maximum density obtained is $2168 x 10^{-9}$ kg/m^3 at 0% of replacement. This value falls in ranges of 2000-2600 kg/m^3 for normal weight concrete (BS EN 206 Part 1). The coconut shell's replacement for 12.00 % obtained $1923 x 10^{-9}$ kg/m^3 result in the lowest density, which lies in the range of 800-2000 kg/m^3 for normal lightweight concrete (BS EN 206 Part 1). For 4.00 % and 8.00 % replacement of coconut shells have resulted at $2133 x 10^{-9}$ kg/m^3 and $2034 x 10^{-9} kg/m^3$ which lies on normal weight concrete.

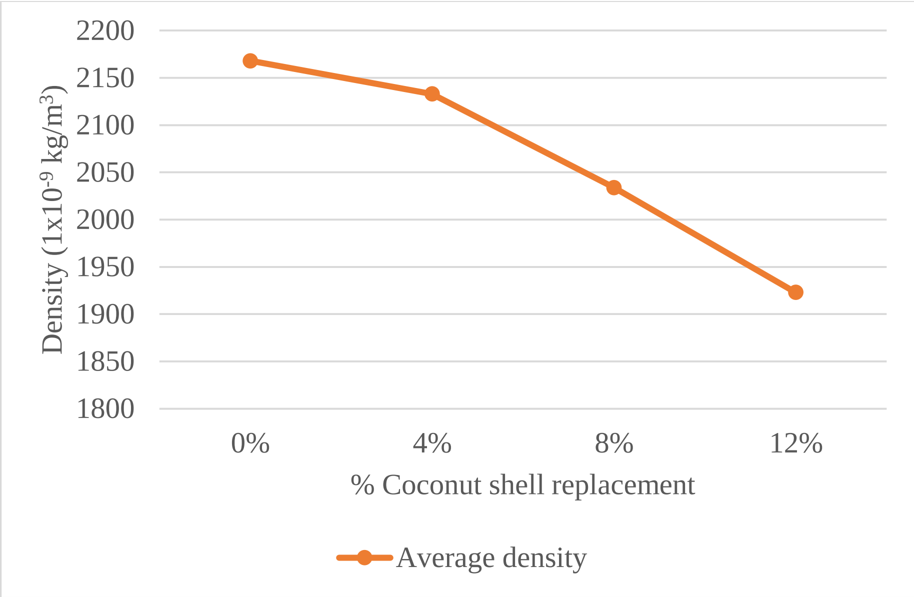

Figure 6: The density vs % Coconut shell replacement

From the observation, the density of the concrete specimen is decreasing due to some factors. One of the factors is the presence of honeycombs. The honeycombs could be happened due to improper workability of concrete (low of concrete slump) or unbalance vibrations of concrete. Besides, the various size of coarse aggregate (coconut shells) used have led to concrete voids during compaction in the concrete mold. The large particles are hard to penetrate through the paste that causes honeycombs. Besides, the low specific gravity of coconut shell is also one factor in decreasing concrete density [12].

4.3 Water absorption test

The concrete cube at ages 28 days was dried in drying oven for 72 hours. The concrete cube is weighing before and after immersed in the curing tank for 30 minutes. The result of water absorption was shown in Figure 7:

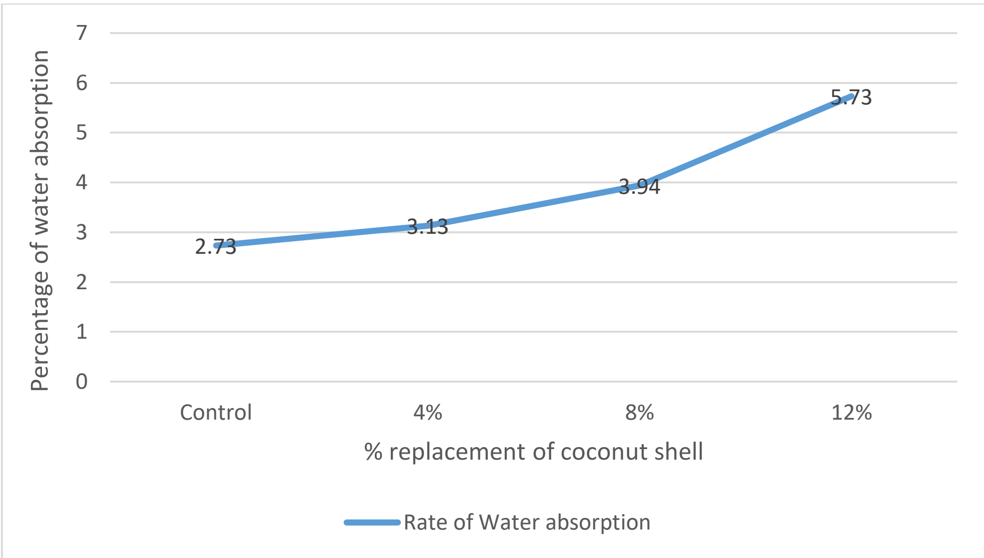

Figure 7: The plot of percentage of water absorption vs % replacement of coconut shell

