Strength performance of fly ash and rice husk ash geopolymer as sustainable infrastructure green materials in supporting SDG 9 and SDG 13

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Abstract. Cement, the primary material of concrete, is one of the main causes of global warming and climate change issues due to its production process. This paper reports the strength performance of fly ash and rice husk ash geopolymer as cement replacements in sustainable infrastructure green materials in supporting SDG 9 and SDG 13. A comparison with cement-based concrete was applied to identify the strength performance as a cement replacement material. The strength performance was carried out by compressive strength test. The results show that fly ash and rice husk ash can be used as alternative cement replacement materials. Fly ash-based geopolymer exhibited superior strength performance compared to all materials which can be used in paving block infrastructure innovation to support SDG 9. A combination of fly ash and rice husk ash can be used as alternative cement replacement materials for geopolymers to address the global warming issue which leads to global climate change in supporting SDG 13.

1 Introduction

The global warming issue as the main cause of climate change has emerged as a significant global concern [1, 2]. This phenomenon leads to natural disasters around the world, such as forest fires, droughts, floods, and various others. Cement as the primary material in construction is a significant trigger of global warming. The manufacturing of 1 ton of cement also generates approximately 0.7 – 1 ton of CO_2 [3], contributing to the greenhouse effect and thus leading to global warming. Therefore, it is imperative to find an eco-friendly material that can replace the role of cement as a construction material.

The use of fly ash, a by-product material from the combustion of coal power plants, and rice husk ash, a waste material from burning rice husks in paddyland, can address this climate change issue. According to previous research [4, 5], fly ash and rice husk ash can be used as cement replacement materials due to their chemical component characteristics with cement. The primary components of fly ash are silicate (Si), aluminate (Al), and ferrite (Fe) [6], while rice hush ash consists of primarily silicate (Si) and small amounts of aluminate (Al) [7]. These two types of materials are required to be activated by alkaline activators and are known as

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geopolymers, non-cement-based materials [4, 5]. In addition, fly ash and rice husk ash have been widely used as additive materials in concrete to improve the mechanical and durability of concrete [8-10]. The use of fly ash and rice husk ash as cement replacement materials is allegedly able to solve the global warming issue caused by the cement production process. However, research on the use of fly ash and rice husk ash as cement replacement materials in supporting Sustainable Development Goals (SDGs) is very limited.

This paper aims to investigate the strength performance of fly ash and rice husk ash geopolymer as cement replacements in sustainable infrastructure green materials in supporting SDG 9 (industry, innovation, and infrastructure) and SDG 13 (climate change). The strength performance was carried out by compressive strength test at 7 and 28 days. These results were compared to conventional concrete (cement-based material).

2 Methods

2.1 Materials

Three basic materials were used in this research, i.e. cement, fly ash, and rice husk ash The standard construction material was prepared by cement. from a local supplier. Fly ash and rice husk ash were prepared to develop geopolymer, a non-cement green construction material. Fly ash was provided from the coal power plant. While rice husk was obtained from burning rice husks from local paddyland. All materials were available in Indonesia. The chemical composition of all materials was performed by X-ray fluorescence (XRF) test as shown in Table 1.

Table 1. Chemical compositions of materials (%)

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO
Cement	7.4	1.3	5.4	76.9
Fly ash	30.8	12.2	28.1	21.8
Rice husk ash	92.7	-	0.34	1.7

2.2 Mix design

The mix design of all mortar specimens was determined to conform to ASTM C109 [11] as shown in Table 2. The ratio of binder to fine aggregate was kept at 1:2.75. The water-to-cement ratio of cement mortar (M1-PC) was set at 0.485. The water-to-solid ratio of fly ash (M2-FA) and rice husk ash (M3-RH) geopolymer was maintained at 0.45 and the ratio of sodium silicate was set at 2.0.

Table 2. Mix design of mortar specimens

Mix	PC	Fly ash	Rice Husk Ash	Fine Aggregate	Sodium Silicate	NaOH	Added Water
M1-PC	500	-	-	1375	-	-	243
M2-FA	-	500	-	1375	170	83	90
M3-FARH	-	250	250	1375	170	83	90

2.3 Specimen preparation and testing

All specimens were prepared using a standard mortar mold of 5 x 5 x 5 cm^3 by ASTM C109 [11]. A standard normal curing regime was applied for the cement-based mix (M1-PC).

While heat curing treatment (100^{O}C for 24 hours) was applied for fly ash (M2-FA) and rice husk ash (M3-FARH) specimens [12]. These specimens are then taken out at laboratory temperature before being tested.

The strength performance of all specimens was carried out by the compressive strength test conforming ASTM C109 [11]. All specimens were tested at 7 and 28 days. A compressive strength comparison from the test results will be performed to identify the final strength of all materials.

3 Results and discussion

3.1 Strength performance

The compressive strength performance of all mortar specimens at 7- and 28-day compressive strength test results are shown in Table 3 and Figure 1.

Table 3. Compressive strength at 28 days (MPa)

Mix	Compressive strength at 7 days (MPa)	Compressive strength at 28 days (MPa)
M1-PC	9.5	21.2
M2-FA	28.3	32.8
M3-FARH	7.6	11.2

All mixes exhibit a significant compressive strength at 28 days. The highest performance was demonstrated by mix M2-FA (fly ash-based geopolymer) with a strength of 32.8 MPa. It also showed a significant strength increase of 15.9% from 28.3 MPa (7 days) to 32.8 MPa (28 days). On the contrary, the use of rice husk ash as cement replacement material (M3-FARH) did not show a good performance according to the expected criteria. It showed the lowest strength performance with the strength of 7.6 MPa and 11.2 MPa at 7 and 28 days, respectively.

