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Utilization a Mixture of Eggshells and Husk Ash to Reduce Environmental Impact

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Eggshell waste and husk ash are abundant in Indonesia, with a population of 263 million, which is estimated to reach 483,920 tons and 10 million tons, respectively. However, this waste has not been utilized optimally, so it has a negative impact on the environment. This study aims to analyze the quality (compressive strength and water absorption) of a mixture of eggshells and husk ash as paving blocks for buildings to reduce the environmental burden. The experiment was carried out using a 2 factor factorial design: eggshells (4 levels: 0%, 5%, 7% and 15%); and husk ash (4 levels: 0%, 5%, 8% and 10%). The data were analyzed using analysis of variance, followed by analysis of mean using the least significant difference (LSD). The results showed that the mixture of eggs and husk ash had good quality, so it could reduce the need for Portland cement, which has a negative impact on the environment during production process. The best quality of a paving block was a mixture of 10% of husk ash and 15% of eggshells (A_4B_4 treatment) with the compressive strength value of 39 Mpa and water absorption of 5.8% (good).

Keywords: eggshells, husk ash, paving block, compressive strength, water absorption, environmental impact.

Introduction

Eggshell is one of the organic wastes with a hard and rough physical structure, fishy smell, and an unattractive colour, thus making it less desirable as food (Yonata et al., 2017). The main composition of eggshell is $CaCO_3$, which can cause pollution due to microbial activity and cause unpleasant odours. The chemical composition of eggshells (by weight) is as follows: calcium carbonate (94%), magnesium carbonate (1%), calcium phosphate (1%), and organic matter (4%) (Faridi and Arabhosseini, 2018). Hunton (2005) has also stated that eggshells have a very high mineral composition which is useful for humans. Based on the Statistics Indonesia's data in 2021, during 2017–2021, the production of broiler eggs in Indonesia increased by an average of 4.87% per year, while the consumption increased by an average of 4.18%. The total production of laying hens in Indonesia in 2018 reached 4,688,120 tons and increased to 5,044,394 tons in 2020. Egg consumption in Indonesia in 2018 reached 18.44 kg per capita per year and increased in 2020 to 28.16 kg per capita per year. With a population of 263 million, egg consumption is estimated to be at 4,839,200 tons per year. Of this amount, it is estimated that 10% is eggshell waste, so a very large amount of 483.920 tons will be produced, which is only disposed of as waste so that it has the potential to become a foul odor that can pollute the environment. Therefore, it needs to be utilized to have economic value and not to pollute the environment.

The eggshell is a calcareous layer that makes up 9–12% of the total egg weight. The source of eggshell comes from eggshell that is consumed and comes from hatchery waste from hatchery industries or embryos from dead chickens. Eggshell comprises approximately 94% calcium carbonate, 1% magnesium carbonate, 1% calcium phosphate, and 4% organic matter, especially protein (Wowor et al., 2015; Agustini et al., 2011). The $CaCO_3$ component in the shell can be used as a source of calcium for humans through the immersion method using chemical solvents. Several quite effective solvents can be used in the process of refining $CaCO_3$ in shells, such as the use of CH_3COOH in the purification of calcium shrimp waste content. Eggshell generally consists of water (1.6%) and dry matter (98.4%) (Jamila, 2014). Eggshells contain minerals (95.1%) and protein (3.3%) of the total dry matter. Based on the existing mineral composition, the eggshell is composed of $CaCO_3$ crystals (98.43%), $MgCO_3$ (0.84%), and $Ca_3(PO_4)_2$ (0.75%). Setiyawan et al. (2021) have stated that the analysis resulted in the content of free-range chicken shells of 6.03% crude protein, 91.05% ash content, and 0.84% crude fibre content. Meanwhile, duck shell has 5.77% of crude protein, 88.59% of ash content, and 1.39% of crude fibre. From the study results, it can be concluded that the eggshell waste of free-range chickens and ducks still has a nutritional value, which can be used as raw material for food, feed, or other materials. Eggshell consists of two main ingredients, namely shells and membranes. The high mineral and protein content of eggshell waste can be used for various purposes, which can be of economic value. Many studies on eggshells have been carried out, especially on nutritional and health aspects (King'ori, 2011), clay stabilization (Amu et al., 2005), health and cosmetic therapies (Long et al., 2008), and contents of carbon, nitrogen, and hydrogen in eggshells (Khairnar and Nair, 2019). Recent studies have been carried out by Gbylik-Sikorska et al. (2021) on the analysis of 50 antibacterial compounds in eggshells.

