The Role of Rice Husk Ash in Enhancing the Fresh Properties, Density, and Compressive Strength of Fly Ash Based Self Compacting Geopolymer Concrete

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Abstract: This paper describes the effect of rice husk ash on the fresh properties, density, and compressive strength of fly ash-based self compacting geopolymer concrete (SCGC). Fresh properties were tested by the slump flow test. Density and compressive strength were tested with cylindrical concrete samples. Diameters of samples were about 150 mm and 300 mm high. The variations of Rice Husk Ash (RHA) as Fly Ash (FA) substitution were 0%, 5%, 10%, and 15%. The alkaline activators used Na2SiO3 and NaOH with ratio at 1.0 and a molarity value of NaOH was fixed at 14 M. The water-binder ratio was fixed at 0.3. The dosage of superplasticizer used 1%. The treatment of concrete used ambient temperature. The test results showed that rice husk ash decreased the slump flow; was not affected on the concrete density; and increased the compressive strength of SCGC. The maximum percentage of rice husk ash substitution to achieve the EFNARC slump flow standard was 7.16%. The density of the SCGC was 2076.4 kg/m³–2104.3 kg/m³, and classified to the normal concrete. The maximum compressive strength of SCGC was 11.476 MPa at the percentage of rice husk ash substitution about 8.65%.

1. Introduction

Environmental issues are the main concern to be researched at this time. Cement industry is one of the biggest causes of environmental damage, the use of raw materials that consumes a lot of natural resources, also its production which produces a lot of CO2 emissions and greenhouse gases causing global warming to worsen. Cement production in the world is estimated to increase from 3.27 billion metric tons in 2010 to 4.83 billion metric tons in 2030[1]. CO2 emissions from global cement production reached 1.48 ± 0.2 Gt in 2018[2]. To protect our earth from environmental damage and global warming because of cement production, the eco-friendly and sustainable environment binding material is needed.

Geopolymer concrete is a new innovation of concrete without Portland cement as the binders material. Geopolymer concrete is more eco-friendly than Portland cement because it can reduce CO2 emissions. Geopolymer concrete reduces carbon dioxide (CO2) emissions up to 80% less than Portland cement[3]. Geopolymer concrete comes from a variety of materials and formed by inorganic molecules. High silica and alumina on the fly ash will react with alkaline solutions such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na2SiO3) or potassium silicate (K2SiO3) and will be formed to gel with fine aggregates and coarse aggregates[4].

Rice Husk Ash (RHA) has a high content of silica, it can be used as a geopolymer concrete material[5]. Based on data from the Food and Agriculture Organization (FAO), world rice production...
in 2018 reached 769.9 million tons[6]. Rice husk waste reaches 20% of total rice production in the world[5]. Burning rice husk will produce rice husk ash about 18-20% of the total weight of rice husk[7].

Concrete compaction is one of the problems in construction work. Concrete compaction causes environmental noise and increases work costs. Self-compacting concrete can solve this problem. Self Compacting Concrete (SCC) is concrete that can flow and compact independently without compaction[8]. Self Compacting Geopolymer Concrete is an innovative concrete that combines the advantages of geopolymer concrete and SCC [9].

SCGC is a solution for environmentally friendly concrete with low carbon dioxide (CO2) emissions and self-compacting ability. The purpose of this research is to investigate the role of rice husk ash in increasing fresh properties, density, and compressive strength of fly ash - based self compacting geopolymer concrete.

2. Theoretical Foundation

2.1. Self Compacting Geopolymer Concrete

Self Compacting Geopolymer Concrete (SCGC) is an innovative concrete that can achieve the combined advantages of geopolymer concrete and Self Compacting Concrete (SCC) technology [9].

2.1.1. Geopolymer Concrete. Geopolymer concrete is concrete without portland cements as binder, but uses other materials such as fly ash, rice husk ash, and other materials containing high silica and alumina. Geopolymer concrete comes from the chemical reaction of silica and alumina oxides with alkaline polysilicate to form a polymer with Si-O-Al bonds[10].

2.1.2. Self Compacting Concrete. Self Compacting Concrete is concrete that has the ability to flow and compact itself without compaction or vibration. The fresh SCC mortar has more fluid characteristics. This mortar is able to compact, fill, and flow at every corner or gap of reinforced concrete structures whose difficult to reach. Fresh SCC mortar also more cohesive and resistant from bleeding and segregation.[8].

