The potential utilization of rice straw ash as cement replacement in mortar material

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Abstract. This paper explored the suitability of rice straw ash, cement and water to produce mortar. The purpose of this experimental study was to investigate the possibility of using rice straw ash in mortar mixes as cement replacement to reduce the environmental effects of cement manufacture. For this purpose the mechanical properties of mortar mixes were compared with control samples. This study focused on the parameters of compressive strength. The rice straw ash used in this study was in the form of granules of about finer than 0.075 mm diameter which would replace (by weight of cement) a portion of the binder of an equal size (0.075 mm). In this investigation, four different percentages of cement replacement were used and air curing has been applied. Based on the result, air curing condition showed that the hardener mortar can be produced and exhibited the decreasing of compressive strength of mortar from 100% cement to 70% cement.

1. Introduction

Portland cement has been widely used as a binding material in concrete and mortar production, where its demand increases along with rapid growth of infrastructure development. The problem emerges in Portland cement production because it releases much of carbon dioxide (CO_2) into the atmosphere and it could harm the environment. To reduce carbon dioxide emissions due to the Portland cement production, it is necessary to find other materials as Portland cement replacement materials. In this concern, rice straw ash is one of the alternatives to Portland cement replacement as a binder on the concrete or mortar mixture.

It is also well known that the Asian countries produce a large amount of paddy. Rice straw, a by-product, is used as a fuel in a boiler in the rice mill or in the small electricity generating plant and other applications. Although the increased use of rice straw is evident, much of the straw is disposed of by open-field burning. Therefore, making cement from rice straw has attracted interest worldwide. Rice straw, when burnt, is found to contain a very high percentage of silica, which is one of the main constituents in producing mortar. With proper burning and grinding, the amorphous reactive rice straw ash (RSA) could be produced and used as pozzolan [1]. The SiO2 rich RSA can also be used to adjust the SiO2 content of the mortar. The use of high silica to alumina ratio results in mortar with higher elasticity [2]. In addition, the bulk density of RSA is lower than the cement. The use of RSA should, therefore, result in the lighter weight cement and hence lighter mortar and concrete, which is desirable.

Rice has a good bulk which can be converted into ash by adopting inexpensive methods of burning. The potentiality of rice straw as a good source of high technological materials in mortar construction is the subject of this research. This study also presents an investigation on different characteristics rice

straw ash as cement replacement in mortar material by performing mechanical tests like compressive strength.

2. Material and Methods

2.1. Ordinary Portland Cement

The experiments were carried out using ordinary portland cement and produced by Indonesia cement manufacture. Physical properties of cement used in this research are shown in Table 1, respectively. The component oxides and physical properties meet the requirement of SNI 15-2049-2004 [3].

Table 1. Physical properties of OPC.

No	Physical properties	SNI 15-2049-2004	Cement used (OPC)
1.	Air content of mortar (%)	12 max	11.5
2.	Fineness/Blaine meter (m^2/kg)	280 min	582
3.	Expansion, % (max)	0.8 max	-
4.	Compressive strength		
	a. 3 days (kg/cm^2)	125 min	285
	b. 7 days (kg/cm^2)	200 min	293
	c. 28 days (kg/cm^2)	280 min	460
5.	Time of setting (Vicat test) :		
	a. Initial set, minutes	45 min	137.5
	b.Final set, minutes	375 max	205
6.	False setting time (minutes)	50 min	-
7.	Heat of hydration 7 days, cal/g	-	65
8.	Normal consistency (%)	-	29.15
9.	Specific gravity	-	3.19

2.2. Rice Straw Ash

Locally available rice straw ash (RSA) was collected from open-field burning in locally small heaps, in Gowa, South Sulawesi, Indonesia. Locally available rice straw ash was incinerated in tin box furnace under controlled conditions for production of RSA. After combustion at 800 - 900°C, the ash was finally ground in a ball mill until the average particle size was passing in sieve no. 50 (0.3 mm) (100%) and 10 % passing sieve no. 50 (0.3 mm).

