Investigation of Rice Husk Ash Substitution as An Alternative Material on Fly Ash-based Geopolymer Mortar

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Abstract. Portland Cement (PC), as the primary construction materials, is a significant contributor to global warming. Thus, it is important to find alternative materials that are more environmentally friendly than PC. One alternative is to utilize fly ash and rice husk ash. This paper presents the effect of rice husk ash substitution of fly ash on the strength development of fly ash-based geopolymer mortar at normal temperatures. Fly ash (FA) and rice husk ash (RHA) were used as primary materials. The alkaline activator was prepared by mixing sodium silicate and 15 Molar NaOH. The proportions of FA to RHA were 1.0 : 0 to 0.75 : 0.25 with the interval of 0.5, respectively. The result showed that RHA significantly affects the strength of fly ash-based geopolymer mortar. The highest compressive strength was achieved by a ratio of 95% fly ash to 5% RHA at 28-days. Increasing the RHA content by more than 10% tends to decrease the fly ash-RHA geopolymer strength. It might be attributed to the high silicate content in geopolymer from the precursor materials, i.e. fly ash and RHA, which affect the Si/Al ratio of geopolymer and leads to the strength degradation of fly ash-RHA geopolymer performance. However, RHA can be used as an alternative substitution material for fly ash in geopolymer at a specific ratio to support the green economy concept and overcome the global warming issue.

Keywords: Geopolymer, Fly Ash, Rice Husk Ash, Compressive Strength.

1 Introduction

The utilization of Portland Cement (PC) as the primary constituent for concrete in construction is a contributing factor to the global warming issue, which in turn affects climate change [1-2]. This is because the production of 1 ton of PC also results in the emission of approximately 1 ton of CO_2 gas [3]. Hence, it is imperative to seek out eco-friendly substitute materials that can supplant the function of PC. Previous studies have demonstrated that geopolymer, a non-cement material composed of fly ash, has the capability to resolve this issue [4-5]. The primary constituents of fly ash, specifically silicate (Si), aluminate (Al), ferrite (Fe), and calcium (Ca) [6], have comparable properties to PC. Nevertheless, the issue with fly ash, a byproduct of coal power plants,

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is in its diminishing availability and escalating costs. Hence, it is imperative to seek an alternate substance to fly ash that can serve as a substitute for fly ash in the production of geopolymer.

Rice husk ash (RHA) as waste from burning rice husks is an alternative to fly ash [7]. Previous research showed that RHA can be used as an additive or substitute material in both cement-based concrete and geopolymer concrete [8-10]. The primary constituent of RHA is silicate (Si) which is one of the main compositions of fly ash as a geopolymer matrix in the form of a Si-Al-O matrix [11]. The silicate content in RHA is expected to have a significant influence on the geopolymer matrix as an alternative to fly ash [12]. This paper aims to investigate the effect of RHA as fly ash substitution on strength development of fly ash-based geopolymer mortar at normal temperatures. The primary materials of geopolymer consists of fly ash (FA) and rice husk ash (RHA). The variations of fly ash to RHA were from 1.0 : 0 to 0.75 : 0.25 with the interval of 0.5, respectively. The strength performance of fly ash-RHA geopolymer was investigated by a compressive strength test at 28-days age.

2 Methods

2.1 Materials

The materials of geopolymer mortar specimens were fly ash and rice husk ash. Fly ash, a waste material from coal power plants, was used as geopolymer primary material. While rice husk ash was provided from the waste material of burning rice husks from local farmland. The chemical composition of all materials was performed by X-Ray Fluorescence (XRF) test as displayed in Table 1.

Table 1. Composition of materials (%)

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO
Fly ash (FA)	43.7	22.8	16.5	4.9
Rice husk ash (RHA)	85.2	-	2.4	5.2

Geopolymer alkaline activator was prepared by mixing 15 Molar sodium hydroxide (NaOH) solution with sodium silicate (Na_2SiO_3) liquids. All materials were provided from local supplier.

2.2 Mix Design Ratio

The mix design ratios of fly ash and rice husk ash geopolymer (FARHA-G) mortar specimens are listed in Table 2. The water-to-solid ratio (w/s) was set at a high value of 1.4 due to the rice husk ash material characteristic of high absorption. The sodium silicate to NaOH ratio was kept at 4.0. The ratio of total fly ash (FA) and rice husk ash (RHA) to fine aggregate was kept at 1:2.75 for all mixtures following ASTM C109 [13].

Table 2. Mix design ratio of fly ash and rice husk ash (FARHA-G) geopolymer mortar

Mix design	Fly Ash (FA)	Rice Husk Ash (RHA)	Fine Aggregate	NaOH 15M	Sodium Silicate	Water
FARHA-G1	1	0	2.75	0.11	0.44	1.5
FARHA-G2	0.95	0.05	2.75	0.11	0.44	1.5
FARHA-G3	0.90	0.10	2.75	0.11	0.44	1.5
FARHA-G4	0.85	0.15	2.75	0.11	0.44	1.5
FARHA-G5	0.80	0.20	2.75	0.11	0.44	1.5
FARHA-G6	0.75	0.25	2.75	0.11	0.44	1.5

2.3 Specimen Preparation

The geopolymer mortar specimens was prepared by a standard 50 mm x 50 mm x 50 mm steel cube mold. A standard normal curing regime at room temperature ($30^{O}C \pm 3^{O}C$) was applied for all geopolymer mixtures prior to be tested.

2.4 Testing

The strength performance of FARHA-G geopolymer mortars were measured by compressive strength test conforming ASTM C109 [13] at the age of 28-days after casting.