2.2. Materials

2.2.1. Fly Ash. Geopolymer concrete is formed by polymerization of alumino-silicate with an alkaline activator [9]. In previous research, it was found that the specific gravity of fly ash was 2.28 gr / cm$^3$ and Brunauer-Emmet-Teller (BET) surface area was 4200 m$^2$ / kg.[11]. The chemical composition of fly ash can be seen in table 1.

| Chemical Composition | Percentage (%) |
|----------------------|---------------|
| SiO$_2$              | 51.75         |
| Al$_2$O$_3$          | 34.75         |
| Fe$_2$O$_3$          | 6.00          |
| CaO                  | 1.40          |
| MgO                  | 1.35          |
| SO$_3$               | 0.04          |
| Na$_2$O              | 1.35          |
| K$_2$O               | 0.25          |
| LOI                  | 0.45          |

2.2.2. Rice Husk Ash. Rice husk ash has a high silica content that can be used in geopolymer concrete[5]. In previous research, it was found that the specific gravity of rice husk ash was 2.06 gr / cm$^3$ and
Brunauer-Emmet-Teller (BET) surface area was 22500 m$^2$/kg. [11]. The chemical composition of rice husk ash can be seen in table 2.

| Chemical Composition | Percentage (%) |
|----------------------|----------------|
| SiO$_2$              | 92.30          |
| Al$_2$O$_3$          | 0.40           |
| Fe$_2$O$_3$          | 0.45           |
| CaO                  | 0.70           |
| MgO                  | 0.85           |
| SO$_3$               | 0.45           |
| Na$_2$O              | 0.70           |
| K$_2$O               | 0.85           |
| LOI                  | 3.15           |

2.2.3. Sodium Silicate (Na$_2$SiO$_3$). Sodium silicate (Na$_2$SiO$_3$) is used to increase the amount of silica in the geopolymer mixture. The increase of reactive silica content in the geopolymer mixture will accelerate the geopolymerization reaction[12]. Based on previous research, the Na$_2$SiO$_3$:NaOH ratio for geopolymer concrete was ranged from 0.4 - 2.5[13]. The liquid sodium silicate was used in this study. Ratio of Na$_2$SiO$_3$:NaOH this research was fixed at 1.0.

2.2.4. Sodium Hydroxide (NaOH). Sodium hydroxide (NaOH) is used to activate silica and alumina in fly ash and rice husk ash. NaOH reacts with silica and alumina in the polymerization process[12]. The molarity of NaOH for geopolymer concrete ranged from 8M - 14M[13]. NaOH flakes were used in this research and then dissolved with aquadest to NaOH molarity at 14M.

2.2.5. Aggregates. Aggregates are granular materials such as sand, gravel, crushed stone, and slag, which are mixed with adhesive to form concrete or hydraulic cement mortar.[14]. Maximum sludge content of fine aggregate was required about 5%. Grain fineness modulus 2.3 - 3.1. Grain fineness modulus of coarse aggregate was required from 6.0 - 7.1. Abrasion of coarse aggregates for a compressive strength of concrete more than 40 MPa was fixed maximum 27%[15].

2.2.6. Superplasticizer. Superplasticizer included in type F admixture with function to reduce water and produce concrete with a certain consistency. Superplasticizer is used to obtain good workability concrete mortar. The superplasticizer in this research used Consol SS-74N. Consol SS-74N is a superplasticizer product from PT. Indonesian Construction Chemicals. The dosage of superplasticizer for this research was fixed at 1%.

3. Research Methodology

3.1. Material Preparation and Testing
Material testing was used to determine the physical properties and characteristics of the materials that will be used in making SCGC concrete.

3.1.1. Fine Aggregates. Fine aggregates testing were; silt content testing, grading testing, specific gravity testing, absorption testing, and moisture content testing. Testing of sludge content based on SK SNI M-09-1989-F. Grading testing based on SNI 03-1968-1990. Water content testing based on SNI-03-1971-1990. The specific gravity and absorption test based on SNI-1970-2008. Fine aggregate came from PT Panca Beton, Karanganyar, Central Java. The results of fine aggregate testing can be seen in table 3.
Table 3. Results of fine aggregate testing

| Characteristics                  | Value   |
|----------------------------------|---------|
| Maximum size (mm)                | 4.75    |
| Fineness modulus (gr / cm$^3$)   | 2.67    |
| Specific gravity (gr / cm$^3$)   | 2.50    |
| Absorption (%)                   | 2.90    |
| Moisture content (%)             | 2.86    |
| Silt content (%)                 | 5.28    |

Overall, fine aggregate qualified the standards for usability. But the silt content of the fine aggregate under standards, fine aggregate washed by water before used.

