

STUDY ON PORONG MUD-BASED GEOPOLYMER CONCRETE

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Abstract

This paper describes the efforts of how to use the solid form of the hot mud in Sidoarjo, Indonesia, as a base material of geopolymer concrete. The experimental study shows that the mud mixed with fly ash in certain composition is potential to become a binder in concrete, instead of Portland cement. It also shows that the mud mixed with Portland cement and lime does not have any compression strength although it is mixed with fly ash and alkaline activator. Dry mud has similar chemical composition to fly ash, but the compound of dry mud is not amorphous. Wet mud can only be used as a binder paste when mixed with a fly ash and alkaline activator solution. Test results show that the compressive strength of the binder does not vary with age and curing, but the concrete does. The longer the curing period and the higher ratio of the binder: aggregates will result in the higher compressive strength of geopolymer concrete. Furthermore, the size of coarse aggregate and the molarity of alkaline activator play very important role in the improvement of compressive strength.

Keywords: Geopolymer concrete, mud, fly ash, alkaline activator, binder

Abstrak

Makalah ini mendeskripsikan usaha untuk menggunakan lumpur panas Sidoarjo, Indonesia, sebagai material dasar dari beton *geopolymer*. Percobaan eksperimen menunjukkan bahwa lumpur yang bercampur dengan abu terbang pada komposisi tertentu berpotensi untuk menjadi pengikat di beton, disamping semen Portland. Hasil penelitian menunjukkan juga bahwa lumpur yang bercampur dengan semen Portland dan *lime* tidak memiliki kekuatan tekan meskipun dicampur dengan abu terbang dan *alkaline activator*. Lumpur kering memiliki komposisi kimia dengan abu terbang, tetapi pasangan dari lumpur kering tidak memiliki bentuk formula yang tetap. Lumpur basah hanya dapat digunakan sebagai campuran pasta saat pencampuran dengan menggunakan abu terbang dan *alkaline activator*. Hasil test menunjukkan bahwa kekuatan tekan dari campuran tidak menunjukkan variasi dari umur dan curing. Lamanya waktu *curing* dan rasio dari campuran agregat akan menghasilkan peningkatan kekuatan tekan dari beton *geopolymer*. Selanjutnya, ukuran dari agregat kasar dan molaritas dari *alkaline activator* memainkan peranan penting dalam peningkatan kekuatan tekan.

Kata kunci: Beton *geopolymer*, lumpur, abu terbang, *alkaline activator*, perekat

1. INTRODUCTION

Since May 29, 2006, Porong mud materials have become a big major issue from the bowels of the earth as a side effect of the missed gas mining process in Porong, Sidoarjo. The quantity of hot mud is equal to 50.000 m³ per day and became greater to 126.000 m³ since September 2006. It is flowing continuously, oozing out and spreading so that it has now covered more than 400 Ha of productive land and has completely immersed many villages around the mining area as shown in Figure 1 (a) and 1 (b).

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(a)



(b)

Figure 1.

- (a). The mud has hampered productive land in Porong City.**
(b) The mud has immersed many villages

The spreads of this mud also threatened the ecosystem of thousands fishponds, hampered the infrastructure, economical, education and social life. Many efforts have been applied to minimize its volume and to stop its flow. And some geologists have proposed a hypothesis about it, that a mud volcano is oozing out and that the efforts to stop the outpouring of mud is impossible.

An alternative effort to spillway mud to the sea has become a controversial issue. Another alternative is using the mud on a large scale to use it for construction material. One of the efforts is to use its solid form as a base material for geopolymer concrete. Some real efforts have been done so far, which is creating bricks and paving blocks. To make use of this material as a simple concrete, it is mixed with polymer liquid and ordinary Portland cement.

Chemical analysis of this mud shows that it consists of materials such as alumina and silicate, which could be used as a binder in concrete if it is mixed by activator solution. Concrete without Portland cement is known as geopolymer concrete. This concrete usually uses fly ash as a base material. Research has shown that the performance of geopolymer concrete produces high compressive strength and greater durability than ordinary concrete. It is also well known that geopolymers possess excellent mechanical properties, as well as fire and acid resistance (Cheng, 2003) and (Yodmuneet al., 2006). This geopolymer paste, induced by high-alkaline solutions, can be used as a binder to produce concrete instead of the ordinary cement paste.

The aims of this research are to analyze certain chemical composition of this mud in order to use it for construction materials, mix mud with fly ash and activator solution in an appropriate composition to get the binder and make geopolymer concrete base on the selected binder.