The eggshell waste can be used in the following ways: (a) in biodiesel production as a solid base catalyst used for biodiesel pollutants minimization; (b) as an absorbent of heavy metals from wastewater as it is a serious environmental problem in the ecosystem; (c) as biomaterial in order to replace bone tissues due to the rise in the number of patients; and (d) as a fertilizer and calcium supplement in nutrition for humans, animals, plants, etc. (Faridi and Arabhosseini, 2018). Meanwhile, Mignardi et al. (2020) have stated that eggshells could be used for sustainable environmental remediation. It can also reduce heavy metals in water (Setiawan et al., 2018). Rahayu and Hanifa (2017) have shown that eggshells can increase growth and facilitate digestion in piglets by mixing in pig food. Habeeb et al. (2014) have investigated the benefits of eggshells that can be used for alternative cement materials. The same thing has also been revealed by Dapas (2020), Nandhini and Karthikeyan (2021) and Sathiparan (2021) that the high content of calcium carbonate in eggshells when powdered can be used as a substitute for Portland cement which has calcium carbonate as the main element (55–60%). Utilization of this eggshell will be able to substitute 10–15% of the main ingredients of Portland cement (Sathiparan, 2021; Nandhini and Karthikeyan, 2021; Bandhavya et al., 2017). The increase of building construction, especially in the tourism and other sectors, has pushed the demand for cement and other building materials. Paving blocks have been widely used by the community for road construction, especially in tourism areas, residential areas, offices, parking areas, etc. The basic materials of the paving block consist of sand, Portland cement, and water in a rectangular shape with a size (length x width x height) of 21 x 10 x 6 (cm^3). Besides the rectangular shape, there are also hexagon, tri-hex, or grass blocks. Quality (water absorption and compressive strength) should meet the quality required by Indonesian National Standard: SNI 03-0691-1996, (BSN, 1996).

Besides eggshells, rice husk ash is used as a building material for paving blocks when mixed with eggshells. Rice husk ash is waste from rice which has special properties containing chemical compounds that can be pozzolanic, namely containing more than 70% SiO_2 + Fe_2O_3 + Al_2O_3 according to the quality of the pozzolan, which is required as an alternative additive material and as a metal binder (Sandya et al., 2019). Rice husk ash can also be used as a building material because it contains a geopolymer, which is an inorganic aluminosilicate compound (Lisantono and Purnandani, 2010b; Ais, 2017). Rice husk ash is untapped rice milling waste, just thrown away or burned, because most people do not know how to use it; thus, as a result, the environment becomes polluted. Tentama et al. (2017) have stated that the potential of husk ash in Indonesia is very large. According to the Statistics Indonesia (BPS Indonesia, 2021), rice production in Indonesia was estimated to reach 55.27 million tons, of which rice husks and rice husk ash were estimated to be more than 10 million tons (BPS Indonesia, 2021). Using husk ash as a mixture of paving blocks will reduce the need for Portland cement, which is economically more expensive and damaging to the environment. The main problem is how to make quality paving blocks by utilizing eggshell waste and husk ash. Therefore, this study aims to determine the appropriate composition of a mixture of eggshell and husk ash as a paving block material with good quality indicators of compressive strength and water absorption. Compressive strength is the ability to withstand a load to be stressed. The measured compressive strength is the compressive strength of paste, mortar, and concrete against a given load. Compressive strength in concrete is an important property of concrete. The main mineral influences compressive strength and C_2S (carbon disulfida) contributes greatly to developing the initial compressive strength and provides cement strength at a longer age (Manurung, 2020). Based on the real problem that has been revealed, the frame of thinking in this study can be seen in *Fig. 1*.

