Investigating properties of pervious concretes containing coconut shell flake and ash

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Abstract. Pervious concrete or non-fine concrete is a simple form of lightweight concrete made by eliminating the use of fine aggregates. As a result of not using a fine aggregate in pervious concrete, then created a cavity filled with air and water can be passed. This cavity resulted in a reduced density of the concrete and the reduced amount of area that needs to be covered by a cement paste, thereby reducing the compressive strength. This study aimed to utilize waste material to increase the compressive strength of pervious concrete. The waste material was the coconut shell ash and coconut shell flake. The method was to strengthen the coarse aggregate concrete mixture. It was expected to increase the compressive strength along with the increase in permeability. Thus, in this study, the researchers will replace part of the coarse aggregate with coconut shell flake with percentage 0%, 2.5%, 5%, 7.5%, 10% and partially replace cement with coconut shell ash with percentage 0%, 2.5%, 5%, 7.5%. The results show that the combination of coconut shell flake and coconut shell ash does not increase the compressive strength of the concrete mixture. However, it increases the porosity, permeability, and as a result, the density is getting lower. Further study will be performed on porous concrete using coconut shell flake for lower load facilities, such as pedestrian or bicycle pathways.

Keywords: pervious concretes, coconut shell, coconut ash

1. Introduction
Non-fine concrete or permeable concrete or pervious concrete is concrete formed from a mixture of cement, coarse aggregate, water with added material or admixture. Pervious concrete is made using a small amount fine aggregate or even eliminating the fine aggregate. The weakness of pervious concrete is its compressive strength tends to be low. This is due to the cavities in the previous concrete, so it has permeability capability by eliminating the use of fine aggregates on concrete mixtures. However, since there is no fine aggregate filler, pervious concrete does not have a strong enough bond between the coarse aggregates, resulting in low compressive strength.

In some areas, sometimes it was found difficult to obtain material for the manufacture of concrete. To overcome this problem, this research will be done by using waste. It is coconut shell as a partial replacement material of coarse aggregate, and coconut shell ash as partial replacement material of cement for mixed material of pervious concrete. In addition, if the use of ash and coconut shells is technically capable of improving the characteristics of pervious concrete, it is also expected to reduce the impact of environmental pollution and have economic value added because the materials used are recycled from waste. Previously, coconut shell ash was once applied to conventional concrete and increased the compressive strength of concrete to a maximum at a percentage of cement replacement by...
7.5% [1][2]. Similarly, the coconut shell can increase the conventional concrete compressive strength to a maximum of 5% percentage of coarse aggregate material replacement [3][4].

This study will use a combination of ash and coconut shell on a pervious concrete mixture. So, it is expected that the use of these materials can increase the compressive strength of pervious concrete, which is one of the weaknesses of pervious concrete [5][6][7]. In addition, to increase the compressive strength, it is expected that a mixture of ash and coconut shell can also increase porosity, permeability, and lighten pervious concrete density.

The purpose of this research is to determine the compressive strength and permeability of a variation of the pervious concrete mixture with a variety of replacement materials. Also, it analyzes the variations of replacement materials that increase the compressive strength and permeability of pervious concrete. The benefit of this research is to obtain pervious concrete with a high absorption rate and maximum compressive strength with the variation of coarse aggregate replacement material i.e., coconut shell and cement replacement material variation i.e., coconut shell ash. It is hoped that pervious concrete results from this research can be applied to light facilities such as the hard drainage layer in the exterior mall area, the surface layer of the park, the floor for the zoo area, and the livestock area.

2. Methods and analysis

2.1. Concrete mixture

The coarse aggregate size used in this study was from 2.5 mm to 12.5 mm, which is the size of no. 8 in standard ASTM C33. While coconut shell (Figure 1a) as partial replacement of coarse aggregate to be used is clean from the flesh and dried in the sun or dried oven. The coconut shell is then crushed into a small flake with a maximum size of 12.5 mm x 12.5 mm. This is done so that the size of the coconut shell is uniform with coarse aggregate size.