2. PREVIOUS RESEARCH

Very limited research data is currently available in published literature. Most of the past research on the behavior of geopolymeric material was based on the binder paste formed from fly ash using only small laboratory scales and samples.

The chemical composition of geopolymer is amorphous (Davidovits, 1999). The silicone and the aluminum atoms in the source materials are induced by alkaline solutions to dissolve and form a gel to

be a binder. The gel binds the aggregates and other un-reacted materials together to form geopolymer concrete.

Some test results show that the compressive strength of geopolymer concrete does not vary with age. Longer curing, molar H₂O-to-Na₂O and water content in the concrete play vary important role in the improvement of higher compressive strength (Hardjito et al., 2004; Hardjito et al., 2005)

Earlier work by the author (Ekaputri et al., 2006) reported the effect of various parameters such as curing time, sodium silicate to sodium hydroxide ratio and diameters of coarse aggregate. Some preliminary research has been done on a small scale to assess the mechanical properties of geopolymer concrete based on wet, dry, and calcified mud mixed with a fly ash-alkaline activator solution. Some suitable compositions of the binders have been created and show good potential. Wet mud mixed with an alkaline activator does not have any potential as a binder: it can only be used as a binder paste when mixed with a fly ash and alkaline activator solution. Good performance has been demonstrated by wet, dry and calcified mud mixed with a fly ash-alkaline activator solution, but wet mud mixed with ordinary Portland cement and lime has very poor performance.

3. EXPERIMENTAL WORK

3.1 Materials

In the experimental work, the solid mud form was obtained from Porong, Sidoarjo, Indonesia. It was used as the filler in the binder composition. Fly ash, as a base material was obtained from Jawa Power Paiton, Indonesia. Tabel 1 shows the chemical composition of dry mud and fly ash. Figure 2 shows the samples of wet mud and fly ash.

Table 1. Composition of Dry Mud and Fly Ash as Determined by XRD (% mass)

MATERIALS	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	TiO ₂	MgO	P ₂ O ₅	SO ₃	SO ₂	LOI	Microstructure
Mud	53.08	18.27	5.6	2.07	2.97	1.44	0.57	2.89	-	-	2.96	10.15	Crystallin
Fly Ash	52.24	38.58	2.94	0.69	0.52	0.44	2.42	0.49	0.13	1.21	-	1.39	Amorphous

Data was taken from "Balai Besar Keramik", Bandung, Indonesia



Figure 2. (a). Strained Solid Mud (b) Fly Ash

Majority compound of the dry mud consists of Kaolin and Feldspar, so it can be used as ceramics materials.

Alkaline activator contains of sodium silicate solution ($\text{Na}_2\text{O} = 8.5\%$, $\text{SiO}_2 = 28.5\%$ and $\text{H}_2\text{O} = 63\%$) and flake form of sodium hydroxide.

3.2 Binder

Experimental work has been done to find the binder which is used to make geopolymer concrete. Some compositions of fly ash to wet, dry or calcified mud ratio by mass and the molarity of alkaline activator have been tried in small size of sample.

The binder consists of fly ash mixed with alkaline activator, as the main binder, and wet or dry mud as the filler since the microstructure of the mud is crystalline. All of the samples are compared to the base binder: pure fly ash mixed with alkaline activator. Each mixture needs 223 grams of fly ash. The activator liquid-to-fly ash ratio was kept constantly at 0.35. Wet or dry mud is added in vary ratio of mass fly ash. Mud and fly ash were mixed drily in a bowl mixer for 2 minutes. The alkaline activator was added to the paste, and mixed together for another 2 minutes. In order to avoid the hardening process, which happened too fast, the paste should not be mixed in the long time. The paste was then prepared to cast in the 2 x 4 cm cylinder fiber moulds and left in ambient temperature. After 24 hours, the samples were then removed from the moulds and then cured in a waterproof cover for 2 days. At the end of the curing period, the specimens were left at room temperature until loaded in compression at the specified age.

The best performance of the binders created, would be chosen to find a fixed paste composition for the production of mud-based concrete.

3.3 Geopolymer Concrete

The binder chosen was then mixed with coarse and fine aggregate to make geopolymer concrete. Two types of locally aggregate were used and compared: 0.5 – 1 cm mixed with fine sand and 1 – 2 cm aggregate mixed with sand. Some compositions of mass ratio binder to aggregate have been tried in 10 x 20 cm cylinder samples. All of the samples are compared to the base mixing: pure fly ash mixed with alkaline activator and aggregates.

Due to its substantial fast process, the chemical reaction of the binder gel, the mixture should not be mixed in more than 3 minutes. Figure 3 shows the sequence of geopolymer concrete casting and figure 4 shows the specimens.

