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Review

Structural and material performance of geopolymer concrete: A review

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HIGHLIGHTS

- The taxonomy in the field of geopolymer concrete studies, both performances in material and structure are discussed.
- Parameters tested in the previous studies in geopolymer concrete is critically reviewed.
- The research lacking in this area is discussed.
- Barriers to the widespread use of geopolymer concrete in construction industry are critically analysed.

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ABSTRACT

Off late, the continuously depletion of the ozone layer and global warming issue have increased the awareness of the construction industries in using more eco-friendly construction materials. Against this background, geopolymer concrete has started to gain significant attention from the research scholars and construction practitioners, due to its advantageous in using by-product waste to replace cement and reducing greenhouse gas emission during its production. It also possesses better mechanical properties and durability compared to conventional concrete. Despite its advantageous, the use of geopolymer concrete in practical is considerably limited. This is mainly due to the lacking in the studies in terms of structural elements, design and application studies. This paper reviewed the material and structural performances of geopolymer concrete to identify the research gaps in this area for future research development. Analysis shown that geopolymer concrete can replace conventional concrete as they presented better mechanical properties, higher durability and more desirable structural performances compared with conventional counterparts. More studies are still needed for practical design standards and finally, the full scale studies on the structural elements should be established to ensure its feasibility in practical.

Contents

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1. Introduction

Geopolymer is adjudged as the latest wave of cement, after gypsum cement and ordinary Portland cement (OPC). It has appeared to be one of the major construction material internationally. ‘Geopolymer’ can be referred as amorphous alkali aluminosilicate or alkali-activated cements [1]. Geopolymer concrete can be produced by polymerizing the aluminosilicates such as fly ash (FA), metakaolin (MK), slag (SG), rice husk ash (RHA), and high calcium wood ash (HCWA) through activation using alkaline solution. Hence the efficiency in producing geopolymer concrete is highly dependent on the activators as well as types of aluminosilicates resources [2].

In general, geopolymer is one of the inorganic polymers. It is amorphous rather than crystalline compared to other natural zeolitic materials [3]. The polymerization requires a considerably quick reaction of silica (Si)-alumina (Al) under alkaline condition which subsequently create three-dimensional polymeric chain of Si—O—Al—O bonds. Dissimilar to OPC or pozzolanic cements, geopolymer utilizes the polycondensation of silica and alumina and a high alkali content to attain compressive strength [4]. On the other hand, geopolymer incorporating OPC develops calcium silicate hydrates (C-S-H) as well as polycondensation of silica and alumina and a high alkali content to attain compressive strength. The following reactions occur during geopolymerization [5].

$$(Si_2O_5Al_2O_2)_n + H_2O + OH^- \rightarrow Si(OH)_4 + Al(OH)^{4-} \quad (1)$$

$$Si(OH)_4 + Al(OH)^{4-} \rightarrow (\overset{|}{\underset{|}{Si}} - O - \overset{|}{\underset{|}{Al}} - O)_n + 4H_2O \quad (2)$$

Anything that contains amorphously Si and Al can be used to produce geopolymer concrete. These materials can be either natural mineral or industrial by-product. It was found that the products of hydration of FA/MK are sodium aluminosilicate hydrate gels. Meanwhile, the hydration products of SG activation are calcium silicate hydrate gels [1]. MK-based geopolymer is better than the other hydrates as it can be as its properties is more persistent. Despite its advantages, it required higher water-demand hence resulted in severe rheological problems. In the meantime, FA-based geopolymer presented higher durability. SG-based polymer, on the other hands, has higher early strength and greater acid resistance [2].

Fig. 1 shows the current trend in the research of geopolymer concrete. Apparently, the studies done on geopolymer concrete before 2001 is considerably limited. The number of studies increased dramatically from year 2016, indicating the high attention given by global scholars in this particular field. Despite vast and substantial studies being performed in this regard, geopolymer concrete has yet to procure international acceptance as construction material. The causes can be summarized as follows:

a) The cost of production of geopolymer concrete requires to be reasonably competitive.
b) Extensive and more reliable data are needed on the practicality of using geopolymer concrete as structural elements.

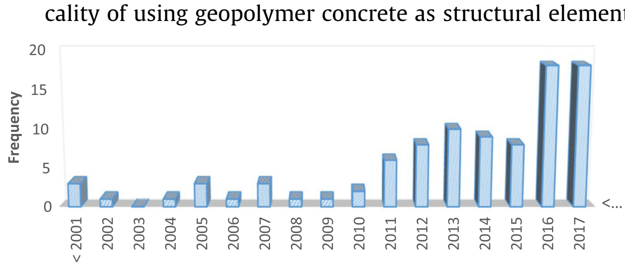

Fig. 1. Research trend in geopolymer concrete.

c) The establishing of design of geopolymer concrete elements is perquisite.

