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Review

Geopolymer concrete: A review of some recent developments

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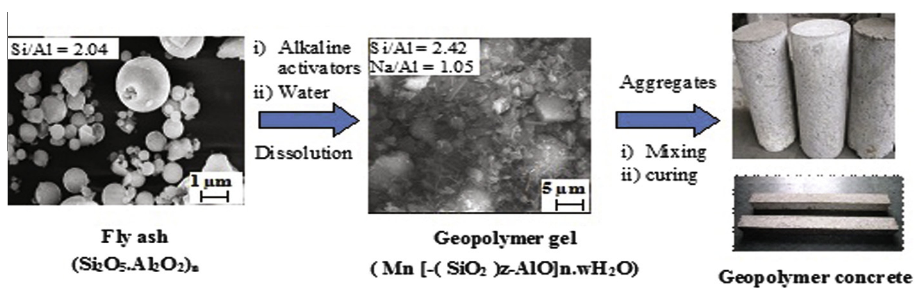
H I G H L I G H T S

- An overview of geopolymer is presented alongwith its processing parameters.
- The hardened properties and durability of geopolymer concrete are discussed.
- The design guidelines for OPC concrete are applicable to geopolymer concrete also.
- Geopolymeric building products developed at CSIR-CBRI are highlighted.
- Ambient cured single component geopolymer may enhance its wider use in the field.

G R A P H I C A L   A B S T R A C T

Conversion of fly ash into geopolymers/concrete.



A R T I C L E   I N F O

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An overview of advances in geopolymers formed by the alkaline activation of aluminosilicates is presented alongwith opportunities for their use in building construction. The properties of mortars/concrete made from geopolymeric binders are discussed with respect to fresh and hardened states, interfacial transition zone between aggregate and geopolymer, bond with steel reinforcing bars and resistance to elevated temperature. The durability of geopolymer pastes and concrete is highlighted in terms of their deterioration in various aggressive environments. R&D works carried out on heat and ambient cured geopolymers at CSIR-CBRI are briefly outlined alongwith the product developments. Research findings revealed that geopolymer concrete exhibited comparative properties to that of OPC concrete which has potential to be used in civil engineering applications.

Contents

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1. Introduction

The concrete industry faces challenges to meet the growing demand of Portland cement due to limited reserves of limestone, slow manufacturing growth and increasing carbon taxes. It is reported that the requirement of cement in India is likely to touch ~550 million tonnes by 2020 with a shortfall of ~230 million tonnes (~58%) and the demand for cement has been constantly increasing due to increased infra-structural activities of the country [1]. One effort to combat shortfall is the development of alternate binders to Portland cement aiming at to reduce the environmental impact of construction, use of greater proportion of waste pozzolan, and also to improve concrete performance. Search for several alternatives such as alkali-activated cement, calcium sulphoaluminate cement, magnesium oxy carbonate cement (carbon negative cement), supersulphated cement etc. are being made with the advantages of Portland cement [2]. As the family of the alkali-activated cement is growing, the alkaline cement is classified based on a phase composition of the hydration products: R-A-S-H (R = Na^+ or K^+) in the aluminosilicate based systems and R-C-A-S-H in the alkali-activated slag or alkaline Portland cements [3]. In recent years, geopolymer has attracted considerable attention among these binders because of its early compressive strength, low permeability, good chemical resistance and excellent fire resistance behaviour [4–9]. Because of these advantageous properties, the geopolymer is a promising candidate as an alternative to ordinary Portland cement for developing various sustainable products in making building materials, concrete, fire resistant coatings, fibre reinforced composites and waste immobilization solutions for the chemical and nuclear industries.

2. An overview of geopolymers

Geopolymer is considered as the third generation cement after lime and ordinary Portland cement. The term "geopolymer" is generically used to describe a amorphous alkali aluminosilicate which is also commonly used for to as "inorganic polymers", "alkali-activated cements", "geocements", "alkali-bonded ceramics", "hydroceramics" etc. Despite this variety of nomenclature, these terms all describe materials synthesized utilising the same chemistry [4]. It essentially consists of a repeating unit of sialate monomer (–Si–O–Al–O–). A variety of aluminosilicate materials such as kaolinite, feldspar and industrial solid residues such as fly ash, metallurgical slag, mining wastes etc. have been used as solid raw materials in the geopolymerization technology. The reactivity of these aluminosilicate sources depends on their chemical make-up, mineralogical composition, morphology, fineness and glassy phase content. The main criteria for developing stable geopolymer are that the source materials should be highly amorphous and possess sufficient reactive glassy content, low water demand and be able to release aluminium easily. The alkaline activators such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate (Na_2SiO_3) and potassium silicate (K_2SiO_3) are used to activate aluminosilicate materials. Compared to NaOH, KOH showed a greater level of alkalinity. But in reality, it has been found that NaOH possesses greater capacity to liberate silicate and aluminate monomers [4]. The properties of geopolymers can be optimised by proper selection of raw materials, correct mix and processing design to suit a particular application [4]. Viewing the importance of the subject, a collaborative project sponsored by the European Commission – BRITE was undertaken jointly by France, Spain and Italy on development of "Cost-effective geopolymeric cement for innocuous stabilization of toxic elements (GEOCISTEM)". The project was aimed at manufacturing geopolymeric cement by replacing potassium silicate with cheaper alkaline volcanic tuffs [9].

Geopolymers are synthesized by the reaction of a solid aluminosilicate powder with alkali hydroxide/alkali silicate [8]. A schematic representation on formation of fly ash-based geopolymers/concrete is shown in Fig. 1. Under highly alkaline conditions, polymerisation takes place when reactive aluminosilicates are rapidly dissolved and free $[SiO_4]^-$ and $[AlO_4]^-$ tetrahedral units are released in solution. The tetrahedral units are alternatively linked to polymeric precursor by sharing oxygen atom, thus forming polymeric Si–O–Al–O bonds. The following reactions occur during geopolymerisation [7].

$$(Si_2O_5.Al_2O_2)_n + H_2O + OH^- \rightarrow Si(OH)_4 + Al(OH)^{4-} \quad (1)$$

$$Si(OH)_4 + Al\,(OH)^{4-} \longrightarrow (\text{-}\underset{|}{\overset{|}{Si}}\text{-O-}\underset{|}{\overset{|}{Al}}\text{-O-})_n + 4H_2O \quad (2)$$
$$\qquad\qquad\qquad\quad O \quad\; O$$

This process releases water that is normally consumed during dissolution. The water, expelled from geopolymer during the reaction provides workability to the mixture during handling. This is in contrast to the chemical reaction of water in Portland cement mixture during the hydration process. It is reported that the hydration products of metakaolin/fly ash activation are zeolite type: sodium aluminosilicate hydrate gels with different Si/Al ratio whereas the major phase produced in slag activation is calcium silicate hydrate with a low Ca/Si ratio. Though many physical properties of geopolymers prepared from various aluminosilicate sources may appear to be similar, their microstructures and chemical properties vary to a large extent. The metakaolin-based geopolymer has an advantage that it can be manufactured consistently, with predictable properties both during the preparation and development. However, its plate-shaped particles lead to rheological problems, increasing the complexity of processing as well as the water demand of the system [6]. Contrary to this, the fly ash-based