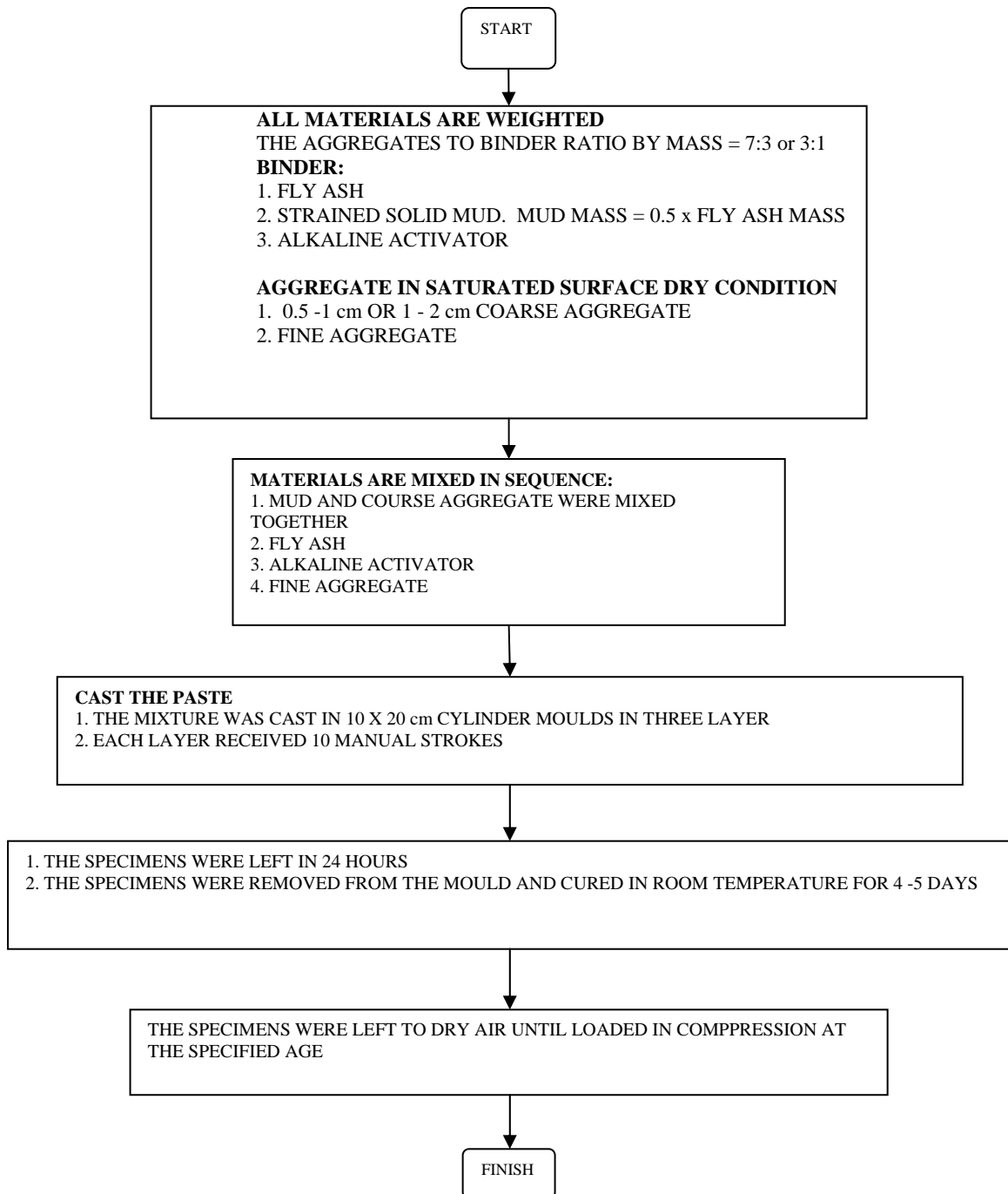


Figure 3. Process casting in creating mud-based geopolymer concrete



Figure 4. (a) Geopolymer Concrete Mixture in the Steel Moulds (b) Concrete Specimens

4. TEST RESULTS

In this paper, the effect of various parameters on the compressive strength of both the binder and the geopolymer concrete are reported. Each of the test data points plotted in various graph corresponds to the mean value of the compressive strength of two test cylinder specimens.

4.1 Compressive Strength of The Binders at Different Ages

Details of the mixture composition used in the binders are given in Table 2 and Table 3 shows the other mixtures used in the binder.

