Thermal Properties of Geopolymers with Silica Fume

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Abstract. Fly ash-based geopolymer is a renewable technology to minimize the use of cement in the construction field. The development was not only the use of fly ash but also the addition of other materials such as silica fume to geopolymer paste. Insulating materials is one of the examples of fly ash-based geopolymer applications. This paper examines the influence of varied activating solution of fly ash ratio and silica fume on the behavior of thermal properties of the geopolymer paste. The activating solution of fly ash ratio (A/F) was 40%, 45%, and 50%. Silica fume acts as a substitution of fly ash varied from 1%, 2%, and 4%. The activating solution was mixed with NaOH 10 M and Na₂SiO₃ with Na₂SiO₃/NaOH ratio constant at 2. Geopolymer paste was subjected to different tests such as thermal conductivity, bulk density, and compressive strength. The results showed that the geopolymer paste with substitution of silica fume had thermal conductivity, bulk density and compressive strength in the range of 0.051 to 0.932 W/m.C, 1752.457 to 1870.309 kg/m³ and 25.41 to 38.48 MPa respectively. The thermal conductivity values for all variations are below 1 W/m.C. Results from this work shows that the mixture suitable as a thermal insulation material.

1. Introduction

Geopolymers have recently emerged as an excellent alternative to replacing cement in the construction industry because of its superior mechanical properties and durability. This technology is very promising because CO₂ in the manufacturing process.[1]. Geopolymers are produced from alumino-silicate. Fly ash is commonly used as a geopolymer base. It is one of waste material from coal combustion or electricity generation [2]. The geopolymerization itself is formed between the reaction of alumino silicate source material and the alkali activator. Some studies evaluated the use of different types of alumino silicate and alkali activators on properties of geopolymers. The Alkali activator usually is produced using sodium silicate (Na₂SiO₃) and sodium hydroxide (NaOH) [3,4]. Most research was carried out to study mechanical properties, durability, and thermal conductivity as well as density of geopolymers[5,6]. One of important mechanical properties of geopolymer is compressive strength
In the further development of geopolymers, many studies have been carried out on the addition of silica fume to improve the acid and thermal resistance of the geopolymer [5–7]. Geopolymers with silica fume which have thermal conductivity less than 1 W/m.C is suitable as thermal insulation materials [6,8]. The use of silica fume will also increase the compressive strength [7]. However, there is no reports on mechanical properties of geopolymer for insulation material. This information is important because the stability of the insulation material structure depends on its strength. So, the purpose of this research is to find out thermal conductivity, density and compressive strength of geopolymer paste using silica fume substitution.

2. Materials, Specimens, and Experimental Method

2.1. Materials

In this study, fly ash was obtained from Paiton Power Plant and classified as type C according to ASTM C618 [9] with a density of 2.46. Table 1 shows the chemical components of the fly ash. The silica fume was obtained from PT. Sika Indonesia, Co with a density of 2.09. Alkali activator was produced from the reaction of sodium silicate (Na$_2$SiO$_3$) and sodium hydroxide (NaOH) with a density of 1.59 and 1.52 respectively. 10 molarity of NaOH alkali solution was made of NaOH pellets and Aquades. The ratio of Na$_2$SiO$_3$/NaOH was keep constant at 2.0. The activating solution of the fly ash ratio (A/F) were 40%, 45%, 50%. The substitution of silica fume were 1%, 2%, 4%.

| Chemical Components | SiO$_2$ | Na$_2$O | Fe$_2$O$_3$ | CaO | MgO$_2$ | Na$_2$O | K$_2$O | TiO$_2$ | Cr$_2$O$_3$ | SO$_3$ | LOI |
|---------------------|--------|--------|------------|-----|---------|--------|-------|--------|------------|------|-----|
| Fly ash             | 38.79  | 18.21  | 15.2       | 14.61| 7.18    | 1.76   | 1.23  | 0.95   | 0.22       | 0.59 | 0.69|

2.2. Specimens

Three types of specimens were used for compressive strength, thermal conductivity, and density test. For compressive test, a cube-shape specimen was used with dimension of 50 x 50 x 50 mm. For thermal conductivity test, the specimen was made of flat cylinder molds with diameter 4 cm and the thick of 0.2, and 0.4 cm. For density test, similar mold was used with diameter of 3 cm and 1 cm thick. Each types of specimen consists of 3 samples.

Geopolymers mixing process refered to ASTM C305 [10]. The process was done in 2 phases, preparation of alkali activator and final mixing with silica fume. First phase, Na$_2$SiO$_3$ was mixed with NaOH as activator and then left to cool down for about 30 minutes. Second phase, fly ash and silica fume were stirred in the Hobart mixer for about a minute at 140 rpm before the activator was added. The activator was poured slowly until the mixture became homogeneous for about 4 minutes. The mixture was casted into a mold for one day. The specimen was released and kept in room temperature. Mix proportion for all material per cubic meter is shown in Table 2. From Table 2, the symbols Q, R, and SF show the values of A / F, the ratio of Na$_2$SiO$_3$/NaOH, and silica fume substitution. Figure 1 shows a sample for tests of thermal conductivity, density, and compressive strength.
Figure 1. The specimen of each testing: (a). Thermal conductivity, (b). Density, (c). Compressive strength