Fig. 1. *Framework and steps of the study*

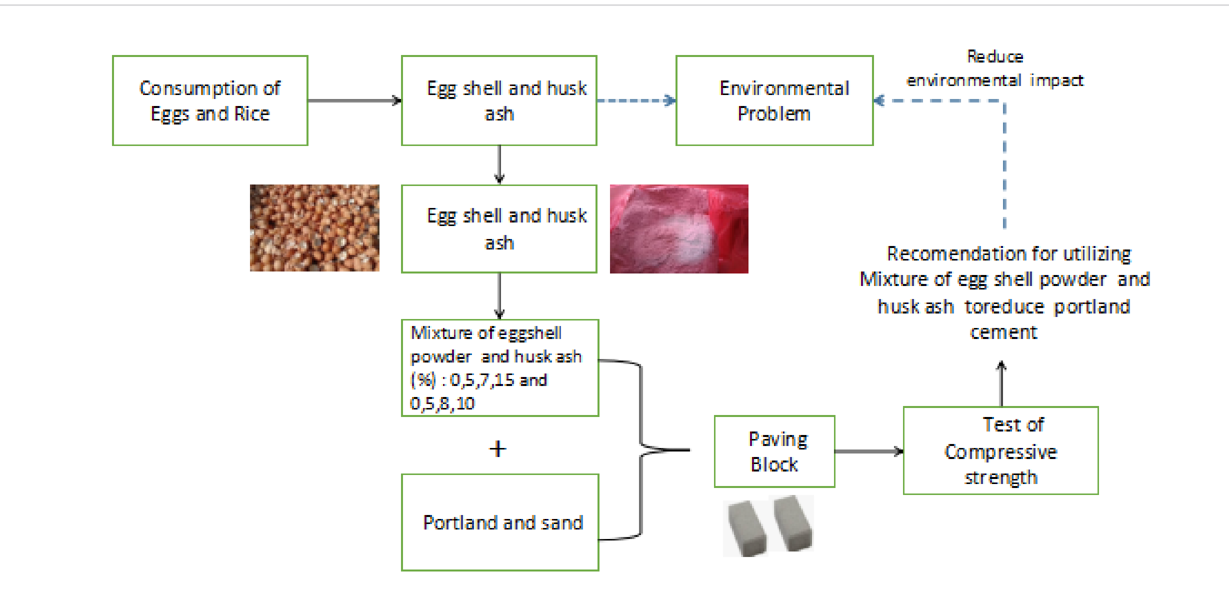


Table 1. *Paving block quality requirements (compressive strength and water absorption)*

Quality	Benefit	Compressive strength (MPa)		Max average water absorption (%)
		Average	Min	
A	Road pavement	40	35	3
B	Parking lot	20	17	6
C	Pedestrian	15	12.5	8
D	City Park	10	8.5	10

Research Methods

This research is a two-factor factorial experimental study, namely eggshell (A) with four levels (%): 0, 5, 7, and 15; and husk ash (B) with four levels (%): 0, 5, 8, and 10, with four replications as a group. The research design model is as follows:

$$Yijk = \mu + A_i + Bj + (AB)ij + \varepsilon ijk \qquad (1)$$

Where: Yij – observations on the i^{th} experimental unit which obtained a combination of treatment at the j^{th} of factor A from the k^{th} level of factor B;

μ – general average;

αi – the main influence of factor A;

βj – the main influence of factor B;

$(\alpha\beta)ij$ – the interaction component of factor A and factor B;

$EijK$ – normal spreading random effect $(0, \sigma^2)$;

Where: i,j,k – 1,2,3,4.

An analysis of variance was used to determine the effect of the treatments, followed by an analysis of the mean with the least significant difference (LSD) test. Based on the design model above, there would be 64 data sets with the distribution of each treatment as follows:

Table 2. *Combination of treatment of mixed eggshell and husk ash*

FACTOR B (HUSK ASH)	FACTOR A (EGGSHELL)			
	A1	A2	A3	A4
B1	A1B1, A1B1 A1B1, A1B1	A2B1, A2B1 A2B1, A2B1	A3B1, A3B1 A3B1, A3B1	A4B1, A4B1 A4B1, A4B1
B2	A1B2, A1B2 A1B2, A1B2	A2B2, A2B2 A2B2, A2B2	A3B2, A3B2 A3B2, A3B2	A4B2, A4B2 A4B2, A4B2
B3	A1B3, A1B3 A1B3, A1B3	A2B3, A2B3 A2B3, A2B3	A3B3, A3B3 A3B3, A3B3	A4B3, A4B3 A4B3, A4B3
B4	A1B4, A1B4 A1B4, A1B4	A2B4, A2B4 A2B4, A2B4	A3B4, A3B4 A3B4, A3B4	A4B4, A4B4 A4B4, A4B4

The material of this study was:

a ingredients: eggshell, husk ash, sand, Portland cement, and water;

b equipment: weighing scale and Forney Testing Machine Model QC 200 DR by Forney Incorporated with a maximum capacity of 180 tons.

