Study on concrete compressive strength due to the cement substitution partially by corncob ash

M Aswin, L Nola, and E S Maranatha

Department of Civil Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan 20155

*Email: ekaisty21@gmail.com, muhammad.aswin@usu.ac.id

Abstract. The development of concrete construction increased gradually, so that it affects the increasing on the cement use. Cement production contributes to produce gas emissions (CO$_2$) which can cause environmental issue. Therefore, alternative materials are needed to use in reducing the using of cement, the aim of this research was to generate the green concrete. Corn is one of the agricultural waste. In addition, to support green concrete, this research also used cement less than 500 kg/m$^3$. The number of cement will substitute by Corncob Ash (CCA) partially with variations are 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, and 17.5% counted as recently cement weight. The using of specimen consist of diameter 150 mm and height 300 mm. The needed of compressive test each variations made of 3 concrete cylinder samples for testing at 7, 14 and 28 days. Based on the results, it can be seen that CCA is able to supply increasing on concrete compressive strength. So that, CCA can be proposed partially as a cement substitutional.

1. Introduction

Nowadays the development of concrete construction is increasing. Concrete is a composite composed of mixed aggregates (fine aggregates and coarse aggregates) that are bound by cement paste and can also be used as an additive in order to get the desired results [1]. In concrete, aggregates occupy 70% to 75% of the volume of concrete, so the characteristics and properties of aggregates have a direct influence on the quality and properties of concrete [2]. The cement also functions to bind aggregate grains to form a solid mass and fill air cavities between these aggregate grains. Although the composition of cement in concrete is only about 10%, but because of its function as a binder, the role of cement is very important [3]. In addition, it takes a certain amount of water which is very influential on the concreteness of concrete. The hydration process in fresh concrete requires approximately 25% of the weight of the cement used. Excessive water from the hydration process is needed for the consistency of the concrete stir to achieve a good speed [4]. The amount of water needed for a particular accident depends on material used [2]. Water has an important role in the work ability, strength, and durability of concrete. Too much water reduces the strength of concrete, while too little will make concrete unable to work [5].

Increasing concrete construction has an impact on increasing the use of cement as a concrete binder. Based on the data of Asosiasi Semen Indonesia (ASI) noted that domestic cement sales in 2017 raised by 7.6% to 66.35 million tons [6]. The cement industry contributes a large amount of carbon dioxide emissions CO$_2$ to the atmosphere. Cement industry supports pollution and damages the environment. To overcome the environmental damage is needed another alternative material that can be used to reduce the use of cement in making concrete. From previous studies, many ideas have been sparked in using alternative materials such as the use of waste to develop environmentally friendly concrete. In realizing the concept of green concrete by using alternative materials from waste, it is necessary to pay attention that the function of concrete must also be good.

In this study, it will be examined how the influence of corncob ash as an alternative material to replace cement with compressive strength of concrete. Based on Ministry of Agricultural data, corn production in Indonesia in 2018 is 30.56 million tons with a harvested area of 5.73 million hectares [6]. Corncob is a hard and thick middle cylindrical core. Corn contains approximately 30% of corncobs and...
the rest are seeds and skin [7]. From this percentage, the amount of corncob waste in 2018 is 9.009 million tons. Corncobs were still not processed properly so that they only become waste for the environment [8]. High numbers of corn production in Indonesia has become a great opportunity to utilize CCA as an alternative material in producing the concrete. The SiO$_2$ content of CCA is 27.69%, which is not dominant. But, CCA has a potential to be used as an alternative material to create the concrete. By utilizing CCA, it is expected that the concept of green concrete can be realized.

2. Method
2.1 Mix Design
This study is refer to SNI 03-2834-2000 in planning a normal concrete mixture. In this case, corncob ash was used as cement substitution partially of 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15% and 17.5% of the cement weight. Basically, corncob ash concrete refers to a normal concrete mix design, but the difference was the amount of cement use which will be decreased related to the amount of corncob percentage. The mix proportion in this case is shown in Table 1 and Table 2.