The result of examination of ash characteristics. From the test results obtained a specific type of weight value of 2.36. From the test results of fine aggregate water absorption, obtained the percentage of straw ash water absorption rate is 172.78%. And the test result of the screening analysis obtained the percentage of straw ash that passes the sieve No. 100 which is the < 10% pass sieve no. 100, with a diameter of grain ranging from 0.00 to 0.15 mm. as in Table 2.

Table 2. Physically characteristic of rice straw ash

No.	Type of inspection	Result of inspection
1	Specific gravity	2.36
2	Fine Aggregate water absorption	172.78%
3	Sieve analysis	100 % pass sieve no.200

2.3. Cement-Rice Straw Ash

The cement-rice straw ash mortar is a mixture of cement-rice straw ash and water. In this study, the cement content was fixed at 100% of the total mix. Cement : RSA ratios were (100%: 0%; 90%:10%; 80%:20% and 70%:30%). From the initial mixed trials, the composition of the mortar design was obtained. The composition of the mortar mixture design can be seen in Table 3. Water are used as a binder material. Mixing of cement material, rice straw ash and water is shown in Figure 1. The amount of water used is also taken into account to obtain the optimum water content for the optimal compaction of cement-rice straw ash.

Table 3. Mortar mixtures (1 m3).

No.	Code	Cement : RSA ratio	Cement (kg)	RSA (kg)	Sand (kg)	Water (kg)
1	A.1	100%:0%	849256.900	0.000	2335456.476	411040.340
2	A.2	90%:10%	764331.210	84925.690		
3	A.3	80%:20%	679405.520	169851.380		
4	A.4	70%:30%	594479.830	254777.070		

2.4. Mixing Procedure

Mixing method used in this research as follows:

- Cement + rice straw ash, mix in dry conditions for 1 minute (slow speed).
- Enter the binder (water), mix for 2 minutes.
- Blend manually for 1 minute and afterwards cement and rice straw ash and water, mix with mixing machine with high speed for 10 minutes. So the total mixing time is 11 minutes.

Figure 1. Mixing mortar materials.

2.5. Flow Testing (Consistency)

Flow or consistency of the mixture is important to know in order to obtain an indication showing the ability to use of fresh mortar in. In this case, there is a tendency of flow or consistency of each addition of water resulting in a decrease in consistency. Flow testing is done based on [4]. In this research used water to solid ratio of 0.2 (water weight divided by total weight of mixture) with flow equal to 110 ± 5% of fresh mortar. The value of flow or consistency is then maintained for each mix design performed as an indication that the mixture used has the same condition.

2.6. XRF Analysis

Chemical composition of rice straw ash by XRF test were shown at Table 4.

2.7. Compaction and Curing Method

This study was designed on a mortar geopolymer with a silinder mold with a size of 5 x 10 cm. For all specimens performed treatment (curing) that is the cooling in the room. There are 2 types of treatment of the specimen after removal from the silinder mold, the first is the air treatment that is the test object is stored in the storage space of the specimen with the room temperature. The test specimen treated at room temperature is a standard test object. The second treatment is cooled to room temperature for 24 hours, the specimen is immersed in water until the age of compressive strength testing is carried out. The test piece was treated until the age of compressive strength testing was carried out.

2.8. Compressive Strength and Modulus Elasticity

Based on SNI-03-6825-2002, a compressive strength test is to provide a continuous monotonic static load at a constant rate on the test specimen that creates compressive stress. Two test specimens were used for the compressive strength test, the results obtained were then averaged. A compressive strength test was performed using a Universal Testing Machine, two vertically mounted LVDT 10 mm and a set of data logger tools connected to a set of computers. LVDT is placed to measure the displacement that occurs when receiving a compressive load, the value of change or decrease that is analyzed to obtain strain due to the compressive load.