3.1.2. Coarse Aggregates. Testing on coarse aggregates were; Grading testing, abrasion testing, absorption testing, and specific gravity testing. Grading testing based on SNI-03-1968-1990. Abrasion testing based on SNI-2417-2008. The specific gravity and absorption test based on SNI-1969-2008. Coarse aggregate came from PT Panca Beton, Karanganyar, Central Java. The results of the coarse aggregate test can be seen in table 4.

Table 4. Results of coarse aggregate testing

| Characteristics                  | Value   |
|----------------------------------|---------|
| Maximum size (mm)                | 19      |
| Fineness modulus (gr / cm$^3$)   | 6.69    |
| Specific gravity (gr / cm$^3$)   | 2.51    |
| Absorption (%)                   | 2.20    |
| Abrasion (%)                     | 21.77   |

3.1.3. Rice Husk Ash. The Rice Husk Ash came from Sukoharjo, Central Java. The first process of making rice husk ash was drying the rice husks. After that the rice husks were burned to ashes. Then the rice husk ash filtered with a sieve number 200 or 0.075 mm in diameter. The rice husk ash that passed the sieve was used as a substitute for fly ash in SCGC.

3.2. Mix Design

The SCGC mix design used the EFNARC Self Compacting Concrete standard with a quality of concrete compressive strength of 30 MPa. Coarse aggregate used 50% from the total volume of solid aggregate. The volume of fine aggregate used 45% of the total volume of the mortar. The water-binder ratio was fixed at 0.3 [16]. The alkaline activators used Na$_2$SiO$_3$ and NaOH, with a ratio of 1.0 and a NaOH molarity of 14 M. The dosage of superplasticizer (SP) was 1%. The variation of RHA substitution was 0%, 5%, 10%, and 15%. The sample for each variation were 4 samples, the total of all samples were 16 samples. The samples used cylindrical concrete with a diameter of 150 mm and a height of 300 mm. Details of material requirements can be seen in table 5.

Table 5. Material requirements

| Materials     | Variation |
|---------------|-----------|
|               | 0% | 5% | 10% | 15% |
| Fly Ash (kg)  | RHA | RHA | RHA | RHA |
| RHA (kg)      | 6.88 | 6.54 | 6.20 | 5.85 |
| Na$_2$SiO$_3$ (kg) | 1.85 | 1.85 | 1.85 | 1.85 |
| NaOH (kg)     | 1.85 | 1.85 | 1.85 | 1.85 |
| Fine Agg. (kg) | 17.55 | 17.55 | 17.55 | 17.55 |
| Course Agg. (kg) | 14.42 | 14.42 | 14.42 | 14.42 |
| SP (kg)       | 0.11 | 0.11 | 0.11 | 0.11 |
| Water (kg)    | 3.18 | 3.18 | 3.18 | 3.18 |
3.3. Fresh Properties Testing and Concrete Curing

3.3.1. Fresh Properties Testing. The fresh properties testing of SCGC in this study was in a slump flow. The purpose of slump flow test was to evaluate the flow capability of the fresh SCGC mortar. The fresh SCGC mortar inserted into the Abram's cone with a slump flow board base. The SCGC mortar was inserted without stabbing. After fully filled, the Abram's cone was removed and the diameter of the mortar flow was measured. The diameter of the mortar flowing for normal applications (SF2) EFNARC was 65-75 cm[16].

3.3.2. Concrete Curing. Based on previous research had shown that the geopolymer concrete can be fixed in several methods. The curing of SCGC can be done at ambient temperature, elevated temperature, and a combination of elevated temperature and immersion in water[17]. In this research, the curing of SCGC used ambient temperature.

3.4. Density and Compressive Strength Testing

3.4.1. Density Testing. Density testing for SCGC concrete based on SNI 1973: 2008. Density was calculated by dividing the total weight of concrete (kg) by the total absolute volume (m3). The theoretical unit of concrete density was kg / m³ [18].

3.4.2. Compressive Strength Testing. Compressive strength testing of SCGC based on SNI 1974: 2011. The test was calculated by dividing the compressive load (N) by the cross-sectional area of the test object (mm²). The theoretical unit for the compressive strength of concrete was N / mm² or MPa[19].

