Geopolymer

The dominant aluminosilicates are class F fly ash and ground granulated blast furnace slab (GGBS).

Provis (2014) reports that the chemistry of low calcium ("geopolymer") and high calcium (blast furnace slag-derived) alkali-activated material differ from each other. He also reports that the underlying mechanisms of degradation in such materials may not be always the same for alkali-activated binders as for Portland cement-based binders. According to Chao, Sun, & Longtu (2010), there are two main models of alkali-activated cements. They are activation of slag and metakaolin. In the first case of alkali activation of GGBS, the Si + Ca system dominates. In the second case of a geopolymer made with metakaolin and fly ash, Si + Al dominate. The main drawback in this case is a very high water requirement, which in turn causes difficulties related to drying shrinkage and cracking of the material.

Geopolymer composites have a very small greenhouse footprint when compared to traditional cement composites. The study by Shi & Fernandez-Jiménez (2006) concludes that alkali-activated cements are a better matrix for solidification/stabilization of hazardous and radioactive wastes than ordinary Portland cement. Geopolymer concrete possesses excellent similar strength and appearance similar to conventional concrete made from Portland cement (Hardjito, Wallah, Sumajouw, & Rangan, 2004). It is also well-known that geopolymers possess excellent mechanical properties, fire resistance and acid resistance (Davidovits & Davidovits, 1988; Palomo, Macias, Blanco, & Puertas, 1992).

The choice of the source materials for making geopolymers depends on availability, cost, type of application, etc. Studies by Zhao, Ni, Wang, and Liu (2007) have confirmed the formation of mainly ettringite and calcium silicate hydrate gel in the activation of GGBS and class F fly ash pastes. According to Astutiningsih & Liu (2005), the strength of alkali-activated slag decreases as the water content increases.

According to Montes, Islam, Shi, Kupwade-Patil, & Allouche (2013), the materials prepared by geopolymerization of fly ash and GGBS offer considerable resistance to freeze-thaw action, sulfate attack, sulfuric acid attack and nitric acid attack compared to Portland cement products. Sakkas, Nomikos, Sofianos, & Panias (2014) report that the sodium-based geopolymer from slag would be an appropriate material for passive fire protection systems. In the absence of long-term durability of geopolymers, comparable in scale and longevity to Portland cement, well-established testing methods and research are essential to validate the laboratory trials. Van Deventer, Provis, & Duxson (2012) are of the opinion that colloid and interface science, gel chemistry, phase formation, reaction kinetics, transport phenomena, communication, particle packing and rheology play a salient role in the development of geopolymer technology.

A report by Dahmen & Muñoz (2014) indicates that geopolymerization of abundant minerals such as aluminosilicates has the capacity to radically transform traditional cement-based masonry products on a global scale.

It is possible to tailor the geopolymer material to attain the required strength and durability to optimize the cost. Given the correct mix design and formulation development, geopolymeric materials derived from fly ash and GGBS can exhibit superior chemical and mechanical properties over those of OPC composites. But no literature is reported so far about the logical mix proportioning of the geopolymer mix except those of Rangan (2008a, 2008b). Trial mix is essential for exact proportions of the concrete mix. As geopolymers are highly complex and yet relatively poorly understood, there are clearly many areas in which further work is required (Duxson, Provis, Lukey, & Van deventer, 2007). There are attempts to develop phenomenological models to reproportion geopolymer mortar and concrete (Radhakrishna, Madhava, Manjunath, & Venugopal, 2013; Radhakrishna & Udayashankar, 2008; Radhakrishna, Udayashankar, & Renuka Devi, 2010). Such models were reported for fly ash, as well as lime-based masonry blocks (Radhakrishna & Niranjan, 2013).

The vast majority of research conducted in the field of geopolymers has to date focused on manipulation of engineering properties, short-term durability and waste immobilization efficacy. The objective of this chapter is therefore to remedy this situation by developing methods to reproportion the geopolymer mortar under the framework of scientific laws rather than simply by empirical mix formulation. The possibility of developing phenomenological models to take care of this situation merits examination. Methods of accounting different parameters involved in strength development of fly ash and GGBS-based thermal cured/ambient cured geopolymer masonry blocks is the major outcome of this chapter.