Figure 7 shows the sample of different percentages of coconut shells as a replacement of coarse aggregate with water absorption rate. It can be seen that the rate of water absorption is increased when the replacement is increased. The result shows that concrete M4 has the highest water absorption, which is 5.73 %, while the lowest value of water absorption is for concrete control, which is 2.73 %. The concrete M2 and M3 shows increasing water absorption, from 3.13 % to 3.94 %.

Based on Figure 7, a better result is the lowest rate of water absorption. The water from outside was absorbed through the capillary pores. The sample with more replacement of coconut shell shows the high ability for water absorption. The concrete control shows the lowest absorption rate rather than the 4.00 %, 8.00 %, and 12.00 % of the coconut shell replacement. According to BS 1881 (Part 122- Method for the determination of water absorption), the result for concrete M4 is not acceptable because the value achieved is more than 5.00 % [18]. The percentage was increased from the observation due to increasing voids due to various size and shapes of coconut shells.

4.4 Compressive strength

The compressive test was carried out at 7 and 28 days of cube concrete to determine the ability of concrete to withstand the load. Figure 8 shows the plot of compressive strength versus percentage replacement of coconut shell used to replace coarse aggregate for both ages.

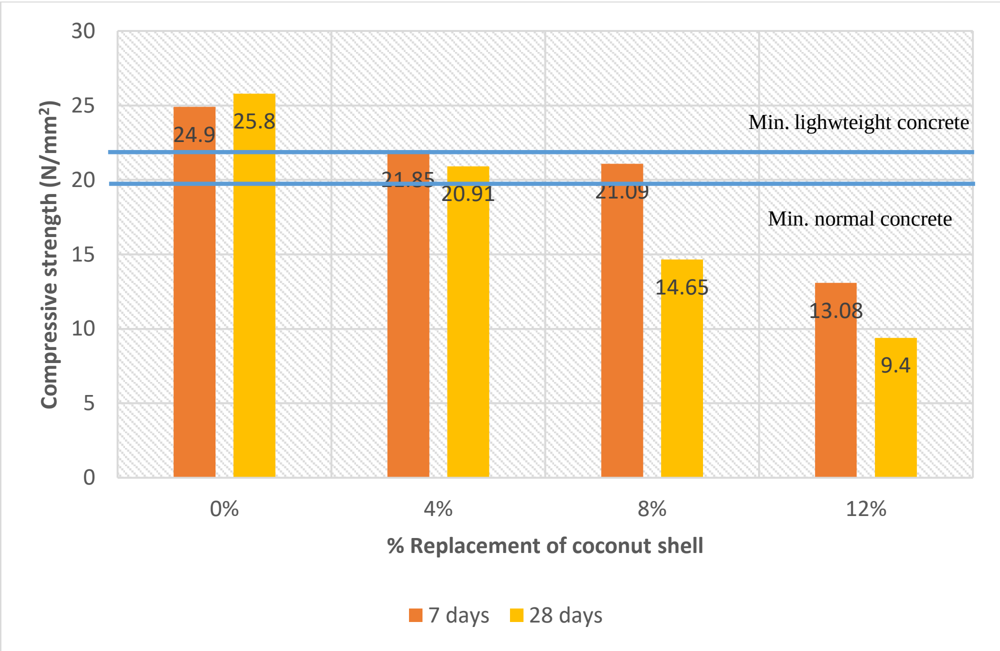

Figure 8: Relationship between compressive strength versus % replacement of coconut shell

Based on Figure 8 above, the concrete control (0.00 % replacement) shows increasing strength for both ages' day while the concrete with the replacement of coconut shell shows decreased compressive strength. The normal concrete's compressive strength for 28 days was higher, with an average value of 25.8N/mm^2 compared to strength for 7 days with 24.9 N/mm^2. The maximum strength is 25.8 N/mm^2 at 0.00 % of replacement (control concrete), while the minimum strength is 9.4 N/mm^2 at 12.00 % of replacement. The increase of compressive strength for 28 days (0.00 % coconut shell replacement) happened because the concrete already achieved the concrete's maturity level of real strength. Compare to concrete day 7, it reaches in range of 65.00 % from its strength. However, both specimens are exceeding the requirement for the characteristic strength for normal and lightweight concrete [19].

