Feasibility of Utilize Sidoarjo Mud as Replacement Material in Fly Ash Based Geopolymer Binder

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Abstract. Sidoarjo mudflow (SM) is an alternative source material in the construction which was generated from natural disasters of volcano mudflow in Porong, Sidoarjo, East Java, Indonesia. The source material of SM has high Si and Al content that contributed to geopolymer binder. Yet, it was categorized as low Ca content that caused prolong setting time in the geopolymer binder. This study aimed to increase the Ca content by incorporating the source material of SM in FA based geopolymer so that was able to provide short setting time in the field. The results showed that the particle properties of SM material were agglomerate irregular shape and rough surface. The increase of SM replacement caused the reduction of workability in fresh geopolymer mortar. Replacement of 40% SM in FA based geopolymer provided the short setting time less than 2.5 hours. The replacement of 15% SM in FA based geopolymer enhanced the compressive strength of 7.6%. However, the highest compressive strength of 9.4% was obtained by the replacement of 10% SM.

1. Introduction

Sidoarjo Mudflow (SM) is a novelty source material that was generated from drilling fault of a gas exploration well in Sidoarjo, Surabaya, and East Java, Indonesia [1]. In September 2006, it was around 180,000 m³/day of mudflow that flowed to the environment and it is predicted to continue until next 25 to 30 years [2]. The volume of mudflow caused a tremendous impact on the environment and surrounding community.

The utilization of SM as a cement replacement in the concrete industry had been investigated by Nuruddin and Aishah [3, 4]. They found that the source material of SM was rich in Si, Al and Fe content but low in Ca content. Furthermore, the source material of SM was also utilized as an alternative material in geopolymer binder [5-7]. The chemical content of Si and Al generated more gel of Si-O-Si and Si-O-Al that contributed to mechanical properties whereas low Ca content generated gel of N-A-S-H that caused prolong setting time in geopolymer binder. So that, SM based geopolymer required the high temperature to accelerate the geopolymer reaction [8]. As a result, the source material of SM cannot be utilized as the geopolymer material in the ambient temperature. This study aimed to investigate the feasibility of utilizing SM as replacement material in FA based geopolymer at the ambient temperature.

The replacement material in FA based geopolymer has been investigated. It is recorded that the blast furnace slag (BFS) was able to replace 50% FA material in geopolymer binder with the increase
of compressive strength more than 50Mpa [9-11]. Then, the incorporating of hydrated lime on the source material of BFS and FA improved the significant compressive strength at early ages, good permeation resistance, elevated temperature and fire resistance, and sodium sulphate attack resistance [12].

Furthermore, the incorporating of silica fume (SF) in FA based geopolymer was investigated by Khater. He mentioned that the replacement of 7% SF led to the dissolving of calcium hydroxide (CH) crystal, decreased the orientation of CH crystals, reduced the CH crystal size gathered at the interface, and improved the interface effectively. Moreover, it appeared precipitation of the nucleation CSH formation in the geopolymer product that provided maximum compressive strength in geopolymer [13].

Moreover, Okoye et al. studied the effect of silica fume as a replacement in FA based geopolymer with the combination of sodium hydroxide (14M) and sodium silicate [14]. They revealed that SF replacement of 20% in the FA base geopolymer provided the highest compressive strength. In addition, SF replacement of 40% provided highest flexural and tensile strength. Dutta et al. mentioned that the SF replacement of 5% enhanced the compressive strength of geopolymer mortar with the formation of a well-refined and compact matrix. However, further increasing replacement of silica fume caused a decrease of compressive strength in geopolymer [15].

2. Materials and Method
This study utilized the source material of SM as the alternative material in geopolymer which was imported from Sidoarjo, Surabaya, East Java, Indonesia. Whereas the source material of FA was used as the benchmark material which was derived from electric power generating plants, Manjung, Perak, Malaysia. The source material of SM was calcined at high temperature to reduce the impurities in its material. The treatment process of SM material can be seen in Figure 1. Fresh SM was dried in the oven with the temperature of 100°C for 24 hours to reduce the water content, so that did not cause the smoke during the high calcination treatment. The dried SM was calcined by the high temperature of 400°C to 900°C within 5 hours and then grinded for 2 hours to obtain the fine particle size. This study used the alkaline solution with the ratio of sodium silicate (Na2SiO3) to sodium hydroxide (NaOH) solution of 3.0 [16, 17]. The specific gravity of Na2SiO3 was 1.53 g/cc and the concentration of NaOH solution was 10M.

3. Results and Discussion

3.1. Chemical Composition
The chemical composition of SM with the calcination temperature level of 400°C to 900°C and FA is seen in Table 1. It is clear that the calcination temperature of 700°C enhances the Si and Al content of 14.5% and 12.6%, respectively. In addition, the content of Si and Al in the source material of SM is 1.5 and 1.3 times more than the source material of FA. It means that the source material of SM generates more gel of Si-O-Si and Si-O-Al in geopolymer binder compared to the source material of FA. Furthermore, the content of Ca in the source material of SM and FA are 7.46% and 20.9% of total
mass. It means that the source material of SM is categorized as low Ca content which generates gel of N-A-S-H and causing prolong setting time in geopolymer binder. Whereas the source material of FA is categorized as high Ca content which generates gel of C-A-S-H and provides the short setting time.

