



Synthesis of heat and ambient cured one-part geopolymer mixes with different grades of sodium silicate

Behzad Nematollahi^{a,*}, Jay Sanjayan^a, Faiz Uddin Ahmed Shaikh^b

^aCenter for Sustainable Infrastructure, School of Engineering, Faculty of Science, Engineering and Technology, Swinburne University of Technology, Melbourne, Victoria, Australia

^bFaculty of Science and Engineering, School of Civil and Mechanical Engineering, Department of Civil Engineering, Curtin University of Technology, Perth, Australia

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Abstract

The use of solid activators in the manufacture of geopolymer enhances its commercial viability as it aids the development of a one-part “just add water” geopolymer mixture, similar to the conventional Portland cement-based materials. This study is aimed to synthesize heat and ambient cured one-part geopolymer mixes. Appropriate combinations of low calcium (Class F) fly ash, slag and hydrated lime as the aluminosilicate source materials were activated by three different grades of sodium silicate and a combination of sodium silicate and sodium hydroxide powders. A conventional two-part geopolymer mix with the commonly used sodium hydroxide and sodium silicate solutions was also made for comparison. Effects of the type and amount of the solid activator, the amount of fly ash replacement with slag and hydrated lime and water content on short term mechanical properties of the heat cured one-part geopolymer mixtures including workability of the fresh mix, hardened density and compressive strength were evaluated. Subsequently, effects of ambient curing on the properties of the developed one-part geopolymer mixes were also investigated. Moderate to high compressive strength of over 37 MPa developed for the heat and ambient cured one-part geopolymer mixes. The 28-days compressive strengths of the ambient cured one-part geopolymer mixtures, regardless of the type of activator and geopolymer source materials, were comparable to those of the counterpart heat cured one-part geopolymer mixes. Such one-part geopolymer mixes could enhance the commercial viability and large-scale applications of the geopolymer in the construction industry.

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1. Introduction

Nowadays, the necessity of using environmental friendly construction materials which support the concept of sustainable development is one of the main environmental issues in the construction industry. Production of ordinary Portland cement (OPC) is said to be one of the main contributors of global warming. The cement industry is responsible for almost 5% of total CO₂ emission worldwide which is the main cause of global

warming [1]. However, the use of concrete and cement-based composites, as the most widely used construction materials, are still inevitable in the foreseeable future. Thus, the use of supplementary cementitious materials such as a fly ash and slag or finding alternative cement-less binders to the OPC are essential. Development of geopolymer as an alternative cement-less binder to OPC was one of the significant breakthroughs in the field of concrete technology in the 20th century. The term geopolymer was initially introduced by Davidovits [2]. Geopolymer is synthesized from materials of geological origin (e.g. metakaolin) or industrial by-products such as the fly ash and slag that are rich in silica and alumina with high alkaline activators. Manufacture of fly ash based geopolymer has at least 80% less CO₂ emission and approximately 60% less embodied energy compared to production of the OPC [3,4]. Over the last few

*Correspondence to: Swinburne University of Technology, Mail 38, FSET, Hawthorn, Victoria 3122, Australia. Tel.: +61 452593912.

E-mail address: bnematollahi@swin.edu.au (B. Nematollahi).

¹Postal address: Swinburne University of Technology, Mail 38, FSET, Hawthorn, VIC 3122, Australia.

decades, extensive research and development on geopolymer technology have been undertaken worldwide with hopes to promote the geopolymer concrete as an ultimate sustainable construction material for the future [5–12]. It has been found that fly ash-based geopolymer exhibits high compressive strength, negligible drying shrinkage, low creep, good bond with reinforcing steel, and good resistance to acid, sulfate and fire and the performance of geopolymer concrete structural members such as beams and columns was similar to that of the OPC concrete members [6–8,13].