Table 2. Detail of the Binder Mixture Composition

BINDER CODE	Molarity of NaOH Solution	Sodium Silicate/NaOH Solution by Mass	Fly Ash/Mud by Mass	Additional Materials
D	14 M	2.5	1:1	-
E	14 M	2.5	1:1	5 % Lime
F	14 M	2.5	1:1	5 % Lime + 5% Portland cement
G	14 M	2.5	-	Pure calcified mud with 60 mL distilled water
I	14 M	2.5	0.75:0.75	

Table 3. Detail of the Binder Mixture Composition

BINDER CODE	Molarity of NaOH Solution	Sodium Silicate/NaOH Solution by Mass	Fly Ash/Mud by Mass	Additional Materials
A	14 M	2.5	Pure Fly Ash	-
B	14 M	2.5	1:1	-
H	14 M	2.5	0.5:0.5 Dry Mud	30 mL water
K	8 M	1.5	1:0.5	-

Figure 5 and 6 show the compressive strength of The Binders in different Ages. In Figure 5, it is found that wet mud mixed with flay ash and ordinary Portland cement or lime has very poor

performance and mass ratio fly ash: wet mud = 1: 1 likewise. Only calcified mud mixed with alkaline activator given by Binder G shows a good potential. Figure 6 shows that good performance has been demonstrated by wet and dry mud mixed with a fly ash-alkaline activator solution. The compressive strength of the binder does not vary with age. Fly ash to dry mud ratio by mass equal to 0.5:0.5 shown as Binder C gives good performance. And fly ash to wet mud ratio by mass equal to 1:0.5 shown as Binder B is sufficient to achieve satisfactory results. Thus, Binder B as suitable compositions was then chosen as a binder to make geopolymer concrete.

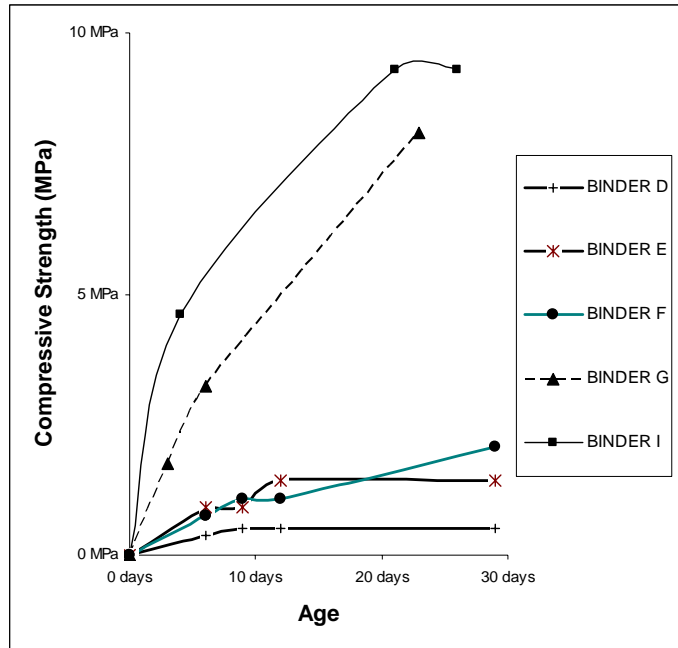


Figure 5. Compressive Strength of The Binder at Different Ages

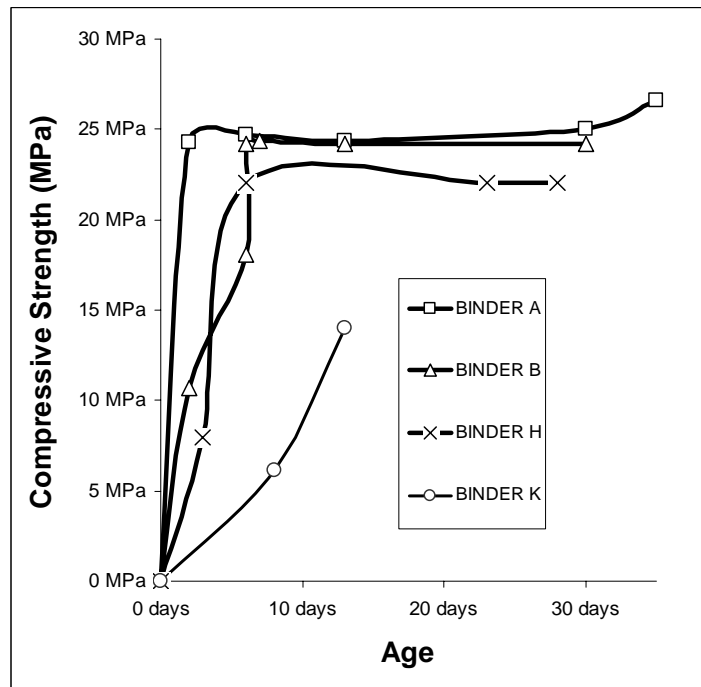


Figure 6. Compressive Strength of Binder at Different Ages

4.2 Compressive Strength of Geopolymer Concrete at Different Ages

The details of the mixture composition used in the geopolymer concrete are given in Table 4.

