Compressive Strength Analysis of Renewable Mortar after Portland Cement Replacement with Waste Ash

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ABSTRACT

There are many environmental problems caused by factory waste. Sugar factory waste, in the form of bagasse ash, and PLTU factory waste, in the form of fly ash, are currently in the spotlight of science studies. This study used waste bagasse and fly ash to substitute Portland cement as the main ingredients for mortar. Baggash and fly ash waste were collected, processed, and then used to replace cement by up to 40% to determine to what extent they could be used in brick masonry work, wall plastering, and masonry paste. Experimental tests were carried out on mortar cube samples measuring 5×5×5 cm, comparing four types of samples consisting of Portland cement, bagasse ash, and fly ash. The compressive strength results were obtained after 28 days. Normal Mortar (MN=11.75 MPa) had higher compressive strength than the substitute mortar types MA (3.23 MPa), MB (3.09 MPa), and MC (2.98) MPa. According to SNI 6882-2014, MA, MB, and MC mortars can be used as O-type mortar (2.4 MPa). Therefore, they can be applied to wall plastering or walls not bearing loads.

Keywords-compressive strength; renewable mortar; wall plastering; paste; cement

I. INTRODUCTION

Rapid population growth requires livable housing. The implementation of residential development, infrastructure, and construction, in general, must be supported by the availability of relevant materials. In general, residential development and infrastructure tend to be made from materials related to Portland cement. Nowadays, many studies investigate alternative building materials that are environmentally friendly, cost-effective, and safe to use. This study analyzes the feasibility of fly ash waste and bagasse ash waste as a substitute material for Portland cement to produce mortar as a renewable alternative building material to be used in construction. From various field and documentary facts, it can be assumed that the use of mortar made from bagasse ash and fly ash waste as a cement substitute in residential development or infrastructure requires more research. Mortar is a binding material made from mixing sand, cement, and water in a certain ratio, which is used in construction to connect one layer of bricks to another, and is also used as a plastering material for walls. The adhesion of mortar is greatly influenced by cement because it functions as a binder for the homogeneity of the mortar-forming material.

The utilization of bagasse ash and fly ash waste is expected to become one of the solutions for handling industrial waste and to be used as an environmentally friendly alternative building material to minimize greenhouse gas emissions produced during the combustion of cement raw materials [1]. Various studies have investigated methods to obtain renewable alternative cement, including organic cement as the main ingredient in the production of mortar and concrete, and the results showed similarities to the physical properties of Portland cement [2]. $CaCO_3$ is the element with the highest content in Portland cement, reaching 63.9% [3]. Bagasse ash waste results from burning sugar cane, which tends not to be used and is a problem in various countries, especially for people living close to factory areas [4]. The area of sugar cane plantations in Indonesia is 321,000 ha, and the total sugar production for 2021 was more than 2 million tons [5]. Cement mortar can be examined for its microstructural analysis using X-Ray-Fluorescence (XRF) and X-Ray-Diffraction (XRD) analysis to determine the level of grain fineness and its specifications, including loose density, consistency, hardening time, and content of the elements present [6]. In [7], carbon powder (graphite-carbon) was used to reduce the use of Portland cement by up to 25% by weight, with a design quality of 20.75 MPa, and the highest compressive strength results obtained were 22.39 MPa [7]. Material model management is required to produce superior renewable alternative building adhesive materials, modified and evaluated synthetically in terms of physical and mechanical properties [8]. The use of Portland cement along with industrial waste to produce environmentally friendly concrete is cost-effective and can provide social benefits, reducing cement consumption and industrial waste [9-11].

Concrete samples having 10% marble powder, 5% sugarcane bagasse powder, and 10% river sand with the addition of sodium hydroxide binder resulted in a significant increase in compressive, split tensile strength, and flexural strength [12]. Increasing compressive strength and micro density are in line with reduced concrete age, porosity, and pore size. The Calcium Silicate Hydrate compound (CSH) influences the physical properties of porosity and compressive strength in Self-Compacting Concrete (SCC) [13]. Fly ash, in the form of bottom ash, is the result of burning coal in a PLTU. Fly ash has a high silica content, so it is pozzolanic. Combining fly ash (10 and 20%) and magnesium oxide (MgO) as mortar ingredients with recycled cement (5 and 10%) can increase the mechanical properties of concrete [14]. Adding 5 and 10% hydrated lime to 20% fly ash can increase concrete strength by 12.47% and reduce porosity and water absorption by 9.87 and 23% [15]. Adding 70% type F fly ash, 30% Portland cement, and silica fume can reduce hardening performance and strain formation [16]. In general, the use of large amounts of fly ash in concrete reduces its quality and the formation of strains as it ages [17].