| Table 1. Mix Proportion Normal Concrete, CCA 2.5%, CCA 5% and CCA 7.5% |
| --- |
| Ingredients | Material Weight for 1 m$^3$ |
| | Normal Concrete | CCA 2.5% | CCA 5% | CCA 7.5% |
| | Factor | Volume Weight (kg/m$^3$) | Factor | Volume Weight (kg/m$^3$) | Factor | Volume Weight (kg/m$^3$) | Factor | Volume Weight (kg/m$^3$) |
| Cement | 1.00 | 455.00 | 1.00 | 443.63 | 1.00 | 432.25 | 1.00 | 420.88 |
| CCA | 0.00 | 0.00 | 0.025 | 11.38 | 0.050 | 22.75 | 0.075 | 34.13 |
| Water | 0.55 | 250.25 | 0.55 | 250.25 | 0.55 | 250.25 | 0.55 | 250.25 |
| Fine Aggregate | 1.80 | 820.00 | 1.80 | 820.00 | 1.80 | 820.00 | 1.80 | 820.00 |
| Coarse Aggregate | 2.04 | 927.00 | 2.04 | 927.00 | 2.04 | 927.00 | 2.04 | 927.00 |
| Concrete Volume Weight | 2452.25 | 2452.25 | 2452.25 | 2452.25 |

| Table 2. Mix Proportion CCA 10%, CCA 12.5%, CCA 15% and CCA 17.5% |
| --- |
| Ingredients | Material Weight for 1 m$^3$ |
| | CCA 10% | CCA 12.5% | CCA 15% | CCA 17.5% |
| | Factor | Volume Weight (kg/m$^3$) | Factor | Volume Weight (kg/m$^3$) | Factor | Volume Weight (kg/m$^3$) | Factor | Volume Weight (kg/m$^3$) |
| Cement | 1.00 | 409.50 | 1.00 | 398.13 | 1.00 | 386.75 | 1.00 | 375.38 |
| CCA | 0.10 | 45.50 | 0.125 | 56.88 | 0.150 | 68.25 | 0.175 | 79.63 |
| Water | 0.55 | 250.25 | 0.55 | 250.25 | 0.55 | 250.25 | 0.55 | 250.25 |
| Fine Aggregate | 1.80 | 820.00 | 1.80 | 820.00 | 1.80 | 820.00 | 1.80 | 820.00 |
| Coarse Aggregate | 2.04 | 927.00 | 2.04 | 927.00 | 2.04 | 927.00 | 2.04 | 927.00 |
| Concrete Volume Weight | 2452.25 | 2452.25 | 2452.25 | 2452.25 |
2.2 Materials
a. Corncob Ash
Corncobs were obtained from corn cobs waste from the corn refinery in Simalingkar, North Sumatera and its vicinity. Before being used as a concrete mixture, CCA was tested at Palm Oil Research Center (PPKS) to determine its chemical composition. The corncobs were dried firstly before burned. The dried corncobs were burned manually without using any special tools or other mixtures to help the combustion process. Combustion temperature was not measured. No checking such as sieve analysis or specific gravity test were carried out on CCA, no refinement and others. CCA needed in this study was 17.47 Kg.

b. Portland Cement
The amount of Type-I OPC cement which was used in this study was around 400-500 kg/m³.

c. Fine Aggregate
The sand which was used in this study was from PT. Kraton. The sand was through the examination of sand sieve analysis (SNI 03-1968-1990) and specific gravity test (SNI 03-1970-1999).

d. Coarse aggregate
The maximum size of used coarse aggregate is 10 mm gravel from PT. Kraton. The used gravels were through gravel sieve analysis and specific gravity test.

e. Water
The water used in making concrete must be visually clear, colorless and does not contain any impurities such as oil or other organic substances. The water which was used in this study was from clean water for mixing and curing concrete. The water was from PDAM Tirtanadi, in the Concrete Materials and Engineering Laboratory, Department of Civil Engineering, Faculty of Engineering, University of North Sumatra.