**Table 1.** The chemical composition of FA and SM material at calcination temperature level.

| Chemical Composition | FA | The calcination level of SM (°C) |
|----------------------|----|---------------------------------|
|                      |    | 0     | 400   | 500   | 600   | 700   | 800   | 900   |
| SiO₂                 | 24.9| 32.5  | 34.4  | 35.5  | 36.5  | 37.2  | 38.0  | 38.3  |
| Fe₂O₃                | 32.2| 26    | 26.4  | 26.9  | 27    | 27.8  | 28    | 28.2  |
| Al₂O₃                | 10.3| 11.1  | 11.6  | 11.6  | 12.1  | 12.5  | 12.8  | 13.1  |
| CaO                  | 20.9| 7.63  | 7.63  | 7.63  | 7.46  | 7.46  | 6.89  | 6.85  |
| Cl₂O                 | 0   | 5.31  | 3.78  | 3.23  | 2.03  | 0.34  | 0.34  | 0.34  |
| K₂O                  | 2.8 | 4.25  | 4.34  | 4.29  | 4.22  | 4.12  | 4.06  | 3.88  |
| SO₃                   | 0.7 | 1.24  | 1.20  | 1.16  | 1.16  | 1.11  | 0.88  | 0.49  |
| MgO                  | 2.08| 1.07  | 1.11  | 1.16  | 1.2   | 1.27  | 1.3   | 1.33  |
| LOI                  | 6.12| 8.3   | 9.54  | 8.53  | 8.33  | 8.20  | 7.73  | 7.51  |

3.2. Surface image and chemical identification

Figures 2-4 show the particle shape of FA, fresh SM, and SM particle. Figure 2 shows that the particle properties of FA are an amorphous sphere shape and glassy surface. These properties contribute to maintain the workability and fill the concavity in fresh geopolymer mixture. Furthermore, source material of FA shows the strong signal intensity in Si and Al element as mentioned in the chemical composition.

![Figure 2](image2.png)  
**Figure 2.** The particle properties of FA

![Figure 3](image3.png)  
**Figure 3.** The particle properties of fresh SM
Furthermore, the particle properties of SM are irregular agglomerate shape and rough surface. These properties enhanced the absorption of the alkaline solution to the particle surface of SM which it reduced the workability in fresh geopolymer mixture. In addition, it is considered that the particle of SM is not able to fill the concavity in geopolymer binder as good as the particle of FA. The source material of SM shows the strong signal intensity in C, K and Ca element. These elements are not in accordance with the chemical composition of fresh SM. It is attributed to the element of Si and Al that was hindered by the impurities. However, the calcination temperature is believed to be able to reduce the impurities. It can be confirmed in the source material of SM that has the strong signal intensities in the element of Si and Al. Although, the calcination temperature does not change the particle properties.

3.3. Workability

![Figure 4](image)

**Figure 4.** The particle properties of SM

3.4. Setting Time

The effect of the additional liquid on the setting time of SM is illustrated in Figures 6-8. The addition of extra water, extra alkaline solution, and superplasticizer does not affect the setting time in fresh geopolymer mixture. It is due to the setting time of fresh geopolymer mixture was affected by the Ca content. The replacement of SM up to 40% has short final setting time in fresh geopolymer mixture even close to the initial setting time. It indicates that there is an extreme change condition from the plastic state to harden state in fresh geopolymer mixture. It is attributed to the source material of 40% SM replacement that had a high Ca content.

The replacement of 10%, 20%, 30% and 40% SM in the FA based geopolymer has a constant setting time. It is attributed to high Ca content of these replacements that was 19.56% (10% x 7.46 + 90% x 20.9), 18.21% (20% x 7.46 + 80% x 20.9) and 16.87% (30% x 7.46+ 70% x 20.9) and 15.52% (40% x 7.46+ 60% x 20.9) of total mass, respectively. The final setting time begins to increase in the replacement of 50% SM which it generates the Ca content of 14.18% of total mass. It can be concluded that the Ca content of 14% to 16% of total mass plays an important role in the setting time.
3.5. Compressive Strength

Figure 9 shows the effect of SM replacement on the compressive strength with an alkaline solution to binder ratio of 0.5. The increase of compressive strength at 5%, 10%, and 15% SM replacement is 6.7%, 9.4%, and 7.6%, respectively compared to the FA-based geopolymer mortar. It is attributed to the increase of Si and Al content in the source material of geopolymer. It is displayed that the chemical content of Si and Al in the source material SM was more than the source material of FA. Hence, the incorporation of SM material in the FA based geopolymer generates more gel of Si-O-Al and Si-O-Si which it contributes to the compressive strength.

However, the increase of 20% SM replacement in the FA based geopolymer causes the reduction of compressive strength even is lower than the compressive strength of FA-based geopolymer mortar. It
is attributed to the increase of the rough surface in FA geopolymer that increased the absorption of alkaline solution in the fresh mixture and weakens the chemical bond in the geopolymer binder. In addition, the increase of irregular agglomerate particle caused the increase of concavity in the geopolymer binder. It is due to the agglomerate irregular shape of the SM particle that was not able to fill perfectly the concavity in the geopolymer binder.

**Figure 9.** The effect of SM replacement on the compressive strength with an alkaline solution to binder ratio of 0.50

### 4. Conclusion

This study evaluated the feasibility of utilizing Sidoarjo mud as a replacement in fly ash based geopolymer binder. The main conclusions extracted from the present study are following. The source material of SM has Si and Al the content of 1.5 and 1.3 times more than the source material of FA. It generated more gel of Si-O-Si and Si-O-Al in the geopolymer binder and contributed to better mechanical properties. Additional liquid did not improve the setting time of SM in fresh geopolymer so that the source material with high Ca content was required to enhance the low Ca content of SM material. Particle properties of SM were agglomerate irregular shape and rough surface. The increase of SM replacement increased the particle of SM and caused the reduction of workability in fresh geopolymer mortar. The replacement of 15% SM in FA based geopolymer enhanced the compressive strength of 7.6%. However, the highest compressive strength of 9.4% was obtained at the replacement of 10% SM.

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