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27th European Symposium on Computer Aided Process Engineering

Michael A.B. Promentilla, ... Raymond R. Tan, in Computer Aided Chemical Engineering, 2017

Abstract

Geopolymer is an inorganic polymer binder formed from the alkaline activation of reactive alumino-silicate materials resulting in two- or three-dimensional polymeric network. It is a promising alternative to Portland cement-based materials because of its lower embodied energy and carbon footprint with potential for waste valorization. Studies have been done to develop such material with desired engineering specification by using statistical design of experiment and optimizing the process conditions or mix formulation of waste materials. However, it is not only the engineering properties such as its mechanical and thermal properties, but also other properties pertaining to green materials (e.g., embodied energy and carbon footprint) have to be considered. Conflicting objectives may also have to be satisfied simultaneously to find a compromised solution in the product design such as that of maximizing the strength and minimizing the volumetric weight. This work thus proposes a weighted max-min aggregation approach to multi-objective optimization of the geopolymer product using fuzzy programming approach. The optimization formulation was introduced such that fuzzy sets represent both the aspired product desirability and soft constraints; the optimal mix is then found by maximizing the simultaneous satisfaction of target properties of the desired product. This work also proposes an extension of such fuzzy optimization formulation wherein the nature of trade-off between improving the product desirability and satisfying the fuzzy constraints are made explicit. The relative importance of the properties as represented by priority weights were derived systematically using Analytic Hierarchy Process (AHP). A case study on a ternary blended geopolymer from coal fly ash, coal bottom ash, and rice hull ash is presented to illustrate the proposed method.

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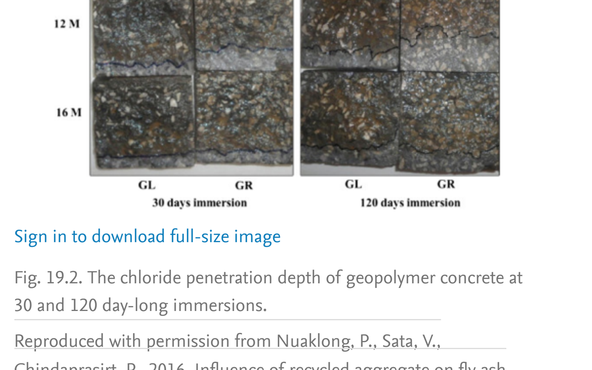

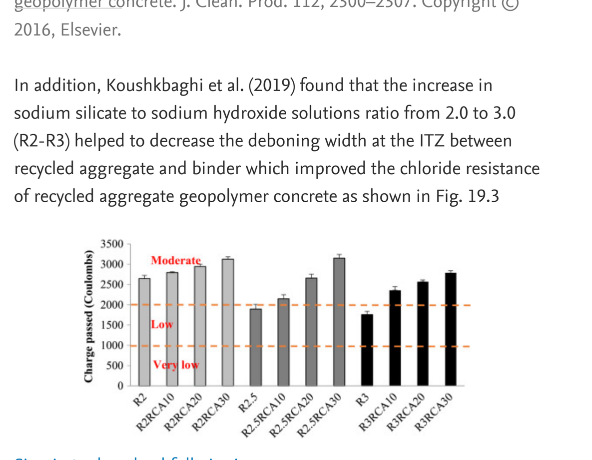

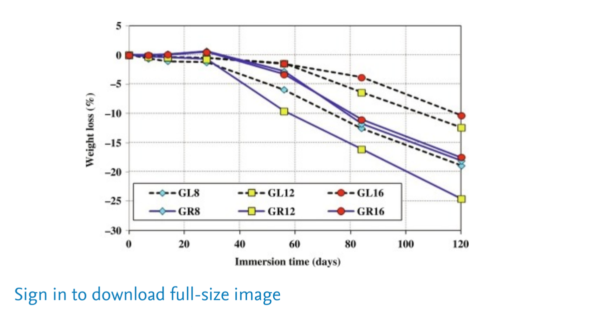

strength of hardened geopolymer concrete increased with a slight loss in the workability of the fresh concrete.