This review paper is targeted to contribute an all-encompassing understanding and assessment of geopolymer concrete. Against this background, a comprehensive database is created based on past literatures. Assessment and analysis are conducted on the influencing variables and their effects on the performances of geopolymer concrete. Eventually, a crucial debate is demonstrated on the facets that significantly affect the properties and performances of geopolymer concrete. It is certain that this review will assist in narrowing the intermission between academic/fundamental research to the construction industry.

2. Previous studies on geopolymer concrete

2.1. Research in materials

Extensive studies have been performed to assess the performances of geopolymer concrete. They including the effects of C-S-H phase, admixtures and curing conditions. Yip et al. [6] reported that in MK/SG-based geopolymer pastes, C-S-H and aluminosilicate gel (N-A-S-H) can be found. This is quite similar to a high calcium FA-based geopolymer, activated particularly by sodium hydroxide (NaOH), as reported by Somna et al. [7]. The strength of concrete paste is contributed by the C-S-H and N-A-S-H. In other words, the strength of geopolymer pastes is highly dependent on the alkalinity level of activators used. Besides, it was also reported that the temperature plays very important role in activating the aluminosilicates. Research found that in FA/SG blends, the activation process at lower temperature (at approximately 27 °C) is dominated by SG activation, whereas at higher temperature level (at approximately 60 °C), both FA and SG is activated. Nevertheless, the SG is contributing in the strength of pastes due to its compactness of microstructure [8]. The hardening of FA/SG- based geopolymer is due to C-S-H and C-A-S-H formation. The hardening is followed by the formation of C-S-H, N-A-S-H and C-A-S-H. However, the formation of hydrate gels is dependent on the calcium ions and pH levels. Prinya et al. [9] reported that acidic environment producing N-A-S-H gel in FA-based geopolymers. High concentration of calcium ion in class C FA-based geopolymers can result in higher compression strength [10]. The presence of high potassium oxide content in HCWA contributed to the early strength development [106] and contributed to the self-activation of geopolymer without the use of alkaline activator [107].

More recent studies shown that material with amorphous structure is most desirable in term of mechanical properties of geopolymer concrete. These are affected by the parameters such as SiO_2/ Al_2O_3 ratio, R_2O/Al_2O_3 ratio, SiO_2/R_2O ratio and liquid-solid ratio (R denotes either Na^+ or K^+) [11–16]. Compression strength of geopolymer paste increased with alkali content. In contrast, strength decreases with level of silica. This is the SiO_2/R_2O ratio effects and contribute to the forming of ring structure. It was reported by Zhang et al. [13] that activation by NaOH alone can form crystalline zeolite or nanosized crystals of another zeolite, depending on the Si/Na ratio. The addition of Sodium Silicate can reduce the crystallite formation significantly. Fig. 2 shows the effects of activators dosage in the microstructure distribution. Higher pore volumes will reduce the strength of pastes. It was also reported that the setting time of paste increase with SiO_2/Al_2O_3 ratio [14].

Effects of different admixtures were studied extensively in the past [17–19]. It was reported that sucrose formed insoluble metal complexes hence retard the hydration process. Citric, on the other hand, reduce the setting time and accelerate

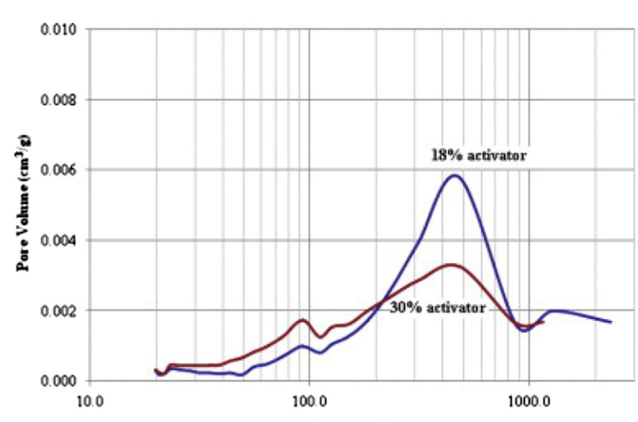

Fig. 2. Pore volume distribution at different activator dosages [14].