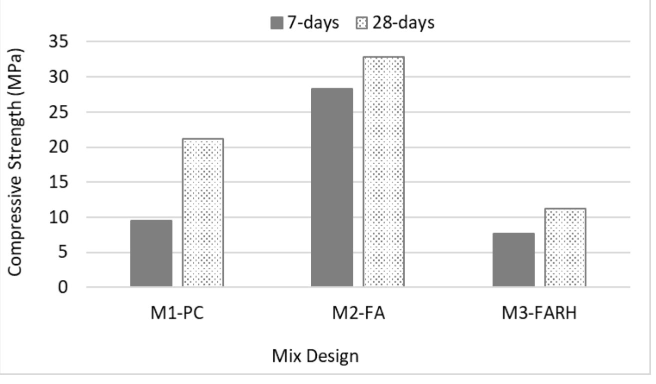

Fig. 1. Strength performance of mortar specimens

According to Figure 1, the strength performance of fly ash-based geopolymer (M2-FA) exhibits a better performance compared to conventional concrete (M1-PC). The initial strength (7 days) of fly ash-based geopolymer (M2-FA) also showed a higher compressive strength of 28.3 MPa compared to 9.5 MPa (conventional concrete, mix M1-PC). It has reached 0.86 from the final strength. Meanwhile, the initial strength of conventional concrete (M1-PC) merely achieved 0.45 from its final strength which indicated a slow strength development. On the other hand, the strength performance of rice husk ash-based geopolymer shows a lower strength compared to conventional concrete (M1-PC) and fly ash-based geopolymer (M2-FA). This superior performance of fly ash-based geopolymer indicated that this innovative material can be used as a substitute for cement to overcome global warming which has an impact on climate change.

3.2 Fly ash and rice husk ash geopolymer in supporting SDG 9 (Industry, innovation and infrastructure)

Fly ash and rice husk ash can be used as alternative and innovative materials in sustainable infrastructure materials. The compressive strength test results indicate that the fly ash-based geopolymer has a strength of 32.3 MPa after 28 days. This strength falls within the minimal category of class B (parking area) by the SNI Standards for paving block products [13] as shown in Table 4. Geopolymers produced from rice husk ash have a maximum strength of 11.2 MPa after 28 days. However, according to SNI regulations, they can only be classified as class D, which is suitable for park areas. Taking these into consideration, geopolymers based on fly ash and rice husk ash can be considered viable substitutes for PC. Thus, it can be utilized as a replacement for conventional cement in the construction industry [14].

Additionally, geopolymer made from fly ash exhibits higher strength in comparison to concrete made from cement. According to previous research [15], fly ash-based geopolymer has excellent mechanical performance and workability. Geopolymer may be customized to meet specific application requirements, offering ideal durability and fire resistance that is comparable to ordinary Portland cement (OPC). However, the application of geopolymer as an environmentally friendly infrastructure innovation is still limited to small industries due to technological limitations in the handling and mixing process, where the process requires special technology and expertise [16]. So special studies are still required in this area. Thus, it can be concluded that fly ash-based geopolymer as a cement replacement material for the paving block is an infrastructure innovation in supporting SDG 9.

Table 4. Paving blocks category (SNI 03-0691-1996) [13]

Quality Class	Compressive strength (MPa)		Mix category
	Average strength	Minimum strength	
A	40	35	
B	20	17	M2-FA, 32.8 MPa M1-PC, 21.2 MPa
C	15	12.5	
D	10	8.5	M3-FARH, 11.2 MPa

3.3 The use of fly ash and rice husk ash in supporting SDG 13 (Climate Change)

Nowadays, the extensive development of infrastructure is also followed by the increasing requirement for cement as the primary material for concrete infrastructure. Nevertheless, the process of cement manufacture is a contributing factor to the phenomenon of global warming, which in turn results in global climate change. According to previous research [1, 2, 5, 15], the manufacturing of 1 ton of cement results in the emission of around 0.7 - 1 ton of CO_2 gas, a significant contributor to the greenhouse impact. Furthermore, the extraction of primary cement components, such as limestone, contributes to environmental degradation and pollution as a result of the mining process and the transportation of mining materials.

The use of fly ash, a waste material from coal power plants, and rice husk ash, a waste material from burning rice husks from paddyland, will automatically eliminate the use of cement as the primary material for concrete. Reducing cement use will have an impact on reducing the amount of cement production. This would effectively mitigate the greenhouse gas effect resulting from the cement production process, which is the primary driver of climate change. Additionally, it is crucial to take into account the utilization of activators, which serve as the primary constituents of geopolymers derived from fly ash and rice husk ash. Additional research about the energy consumption involved in the production of activators and the process of mixing activators should be taken into account.

4 Conclusions

This paper works on the strength comparison between cement, fly ash, and rice husk ash as construction materials in supporting SDGs. It can be concluded that: (1) The use of fly ash-based geopolymer as cement replacement materials has a better strength performance compared to cement-based concrete. While rice husk ash has the lowest strength performance compared to all materials. (2) The superior performance of fly ash-based geopolymer can be used as an innovation of infrastructure application, i.e. paving block, to support SDG 9 (Industry, innovation, and infrastructure). (3) A combination of fly ash and rice husk ash can be used as alternative cement replacement materials for geopolymers to address global warming and climate change issues in supporting SDG 13 (Climate change).

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