Utilization of Coconut Shell Ash as a Substitute Material in Paving Block Manufacturing

by Ahmad Saiful Haqqi

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Abstract. In this study, coconut shell ash (CSA) was used as a substitute for cement in the manufacture of paving blocks. The research aims to determine the CSA substitution effect on the mortar compressive strength. The replacement percentages were 0, 3, 5, 8, 10, and 12%. The immersed and wrapping with plastic were conducted as curing conditions. The mortar compressive strength was 24.97, 16.44, 15.26, 14.61, 14.25, 11.87 MPa for immersed curing at 28 days for 0, 3, 5, 8, 10, and 12%, respectively. While for wrapping plastic, the compressive strength was 21.97, 15.82, 15.10, 14.06, 13.21, and 12.62 MPa. Substitution of coconut shell ash reduced the compressive strength. Based on the optimum compressive strength of mortar, the paving block size of 20×10×6 cm was made and then cut into 6×6×6 cm. The compressive strength was 13.21, 12.02, and 9.65 MPa at the 0, 3, and 5% CSA substitution. The water absorption indicated almost similar around 7% for all substitutions. There were no defects such as cracks found, and the different weights before and after immersed in sodium sulfate were 0.1 to 0.3%.

1. Introduction

Agricultural industries such as oil palm, coconut, sugar cane, and rice are major industries worldwide because most of these agricultural products are used as food sources for people worldwide. However, there are still waste products such as shells, leaves, straw, and stems after harvesting and processing agricultural products. Most of this farm waste is discharged into the environment, with little effort being made to reuse it [1]. Hence, to reduce environmental pollution, waste material can also be used as an alternative material to replace existing building materials such as aggregate [2]–[4] and cement [5], [6]. Crushed coconut shell produces paving blocks as aggregate substitutes that are 19.55 percent lighter and 33 percent more abrasion resistant than conventional paving blocks [7].

On the other hand, massive energy consumption is required in cement production. Carbon dioxide is released into the air. Cement production is estimated to contribute around 6-7% of the total CO_2 emissions [8]. Hence, using agricultural waste in concrete technology will reduce cement as a concrete-forming material and reduce the negative impact on the environment.

The current study describes the effect of coconut shell ash (CSA) as a cement replacement on paving blocks. Based on Indonesia Standard SNI 03-0691-1996 [9], the experimental method is used to evaluate the compressive strength, infiltration ability, and resistance to sodium sulfate for paving blocks.

1.1. Materials, Mixing Composition, and Mixing Procedure

Coconut shells were collected from the traditional market and burned manually, as shown in figure 1. then were sieved through an aperture 75μm sieve. The fine aggregate from the local quarry and the cement type 1 was used in this research.

Figure 1. (a) coconut shell; (b) burnt coconut shell; (c) sieved coconut shell ash (CSA)

Two phases of the experiments were conducted in this research. The first phase evaluated the effect of CSA on the compressive strength of mortar. CSA percentages substituted cement content were 0%, 3%, 5%, 8%, 10%, and 12% of cement weight. The specimen was cube 5×5×5 cm and two curing conditions, immersed in water and wrapped with a plastic bag. The mortar mixing composition for six specimens based on SNI 03-6825-2002 [9] is listed in Table 1. In the second phase, the paving block size of 6×10×20 cm is manufactured based on the two highest mortar compressive strengths in the previous phase and the curing system.

Table 1. Mortar Composition (kg) for six mortars

Percentage of CSA	Sand	Cement	CSA	Water
0	1.375	0.500	0	0.242
3	1.375	0.485	0.015	0.242
5	1.375	0.475	0.025	0.242
8	1.375	0.460	0.040	0.242
10	1.375	0.450	0.05	0.242
12	1.375	0.440	0.06	0.242

Mortar of 5×5×5cm cubes was produced by mixing the material as listed in Table 1 and pouring the mortar fresh into the mold as seen in Figure 2. The molds were opened 24 hours after cast. The mortar cubes were submerged in the water tub until the day of the compressive strength test of mortar. The compressive strength of mortar was evaluated at 14 days and 28 days.