![Coconut Shell and Ash](image1.png)

Figure 1. Coconut Shell and Ash

The cement used for this study is Portland Cement Composite (PCC) with the trademark “Tiga Roda”. Coconut shell ash used is the ash of coconut shell combustion and has passed the filter no. 200. This outcome of combustion of coconut shell ash (CSA), shown in figure 1b, contains silica or SiO₂ compounds so that CSA can be pozzolan [8]

2.2. Model test variations
Calculation of Pervious Concrete Mix Design refers to the calculation of ACI 522R-10 [8]. Samples will be made six samples for each variant, and there are 20 variations. So, the sample is made as much as 120 pieces of the sample, as shown in Table 1.

The dimensions of the cylindrical test specimen for the compressive strength test are 15 cm in diameter and 30 cm in height. The dimensions of the specimen for density, porosity, and permeability tests are 10 cm in diameter and 20 cm in height. The mixture of the specimen will be filled into the mold in three layers; each layer will be compressed with 15 times the puncture evenly. After stirring the sample and then hardening for about 24 hours, the sample mold will be removed.

| Percentage of Coconut Shell Aggregate (CSA) | Total |
|--------------------------------------------|-------|
| 0%                                         | 6     |
| 2.50%                                      | 6     |
| 5%                                         | 6     |
| 7.50%                                      | 6     |

Table 1. The Variation of Sampling

Then for the treatment of specimens, it will be done with curing. The curing method that will be done is to soak the specimen into a water tub. The purpose of curing is to ensure the hydration process that occurs in the concrete. Before the permeability test, it is necessary to calculate its density by weighing the specimen. Next, calculate the porosity of the pervious concrete specimen. To calculate its porosity, it is necessary to parameterize the weight of the specimen when it is dry, the weight of the specimen with water, the volume of the specimen, and the density of the water type. Next porosity calculation can be done by using equation [10] that is:

\[ P = \frac{W_2 - W_1}{\text{Vol} \cdot \rho_w} \]  

(1)

Where P is the total porosity, %; \( W_1 \) is the weight in water, kg; \( W_2 \) is dry weight, kg; Vol is the sample volume, cm\(^3\); \( \rho_w \) is the water density.

The next step is to test the permeability. This permeability test refers to ACI 522R-10 with the falling head permeameter. Furthermore, the calculation of the permeability coefficient can be obtained by entering the time data into the Darcy law equation [10], i.e.:

\[ k = \frac{Q \cdot L}{H \cdot A \cdot T} \]  

(2)

Where k is the permeability coefficient, cm / s; Q is the quantity of water collected, cm\(^3\); H is the water level, cm; A is the area of the sample, cm\(^2\); T is time, s.

After the permeability test then the next step is a compressive strength test. Compressive strength test will be performed when the specimen aged 28 days with a compressive strength tester.

3. Results and discussion
3.1. Proportional of pervious concrete

Referring to ACI 522R-10, the pervious concrete mix design is a pervious concrete proportional calculation, to find out the need of the pervious concrete material. The material needs of coarse aggregates, cement, water, and replacement materials, such as coconut shells and coconut shell ash, have been calculated and presented in Table 2.