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An overview of cementitious construction materials

Nagesh R. Iyer, in New Materials in Civil Engineering, 2020

1.3 Geopolymer concrete

1.3.1 Introduction

Geopolymer cements, eco-cements, and sulfoaluminate cements are considered as three alternative cements holding high potential in recent years [2,13]. Geopolymer cement concretes (GPCCs) are the most preferred among the new binder systems. Geopolymer is a generic and broad term. It comprises nine classes of materials representing a chain of inorganic molecules. However, Class F material consisting of aluminosilicate materials qualifies for civil engineering applications as it has the potential to replace partially at least OPC. However, its utility for structural and nonstructural elements and its durability characteristics need to be established from extensive R&D studies [2].

The program on waste to wealth undertaken internationally to use the large amount of industrial wastes and by-products by cleverly attempting to replace partially or substitute the ingredients of concrete mix mainly, cement and aggregates have been the subject of research and applications. Some of these wastes include FA, ground granulated blast furnace (GGBS), alkaline sludges like red mud, and other materials. The wastes used are not necessarily pozzolanic. Considering these aspects, deployment of GPC can provide significant environmental benefits. Over OPC, the setting process in GPC is much faster and does not affect the hydration process. The polymerization takes place under alkaline conditions on silicon–aluminum minerals. This creates a three-dimensional polymeric chain and ring structure. The ratio of Si to Al determines the final structure of the geopolymer. This mix gains strength over different timescales. However, one disadvantage is that one needs over 30°C temperature scales for curing. This results in a reduction of the extent of amorphous order within the binder. Aside from their application as high-performance cements, GPCs find a range of niche applications such as in automobile car parts, waste immobilization, thermal boards, roof tiles, tooling materials, and decorated ceramics. GPCs result in a microstructure that is more heat resistant, fire resistant, and that has superior thermal expansion, cracking, and swelling properties compared to PC. They exhibit a smooth surface and can be molded easily.

Several studies indicate that for geopolymerization, natural Al–Si minerals are most suitable. Due to the complexity of the reaction mechanisms involved, it is as yet difficult to identify and assess the suitability of the specific mineral. So far, FA and slags such as GGBS which are the by-products, have shown very encouraging results for use as geopolymers in the studies conducted. Between FA and slag, FA exhibits high reactivity—one of the reasons for this being that FA is finer than slag.

1.3.2 Development of structural grade geopolymer cement concretes

There are no standard mix design approaches available for GPCs. As mentioned earlier, the water–cement ratio influences the strength of cement concrete. Studies have been conducted for the formulation of the GPC mixtures on a trial-and-error basis through liquid to binder (l/b) ratio and suitable composition of GPC solids (GPS). This is done till it meets the workability and strength requirements through a good cohesive mix. Recommended requirements for such mix are slump of 75–100 mm and 28-day compressive strength of 20–45 MPa [14–16]. The mixes were designed such that the test specimens cast were demoldable after 24 hours of wet gunny curing and the required strength could be realized after 28 days. Table 1.1 shows the typical mix composition of the geopolymer concrete.

Table 1.1. Typical mix composition for GPCC [2].

Mix ID	Binder	Mix proportion (B:S:CA)	Molar ratios H_2O/Na_2O	SiO_2/Na_2O	SiO_2/Al_2O_3	Na
FAB-1	75% F 25% G	1:1.64:2.82	7.77	2.49	4.24	0.3
FAB-2	75% F 25%G	1:1.43:2.6	10.34	3.18	4.58	0.2
FAB-3	75% F 25% G	1:1.10:1.83	9.61	3.64]	4.43	0.2
GGB-1	0% F 100% G	1:184:2.82	11.96	5.36	4.30	0.1
GGB-2	25% F 75% G	1:1.78:2.82	9.42	3.78	4.16	0.2
GGB-3	50% F 50% G	1:1.64:2.62	6.80	2.72	3.97	0.2
CC1	OPC	1:2.35:2.95	–			
CC2	OPC	1:1.95:2.58	–			
CC3	OPC	1:1.49:2.15				

B, Binder; *CA*, coarse aggregate; *F*, FA; *G*, GGBS; *l/b*, liquid/binder; *S*, sand.