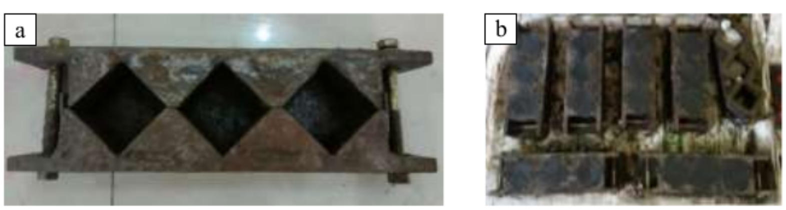

Figure 2. (a) mortar mold cube of 5×5×5cm; (b) after casting

At the next step, the percentage CSA for paving block size was set based on the two highest compressive strength mortar at 28 days. A pressed machine with a hydraulic and a vibrator system equipped, as seen in Figure 3a, was used to produce paving blocks. The size of the paving block was 20×10×6 cm. This machine is commonly used in the paving blocks home industry. The fine aggregate fills the gaps or voids in the paving block during the compaction process. With this method, compact and dense paving block products were obtained.

The manufacturing paving block process used a press machine as follows. Firstly, the fresh mortar mix was filled into the mold, as shown in Figure 3b. Then the vibration system on the engine was turned on for about ± 10 seconds. Replenish the mold again until the mold is filled. Next, the pressing or compacting panel was pressed so that the part of the pressing steel plate went down and carried out the compaction process while the vibrating system was running (Figure 3c). Finally, press the handle to lift the mold, and the paving block was ready for the curing process, as depicted in Figure 3d.

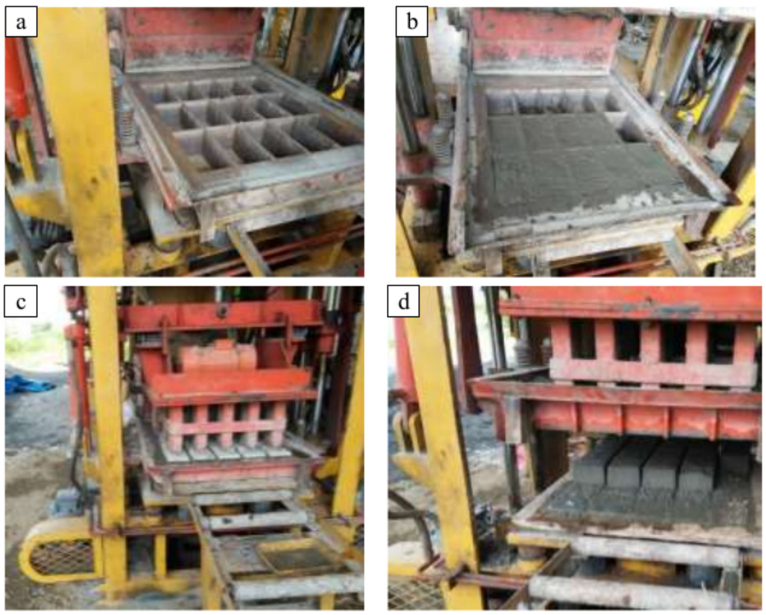

Figure 3. (a) Press paving block machine; (b) filling process; (c) pressing process; (d). paving block

1.2. Testing Procedure

The mortar compressive strength is evaluated by ASTM C109/C109M-16a [10]. Equation (1) is applied to obtain the compressive strength of mortar (f_c') in MPa:

$$f_c' = \frac{P}{A} \quad (1)$$

Where P is the ultimate load in kilonewton (kN), and A is the cross-section area of the specimen in mm^2.

According to Indonesia Standard, evaluating the compressive strength of paving block [9]. After the curing process, the paving block was cut into 6×6×6 cm cubes. The compressive strength of the paving block at 14 days and 28 days used equation (1).