Despite the remarkable greenness potential of geopolymer which promotes its application as a promising alternative binder to OPC; however, the use of geopolymer so far has been restricted to small scale applications. To make the most of the excellent environmental friendliness of geopolymer, large-scale applications of geopolymer in the construction industry should be really taken into consideration. Conventionally, geopolymer is manufactured from a two-part mix, comprising of alkaline solutions and solid aluminosilicate precursors. These user-hostile activator solutions are frequently used to dissolve the aluminosilicate source materials and govern the mechanical properties of the geopolymer binder such as its compressive strength [14,15]. There are several pitfalls with regards to the two-part mix formulations used in the synthesis of “traditional” geopolymers [16]. Handling large quantities of highly corrosive and often viscous alkaline solutions would be difficult to use for commercial and mass production of geopolymer materials and hinders the large-scale application of geopolymer. In addition, the rheology of the geopolymer can be complex and difficult to control as a result of formation of a sticky and thick paste, particularly in geopolymer systems where sodium is the source of alkali [17]. Moreover, the geopolymer system is sensitive to the ratio of alkali to available silicate, which can be challenging to control in practice where waste materials are used as a silica source [18]. Lastly, as a result of movement of alkalis and water to the geopolymer surface during curing or in service there can be a tendency toward efflorescence, and/or high permeability and water absorption, unless the water and alkali content of a geopolymer mix are cautiously controlled [19,20]. Thus, one of the main steps towards the large-scale application of geopolymer in the construction industry is developing a one-part “just add water” geopolymer mixture as an alternative method which is more similar to the utilization of conventional Portland cement-based materials.

Solid activators (e.g. solid silicates) can be used as alternatives to activator solutions (e.g. soluble silicate) to manufacture geopolymers [21,22]. The use of solid activators in the manufacture of geopolymer enhances its commercial viability because it aids the development of a one-part “just add water” mixture, similar to the conventional cement-based materials. To date, few studies aimed to synthesize one-part geopolymer mixes using various approaches. For instance, Koloušek et al. [23] developed a one-part geopolymer mix by making a totally sodium silicate-free geopolymer system by calcination of kaolinite or halloysite together with powdered hydroxides but this was reported to result in low strength development (7-days strengths of < 1 MPa were given). Hajimohammadi et al.

[24–26] attempted to provide a detailed understanding of the chemistry of one-part geopolymer mixes. The effects of water content, high early silica, and high early alumina in the formation of one-part geopolymer mixes composed of geothermal silica and solid sodium aluminate as the solid silica, alkali, and alumina sources for geopolymerisation, with or without additional fly ash were evaluated. Geothermal silica is a waste residue and a source of solid amorphous silica which can potentially be used as a replacement for silicate solutions in geopolymerisation. Although the results of using geothermal silica and solid aluminate for geopolymerisation were encouraging in terms of possibilities for using the “just add water” in practice; however, it should be noted that the method used to purify the raw geothermal silica was relatively complex. In addition, all geopolymer pastes were cured at 40 °C in sealed molds for 2 weeks. These issues may limit the widespread application of this one-part geopolymer mix in the construction industry. Moreover, the focus of their studies was mainly on chemistry and microstructure of the developed geopolymer and mechanical properties of the one-part geopolymer have not been reported. Feng et al. [27] studied the thermal activation (i.e. at elevated temperatures e.g. 850 °C to 1150 °C) of albite with sodium hydroxide (NaOH) or sodium carbonate (Na₂CO₃) powders for the synthesis of one-part mix geopolymers. Albite (sodium feldspar) is often one of the main components in mine tailings. Although the developed geopolymer exhibited acceptable compressive strength over 40 MPa after 28 days; however, the necessity of thermal activation of albite at elevated temperatures (e.g. 850–1150 °C) may limit the common application of this one-part geopolymer in the construction industry.

To be useful in practice, the “just add water” concept needs to be applicable to the fly ash and slag as the commonly used geopolymer source materials. In this regard, Yang et al. [28] and Yang and Song [29] attempted to develop one-part geopolymer mixes with the fly ash and slag as the precursor and using either sodium silicate (Na₂SiO₃) powder or a combination of Na₂SiO₃ and NaOH powders as the solid activator. 100% Fly ash or 100% slag were used individually as the source materials activated by only one grade of Na₂SiO₃ powder (i.e. Anhydrous sodium metasilicate powder) as the solid activator. All the fly ash and slag based specimens were cured at ambient temperature (23 ± 3 °C). Slag based samples were removed from the molds after 1 day; however, fly ash based specimens were de-molded after 3 days of casting because they required more setting time. Where 100% slag as the source material was activated by either Na₂SiO₃ powder or a combination of Na₂SiO₃ and NaOH powders, the compressive strength over 50 MPa after 28 days of curing could be achieved. However, in the case of using 100% fly ash as the source material and Anhydrous sodium metasilicate powder as the solid activator, a maximum compressive strength of 9.45 MPa after 28 days of curing was achieved. Whereas, no meaningful compressive strength was achieved where 100% fly ash and a combination of NaOH and Na₂SiO₃ powders were used as the source material and the solid activator, respectively (i.e. the maximum compressive strength of 3.5 MPa after 28 days of curing was reported). Therefore, further research is required to increase the compressive strength of the one-part geopolymer mixes manufactured from fly

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