Journal of Engineering and Technology Research Vol. 3(1), pp. 1-4, January 2011
Available online at http:// www.academicjournals.org/JETR
ISSN 2006-9790 ©2011 Academic Journals

Review

Review on fly ash-based geopolymer concrete without Portland Cement

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Accepted 19 November, 2010

The consumption of Ordinary Portland Cement (OPC) caused pollution to the environment due to the emission of CO_2. As such, alternative material had been introduced to replace OPC in the concrete. Fly ash is a by-product from the coal industry, which is widely available in the world. Moreover, the use of fly ash is more environmental friendly and save cost compared to OPC. Fly ash is rich in silicate and alumina, hence it reacts with alkaline solution to produce aluminosilicate gel that binds the aggregate to produce a good concrete. The compressive strength increases with the increasing of fly ash fineness and thus the reduction in porosity can be obtained. Fly ash based geopolymer also provided better resistance against aggressive environment and elevated temperature compared to normal concrete. As a conclusion, the properties of fly ash-based geopolymer are enhanced with few factors that influence its performance.

Key words: Fly ash-based geopolymer, alkaline solution, compressive strength.

INTRODUCTION

Ordinary Portland Cement (OPC) becomes an important material in the production of concrete which act as its binder to bind all the aggregate together. However, the utilization of cement causes pollution to the environment and reduction of raw material (limestone). The manufacturing of OPC requires the burning of large quantities of fuel and decomposition of limestone, resulting in significant emissions of carbon dioxide (Kong and Sanjayan, 2008). As such, geopolymer concrete had been introduced to reduce the above problem. Geopolymer concrete also showed good properties such as high compressive strength, low creep, good acid resistance and low shrinkage (Lodeiro et al., 2007). The role of binder in geopolymer concrete is replaced by fly ash which also possess pozzolanic properties as OPC and rich with alumina and silicate. Fly ash is residue from the combustion of coal which is widely available worldwide and lead to waste management proposal. Hence, fly ash-based geopolymer concrete is a good alternative to overcome the abundant of fly ash. In fly ash-based geopolymer concrete, the silica and the alumina present in the source materials are first induced by alkaline activators to form a gel known as aluminosilicate.

This gel binds the loose aggregates and other un-reacted materials in the mixture to form the geopolymer concrete (Wallah, 2009). Besides that, the reaction also depends on a few parameters such as size of aggregates, chemical composition of fly ash, amount of vitreous phase in fly ash, nature, concentration and pH of activators. The curing process of geopolymer concrete play shows a great influence on the development of microstructure, and subsequently on the mechanical characteristics of geopolymer (Komljenovi´c et al., 2010).

This paper summarizes the properties of fly ash-based geopolymer which make it better compared to normal concrete.

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ALKALINE SOLUTIONS

The common materials used as alkaline solution in producing fly ash-based geopolymer are sodium silicate and potassium hydroxide. Usually either of this material was mixed with sodium hydroxide to produce the alkaline solution and the molarity (M) of alkaline solution is 7 to 10 M. The alkaline solution was prepared a day before it is mixed with fly ash. Then, the materials are mixed together with fine aggregate and coarse aggregate to form concrete and curing process been done.

Chindaprasirt et al. (2007) found that, to produce higher strength geopolymer, the optimum sodium silicate to sodium hydroxide ratio was in range of 0.67 to 1.00. Meanwhile, the concentration of NaOH between 10 and 20 M give small effect on the strength.

CURING PROCESS

Setting time of geopolymer depend on many factors such as composition of alkaline solution and ratio of alkaline liquid to fly ash by mass. However, the curing temperature is the most important factor for geopolymer. As the curing temperature increases, the setting time of concrete decreases (Chanh et al., 2008). During curing process, the geopolymer concrete experience polymerization process. Due to the increasing of temperature, polymerization become more rapid and the concrete can gain 70% of it strength within 3 to 4 h of curing (Kong and Sanjayan, 2008).

PROPERTIES OF GEOPOLYMER

Workability of fresh geopolymer

Water also play important role in geopolymer concrete as much as normal concrete. The used of water in geopolymer is to improve the workability, but it will increase the porosity in concrete due to the evaporation of water during curing process at elevated temperature (Sathia et al., 2008).

Chindaprasirt et al. (2007) discovered an increase in sodium hydroxide and sodium silicate concentration will reduce the flow of mortar. The workable flow of geopolymer mortar was in the range of 110 ± 5 to 135 ± 5%.

To improve the workability of mortar, superplasticiser or extra water can be added. However, the use of superplasticiser had an adverse effect on the strength of geopolymer. As such, extra water gives higher strength than addition of superplasticiser.