Using fly ash with hydrated lime at 5-15% increased strength and water absorption at 28 days compared to without fly ash [18]. However, the strength decreases when the fly ash reaches 20 and 25%. Therefore, the maximum ratio to improve the short-term properties of cement paste is 15% fly ash and hydrated lime. The addition of fly ash to cement will inhibit the appearance of premature hydration heat in the cement paste [19]. In [20], bagasse ash was used as a partial replacement material for cement (10-30%) in 3 forms: (i) Ash waste (AC), (ii) waste in the form of soil (G), and (iii) bagasse waste burned in the form of soil (RG). The results showed that there is a correlation between possible economic costs. However, AC was not suitable as a partial replacement for Portland cement, G obtained satisfactory performance, and RG produced the best performance and reduced the economic cost by 8%. In [21], replacing 5% of cement with fly ash and using 50% recycled aggregates decreased compressive strength by 11% after 28 days compared to conventional concrete. In [22], replacing 7% of cement with fly ash and using 50% recycled aggregates decreased compressive strength by 7% after 7 days compared to conventional concrete. Therefore, it can be concluded that using bagasse ash as a partial substitute for Portland cement, based on technical, environmental, and economic considerations, is highly feasible.

A. Mortar Cement

Mortar is an adhesive material for construction produced by mixing fine aggregate, water, and cement in certain proportions. Mortar composition must meet the standards set by [23]. The mortar must have functional performance according to [24] to form a single monolith from the chemical reaction of each material that works integrally. Table I presents the compressive strength requirements test for each type of mortar.

TABLE I. COMPRESSIVE STRENGTH QUALITY FOR MORTAR TYPES BASED ON SNI 6882-2014 [24]

No	Cement mortar	Compressive Strength, at 28 days
1	M	17.2 MPa = 2500 psi
2	S	12.4 MPa = 1800 psi
3	N	5.2 MPa = 750 psi
4	O	2.4 MPa = 350 psi

Cement is a material that has adhesive and cohesive properties to bind all aggregates through the air into a mass that has a sufficient strength value [25]. The chemical element composition of cement is Calcium Oxide (CaO) by 40-60%, Silica Oxide (SiO2) by 20-40%, and Aluminum Oxide (Al_2O_3) by 4-8% [26].

B. Forming Materials

According to [27], the maximum size of the fine aggregate grains should be 4.75 mm in the form of natural sand, processed sand, or a combination of them. According to ASTM C 33 [28], fine aggregate is sand with particles smaller than 5 mm or passing through a no.4 sieve and surviving on a no.200 sieve. Table II shows the composition of the fine aggregate used for mortar test specimens.

TABLE II. PASSING PERCENTAGE OF THE FINE AGGREGATE SIEVE ACCORDING TO ASTM C33 [28]

ASTM sieve size	Percentage passing each filter
9.5 mm	100
4.76 mm	95 – 100
2.36 mm	80 – 100
1.19 mm	50 – 85
0.595 mm	25 – 60
0.300 mm	10 – 30
0.150 mm	2 – 10

C. Water

According to [23], the water used to mix mortar must be clean water that is suitable for drinking and free of oil, acid, alkali, organic substances, and substances/ingredients to avoid damaging the quality of the mortar and affecting its compressive strength [29].

D. Bagasse Ash

Bagasse ash is a waste product from sugar factory milling that has silica content reaching 68.5% and a fine texture and can react with calcium hydroxide to have binding properties [30]. Bagasse ash has been used to make concrete bricks, where the higher the percentage of bagasse ash used, the lower the compressive strength and the higher the water absorption. In [31], the compressive strength of level I concrete bricks with a composition of 22.5% bagasse ash was 103.077 kg/cm^2. Therefore, it can reduce cement use by up to 30%. Table III shows the compound composition of bagasse ash (blotong) [32]. In [33], using 10% bagasse ash as a partial replacement for cement reduced strength.