3.5. Data Analysis

Data was analyzed by the SPSS 23 regression test to determine the significance of the effect of rice husk ash substitution on slump flow, density, and compressive strength of SCGC. The significance of the effect was determined from the value sig. and by comparing the value of F. If the value of sig. <0.05 and F_count > F_table, it can be concluded that the substitution of rice husk ash significantly affected the slump flow, density, and compressive strength of SCGC. If the value of sig. <0.05 and F_count > F_table, it can be concluded that the substitution of rice husk ash did not significantly influence the slump flow, density, and compressive strength of SCGC. The value of R Square on the results of the SPSS regression test showed the percentage of the effect. The research methodology was presented on the flowchart in Figure 1.

![Figure 1. Research methodology’s flowchart](image-url)
4. Result and Discussion

4.1. Slump Flow Test Result
Based on the SCGC slump flow data in SPSS 23, it was found that the addition of rice husk ash had a significant effect on the SCGC slump flow. The results of the regression test on the SPSS 23 program showed a significance value of 0.000 < 0.05 and $F_{\text{count}}$ of 74.314 > $F_{\text{table}}$ of 4.60. The R Square value was 0.841, indicating that the addition of rice husk ash has an effect of about 84.1% on the SCGC slump flow. From the regression equation $Y = 74.125 - 1.275$ from SPSS 23, the maximum percentage of addition of rice husk ash to achieve EFNARC slump flow standard was 7.16%. The results of the SCGC slump flow test presented in table 6. The slump flow value of SCGC with a percentage of 0% rice husk ash substitution was 74.125 cm. In SCGC with a percentage of rice husk ash substitution of 5%, the slump flow value was 67.750 cm, so that the percentage of slump flow reduction was 8.6%. SCGC with a percentage of rice husk ash substitution of 7.16%, the slump flow value was 65,000 cm, so that the percentage of slump flow reduction was 13.3%. SCGC with a percentage of rice husk ash substitution of 10%, the slump flow value was 61.375 cm, so the percentage of slump flow reduction was 17.2%. In SCGC with a percentage of rice husk ash substitution of 15%, the slump flow value was 55,000 cm, so that the slump flow reduction percentage was 25.8%.

| Percentage of Rice Husk Ash Substitution (%) | Slump Flow (cm) |
|---------------------------------------------|-----------------|
| 0                                           | 74.125          |
| 5                                           | 67.750          |
| 7.16                                        | 65.000          |
| 10                                          | 61.375          |
| 15                                          | 55.000          |

The slump flow value of SCGC with a percentage of rice husk ash substitution of 0% (74.125 cm) and 5% (67.750 cm), fulfilled the EFNARC slump flow standard. Meanwhile, the slump flow value of SCGC with a percentage of rice husk ash substitution of 10% (61.375 cm) and 15% (55,000 cm), did not fulfill the EFNARC slump flow standards.

Based on Figure 2, it can be concluded that the variation of rice husk ash substitution reduced the slump flow value of SCGC. Increasing the percentage of rice husk ash substitution decreased the slump flow value of SCGC. The slump flow value decreased because a high reactive silica content in rice husk ash would be accelerating the geopolymerisation reaction of SCGC mortar, so that the setting time or...
binding of the mortar was faster[12]. The nature of rice husk ash which absorbs water caused the SCGC concrete to become thicker so that it was more difficult to flow[20].

4.2. Density Test Result
Based on the data from the density of SCGC results in SPSS 23, it was found that the addition of rice husk ash did not significantly affect the density of SCGC. The results of the regression test on the SPSS 23 program showed a significance value of 0.126 > 0.05 and $F_{count}$ of 2.445 < $F_{table}$ of 3.81. The R Square value was 0.273, indicating that the addition of rice husk ash has an effect of 27.3% on the density of SCGC.

The test results of SCGC density with a percentage of rice husk ash substitution of 0% was 2122.391 kg/m$^3$. SCGC with a percentage of rice husk ash substitution of 5%, the density value was 2127.576 kg/m$^3$. SCGC with a percentage of rice husk ash substitution of 10%, the density value was 2133.939 kg/m$^3$. In SCGC concrete with a percentage of rice husk ash substitution of 15%, the density value was 2126.633 kg/m$^3$. The results of the SCGC density test were presented in table 7.

| Percentage of Rice Husk Ash Substitution (%) | Density (kg/m$^3$) |
|---------------------------------------------|-------------------|
| 0                                           | 2122.391          |
| 5                                           | 2127.576          |
| 10                                          | 2133.939          |
| 15                                          | 2126.633          |

The density of SCGC was 2122.391 - 2133.939 kg/m$^3$. Normal concrete had a density from 2100–2500 kg / m$^3$[21], so that SCGC was included in the classification of normal concrete. The specific gravity of rice husk ash and fly ash did not differ much so that it did not significantly affect the density of SCGC[11].