2.3 Specimen Preparation
Concrete cylindrical specimens with dimensions of 15 cm diameter and 30 cm height. The total number of specimens were 72. Further details can be seen in Table 3.

| Variations     | Total Sample | 7 Day | 14 Day | 28 Day |
|----------------|--------------|-------|--------|--------|
| Normal         | 3            | 3     | 3      |
| CCA 2.5%       | 3            | 3     | 3      |
| CCA 5%         | 3            | 3     | 3      |
| CCA 7.5%       | 3            | 3     | 3      |
| CCA 10%        | 3            | 3     | 3      |
| CCA 12.5%      | 3            | 3     | 3      |
| CCA 15%        | 3            | 3     | 3      |
| CCA 17.5%      | 3            | 3     | 3      |
| Total          | 24           | 24    | 24     |

The steps of specimens casting are follow:
1. Prepare all the materials making up concrete and weigh each material according to the planned weight,
2. Put in the gravel by ½ part of the total amount of gravel, then turn on the concrete mixer. When concrete mixer spins, pour all the water slowly but continuously and spread. Make sure the poured water does not spill out the concrete mixer so as the amount of water does not decrease,
3. After the water has been poured, press the start button on the stopwatch. Let the water and gravel be mixed evenly with an estimated time of approximately 1 minute. Make sure nothing sticks at the bottom of the concrete mixer,
4. When the concrete mixer is on and spinning, put in all the cement and CCA slowly. Make sure the cement mixing is neither too slow nor too fast. Then, let the cement mix evenly with an estimated time of approximately 1.5 minutes,
5. After the cement is evenly mixed, add the remaining gravel and let the mixer continue. When the mixture is evenly mixed, add ½ the amount of sand and let it stir until evenly mixed, then immediately put the remaining sand into the mixer. Wait until the mixture is evenly mixed, after the workability of the concrete mixture is reached, stop the mixer by turning it off. The total time required for this process is approximately 6 minutes,
6. The mixture that has been mixed evenly is poured into a large pan that does not absorb water and then is poured into the Abrams cone to determine the value of the slump.

2.4 Slump test
Stages of slump test refers to SNI 1972:2008.

2.5 Unit weight test
Concrete weight volume testing which was used as the sample weight must be in a saturated surface dry condition.

2.6 Compressive Test
Compressive concrete strength testing was tested at the age of 7, 14, 28 days with 3 samples of each concrete variations of cylinder concrete. Before compressive test was held, specimens must be taken out from curing tub for the last 2 days. Then, dry them in room temperature. Compressive strength was done to test the strength of normal concrete and CCA concrete. Stages of concrete compressive test were refer to SNI 1974:2011.

3. Results and Discussions
3.1 Slump test
Slump test was used to check the mixture quality of fresh concrete workability. The results of slump testing from normal concrete and CCA concrete are show in Table 4 and Figure 1.

Table 4. Testing Results of Slump for Normal Concrete and ABJ Concrete

| Variation (cm) | Normal | 2.5% | 5% | 7.5% | 10% | 12.5% | 15% | 17.5% |
|---------------|--------|------|----|------|-----|-------|------|-------|
|               | 12     | 12   | 11.5 | 10.5 | 10.3 | 10    | 9.8  | 9.3   |

Based on Table 4, the results of slump tests of normal concrete, 2.5% CCA concrete, 5% CCA concrete, 7.5% CCA concrete, 10% ABJ concrete, 12.5% CCA concrete, 15% CCA concrete and 17.5% CCA concrete are 12 cm, 12 cm, 11.5 cm, 10.5 cm, 10.3 cm, 10 cm, 9.8 cm and 9.3 cm.

Based on the slump testing in Table 4 and Figure 1, the higher the CCA substitution is, the lower the slump result in mixing of fresh concrete. The percentage of CCA substitution to the percentage of cement replaced has the same weight, but if it is measured based on its volume, the volume of CCA is more than the granular cement. This condition causes CCA to absorb more water than cement so it causes the value of CCA fresh concrete slump to be smaller than normal fresh concrete slump value. The greater the percentage of CCA causes a decrease in the value of the slump as shown in Table 4 and Figure 1.
3.2 Concrete weight volume test

Testing of concrete weight volume was carried out to check the comparison of normal concrete weight and CCA concrete weight. The results of concrete weight were shown in Table 5 and Figure 2.

| Variations   | Weight Volume (kg/m³) |
|--------------|-----------------------|
| Normal       | 2248.554              |
| CCA 2.5%     | 2440.408              |
| CCA 5%       | 2432.262              |
| CCA 7.5%     | 2420.116              |
| CCA 10%      | 2381.384              |
| CCA 12.5%    | 2355.945              |
| CCA 15%      | 2347.412              |
| CCA 17.5%    | 2323.976              |

Based on Table 4 and Figure 2, it is known that the bigger the number of CCA produced, the smaller the weight volume will be. In the previous data, it is known that CCA substitution value of the percentage of cement replaced has the same weight. But if measured by volume, CCA volume is bigger than the cement volume. However, concerning the hydration of cement, the CCA particle do not react to produce calcium silicate hydrate (CSH) and become free material, so there is a possibility that the
concrete will become more porous. This condition causes the higher the CCA percentage, the smaller the CCA volume.

