Properties of Blended Alkaline System Geopolymer- A Review

Fakhryna Hannanee Ahmad Zaidi1, Romisuhani Ahmad1*, Zarina Yahya1, Muhammad Faheem Mohd Tahir2, Wan Mastura Wan Ibrahim1 and Ahmad Syauqi Safi1

1Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia
2School of Material Engineering, Universiti Malaysia Perlis, Perlis, Malaysia

Email: *fakhryna0508@gmail.com

Abstract. Geopolymers are inorganic material that comprise of silicon(Si) and aluminium(Al) bonded by oxygen atom to form a polymer network. The binder material used for geopolymer such as fly ash and blast furnace are mostly the industrial waste or by-products containing high content of silica and aluminium which acted as precursor for geopolymerization. The raw material plays an important role in the formation of geopolymer for each material may result in different properties of geopolymer. To improve the performance of these binders, numerous studies have been focused on the production of mixes based on blends of reactive precursors. The blends usually involve a Ca-rich precursor such as granulated blast furnace slag (GGBS), and an aluminosilicate source such as metakaolin or low calcium fly ash, to promote the stable coexistence of calcium silicate hydrate (C–S–H) gels formed from the activation of the GGBS and the geopolymer gel (N–A–S–H) produced from the activation of the aluminosilicate. Thus, this paper is intended to review the properties of different type of mixes of blended alkaline system.

1. Introduction
Geopolymer was first introduced by Davidovits in 1970s to describe a group of minerals binders. The chemical structure of geopolymer comprise of silicon and aluminium bonded by oxygen atom to form a polymer network [1]. The raw material for geopolymer includes any pozzolanic compound or source of silica and alumina that is readily dissolve in the alkaline solution which acts as precursor that leads to geopolymerization [2]. Therefore, such material can also be called as alkali activated aluminosilicate binders or alkali activated cementitious material.

For each type of raw material, different chemical composition can be observed thus resulting to different properties of alkali activated binders [3]. As a function of chemical composition of raw materials, the alkaline binder is classified into two groups such that the binder synthesized from raw materials rich in calcium such as blast furnace slag will produce calcium silicate hydrate (C–S–H) gel. While binder synthesized from raw materials low in calcium and rich SiO2 and Al2O3 such as metakaolin and class F fly ash will result in a formation of amorphous material (N–A–S–H) called geopolymer gel [4].

Geopolymers represents an attractive binding material known for high compressive strength, good durability in aggressive environments, low shrinkage and good thermal resistivity [5]. However, taking example of the most common raw material for geopolymer which is fly ash, has a limiting factor such as its low reactivity and consequent low strength gain when cured at room temperature [6]. To improve
the performance of these binders, numerous studies have been focused on the production of mixes based on blends of reactive precursors. The blends usually combines the Ca-rich precursor and an aluminosilicate source to promote the stable coexistence of calcium silicate hydrate (C–S–H) gels and the geopolymer gel (N–A–S–H) [7]. The voids and pores within the geopolymeric binder become filled with the C-S-H gel and helps to bridge the gaps between the different hydrated phases and unreacted particles, thereby resulting the increase in mechanical strength for these binders [8]. This paper intends to review the properties of different type of blended alkaline system geopolymer.

2. Raw Material

2.1. Fly ash

Fly ash is a waste material generated abundantly during the burning of coal. Initially, the usage of fly ash is generally limited to 15-25% of the total cementitious materials for the purpose of reducing the heat of hydration [9]. Due to the high content of silica and aluminium, fly ash is nowadays utilized to produce geopolymer material [10]. The chemical composition of fly ash is tabulated in Table 1. Mustafa Al Bakri et al. (2011) stated that the fly ash consist mostly of glassy, hollow, spherical particles, which were cenospheres (thin-walled, hollow spheres); the appearance of the microstructures of the original fly ash agreed well with previous literatures [11].

| Element | SiO₂ | Fe₂O₃ | Al₂O₃ | CaO | K₂O | Na₂O_eq | SO₃ | MgO | LOI |
|---------|------|-------|-------|-----|-----|--------|-----|-----|-----|
| Fly ash [12] | 55.23 | 10.17 | 25.95 | 1.32 | 1.59 | 1.59 | 0.18 | 0.31 | 5.25 |