The water infiltration test of the paving block after 28 days was also evaluated on 20×10×6 cm size. The paving block was put in the oven at approximately 105ºC for 24 hours. After 24 hours, the paving blocks were removed from the oven. Let the specimens be at room temperature for a while. The oven-dried paving block was weighed as W_1, then soaked in water for 24 hours. After drowning for 24 hours, the paving blocks were taken out and weighed as W_2. The water absorption is as follow:

$$\text{Water Infiltration} = \frac{W_2 - W_1}{W_1} \times 100\% \qquad (2)$$

Where W_1 is the dry weight (kg), and W_2 is the saturated weight (kg)

The resistance of paving blocks to sodium sulfate was carried out at 20×10×6 cm specimens. After 28 days, the paving block was soaked in 0.8% sodium sulfate water. Two paving blocks were cleaned from the adhering dirt, put in the oven at (105±2) ºC to a constant weight, and then cooled in a desiccator. After being cooled, the specimens were weighed to an accuracy of 0.1 grams, then immersed in a deep sodium sulfate solution for 16-18 hours. After that, the specimens were taken out and allowed to drop the rest water. Then put the specimens back in the oven for two hours. After that, the specimens were removed from the oven and kept until the temperature dropped. Then soak them back into the sodium sulfate solution. Repeat this procedure 5 (five) times cycles. For the last cycle, the specimens were washed until no more sulfate salt remained, then put back into the oven until constant weight. After cooling, the specimens were weighed again, then the appearances of test specimens were observed. If the weight difference before and after soaking in sodium sulfate solution was not greater than 1% and the test specimens were not defective, the specimens were declared feasible. However, if the weight difference on the two specimens from the three specimens was more than 1%, while the test specimens were feasible (not flawed), the specimens were declared defective.

2. Result and Discussion

The effect of CSA cement substitution on mortar compressive strength is depicted in Figure 4 and 5. The compressive strength of 12% CSA in immersion curing and 3% in plastic-wrapped curing at 28 days increased 35.35% and 13.34%, respectively, compared to compressive strength at 14 days. There was a decrease in compressive strength in both curing systems compared to the control mortar (0% CSA) at 14 days and 28 days. The higher the percentage of CSA, the more significant the decrease in compressive strength occurred. The curing system affects the compressive strength of the mortar. The compressive strength of mortar in an immersion system provides higher compressive strength than plastic-wrapped, between 1.1% to 12%. However, the percentage of 12% CSA, wrapped-plastic curing presents a higher compressive strength of about 6.3% than submerged in water.

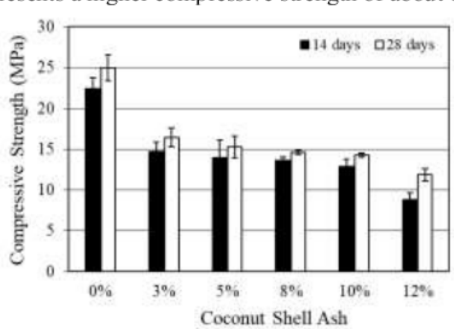

Figure 4. Effect CSA substitution on mortar compressive strength on immersed curing

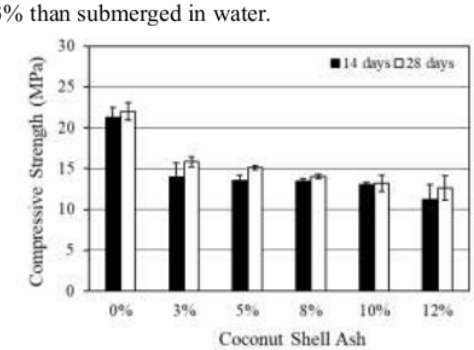

Figure 5. Effect CSA substitution on mortar compressive strength on plastic-wrapped curing

Optimum compressive strength occurred at 3% and 5% CSA substituting at 28 days was 16.44 MPa and 15.26 MPa on immersed curing and 15.82 MPa and 15.10 MPa on wrapped-plastic curing, respectively. Based on SNI 03-0691-1996, it can be categorized into paving blocks quality of C that can be used for pedestrians pathways.