3.3 Compressive strength test

The results of the compressive strength test of normal concrete and CCA concrete are compared for each age of the test so that it can be known easily the optimum variation of CCA. Compressive test results for all variations in CCA percentage and age of the test is presented in Table 6.

Based on Table 6, it is known that CCA when used as a cement substitution gives impact on the compressive strength of concrete in the form of increasing and decreasing the compressive strength of concrete at a certain percentage. The increase in compressive strength of concrete occurs at a percentage of CCA 2.5% and CCA 5%. From this test, the optimum compressive strength results obtained when CCA 5% with the results of compressive strength test at age 7, 14 and 28 days respectively were 21.067 MPa, 24.533 MPa and 30.833 MPa, or an increase of 15.30%, 12.90% and 10%.

| Variation | Average Compressive Strength (MPa) |
|-----------|----------------------------------|
|           | 7 Day   | 14 Day  | 28 Day  |
| Normal    | 18.350  | 21.746  | 28.066  |
| CCA 2.5%  | 19.133  | 22.633  | 28.267  |
| CCA 5%    | 21.067  | 24.533  | 30.833  |
| CCA 7.5%  | 19.000  | 21.567  | 27.067  |
| CCA 10%   | 16.933  | 18.733  | 24.233  |
| CCA 12.5% | 15.933  | 16.433  | 22.800  |
| CCA 15%   | 14.900  | 15.367  | 22.033  |
| CCA 17.5% | 13.200  | 14.167  | 20.100  |

**Figure 3.** Variation of Compressive Strength at Different Curing Days
In this research, 2.5% - 5% CCA of cement substitution render concrete compressive strength of cement bigger and more increasing than normal concrete. This condition shows that SiO\textsubscript{2} compound in CCA is only effective in reacting to the cement hydration process in forming CSH at a percentage of CCA 5%. If the percentage of CCA is greater than 5%, then it is possible that ABJ will become a filler and free material which results in greater CCA content, which will disturb the cement binding phase because more CCA particles enter the aggregate pores. Cement paste is not able to work effectively to bind all aggregate grains. It can be concluded that, if the percentage of CCA substitution is greater than 5%, it can cause the compressive strength of concrete to get smaller.

4. Conclusions
Based of the research, it can be concluded that:
1. The result of chemical composition of CCA in PPKS known that the dominant composition on CCA was SiO\textsubscript{2} which was about 27.69%.
2. The usage of CCA concrete mixture will give impact on slump concrete. The higher the composition of CCA, the smaller the value of slump concrete. But, the bigger the CCA percentage, the more amount of water absorbed by CCA particles.
3. The usage of CCA as substitution material will impact the volume of concrete. The higher the compound of CCA, the smaller the volume of CCA will be.
4. CCA substitutions of 2.5% - 5% give bigger compressive and increase at age 7, 14, 28 days than the result of normal concrete. This shows that compound of SiO\textsubscript{2} in CCA substitution 2.5% - 5% was effective reacted to create CSH in cement hydration process. But, CCA substitution which is bigger than 5% will be filler or free material.
5. The optimum compression was gained 5% CCA substitution because the concrete CCA 5% gave the greatest compressive strength compared to normal compressive strength (control). The result of compressive strength for 7, 14, 28 days respectively were 21.067 MPa, 24.5333 MPa and 30.8333 MPa. Whereas the normal compressive strength of concrete at the age of 7, 14 and 28 days was 18.350 MPa, 21.746 MPa and 28.066 MPa. The compressive strength of concrete ABJ 5% has increased compared to the compressive strength of normal concrete at the age of 7, 14 and 28 by 15.30%, 12.90% and 10%.
6. CCA will be proposed as a replacement material on increasing the compressive strength of concrete.

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