TABLE III. CHEMICAL COMPOUNDS OF BAGASSE ASH WASTE

No	Compound	Percentage
1	SiO_2	48-81
2	Al_2O_3	1-19
3	Fe_2O_3	2-19
4	CaO	2-4
5	K_2O	0.2-1.8
6	MgO	1-4
7	Na_2O	0.2-4
8	P_2O_5	0.5-4

E. Coal Fly Ash

ASTM C 618 [34] describes fly ash as fine granules, resulting from burning coal in the form of coal powder, which can pass through the sieve no. 325 (45 μm). The use of fly ash to make concrete has a positive impact from an environmental perspective [35]. Table IV shows the chemical elements/compounds contained in fly ash. Coal fly ash contains 33.3% silica compounds. Silica is also found in cement, and fly ash has pozzolanic properties. This shows the great benefits of fly ash, which is waste that was not used previously. Using fly ash as a cement substitute can result in a significant reduction in CO_2 emissions. Fly ash as a geopolymer material is very suitable for use because it is an optimal and economical use of waste [36].

TABLE IV. CHEMICAL COMPONENTS OF COAL FLY ASH

No	Compound	Percentage
1	SiO_2	33.3
2	Al_2O_3	14
3	Fe_2O_3	26
4	CaO	22.1
5	K_2O	1.3
6	SO_3	0.5
7	TiO_2	1.18

F. Compressive Strength

Compressive strength describes the ability of the mortar to maintain mechanical conditions until failure or collapse when applying stronger mechanical forces to it [37]. According to SNI 03-6825-2002 [24], the formula for calculating the compressive strength of mortar is:

$$\sigma m = \frac{Pmax}{A} \quad (1)$$

where m is the compressive strength of mortar (MPa), $Pmax$ is the maximum compressive force (N), and A is the cross-sectional area of the test object (mm^2).

II. MATERIALS AND METHODS

Mortar test specimens were made in two forms, namely normal mortar (MN) with only cement, sand, and water, and mortar with bagasse ash, fly ash, cement, sand, and water (MA, MB, and MC, see Table V). The compressive strength tests were carried out after the samples were aged for 7, 14, 21, and 28 days. Table V shows the composition of the mortar mixture samples and Figure 1 shows the equipment used to produce them. Figure 2 shows the principles of material management and testing the compressive strength of samples.

TABLE V. MORTAR SAMPLES' COMPOSITION

No	Sample	Dimensions (cm)	Bagasse ash (g)	Fly ash (g)	Cement (g)	Sand (g)	Water (cc)
1	MN	5x5x5	0	0	500	1375	242
2	MA	5x5x5	125	125	250	1375	242
3	MB	5x5x5	175	175	150	1375	242
4	MC	5x5x5	200	200	100	1375	242

Fig. 1. Equipment for making mortar samples.

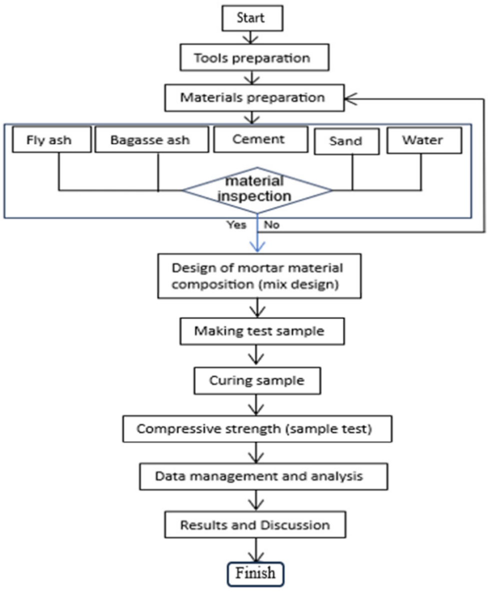

Fig. 2. Flowchart of management and testing sample's compressive strength.