Table 2. Proportional of Pervious Concrete Mixture

| No. | Coconut Shell (%) | Coconut Shell Ash (%) | Coarse Aggregate (kg) | Coarse Shell (kg) | Cement (kg) | Coconut Shell Ash (kg) | Water (kg) |
|-----|------------------|----------------------|----------------------|------------------|-------------|------------------------|------------|
| 1   | 0                | 0                    | 1341.00              | 0.00             | 279.2       | 0                      | 111.9      |
| 2   | 2.5              | 1341.00              | 0.00                 | 272.22           | 6.98        | 111.9                  |
| 3   | 5                | 1341.00              | 0.00                 | 265.24           | 13.96       | 111.9                  |
| 4   | 7.5              | 1341.00              | 0.00                 | 258.26           | 20.94       | 111.9                  |
| 5   | 10               | 1341.00              | 0.00                 | 251.28           | 27.92       | 111.9                  |
| 6   | 2.5              | 1307.48              | 33.53                | 279.2            | 111.9       |
| 7   | 2.5              | 1307.48              | 33.53                | 272.22           | 111.9       |
| 8   | 5                | 1307.48              | 33.53                | 265.24           | 111.9       |
| 9   | 7.5              | 1307.48              | 33.53                | 258.26           | 111.9       |
| 10  | 10               | 1307.48              | 33.53                | 251.28           | 111.9       |
| 11  | 5                | 1273.95              | 67.05                | 279.2            | 111.9       |
| 12  | 2.5              | 1273.95              | 67.05                | 272.22           | 111.9       |
| 13  | 5                | 1273.95              | 67.05                | 265.24           | 111.9       |
| 14  | 7.5              | 1273.95              | 67.05                | 258.26           | 111.9       |
| 15  | 10               | 1273.95              | 67.05                | 251.28           | 111.9       |
| 16  | 7.5              | 1240.43              | 100.58               | 279.2            | 111.9       |
| 17  | 2.5              | 1240.43              | 100.58               | 272.22           | 111.9       |
| 18  | 5                | 1240.43              | 100.58               | 265.24           | 111.9       |
| 19  | 7.5              | 1240.43              | 100.58               | 258.26           | 111.9       |
| 20  | 2                | 1240.43              | 100.58               | 251.28           | 111.9       |

From Table 2, the aggregate requirement decreases as the percentage of coarse aggregate replacement with coconut shell increases. Similarly, the need for cement decreases as the percentage increase of cement replacement with coconut shell ash [11][12]. Conversely, the need for coconut shell and coconut shell ash increases as the percentage increases. For water, needs are not affected by the percentage of coconut shell or coconut shell ash.

3.2. Effect of variation mixture of coconut shell flake and ash and on pervious concrete characteristic test results

Test results of density test, porosity, compressive strength, and permeability of specimens have been summarized and shown in Table 3. It shows that the increasing percentage of ash and coconut shell use increases the percentage of porosity and permeability of specimens. Conversely, density decreases with an increasing percentage of ash and coconut shell use. Increased compressive strength occurs in the use
of ash of coconut shell by 2.5% i.e., from 4.94 MPa to 7.85 MPa, the compressive strength of the test object decreases. Increased maximum compressive strength occurs in the use of coconut shells with 2.5% percentage and 0% ash from 4.94 MPa to 8.35 MPa, then the compressive strength of the test object decreases.

From Table 3, it can also be seen that a mixed combination of coconut shell with coconut shell ash did not increase compressive strength. This can be clearly seen in variation 7 in Table 3, wherein the compressive strength of the specimen decreases as its porosity increases due to the shrink process of coconut shell material. As a result of the aggregate development process, the coconut shell aggregate's dimensions increase to allow for pressure by the coconut shell aggregate in the mixture during the process of mixing and treating the specimens by soaking [13]. Conversely, after the concrete is soaked for 28 days and dried for a day before the compressive strength test, it is possible to occur aggregate shrinkage due to the evaporation of water in the concrete. This will result in the diminution of the coconut shell's aggregate dimensions and enable the creation of new cavities in the space it occupies during the development process [14]. Therefore, it can be concluded that the coconut shell mix with coconut husk ash is not suitable to increase the compressive strength of the specimen. Generally, as the pervious concrete strength increases, the pervious concrete permeability decreases, and vice versa. However, increasing the use of coconut shells from 0% to 2.5% found the compressive strength of the specimen increases with the increase of permeability. The enhancement of the compressive strength occurred from 4.94 MPa to 8.35 MPa, and increased permeability from 0.382 cm/s to 0.417 cm/s.