Table 2. Mix proportions of geopolymer paste by weight [per m³]

| No | Specimen | Ratio of Na₂SiO₃/NaOH | A/F Ratio | Fly ash [Wfa]  | Na₂SiO₃ [Wss] | NaOH [Wsh] | Silica fume [Wsf] |
|----|----------|----------------------|-----------|----------------|--------------|------------|------------------|
|    |          |                      |           | [kg]           | [kg]         | [kg]       | [kg]             |
| 1  | Q40 R2 SF1 | 2                    | 0.4       | 1499.89        | 399.97       | 199.99     | 15.00           |
| 2  | Q40 R2 SF2 | 2                    | 0.4       | 1489.23        | 397.13       | 198.56     | 29.78           |
| 3  | Q40 R2 SF4 | 2                    | 0.4       | 1468.34        | 391.56       | 195.78     | 58.73           |
| 4  | Q45 R2 SF1 | 2                    | 0.45      | 1431.35        | 429.40       | 214.70     | 14.31           |
| 5  | Q45 R2 SF2 | 2                    | 0.45      | 1421.63        | 426.49       | 213.24     | 28.43           |
| 6  | Q45 R2 SF4 | 2                    | 0.45      | 1402.58        | 420.78       | 210.39     | 56.10           |
| 7  | Q50 R2 SF1 | 2                    | 0.5       | 1368.79        | 456.26       | 228.13     | 13.69           |
| 8  | Q50 R2 SF2 | 2                    | 0.5       | 1359.90        | 453.30       | 226.65     | 27.20           |
| 9  | Q50 R2 SF4 | 2                    | 0.5       | 1342.46        | 447.49       | 223.74     | 53.70           |
2.3. Experimental Method
Thermal conductivity was measured according to ASTM C177 [11] by using Thermal Conductivity Apparatus machine, Type: OSK 4565-A Tokyo Meter Co. Model: HVs - 400000SE. The temperature was varied of 50°C, 100°C, 150°C, and 200°C. Bulk density test according to ASTM D792 [12] was conducted by dividing the weight and the volume of specimen. Compressive test of geopolymer was carried out at 7 days based on ASTM C109[13] using Avery Dennison 20 kN machine.

3. Result and Discussion

3.1. Thermal conductivity
Figure 2 shows the value of thermal conductivity for each variation. In general, the trend of thermal conductivity values decreases after 100°C. As a whole, the thermal conductivity values range from 0.051 to 0.932 W/m.C. This indicates that the mixture is suitable as a thermal insulation material. That is because all thermal conductivity values are below 1 W/m.C. The changes of A/F has no effect on the value of thermal conductivity. The use of silica fume causes the paste more porous so that the thermal conductivity value decrease. This result is similar to other work of Henon et al. [5], Prud’homme et al. [14], and Dutta et al. [15]. The use of A/F of 40% also causes decrease in thermal conductivity. The use of alkali activators affect the geopolymer process [16]. The higher amount of alkali activator will increase formation of geopolymer. However, if the amount of alkali activator is excessive, the formation of geopolymer will take longer [16].

3.2. Density
Table 3 shows the results of density test for all variation. The density from all variations range 1752.457 to 1870.309 kg/m³. The changes of A/F variation and silica fume substitution do not affect the density values. It is similar to the results reported in other work [5]. The average value of specific gravity from this research was 1789.351 kg/m³. This mixture can be classified as a lightweight material based on ASTM C567 [17].

| No Specimen | Bulk Density [kg/m³] |
|-------------|----------------------|
| Q40 R2 SF1  | 1835.597             |
| Q40 R2 SF2  | 1767.668             |
| Q40 R2 SF4  | 1757.724             |
| Q45 R2 SF1  | 1819.681             |
| Q45 R2 SF2  | 1826.080             |
| Q45 R2 SF4  | 1755.115             |
| Q50 R2 SF1  | 1752.457             |
| Q50 R2 SF2  | 1782.136             |
| Q50 R2 SF4  | 1807.698             |
| Average     | 1789.351             |
Figure 2. The result of thermal conductivity for variants: (a). Q40 R2 SF1 – Q40 R2 SF4, (b). Q45 R2 SF1 – Q45 R2 SF4, (c). Q50 R2 SF1 – Q50 R2 SF4

3.3. Compressive strength

Figure 3 shows a comparison of compressive strength for all variations at room temperature. Generally, the compressive strength values range from 25.41 to 38.48 MPa. The use of silica fume can improve the mechanical property of geopolymer so that the compressive strength will increase [18]. The optimal A/F of 40% is found the maximum compressive strength [16,19]. If A/F exceeds 40%, the compressive strength of geopolymer significantly decrease. If A/F is more than 40%, the alkali activator concentration will decrease and therefore relatively retard geopolymerization. This reduces the strength of geopolymer [19].
4. Conclusion
This work investigates the effect of silica fume substitution to fly ash on thermal and mechanical properties of geopolymer. The thermal conductivity of silica fume substituted geopolymer is in the range of 0.051 to 0.932 W/m.C. The use of silica fume causes geopolymer paste becomes more porous so that its thermal resistance increase. The density values obtained in the range of 1752.457 to 1870.309 kg/m$^3$. The compressive strength in the range of 25.41 to 38.48 MPa. The mixture is suitable as a thermal insulation material, because the termal conductivity value is below 1 W/m.C.

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