Paving block size of 20x10x6 cm was fabricated by substituting cement with 3% and 5% CSA. The paving blocks were cut into 6×6×6 cm cubes for compressive strength specimens test. At 28 days, the compressive strength was 12.02 MPa for 3% CSA replacement and 9.65 MPa for 5% CSA replacement, as illustrated in Figure 6. Substitute 3% and 5% of CSA reduced the compressive strength by 9.03% and 26.94%, respectively. As shown in Figure 6, the compressive strength of the paving block is lower than the compressive strength of mortar in the previous phase of this research. According to the findings of this investigation, only paving blocks of D quality can be obtained by substituting 3% CSA. The paving block can be used for the park. This is already highly beneficial to small businesses. The characteristics of the CSA are required to improve, one of which is the burning procedure of the coconut shells. Although the use of agricultural waste reduces the strength of concrete, the selection, processing, and treatment of waste materials will improve the performance of the concrete [1].

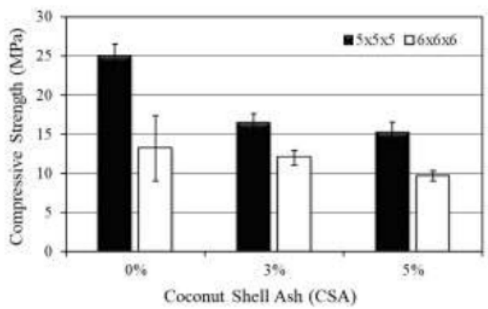

Figure 6. Compressive strength of the paving block

The result of the water absorption test at the age of 28 days can be seen in table 1. The paving block absorption were 7.1% and 7.0% for 3% and 5% CSA replacement, respectively. The result indicated that it fulfills the minimum requirements of the Indonesian Standard for class C, which functions for pedestrians pathway. This result is lower than the research conducted by Setiawan using oil palm shell ash as cement substitution of 0% and 10% with the water infiltration of 9.45% and 9.07%, respectively [11].

Table 2. Water infiltration of paving block

CSA substitution (%)	Saturated weight (gr)	Dry weight (gr)	Water infiltration (%)	The average water infiltration (%)
3	3,464	3,242	7	7.1
	3,444	3,196	8	
	3,446	3,226	7	
5	3,330	3,110	7	7.0
	3,384	3,164	7	
	3,368	3,148	7	

Visual observation is applied to evaluate the resistance of the paving block to sodium sulfate. No defects were found in the test object, such as cracks, and the different weight of the test object after testing was between 0.1 to 0.3%, which is lower than Indonesian Standard that was limited to 1%.

Table 3. The paving block resistant to sodium sulfate

CSA (%)	First weight (gr)	Last weight (gr)	Weight difference (%)	The average (%)	description
3	3,342	3,336	0.2	0.20	No defect
	3,384	3,382	0.1		No defect
	3,304	3,294	0.3		No defect
5	3,358	3,350	0.2	0.27	No defect
	3,378	3,368	0.3		No defect
	3,490	3,478	0.3		No defect

3. Conclusion

From the analysis of the results on compressive strength test and physical tests of paving blocks based on Indonesia Standard above, it can be concluded that:

1. The substitution of cement with CSA affects the compressive strength of the mortar. The higher percentage of CSA replacement to cement content, the lower the compressive strength.
2. The immersion treatment method has a higher compressive strength than covered with black plastic treatment.
3. The optimum compressive strength of mortar occurred at 3% and 5% cement replacement in immersed curing system were 16.44 and 15.26 MPa, respectively, at 28 days. Based on Indonesia Standard for paving block, the compressive strength fulfills the quality C used for pedestrians pathway.
4. Paving block 3% substitution CSA suitable for the park (quality of D) according to the compressive strength (12.02 MPa) required by SNI. This composition also meets the requirement of the water infiltration and resistance to sodium sulfate from Indonesia Standard. Thus the quantified as grade C.

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