The size and weight of paving blocks in this study was in accordance with SNI 03-0691-1996, which is 20 x 10 x 6 cm^3 with a weight of 3.333 kg. The percentage of the mixture of eggshell and chaff ash in each treatment was 25% of the amount of material for each paving block.

Implementation of the treatments:

1 The eggshells were pounded, and then soaked for 24 hours;
2 The husk ash was prepared, the husk ash was taken according to its size, then placed on the bucket provided;
3 For the control treatment, paving blocks were made with ingredients of 2500 g of sand and 833 g of Portland cement; the eggshells and husk ash were mixed by substituting the weight of the cement, while the sand remained 2500 g;

4 according to the treatment, the cement was reduced by adding a mixture of eggshell powder and husk ash, as shown in *Table 1*;

5 measurement of compressive strength and water absorption was carried out on day 28.

The compressive strength test was carried out as follows: (1) the test object was placed on the press machine centrically; (2) the press machine was run with an additional load of within 2–4 kg/cm^2 per second; (3) the loading was carried out until the test object was crushed, and the maximum load that occurred during the test object examination was stated in units (kg/cm^2)(Mpa); (4) the results of the compressive strength test were entered in the formula. The following formula was used to calculate the compressive strength of each paving block:

$$\text{Compressive strength: } Fc = P/A \quad (2)$$

Where: P – maximum load (kg);

A – cross-sectional area of the test object (cm^2);

Fc – product compressive strength (kg/cm^2) (Mpa).

Meanwhile, the water absorption was tested on the paving blocks that had been dry for 28 days with the following steps: (1) the test objects were weighed dry to determine the dry weight; (2) the immersion was carried out for 24 hours; (3) after immersion, the test object was weighed to determine the wet weight; (4) the results of the water absorption test were included in the formula:

$$WA = (m_j - m_k)/(m_k) \times 100\% \quad (3)$$

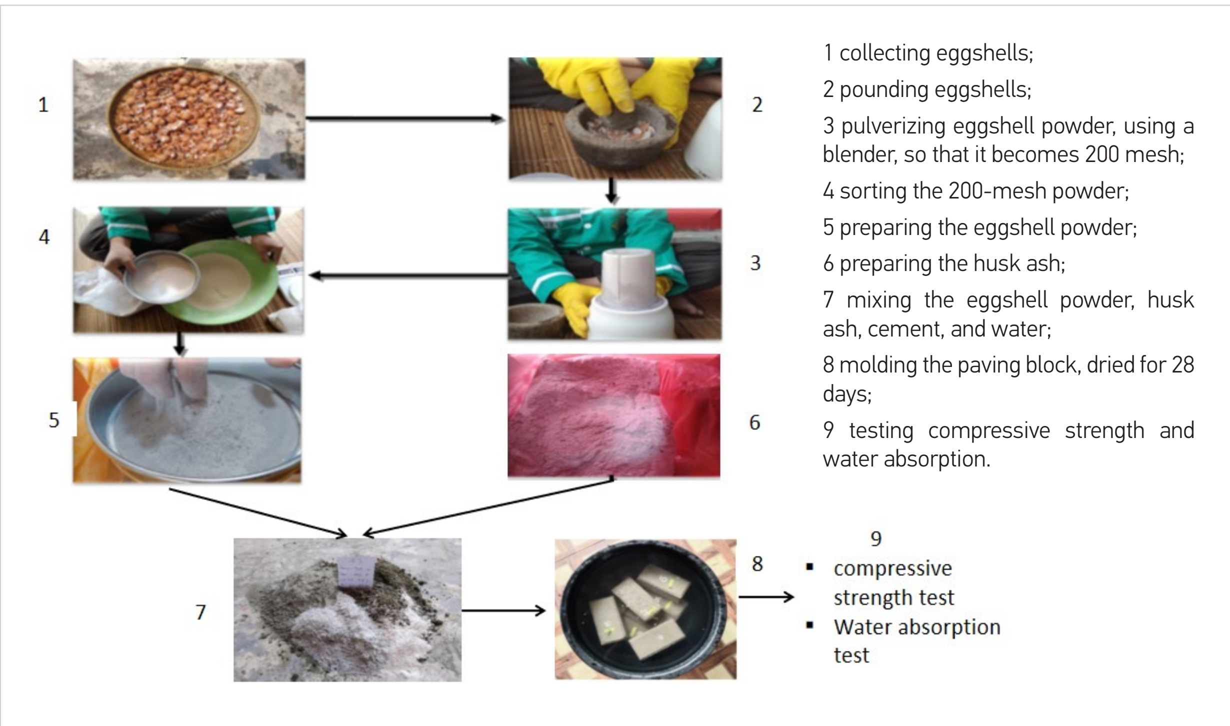
Where: WA – water absorption (gr);

