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Review

A review on microstructural study and compressive strength of geopolymer mortar, paste and concrete

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HIGHLIGHTS

- Compressive strength characteristics analysed using microstructural investigation.
- Binders mixed with lower mass ratio of SS/SH tend to react more efficiently.
- Evaporation of free water molecule causes weight loss in the specimen.
- Nano materials in binders with low pozzolanic oxide content is important to form Si—O—Al—O bond.

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ABSTRACT

The utmost priority in reducing the usage of ordinary Portland cement (OPC) while replicating the cementitious properties by utilizing industrial by-products in construction materials is seriously undertaken by many researchers. The technology of geopolymerization that utilizes materials and activator solution to form geopolymer matrix could lead to alleviate some of the issues related to OPC based concrete. Numerous experiments have established that geopolymer concrete has higher compressive strength, higher acid resistivity and lower shrinkage than ordinary concrete. This review article focusses on the microstructure analyses of the geopolymer specimens and comparison of geopolymers with various binders. The review analysis of various binders used and their microstructural investigations reveal that different molarity of sodium hydroxide or phosphoric acid solution, liquid-to-binder ratio, curing temperature and duration yield geopolymers of diverse properties. Most of the geopolymer products revealed a wide hump in the XRD analysis due to the amorphous structure of aluminosilicate. Investigation of MIP and Micro CT reveals that aged geopolymer has a denser matrix arrangement and produce high compressive strength. Geopolymerization prevents interconnectivity of micropores due to the formation of denser matrix of geopolymer gel. Generally, the use of 12M of sodium hydroxide solution, low liquid-to-binder ratio of about 0.4 and curing temperature at approximately 70 °C for at least 24 h produced high strength geopolymers. The binders mixed with lower sodium silicate to sodium hydroxide mass ratio of 2.0–2.5 tend to react more efficiently.

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1. Introduction

It is well known that limestone hills were being harvested for cement manufacturing throughout the world and that lead to ecological imbalance [1]. As concrete is the most widely used construction material, the exploitation of natural resources such as sand and coarse aggregate pressured construction industry to look for alternatives for these materials; thus, the use of alternative construction materials is on the rise and many research works are being carried out through the globe.

Cement manufacturers rely on limestone as it is the major source in ordinary Portland cement. For the conversion of limestone to calcium oxide, the cement kiln heats all the raw materials at high temperature. Fuel used in heating may be coal, natural gas, sawdust and methane gas or a combination of these fuels. Both the chemical conversion and firing process release carbon dioxide (CO_2), which is the main component in greenhouse gas. Alnahhal et al. [2] reported that about 2.8 billion tonnes of cement products manufactured every year and this in turn produces about 5–7% of the global CO_2 emissions [3,4]. Based on a report by Department of Statistic Malaysia, roughly 20 Mega tonnes of cement were produced in 2016 [5]. It has been reported that the production of cement, besides consuming the natural resources, it also destroys the natural habitat of flora and fauna [1]. Since the beginning of 1990s, the term sustainability has gained significance among all engineering community and more focused works are being systematically carried out throughout the globe in diverse areas of engineering process and products. Thus, more researches have been carried out in the area of building materials, especially on cement-based products by using diverse cement replacement materials which fulfill both the sustainability criterion to conserve the natural resources and preserve the environment.

The production of industrial by-products and waste is increasing rapidly due to unrestrained and fast-growing industrialization & urbanization and some of these could be converted into potential raw materials for building products. One such material that has long been researched is ash that could partially replace cement. The enormous amount of industrial waste ash produced from power generation, timber manufacturing, iron and steel, rice mill, mining industries, etc. posed a great environmental threat as its disposal causes serious concern to environment and health. Some of the industrial by-products and wastes that have been researched include fly ash, bottom ash, silica fume, boiler slag, steel slag, palm oil fuel ash, rice husk ash and fluidized bed combustion ash. In Southeast Asia, the use of coal as fuel in coal power plants and the production of vast amount of rice result in the production of fly ash, bottom ash and rice husk ash. In Malaysia, fly ash and bottom ash are categorized as schedule wastes by the Department of Environment (DOE). DOE of Malaysia does not allow any of the waste ash to be released into sanitary landfills due to its high concentration in toxicity [6]. Thus, this explains that large dump yard is required for the power plant to store the waste ashes.

On the other hand, recent trend on replacement of cement by alkali activated materials and geopolymer concrete opened up new avenue for researchers throughout the globe to embark on utilizing potential waste ashes into commercial entity. Previous studies have shown that geopolymer concrete has high compressive strength, effective in acid resistance, lower shrinkage and effective in heavy metal absorption compared with concrete made with Portland cement [7–12]. Studies also revealed that geopolymer is capable in reducing the power consumption up to 15% for stabilizing indoor temperature [13]. Geopolymers are made up of aluminosilicate materials with three-dimensional amorphous microstructure. Geopolymerization process takes place when the oxides of silicon and aluminium minerals or aluminosilicates are activated by alkaline solution. Materials that are rich in aluminosilicates are calcined kaolinite and industrial waste such as fly ash, bottom ash and rice husk ash are activated by adding sodium hydroxide, sodium silicate, potassium hydroxide or potassium silicate. While the industrial waste ashes are reutilized for geopolymer production, the amount of greenhouse gas emitted to the environment was lowered by 44–64% compared with the production of Portland cement [14]. This is attributed to ambient temperature without external heating of geopolymers that achieve the desire strength in such curing condition.

Research interest in geopolymer concrete and the application has been displayed at the University of Queensland's Global Change Institute (GCI) built in Australia [15]. Combination of slag and FA were used to develop the geopolymer concrete for the construction of CGI; there are other binders studied such as metakaolin, and rice husk ash. OPC has numerous publications expertise in microstructural behavior. However, very limited articles emphasized the microstructural study for GPC.

Thus, this paper aims to present an overview of recent studies of incorporation of waste ashes such as fly ash, bottom ash, palm oil fuel ash, ground granulated blast furnace slag (GGBS) and metakaolin in geopolymers; the investigation on microstructural investigation and its relationship to compressive strength is also reviewed and reported. This review article reiterates the chemical process of geopolymerization and highlights the differences of geopolymers due to materials' chemical composition through scanning electron microscopy (SEM), x-ray diffraction (XRD), x-ray fluorescent (XRF), Fourier transform infrared spectroscopy (FTIR), thermal gravity analysis (TGA), mercury intrusion porosimetry (MIP) and micro computed tomography (Micro CT) analyses.

2. Geopolymerization

In 1978, the term 'geopolymer' is introduced by Davidovits (1991) by producing inorganic polymeric materials [16]. Geopolymers are made up of aluminosilicate materials with three-dimensional amorphous microstructure. Alkaline medium (Na+, K+, Li+, Ca+, etc.) or acidic medium such as phosphoric acid or humic acid can be used to synthesize geopolymer. In alkaline medium, geopolymerization process takes place when the oxides of silicon and aluminium minerals or aluminosilicates reacts with alkaline solution to form a polymeric Si—O—Al bonds. The structures are of Poly(sialate) type (—Si—O—Al—O—), Poly(sialate-siloxo) type