### Table 3. Data Test Result of Specimen

| No. | Coconut Shell Flake (%) | Coconut Shell Ash (%) | Density (kg/m³) | Porosity (%) | Compressive Strength (MPa) | Permeability (cm/s) |
|-----|-------------------------|-----------------------|-----------------|--------------|----------------------------|-------------------|
| 1   | 0                       | 0                     | 1754.24         | 17.18        | 4.94                       | 0.382             |
| 2   | 2.5                     |                       | 1779.7          | 17.82        | 7.85                       | 0.38              |
| 3   | 5                       |                       | 1696.97         | 18.14        | 5.08                       | 0.398             |
| 4   | 7.5                     |                       | 1677.88         | 19.52        | 4.18                       | 0.403             |
| 5   | 10                      |                       | 1673.64         | 19.73        | 3.07                       | 0.406             |
| 6   | 2.5                     | 0                     | 1746.82         | 21.85        | 8.35                       | 0.417             |
| 7   | 2.5                     |                       | 1708.64         | 24.82        | 6.08                       | 0.445             |
| 8   | 5                       |                       | 1705.45         | 23.86        | 4.9                        | 0.449             |
| 9   | 7.5                     |                       | 1695.91         | 24.82        | 3.86                       | 0.46              |
| 10  | 10                      |                       | 1711.82         | 25.14        | 2.67                       | 0.465             |
| 11  | 5                       | 0                     | 1737.27         | 25.45        | 4.46                       | 0.46              |
| 12  | 2.5                     |                       | 1711.82         | 25.45        | 3.67                       | 0.46              |
| 13  | 5                       |                       | 1639.7          | 26.94        | 3.1                        | 0.518             |
| 14  | 7.5                     |                       | 1603.64         | 28           | 2.67                       | 0.536             |
| 15  | 10                      |                       | 1663.03         | 27.36        | 1.56                       | 0.527             |
| 16  | 7.5                     | 0                     | 1660.91         | 27.36        | 4.37                       | 0.584             |
| 17  | 2.5                     |                       | 1616.36         | 28           | 3.26                       | 0.589             |
| 18  | 5                       |                       | 1610           | 28.64        | 2.82                       | 0.594             |
| 19  | 7.5                     |                       | 1603.64         | 29.27        | 1.63                       | 0.62              |
| 20  | 10                      |                       | 1599.39         | 30.12        | 1.24                       | 0.639             |

3.3. The effects of mixture of ash and coconut shells on pervious concrete characteristics

3.3.1. The effect of ash and coconut shell mixture to density and porosity
The effect of a mixture of ash and shell on parameter relation between densities with porosity has been presented in graphical form in Figure 2. It shows the higher the porosity increase, the density will also decrease. This shrinkage caused a loss of weight due to the coconut shell's lightness, acting as a coarse aggregate [4]. Besides, porosity increase can be caused by coconut shell aggregate development and shrinkage process of coconut shell resulting in changes of coconut shell dimension from mixing to the treatment process specimen [10].

![Figure 2. Graph of the Relationship between Density and Porosity](image)

**Figure 2. Graph of the Relationship between Density and Porosity**

### 3.3.2. The effect of ash and coconut shell mixture to 28 days and density

The influence of a mixture of ash and shell on the relationship between the parameters of the compressive strength of the concrete age of 28 days with the density has been presented in graphic form in Figure 3. From figure 3, although the degree of slope of the linear pattern is slightly different, the earlier study with the results still have in common.

![Figure 3. Graph of the Relationship between Compressive Strength and Density](image)

**Figure 3. Graph of the Relationship between Compressive Strength and Density**

The similarity of the respective research that, with increasing density concrete, the compressive strength increases as well, according to ACI522R-10 [9]. The difference, some point to the results of the study have a compressive strength similar to previous studies [10,3], but the density of research currently
tends to be lighter than previous studies. The lighter weight of the research results may be due to partial replacement of coarse aggregates with coconut shell and partial replacement of cement with coconut shell ash [15]. It is due to the coconut shell weighs and the coconut shell lighter than the coarse aggregate weights.

3.3.3. The effect of ash and coconut shell mixture to compressive strength and porosity

The effect of the mixture of ash and shell on the parameter relation between the compressive strength of the concrete age of 28 days old concrete with porosity has been presented in graphic form in Figure 5. Looking at Figure 4, although the degree of slope of the linear pattern is slightly different, the earlier study with the results still have in common [11].

![Figure 4](image)

**Figure 4.** Graph of the relationship between compressive strength and porosity

The graph of each study in Figure 4 shows that the higher porosity, the compressive strength of pervious concrete decreases. Joshaghani [10] obtained results as in Figure 4 because they were influenced by rough aggregate size variations. At the same time, Torress [3] obtained the results as in Figure 4 because it is influenced by a variety of coarse aggregate sizes, and the thickness of cement paste.