Table 4. Detail of the Concrete Mixture Composition

CONCRETE CODE	Molarity of NaOH Solution	Sodium Silicate/NaOH Solution by Mass	Diameter of Aggregate	Curing Time	Binder/Aggregate by Mass
CONCRETE A	14 M	2.5	1 – 2 cm	-	1:3
CONCRETE C	14 M	2.5	1 – 2 cm	4 days	1:3
CONCRETE D (Pure Fly Ash)	14 M	2.5	1 – 2 cm	4 days	1:3
CONCRETE E	14 M	2.5	0.5 – 1 cm	4 days	1:3
CONCRETE F	14 M	2.5	0.5 – 1 cm	5 days	3:7
CONCRETE G	8 M	1.5	0.5 – 1 cm	5 days	3:7
CONCRETE H	8 M	2.5	0.5 – 1 cm	5 days	3:7

Figure 7 shows some effects of the size of aggregate, curing time, molarity of alkaline activator and the binder to aggregate ratio by mass on the compressive strength. The compressive strength of Concrete E, which has smaller diameter of aggregate, is higher than Concrete C. The addition of wet mud equal to 50% mass of fly ash, the workability was considered as desirable. It is still very hard to cast the mixture in the short time and it takes time to harden and dry it. At the early age of concrete, the more curing time is done, the higher the compressive strength improved. The effect of the binder to aggregate ratio by mass and molarity of alkaline activator plays an important role in the concrete compressive strength, so does the age. Concrete F which has higher molarity of alkaline activator and binder to aggregate ratio by mass shows the best performance, besides Concrete D, which contains pure fly ash mixed with alkaline activator in 14 Molar.

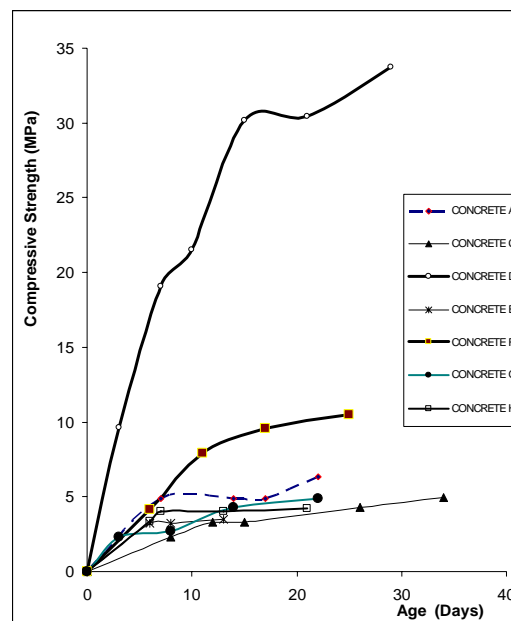


Figure 7. Compressive Strength of Geopolymer Concrete at Different Ages

5. CONCLUSIONS

Based on the experimental results reported in this paper, the following conclusions are drawn:

1. Wet and dry mud are not amorphous materials so that the mixture in geopolymer concrete needs higher alkalinity (in molarity) to bind un-reactive materials so that they can only be used as a filler.
2. The compressive strength of the binder does not vary with the age of mixture. It depends on the addition of wet mud and the other material, such as lime and Portland cement. The addition of lime or Portland cement to the mixture gives very poor performance.
3. Longer curing time improves the polymerization process resulting in higher compressive strength of geopolymer concrete, because of the addition of wet mud equal to 50% mass of fly ash, it takes time for concrete to be hardened or dry. Thus the age influences concrete performance. It is still difficult to carry out the research result in the field.
4. An increase in binder to aggregate ratio increases the concrete compressive strength

In order to optimize the usage of the mud for the community it is essential to carry out research and analysis both in the laboratory as well as in the field.

The use of the research findings would be beneficial not only for the development of research of geopolymers in Indonesia, but also for the community in Porong Sidoarjo, who are the victims of the hot mud disaster, as it would create opportunities for employment using the hot mud as a base building material.

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