Compressive strength

Compressive strength is an essential property for all concrete where it also depends on curing time and curing temperature. When the curing time and temperature increase, the compressive strength also increases. With curing temperature in range of 60 to 90ºC, within time in 24 to 72 h, the compressive strength of concrete can be obtained about 400 to 500 kg/cm^2 (Chanh et al., 2008). In addition, the compressive strength of geopolymers also mainly depended on the content of fly ash fine particles (smaller than 43 µm).

The compressive strength was increase when the finest of fly ash increase. Hence the nature and the concentration of the activators were dominant factors in the reaction of alkali activation. The highest compressive strength was obtained using a solution of sodium silicate as an activator (n = 1.5; 10% Na_2O). Sodium silicate is the most suitable as alkaline activator because it contains dissolved and partially polymerized silicon which reacts easily, incorporates into the reaction products and significantly contributes to improving the mortar characteristics (Komljenovi´c et al., 2010).

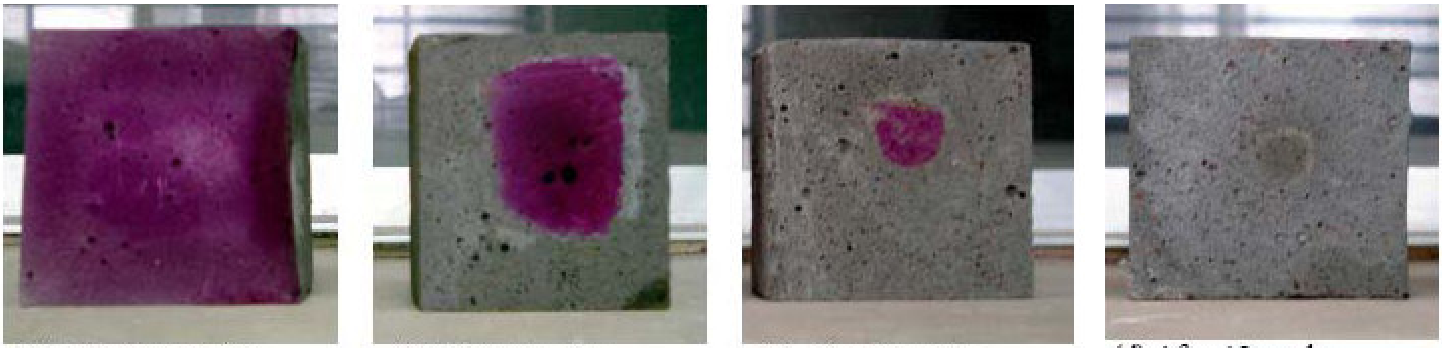
Resistance against aggressive environment

Fly ash-based geopolymer had been proved by many studies to provide better resistance against aggressive environment. As such, this advantage can be used to construct structure that exposed to marine environment (Chanh et al., 2008).

The exposure of geopolymer in acid solution shows that the weight loss due to the exposure is only 0.5% compared to normal concrete when immersed in 3% acid sulfuric (Sathia et al., 2008).

According to Bakharev (2005) in acidic exposure, high-performance geopolymer materials deteriorate with the formation of fissures in amorphous polymer matrix, while low-performance geopolymers deteriorate through crystallisation of zeolites and formation of fragile grainy structures. The formation of aluminosilicate gel is important to determine the stability of geopolymer. More crystalline geopolymer material prepared with sodium hydroxide was more stable in the aggressive environment of sulfuric and acetic acid solutions than amorphous geopolymers prepared with the sodium silicate activator.

Thokchom et al. (2009) expose the geopolymer mortar in 10% sulfuric acid and found specimens still intact and did not show any recognizable change in colour after 18 weeks. When observed under optical microscope, the expose surface reveled a corroded structure and it progress with time of exposure. In addition, the weight loss results obtained in this study showed better performance than OPC and the specimens with higher alkali content were observed to lose more weight than specimens with lower alkali content. At 18 weeks, the specimens were fully dealkalized by the sulfuric acid as in Figure 1, but it still had substantial residual compressive strength to prove the higher resistance against acid exposure (Thokchom et al., 2009). Thokchom et al. (2009) investigated the effect of sodium oxide content on durability of geopolymer in sulphuric acid. Specimens with



(a) Before immersion (b) After 6 weeks (c) After 12 weeks (d) After 18 weeks

Figure 1. Residual alkalinity in 10% acid sulfuric solution.