3.3.4. The effect of ash and coconut shell mixture to porosity and permeability

The effect of ash and coconut shell mixture on parameter relation between permeability and porosity has been presented in graph form in figure 5. Figure 5 shows that the three studies have different degrees of the slope of the linear line.

Although each study has different degrees of slope, Figure 5 still shows that the higher the porosity, the higher the permeability. Although the percentage of porosity is the same, it does not mean that the permeability is the same. This is because the pervious concrete pores are not necessarily directly connected, so the water does not flow down directly. However, the increase in permeability is affected by the percentage of porosity [9].
3.3.5. The effect of ash and coconut shell mixture to compressive strength and permeability

The effect of the mixture of ash and shell on parameter relation between compressive strength with permeability has been presented in graphic form in figure 6. Figure 6 shows that along with increasing compressive strength, porous concrete permeability capability decreases. Likewise, on the contrary, as the increase of permeability, the compressive strength of pervious concrete decreases. This can be due to the concrete density, where the denser concrete the percentage of porosity decreases. Because of the low porosity percentage, the permeability will be low.

In this study was found, where permeability increases along with the increase in compressive strength. This happens to a combination of a 0% coconut shell with 0% ash mixture and a coconut shell of 2.5% with 0% ash mixture. The data of the test results can be seen in Table 3.
3.4. Characteristic of crack in specimen after compressive strength test

![Figure 7. Specimen Before (a), At the Beginning (b), and After (c) the Compressive Strength Test](image)

Characteristics of cracking of specimens from before until the specimens have been tested for compressive strength will be discussed. Figure 7 shows the condition of the specimen before the compressive strength test. When testing the compressive strength, the specimens in this study tend to begin to crack in the middle of the test specimen. Figure 7 shows, in the red circle, is the cracked model of the specimen when in a compressive strength test, the crack starts at the center of the specimen. From the crack, the test object starts to crumble in the middle of the test specimen, which can be seen in Figure 7b. It might be due to a low concrete tension value.

4. Conclusion
The results of the analysis are as follows:
1. As the percentage of the coconut shell flake and coconut shell ash content is increasing, the porosity and permeability continue are also increasing, and the density is lighter.
2. The increase of compressive strength from 4.94 MPa to 7.85 MPa is achieved by 0% coconut shell flake and 0% to 2.5%. Coconut shell ash. Also, the compressive strength decreases in the percentage of coconut shell ash over 2.5%.
3. The increase of maximum compressive strength from 4.94 MPa up to a maximum of 8.35 MPa occurs with a coconut shell flake of 0% to 2.5. Moreover, the compressive strength decreases below 8.35 MPa if the coconut shell percentage is above 2.5%.
4. Increasing maximum permeability occurs when the mixture consists of 7.5% of coconut shell flake and coconut shell ash as 10%.
5. In theory, if the permeability is increasing, then the compressive strength is decreasing. However, in the aggregate mixture of 0% to 2.5%, coconut shell flake percentage, both the compressive strength and permeability are increasing. The compressive strength increases from 4.94 MPa to 8.35 MPa and permeability increases from 0.382 to 0.417 cm/s. If the aggregate mixture of coconut shell flake is 2.5% and above, then the compressive strength is below 8.35 MPa. If the percentage of coconut shell flake is 0% and above, permeability is increasing steadily with the permeability coefficient starting from 0.382 cm/s.
6. The profile of pervious concrete destruction is a fracture pattern. The fracture starts from the center of the cylinder test specimen. It might be due to a low concrete tension value. Therefore, it is less suitable to be used as a rigid pavement.
7. Specimen of variation coconut shell flake and ash, of 2.5% and ash 0%, respectively, is incorporated in the mixture of concrete with K100 quality standard. So, it will become suitable for light facilities loads.
8. This study shows that the combination of coconut shell flake and coconut shell ash does not increase the compressive strength of the concrete mixture. The shrinkage of coconut shell flake aggregates causes enlargement of cavities on the specimen, causing a decrease in compressive strength. However, it increases porosity and permeability, and as a result, the density is getting lower.

We propose a further study on porous concrete using coconut shell flake for lower load facilities, such as pedestrian or bicycle pathways.

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