Next, the concrete added with 4.00 % and 8.00 % of coconut shell shows the same strength pattern where both of the values show decreasing in compressive strength. The compressive strength with 4.00 % of coconut shell replacement is reduced from 21.85 N/mm^2 at 7 days and 20.91 N/mm^2 at 28 days. This sample exceeds the minimum characteristic strength for normal concrete with grade of M20 but exclude from minimum characteristic for lightweight concrete. Next, the compressive strength drastically reduces at the replacement of 8.00 % and 12.00 % at 28 days. The strength for 8.00 % replacement of 7 days is 21.09 N/mm^2 (exceed 20 MPa for normal concrete), while for 28 days is 14.68 N/mm^2, which precludes from the minimum requirement of compressive strength for grade M20.

This might happen due to some factors. The first reasons are the increasing surface area of coconut shell that requires more cement to bond the aggregates [20]. Secondly, due to the low strength of coconut shell compared to coarse aggregate and the quantity of coconut shell is used since the proportion are depends on the weight of coarse aggregate. Besides, data collected from the sieve analysis test shows the value obtained for coarse aggregate and fine aggregate outside the range gradation of sieve analysis.

5. Conclusion

In general, the coconut shell aggregate can be used for lightweight aggregate however the performance of coconut shell concrete is lower than the conventional concrete. The main point of this study are:

i. The addition of coconut shells shows the inconsistency of slump height but resulting in a high degree of workability. It might have happened due to the various shape and sizes of coconut shells that affected the bonding of paste of cement.

ii. The density concrete M4 (12.00 % replacement of coconut shell) are lies in normal lightweight concrete. The concrete density is obtained at $1923x10^{-9}$ kg/m^3, which lies in the range for normal lightweight concrete where it already answers for objective one. The coconut shells have a high possibility of substituting lightweight aggregate based on the discussion's density. However, it is not suitable to produce lightweight concrete.

iii. The second objectives are to compare the strength of coconut shell for coconut shell concrete with conventional concrete. The compressive strength of concrete control is increased while coconut shell concrete decreases with an increase in coconut shell content. The concrete control (M1) shows the highest value of strength for 7 and 28 days compared to concrete M2, M3 and M4. Both compressive strength value for concrete control (M1) reaches the JKR standard for normal and lightweight concrete strength.

iv. For coconut shell concrete's absorption rate, the increasing percentage replacement has shown that the rate absorption is high. The highest absorption water value is for 12.00 % replacement, which is 5.73 %, while concrete control only absorbs 2.73 %. The high rate of water absorption only leads to a decrease in the strength of concrete.

v. It has been proved that a high rate of water absorption is causing the low strength of coconut shell concrete. The lowest value of strength is 9.40 N/mm^3 at days 28 for 12.00 % of coconut shell replaced. Compared to conventional concrete, it shows an improvement in strength. The majority of concrete with replacement of coconut shows diminution of strength. Only coconut shells with 4.00 % replacement for both ages are meet the minimum requirement of grade M20.

vi. However, the coconut shell could be used as a replacement coarse aggregate in decreasing the depletion of natural resources.

Based on the result obtained from the experiment, there are some suggestions for better improvement for other researchers. The recommendations are:

i. The coconut shells need to be cleaned from any fibers where the properties could affect coconut shells' strength. The easy way to remove the fibers is by drying the coconut shells for one day in the oven and clean the surfaces using a brush before crushing them into a specified size.

ii. Chop or crush the coconut shell in a same size or shape to easy the concrete paste to bind together. This is to avoid any voids or honeycombs due to the different surface areas of coconut shells.

iii. Add some mixture to improve the bonding of coconut shell with the paste. For example, use superplasticizers as it can transform the stiff concrete to become more freely. Using this admixture will increase the strength of concrete without increasing any quantity of water.

iv. Use a quality of fine aggregate and coarse aggregate that lies on the typical range of degradation for fine and coarse aggregate value of sieve analysis.

v. For the future research could use a fixed size of coconut shell such as 12 mm to identify the idea size that can increase the compressive strength

vi. Use specimen in cylinder and carry out tensile strength test to identify the behavior of concrete when load is applied on it.

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