TABLE VI. COMPRESSIVE STRENGTH TEST RESULTS

Sample	Days	Dimensions (cm^2)	Average compressive strength (kg/cm^2)	Average compressive strength (MPa)	Type
MN	7	25	65.33	6.41	S
	14	25	101.20	9.92	S
	21	25	106.27	10.42	S
	28	25	119.87	11.75	S
MA	7	25	28.40	2.79	O
	14	25	30.27	2.97	O
	21	25	32.00	3.14	O
	28	25	32.93	3.23	O
MB	7	25	26.0	2.55	O
	14	25	27.7	2.72	O
	21	25	29.9	2.93	O
	28	25	31.5	3.09	O
MC	7	25	25.1	2.46	O
	14	25	27.2	2.67	O
	21	25	29.5	2.89	O
	28	25	30.4	2.98	O

III. RESULTS AND DISCUSSION

Table VI and Figure 3 show the results of the compressive strength test for each sample. The compressive strength of normal mortar was higher than that of mortar with substitutes. The greater the addition of bagasse ash and fly ash composition, the lower the compressive strength of the resulting mortar.

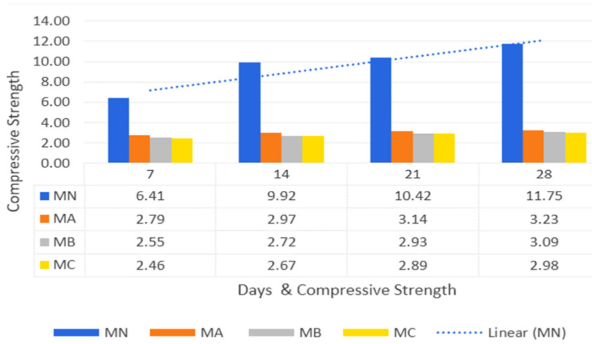

Fig. 3. Compressive strength of mortar samples.

Figure 4 shows the process of weighing samples and testing compressive strength.

Fig. 4. Process of weighing samples and testing compressive strength.

As shown in Table VII, the compressive strength of the MA, MB, and MC samples at 28 days was less than that of MN.

TABLE VII. COMPRESSIVE STRENGTH OF SAMPLES AT 28 DAYS AGAINST SNI 6882-2014 [24]

No	Days	Compressive strength (MPa)				Cement mortar type [24]
		MN	MA	MB	MC	M = 17.2 MPa
1	28	11.75	3.23	3.09	2.98	S = 12.4 MPa
						N = 5.2 MPa
						O = 2.4 MPa

However, mortar types MA, MB, and MC can be used for mortar type O according to SNI 6882-2014 [24], because their compressive strength is greater than 2.4. Table VIII shows the detailed composition and compressive strength test results for the mixes. Table IX shows how each type of mortar is classified according to SNI 6882-2014 [24].

TABLE VIII. MATERIAL COMPOSITION AND MECHANICAL PROPERTIES OF RENEWABLE MORTAR.

No	Sample test	Dimensions	Materials Composition					Compressive Strength
			Bagasse ash (gr)	Fly ash (gr)	Cement (gr)	Sand (gr)	Water (cc)	
1	MN (0% CW)	5×5×5	0	0	500	1375	242	11.75
2	MA (25% CW)		125	125	250	1375	242	3.23
3	MB (35% CW)		175	175	150	1375	242	3.09
4	MC (40% CW)		200	200	100	1375	242	2.89

CW: Cement weight.

TABLE IX. TYPES OF MORTAR BASED ON USES ACCORDING TO SNI 6882-2014 [24]

Location	Building Segment	Mortar Type	
		Recommended	Alternative
Exterior above ground	Load-bearing walls. Wall not bearing load. Parapet walls.	N O N	S or M N or S S
Underground exterior	Foundation walls, retaining walls. Check holes, channels, road pavement, sidewalks, and terraces	S	M or N
Interior or exterior	Load-bearing walls. Partitions not carrying loads	N O	S or M N

IV. CONCLUSIONS

Based on the results of compressive strength tests between normal and substitute mortar with a combination of bagasse ash and fly ash on cement, the quality of the conventional (MN) mortar was higher than that of the MA-, MB-, and MC-type mortars. However, based on the results of the compressive strength test, substitute mortars, using bagasse and fly ash (MA, MB, MC types), have compressive strength above the requirement of SNI 6882-2014 [24] for type O (2.4 MPa). Therefore, mortar types MA, MB, and MC can be used for permanent house construction by applying them to wall plastering or partition walls.

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