m_k – mass of dry sample (gr);

m_j – mass of sample after soaking (gr)

In general, the process of making and testing paving blocks is as follows:

Fig. 2. *Stages of making and testing paving blocks*



Results and Discussion

According to Indonesian National Standard (SNI 03-0691-1996), the quality of paving blocks can be measured from the compressive strength and water absorption capacity (BSN, 1996). Based on the results of data analysis, a mixture of eggshell and husk ash has a very significant effect on the compressive strength of paving blocks, as shown in *Table 3.*

Table 3. *Analysis of variance on the effect of eggshell and husk ash treatment on the compressive strength test*

Source	DF	SS	MS	F (value)	F (table)	
					0.05	0.01
Eggshell	3	10531.69	3510.56	103.77**	2.81	4.25
Husk ash	3	25923.94	8641.31	255.43**	2.81	4.25
Eggshell* husk ash	9	3848.06	427.56	12.63**	2.81	4.25
Error	45	1522.56	33.83			
Total	63					

*** very significant; SS, sum square; MS, mean square.*

Table 3 above shows that the F_{value} for all treatments is greater than the $F_{(table)}$, both 5% and 1% error levels, which shows that eggshell, husk ash, interaction eggshell and husk ash, and block/groups have a significant effect on the compressive strength of paving blocks. This means that the mixture of eggshell and husk ash will determine the compressive strength of the paving block. To find out the level of the optimum compressive strength, we continued to test the mean value using the LSD. This mean test was only carried out on treatments i and j for i = j, for i = 1,2,3,4 and j = 1,2,3,4 (on the diagonal line: A_1B_1, A_2B_2, A_3B_3 and A_4B_4), where A is eggshell and B is husk ash. LSD test results are shown in *Table 4.*

Table 4. *LSD test result for compressive strength*

Treatment	Result (Mpa)	LSD
A1B1	19	27.28^{a}
A2B2	30	36.28^{bc}
A3B3	30.5	39.78^{c}
A4B4	39	47.28^{d}

The numbers followed by the same letter are not significantly different

Table 4 shows that A_1B_1 (27.28^{a}) and A_2B_2 (36.28^{bc}), A_2B_2 (36.28^{bc}) and A_4B_4 (47.28^{d}), and A_3B_3 (39.78^{c}) and A_4B_4 (47.28^{d}) are significantly different, while A_2B_2 (36.28^{bc}) and A_3B_3 (39.78^{c}) are not significantly different. The results of the compressive strength test using Formula 2 show that the value of compressive strength of the entire treatment is 19–30 mpa, and the highest value on A_4B_4 (30 mpa) is with a composition of 15% of eggshell and 10% of ash husk.

The analysis of variance on water absorption also shows that the mixture of eggshell and husk ash has a significant effect on water absorption, as shown in *Table 5.*

Table 5. *Analysis of variance on the effect of eggshell and husk ash treatment on water absorption*

Source	DF	SS	MS	F (Value)	F (Table)	
					0.05	0.01
Block	3	9.93	3.31	11.61**	2.81	4.25
Eggshell	3	318.27	106.09	372.2**	2.81	4.25
Eggshell* Husk Ash	3	745.59	248.53	872.03**	2.81	4.25
Husk Ash	9	106.83	11.87	41.64**	2.81	4.25
Error	45	12.85	0.285			
Total	63	343.27				

*** very significant; SS, sum square; MS, mean square*

Table 5 above shows that all the results of the $F_{(value)}$ for all treatments A (eggshell), B (husk ash), A*B (interaction eggshell and husk ash), and Group are greater than the $F_{(table)}$ for both 5% and 1%, which means that statistically eggshell and husk ash treatments affect water absorption.

