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Review

An overview on the influence of various factors on the properties of geopolymer concrete derived from industrial by-products

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HIGHLIGHTS

- A review on the latest trends of geopolymer concrete derived from industrial wastes.
- A critical review on the various influences on the properties of geopolymer concrete.
- Potential solution for environmental and waste disposal issues in various industries.

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ABSTRACT

The enormous amount of industrial waste ash generated by power generation industry, timber manufacturing industry, iron and steel making industry, rice milling industry, mining industry etc have posed the aforementioned industry players a great challenge when it comes to the disposal of these ash materials due to the environmental, health, scarcity of lands and other issues. The best approach in overcoming the aforementioned waste management problems is to promote large volume recycling/reuse of these waste materials. In recent years, the rapid growth in research and development related to geopolymer binders has indeed indicated that the use of geopolymer offers the greatest potential in solving not only the waste management problems related to the aluminosilicate solid waste materials generated from various industries, but also the environmental degradation related to the use of OPC as primary binder material in the construction industry. Results of recent studies are indicative that geopolymer concrete fabricated using various industrial by-products exhibited similar or better mechanical, physical and durability properties as compared to OPC concrete. This paper presents a concise review of the current studies on the utilization of industrial by-products as the primary binder materials in the fabrication of geopolymer concrete. The effects of a number of major factors such as the use of chemical activator, post fabrication curing regime, particle size distribution of source materials, and aggressive environment exposure on the mechanical strength, physical properties, microstructures and durability properties of the geopolymer concrete are exhaustively deliberated. Besides, the current material design, fabrication procedures and post fabrication treatment procedures were rigorously reviewed to identify the limitations of the current geopolymer technology which impede its wide implementation in the construction industry. It has been identified that the high alkaline content in the material design and requirement for elevated temperature treatment of the contemporary geopolymeric binder are among the major technical challenges which resulted in the limited use of the material in the construction industry. Based upon that, numerous strategies were proposed to overcome the current limitations of the geopolymer technology towards promoting a large scale implementation of the technology in the production of construction materials.

Contents

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1. Introduction

Ordinary Portland cement (OPC) has long been the traditional and widely used binder material in the manufacture of concrete. However, the use of OPC as primary construction material has been questioned extensively over the last decades due to the environmental impact of clinker production [1,2]. In fact, the production of Portland cement clinker from the cement production plants worldwide emit up to 1.5 billion tons of CO_2 annually, which accounts for around 5% of the total man-made CO_2 emission and if the undesirable trend continues, the figure will rise to 6% by year 2015 [3–5]. Apart from OPC, sand and aggregate are also the main constituent source materials in the production of concrete, which originated from the quarrying operations which are both energy intensive and produces high level of waste materials. Shortage of natural resources for construction materials in many developing countries has also led to long distance haulage and thus significantly increased the production cost of construction materials. All of the issues mentioned above are against the context of sustainable development in construction industry and immediate remedy actions must be taken to ensure sustainability in the construction industry [1].

The aforementioned issues prompted various researches in an attempt to reduce the global carbon footprint ranging from utilizing supplementary cementitious materials (SCMs) as partial cement replacement materials [6–10] to developing a whole new cementless binder, namely geopolymers [11–14]. Geopolymers are alternative cementitious materials synthesized by combining source materials which are rich in silica and alumina such as fly ash (FA), ground granulated blast furnace slags (GGBFS) with strong alkali solutions such as potassium hydroxide (KOH), sodium hydroxide (NaOH) and soluble silicates (in most cases) such as sodium silicate where the dissolved Al_2O_3 and SiO_2 species undergoes geopolymerization to form a three-dimensional amorphous aluminosilicate network with strength similar or higher than that of OPC concrete. Generally, the mechanism of geopolymerization can be divided into three main stages: (1) Dissolution of oxide minerals from the source materials (usually silica and alumina) under highly alkaline condition; (2) transportation/orientation of dissolved oxide minerals, followed by coagulation/gelation; (3) polycondensation to form 3D network of silico-aluminates structures [15]. Based on the types of resultant chemical bonding, three types of structures can be derived from the 3D aluminosilicate network: poly(sialate) (–Si–O–Al–O–), poly(sialate-siloxo) (Si–O–Al–O–Si–O) and poly(sialate-disiloxo) (Si–O–Al–O–Si–O–Si–O–) [16].

The potential of geopolymer binders to replace the traditional OPC binders was supported by the fact that there is abundant of industrial by-products generated in various industries that was found to be suitable to use as geopolymer source materials, all of which are causing problems in term of finding an ideal solution for disposal purposes. For instance, pulverized fuel ash (PFA) or more commonly known as fly ash (FA), an industrial by-products of coal burning power plant industry, makes up of 75–80% of global annual ash production [17], yielded geopolymer concrete with superior mechanical and durability properties as compared to OPC concrete [18–20]. GGBFS, by-products of iron pig manufacture from iron ore, has also found significant use in the production of high strength geopolymer concrete [21,22]. The use of palm oil fuel ash (POFA), waste materials derived from the burning of empty fruit brunches, oil palm shells and oil palm clinker from the oil palm industry to generate electricity as geopolymer binder, has gathered pace in recent years. POFA is widely used as geopolymer binder especially in oil palm-rich country such as Malaysia and Thailand due to its increasing amount which rendered the disposal method in the mean of landfilling not feasible [4,11,23]. Other industrial by products, for examples rice husk ash (RHA) from the rice milling industry, red mud (RM) from the alumina refining industry, copper and hematite mine tailings from the mining industry etc [14,20,24,25] has also find considerable interest in the fabrication of geopolymer concrete.

The ever present problem in reducing the use of OPC in construction industry, coupled with the problems in disposing industrial by-product in various industries, geopolymer binder certainly has all the potential to replaces OPC as the binder in construction industry. Thus, it is the aim of this paper to review the current trends in geopolymer concrete, focusing solely on geopolymeric binders based on industrial waste materials, along with the various effects such as chemical activators, curing regime, additives,