2.2. Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag (GGBS) is a by-product of iron manufacturing. The main constituents of GGBS are CaO, SiO₂, Al₂O₃ and MgO such tabulated in Table 2. These are the minerals usually found in cementitious substances thus have the potential to improves the properties such as strength and durability when added into concrete.

| Element | SiO₂ | Fe₂O₃ | Al₂O₃ | CaO | K₂O | Na₂O_eq | SO₃ | MgO | LOI |
|---------|------|-------|-------|-----|-----|--------|-----|-----|-----|
| GGBS [13] | 30.53 | 0.33 | 13.67 | 46.02 | 0.36 | 0.24 | - | 5.09 | 0.22 |

2.3. Metakaolin

Metakaolin is a supplementary cementitious material with high pozzolanic activity. To produce metakaolin, kaolin was heated up to 650–800 °C where the long-range order of silicon–aluminium layer structure deteriorate with structure deformation due to the loss of interlayer water and OH⁻ [3]. The chemical composition of kaolin and metakaolin is as tabulated Table 3.

| Element | SiO₂ | Fe₂O₃ | Al₂O₃ | TiO₂ | K₂O | MnO₂ | ZRO₂ |
|---------|------|-------|-------|------|-----|------|------|
| Kaolin  | 54.5 | 4.32  | 32.4  | 1.33 | 5.58| 0.09 | 0.08 |
| Metakaolin | 554.1 | 4.41 | 33.0  | 1.34 | 5.67| 0.11 | 0.09 |
3. Properties of Blended alkaline system

Low-calcium fly ash (Class F) has been investigated as a suitable material for geopolymer because of its wide availability, high in silica and alumina composition and less water demand [15]. However, one challenge for wide application of fly ash based geopolymer is the requirement of curing at elevated temperature. Many researchers attempted to enhance the reactivity of fly ash by adding some calcium containing material [16]. The addition of calcium oxide (CaO) forms hydrated products such as calcium silicate hydrates (CSH) along with the aluminosilicate geopolymer network [17].

Typically, GGBS incorporated low calcium fly ash are intensely researched [18]–[20]. The main product of alkali activation of fly ash is alcaline amorphous aluminosilicate gel, N-A-S-H gel in which is limited due to its low reactivity and low strength when cured. While the main product of alkali activation slag is calcium silicate hydrate with Al in the structure, C-S-H gel also known to give high strength but poor workability [21].

For example, research by Nagaraj et al. (2018) uses fly ash and GGBS as the raw material and the different percentage addition of materials is investigated. As the percentage of fly ash increases, it also increases the workability which in return, reduces the strength. Oppositely, GGBS reduces the workability and increases the strength of the concrete. Therefore, according to the application of the concrete, the amount of each material have to be controlled [22].

Research by Marjanovic (2014) investigates the physical and mechanical properties of alkali activated fly ash- GGBS blends [21]. The optimal characteristics of investigated alkali-activated binder with exceptionally high compressive strength and acceptable setting time were achieved with the blend composition of 25 % FA and 75% GGBS.

Aside from incorporating GGBS with low calcium fly ash, metakaolin is also used providing similar role as low calcium fly ash as the aluminosilicate source. Research by Borges et al. (2016) investigates the performance of blended metakaolin and GGBS alkali activated mortar with 60/40 MK/GGBS and the main binder. The microstructure was assessed using Scanning Electron Microscopy (SEM) where results shows that the addition of GGBS significantly alters the microstructure of alkali-activated mortars thus promotes the reduction of porosity and capillary sorption [23].

Similarly, Huseien et al. (2018) prepares geopolymer by substituting metakaolin with range 0-15% into GGBS. The result shows that metakaolin with 5% substitution obtains the highest bonding strength in early 1 days and 28 days of testing [13]. Thus, it is noted that the blended alkaline system helps counterbalance the disadvantages and alter the properties of geopolymer according to the intended application.

4. Conclusion

This paper reviews on the properties of blended alkaline system geopolymer. The blends usually combine the Ca-rich precursor such as GGBS and an aluminosilicate source such as metakaolin and fly ash to promote the stable coexistence of calcium silicate hydrate (C–S–H) gels and the geopolymer gel (N–A–S–H). It is clear that blended alkaline system helps to improve the properties of geopolymer. With the further development, this understanding will give the ability to design geopolymers with specific applications in mind.

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