The LSD test was carried out to determine which treatment/composition was different from the others. As in the compressive strength test, the test of water absorption was carried out on the A_iB_j treatment for i = j (I = 1,2,3,4), and the test results are shown in *Table 6.*

Table 6. *LSD test results for water absorption*

Treatment	Result (%)	LSD
A1B1	4.6	5.36^{a}
A2B2	4.6	5.38^{ab}
A3B3	5.5	6.26^{c}
A4B4	5.8	7.86^{cd}

The numbers followed by the same letter are not significantly different

Tables 6 shows that A_1B_1 (5.36[a]) and A_2B_2 (5.38[ab]), A_3B_3 (6.26[c]) and A_4B_4 (7.86[cd]) are not significantly different, while A_1B_1 (5.36[a]) and A_3B_3 (6.26[c]), A_2B_2 (5.38[ab]) and A_4B_4 (7.86[cd]) showed significant differences. The highest value was obtained at A_4B_4 (5.8%), derived from a mixed composition of 15% of eggshells powder and 10% of husk ash. Based on Indonesian National Standard SNI 03-0691, this result can be classified into group B (good). This shows that A_4B_4 treatment (composition of 15% of eggshells powder and 10% of husk ash) is the best quality with a compressive strength value of 30 mpa and a water absorption of 5.8%. These results are relevant to those obtained in studies conducted by Jamila (2014), Habeeb et al. (2014), Agustini et al., (2011), Sathiparan, (2021), Sandya et al. (2019), Lisantono and Purnandani (2010a), and Ais (2017).

Discussion

Eggshell and husk ash waste in Indonesia is abundant, based on BPS data (2021), which is estimated at 483,920 tons for eggshells and 10 million tons for husk ash, but it is still not utilized optimally and is still considered as waste that will have a negative impact on the environment. The results of this study indicate that eggshells can be used as a mixture to replace Portland cement for paving blocks or other building materials. According to Lestari (2021), the demand for cement in Indonesia in 2021 was estimated to reach 66.5 million tons and will continue to increase with a growth of 6% per year. Currently, the demand for cement is provided by several cement factories such as Indocement, Semen Tiga Roda, Semen Padang, Semen Baturaja, and others. All of these factories use limestone as the main ingredient and clay, which has a negative impact on the environment, because it will deplete limestone mountains and create dust that will disturb human health and the surrounding plants.

The utilization of eggshell waste and husk ash will reduce the exploitation of non-renewable natural resources. Besides, it will also reduce the environmental impact of eggshell waste and husk ash. From the socio-economic aspect, it will encourage the growth of business activities by collecting eggshell waste and husk ash and will absorb a very large workforce so that it will be a solution to reduce unemployment. The practical implementation of the results of this study is the need for government policies through a tax amnesty for cement factory entrepreneurs who use eggshell waste and husk ash to reduce environmental damage.

The results of this study showed that the quality of the paving block (compressive strength and water absorption) was influenced by the composition of the mixture of eggshells and husk ash. The composition of A_4B_4 treatment (15% of eggshells powder and 10% of husk ash) is the best quality, which resulted in 39 Mpa of compressive strength and 5.8% of water absorption. This is because the eggshell contains 98.43% of $CaCO_3$ and the husk ash contains 70% of SiO_2; so, the mixture of these two materials produces a composite containing $CaSiO_3$ (calsium silicate). Thus, the mixture has a high compressive strength and good water absorption of paving blocks.

Further studies need to be carried out with more variations of a mixture of eggs hells and husk ash to find out the optimal composition of the mixture.

Conclusions

A mixture of eggshells and husk ash can be used as an alternative material for Portland cement for paving blocks or other buildings with relatively good quality (compressive strength and water absorption). A_4B_4 treatment (15% of eggshells powder and 10% of husk ash) was the best quality, with a compressive strength value of 39 Mpa and water absorption 5.8%. The quality of the compressive strength and water absorption of paving blocks is classified as good based on SNI 03-0691-1996. Utilization of the mixture of eggshell and husk ash for building materials is proposed to reduce the use of Portland cement and environmental impact.

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