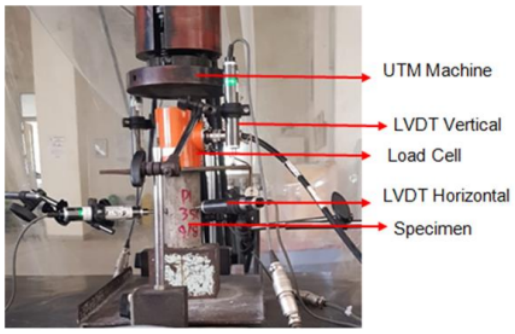

Figure 2. Test of compressive strength.

3. Result And Discussion

3.1. Chemical Content of Rice Straw Ash

Table 4 shows the oxide content of rice straw ash. The rice straw ash used in this study containing SiO_2, P_2O_5, $CaCO_3$ and K_2O.

Table 4. Oxide content of rice straw ash (XRF result).

Oxide Content	Concentration (%)
	Rice straw ash
Fe_2O_3	2.31
SiO_2	70.80
K_2O	15.89
CaO	5.34
P_2O_5	3.61

3.2. Flow Testing

Flow of fresh mortar of A.1, A.2, A.3 and A.4 were 230 mm, 185 mm, 170 mm and 120, respectively. Mixed mortar is able to bind the cement and rice straw ash so that the fresh mortar can flow and spread evenly without any accumulation in the middle of the circle and without any bleeding. Figure 3 shows the flow of fresh mortar.

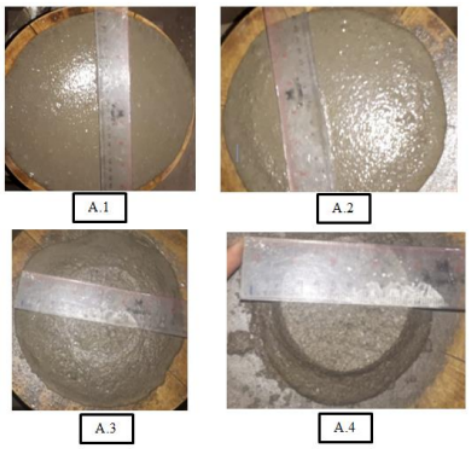

Figure 3. Flow of fresh mortar.

3.3. Compressive strength

The results of the test samples on the water curing at 7 days and the average of compressive strength of mortar can be seen on Figure 4.

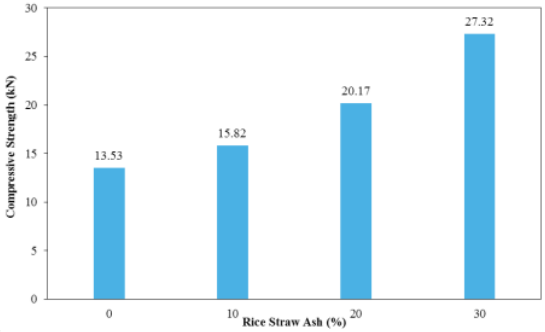

Figure 4. Compressive strength average of mortar.

Based on Figure 4 above, the test sample on 7 days water curing 0% rice straw ash has average compressive strength value of 13.53 kN while 10%, 20% and 30% rice straw ash water curing gave 15.82 kN, 20.17 kN and 27.32 kN of average compressive strength. It increased about 14.47%, 32.92% and 50.47% from 0% rice straw ash in mortar. Besides that, it shows that the test sample for 0%, 10%, 20% and 30% rice straw ash, the compressive strength increased without oven curing. This caused by the presence of rice straw ash in this mortar mixture contributes to the heat, hence without the curing of oven temperature, the rice straw ash mortar with this Portland composite cement (PCC) and ordinary Portland composite (OPC) material can still provide strength. This result also indicated that compressive strength increased without oven curing similar because the oxide content of rice straw ash, PCC and OPC SiO2 able to bind well and produce amorphous silica.

4. Conclusion

- In fresh condition the mortar is able to bond well without segregation and bleeding.
- From the research results of the mortar compressive strength that has been done, it can be seen that along with the addition of straw ash to the mortar mixture, the compressive strength of the mortar is higher. Compressive strength values with rice straw ash content of 0%, 10%, 20% to 30% are 13.5 kN, 15.8 kN, 20.2 kN, and 27.3 kN, respectively.

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