3 Results and Discussion

3.1 Strength Performance

The strength development of FARHA-G for all geopolymer mortar mixtures are shown in Table 3 and Fig. 1.

Table 3. Compressive strength of FARHA-G geopolymer mortars (MPa)

Mix design	28-days
FARHA-G1	6.3 ± 0.58
FARHA-G2	9.8 ± 0.74
FARHA-G3	8.8 ± 0.98
FARHA-G4	8.3 ± 0.35
FARHA-G5	8.1 ± 0.51
FARHA-G6	7.6 ± 0.85

All fly ash-RHA geopolymer mortars exhibited higher strength performance compared to that fly ash geopolymer (FARHA-G1, 0% RHA substitution). The highest compressive strength was performed by FARHA-G2 (5% RHA substitution) followed by FARHA-G3 (10% RHA substitution) with the strength of 9.8 MPa and 8.8 MPa at

28-days, respectively. The lowest strength was demonstrated by FARHA-G1 (0% RHA substitution). The substitution of RHA significantly affected the strength of fly ash-RHA geopolymer with the increase of 55.3% from 6.3 MPa (FARHA-G1, 0% RHA) to 9.8 MPa (FARHA-G2, 5% RHA).

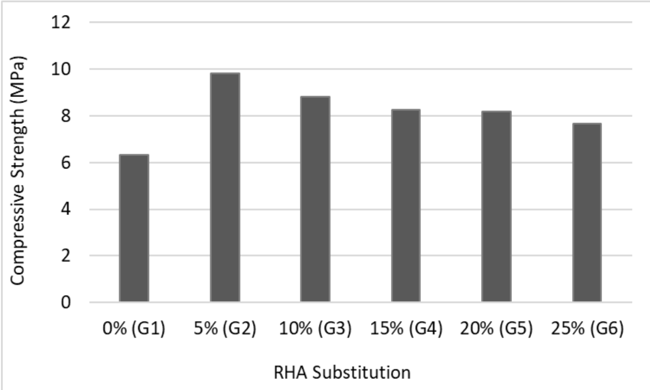

Fig. 1. Strength development of FARHA-G geopolymer mortars at 28-days

In general, the substitution of RHA in fly ash geopolymer significantly increased the strength performance of geopolymer mortar as shown in Fig 1. However, further addition of RHA more than 10% tends to reduce the strength performance of the geopolymer. This can be seen in the average decrease in compressive strength of 7% - 8% along with the addition of RHA. This shows that there is a maximum allowable value for the use of RHA in geopolymer. In addition, the character of the RHA material which tends to absorb water [14-15] is assumed to be the cause of the decrease in strength.

3.2 Effect of RHA on Strength Development

The effect of RHA on strength development in terms of Si/Al ratio prediction is shown in Table 4. The silicate and aluminate contents were calculated based on geopolymer precursor materials, i.e. fly ash, sodium silicate (Na_2SiO_3), and RHA.

Table 4. Total Si/Al ratio (prediction) from precursor materials

Mix design	Silicate from FA and Na_2SiO_3	Silicate from RHA	Aluminate from FA	Si/Al Ratio (prediction)
FARHA G1 (0% RHA)	0.569	0	0.228	2.496
FARHA-G2 (5% RHA)	0.547	0.043	0.228	2.587
FARHA-G3 (10% RHA)	0.525	0.085	0.228	2.678
FARHA-G4 (15% RHA)	0.503	0.128	0.228	2.769
FARHA-G5 (20% RHA)	0.482	0.170	0.228	2.860
FARHA-G6 (25% RHA)	0.460	0.213	0.228	2.951

The strength performance of geopolymer was affected by its matrix which consists of silicate and aluminate. These components form Si-O-Al matrix. In addition, the component ratio of silicate and aluminate are shown in Si/Al ratio. Substitution of RHA in fly ash-RHA geopolymer increases the total silicate content in the geopolymer matrix which affected the Si/Al ratio. The total silicate content in geopolymer was assumed by the total of silicate from fly ash, sodium silicate (Na_2SiO_3 with 30% of silicate content) activation solution, and RHA. Due to the high silicate content in RHA, replacement of fly ash with RHA increases the silicate content. The highest strength performance was achieved by FARHA-G2 (5% RHA) with Si/Al ratio of 2.587. However, high Si/Al ratio tends to decrease the strength performance of fly ash-RHA geopolymer which might attribute to the high amount of silicate content. A high Si/Al ratio also indicates a high level of unreacted silicate components in forming the Si-O-Al matrix [16]. This unreacted silicate component tends to reduce the compressive strength of geopolymer as in the previous discussion.

However, the use of RHA as an alternative material to replace fly ash in geopolymer materials in a specific ratio is still important in an effort to support the concept of a green economy and overcome the issue of global warming.

4 Conclusions

This paper works on the effect of rice husk ash substitution of fly ash as an alternative material in the strength development of fly ash-based geopolymer mortar specimens. It can be concluded that:

- The use of rice husk ash at specific substitution of 5% - 10% achieved the highest strength performance in normal temperature. However, increasing rice husk ash substitution by more than 10% tends to reduce the strength performance of fly ash - rice husk ash geopolymer.
- The substitution of rice husk ash also increases the silicate content in the geopolymer matrix which affected the Si/Al ratio. High Si/Al ratio tends to decrease the strength performance of fly ash - rice husk ash geopolymer which might attribute to the high amount of silicate content in the geopolymer matrix.
- Rice husk ash can be used as an alternative substitution material for fly ash in geopolymer at a specific ratio to support the green economy concept and overcome the global warming issue.

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Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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