![Figure 3. Diagram of the effect of substitution of RHA on density of SCGC](image)

4.3. Compressive Strength Test Result
Based on the results of the SCGC compressive strength data in SPSS 23, the results showed that the addition of rice ash had a significant effect on the compressive strength of SCGC. The results of the regression test on the SPSS 23 program showed a significance value of 0.000 < 0.05 and $F_{count}$ of 19.782 > $F_{table}$ of 3.81. The R Square value was 0.753, it indicated that the addition of rice husk ash had an effect of 75.3% on the compressive strength of SCGC. From the regression equation $Y_c = -0.037X2 + 0.640X + 8,708$, the maximum compressive strength of SCGC was 11.476 MPa at the percentage of
rice husk ash substitution of 8.65%. The results of the SCGC concrete density testing were presented in table 8.

| Percentage of Rice Husk Ash Substitution (%) | Compressive Strength (MPa) |
|---------------------------------------------|---------------------------|
| 0                                           | 8.708                     |
| 5                                           | 10.983                    |
| 8.65                                        | 11.476                    |
| 10                                          | 11.408                    |
| 15                                          | 9.983                     |

The test results for the compressive strength of SCGC with a percentage of rice husk ash substitution of 0% was 8,708 MPa. SCGC with a percentage of rice husk ash substitution of 5%, the value of compressive strength was 10,983 MPa, so that the increase of percentage in compressive strength was 26.13%. In SCGC with a substitution percentage of rice husk ash of 8.65% was the optimum compressive strength with 11.476 MPa, so that the increase of percentage was 31.78%. SCGC with a percentage of rice husk ash substitution of 10%, the value of compressive strength was 11.408 MPa, so that the increase of percentage was 31.01%. In SCGC with a percentage of rice husk ash substitution of 15%, the value of compressive strength was 9.983 MPa, so that the increase of percentage in compressive strength was 14.64%.

![Figure 4. Graph of the effect of RHA substitution on the compressive strength of SCGC](image)

Based on the graph of the compressive strength test results, the percentage of substitution of rice husk ash by 5% and 8.65% increased the compressive strength of SCGC. The effect of additional rice husk ash increased the Si: Al ratio, so that the polymer bonds were stronger[11]. The optimum compressive strength of SCGC was obtained at the percentage of rice husk ash substitution of 8.6% and after that there was a trend of decreasing compressive strength at the percentage of rice husk ash substitution of 10% and 15%. This effect was caused by the high silica content in rice husk ash which is not directly proportional to its low aluminum content. So when the Si-O-Al bond polymerization reaction occurred, the excess silica content in the rice husk ash not reacted because of the lack of alumina compounds.[11].

5. Conclusion

Based on the research results, the effect of rice husk ash on fresh properties, density, and compressive strength of fly ash - based self compacting geopolymer concrete, the conclusions were:
The substitution of rice husk ash significantly decreased the value of slump flow fly ash based SCGC. The high reactive silica content in rice husk ash accelerated the geopolymerisation reaction of SCGC mortar, so that the setting time or the binding of the mortar was faster. The nature of rice husk ash which absorbs water caused the SCGC to become thicker so that it was more difficult to flow.

The substitution of rice husk ash did not have a significant effect on density fly ash based SCGC. The specific gravity of rice husk ash and fly ash did not differ much so that it did not significantly affect the density of SCGC. SCGC based on fly ash with partial substitution of rice husk ash was included in the classification of normal concrete density.

Substitution of rice husk ash significantly increased the compressive strength of fly ash based SCGC. It is because the addition of rice husk ash increased the Si: Al ratio, so that the polymer bonds were stronger. In the percentage of rice husk ash substitution more than 8.65%, there was a decreasing trend in compressive strength. This effect was caused by the low alumina content of rice husk ash. So when the Si-O-Al bond polymerization reaction occurred, the excess silica content in the rice husk ash not reacted because of the lack of alumina compounds.

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