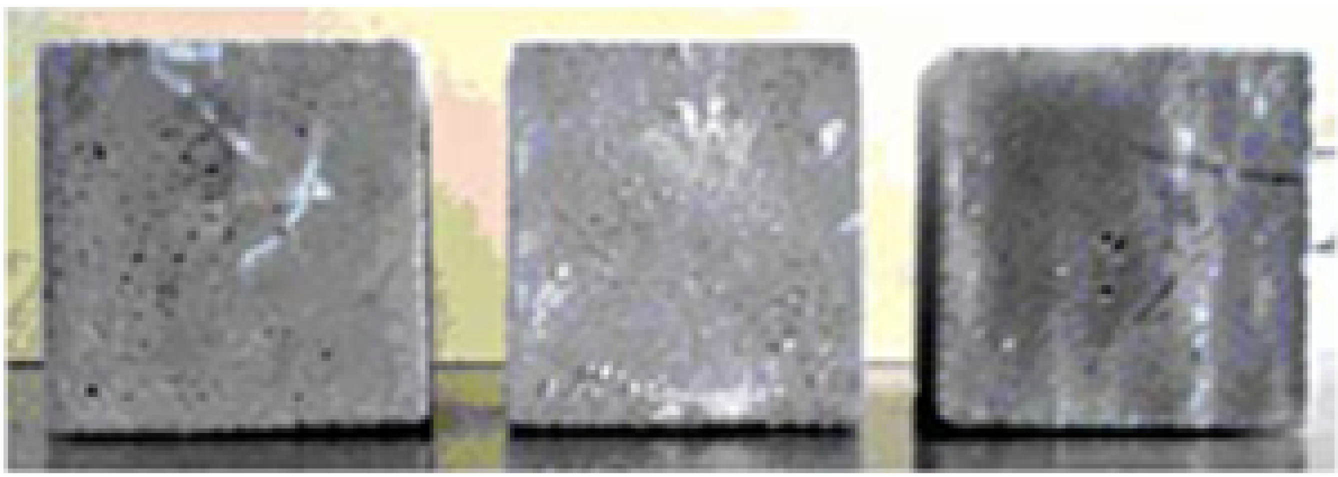


Figure 2. Fly ash-based geopolymer specimens with white deposit after 24 weeks exposure.

varying alkali content showed varying degree of deterioration when exposed to sulphuric acid. Beside that, the specimens showed no visible sign of structural disintegration but under optical microscope observation, the surface deterioration was clearly visible and it appeared more severe in specimen with less alkali content. The specimen with maximum alkali content experienced more reduction in weight compared to minimum alkali content. One the other hand, specimen with minimum alkali content loss more strength. Hence, specimen with higher alkali content performed much better than those with lower alkali content in terms of residual compressive strength.

When the fly ash-based geopolymer was exposed to magnesium sulphate environment for 24 weeks, the white deposit were observed on the surface on the specimens as shown in Figure 2. Nevertheless, the observations under optical microscope shown, only fine cracks were seen on a few specimens but there are no visible cracks observed on the specimen. The gain of specimen weight when immersed in magnesium sulphate depends of the sodium oxide content produced from alkaline activator. The maximum weight gain was produced by specimen with minimum content of sodium oxide. Even so, all the specimens only recorded a small gain weight compared to normal concrete (Thokchom et al., 2010). Lodeiro et al. (2007) discovered that geopolymer are less prone to formation of alkali silica gel.

BEHAVIOUR OF GEOPOLYMER AT ELEVATED TEMPERATURE

Fire resistance of concrete was other properties that are always considered due to the safety of user. Kong and Sanjayan (2008) said that the ratio of fly ash to alkaline solution influence the general strength and fire resistance of geopolymer. It was found that the fly ash-based geopolymer displayed increase in strength after temperature exposure.

Kong and Sanjayan (2010) observed the behavior of geopolymer concrete under elevated temperature affected by the size of aggregates. The aggregate with smaller sized (<10 mm) could lead to spalling and also extensive cracking of geopolymer but the larger aggregate (>10 mm) were more stable. In addition, the thermal incompatibility between the geopolymer matrix and its aggregate components was the most likely cause of strength loss in geopolymer concrete specimens at elevated temperatures. It can be proved by comparison between geopolymer concretes made two different aggregates with distinctly different thermal expansion characteristics. The geopolymer concrete with greater incompatibility led to higher strength loss during elevated temperature. Thus, the expansion of aggregate with respect to temperature was a factor that controls the performance of geopolymer.

Bakharev (2006) observed the thermal stability of the geopolymer materials prepared with sodium containing activators was rather low and significant changes in the microstructure occurred. At 800℃, the strength of the concrete was reduced due to the increase in the average pore size where amorphous structures were replaced by the crystalline Na-feldspars. The reverse situation was observed when potassium silicate was used as activators because it can remain mostly amorphous up to 1200℃. After firing these materials, it reduced average pore size and improved compressive strength of geopolymer. Fly ash based geopolymer prepared using class F fly ash with sodium and potassium silicate show high shrinkage as well as large changes in compressive strength with increasing fired temperature in the range 800 to 1200℃ (Bakharev, 2006).

CONCLUSION

Fly ash-based geopolymer is better than normal concrete in many aspects such as compressive strength, exposure to aggressive environment, workability and exposure to high temperature.

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