The mechanical properties of the GPCC mixes, including the stress–strain characteristics, were evaluated. Table 1.2 shows the strength characteristics of the mixes.

Table 1.2. Strength characteristics of the mixes [2].

Mix ID	Binder	σ_{cu}, MPa	σ_{ft}, MPa	E_c, GPa	σ_{ft}, MPa (IS-456)	E_c, GPa (IS-456)	E_c, GPa (ACI-318)
FAB-1	75% F, 25% G	17	2.35	11.2	2.07	14.79	14.7
FAB-2	75% F, 25%G	49	4.65	20.8	4.47	31.92	25.0
FAB-3	75% F, 25% G	52	4.81	22.4	4.63	33.07	25.8
GGB-1	0% F, 100% G	63	5.53	28.3	5.18	37.00	28.4
GGB-2	25% F, 75% G	57	4.84	26.5	4.89	34.91	27.0
GGB-3	50% F, 50%G	52	4.86	22.7	4.63	33.07	25.8
CC1	OPC	35	4.03		3.62	25.86	24.9
CC2	OPC	41	4.32		4.01	28.61	26.9
CC3	OPC	52	4.85		4.63	33.07	30.3

σ_{cu}, Compressive strength; σ_{spt}, split tensile strength; σ_{ft}, flexural tensile strength; E_c, elastic modulus.

The elastic modulus of high-volume GGBS-based GPCCs was slightly less than that of conventional OPCCs but the high-volume FA-based GPCCs showed considerably lower elastic modulus compared to OPCCs. The strain at peak stress ranged from 3216 to 4516 μm/m for GPCCs, which is higher than that for CCs (around 2700 microstrains). The strain at failure ranged up to 6000 μm/m.

1.3.3 Geopolymer cement concrete building blocks and paver blocks

With the scarcity in availability of fired clay bricks, concrete building blocks and pavers are the most widely used concrete components other than structural concrete [17]. Therefore the use of eco-friendly GPCCs in lieu of OPCCs for the production of building blocks is an attractive proposal. Table 1.3 shows the engineering properties of some of the paver blocks with indigenous materials, the GPCC-based building blocks and pavers are feasible on a large scale and using the same tools and plants as OPCC elements, and these blocks meet the relevant performance requirements. This technology was released by CSIR-SERC to AEON Construction Products Ltd., Chennai, in 2008–09 [18].

Table 1.3. Engineering properties of GPCC building/paver blocks.

ID	Average value of σ_{cu} (MPa)	σ_{spt} (MPa)	SD (MPa)	Suitable application	Grade designation as per IS code	Average value of Water absorption (%)	SD (%)
GB1	18.2	4.85	2.2	Building block	Grade A[a]	3.3	1.0
GB2	36.4	6.33	4.3	Paver block	M-30+	2.4	0.47
GB3	57.2	8.15	4.9		M-50+	1.2	0.29
GB4	58.0	6.14	4.9		M-50+	0.7	0.23
GB5	53.8	5.44	4.3		M-50+	1.4	0.8
FB1	22.6	3.77	2.8	Building block	Grade A[a]	4.3	1.0
FB2	18.3	3.66	3.3		Grade A[a]	4.9	2.5
FB3	26.3	4.14	4.1		Grade A[a]	4.0	1.4
FB4	28.8	5.14	4.6		Grade A[a]	3.7	1.6
FB5	27.2	4.76	4.4		Grade A[a]	3.1	1.9
LWG	23.2	-	4.6		Grade A[b]	5.3	1.5
LWF	20.7	-	4.4		Grade A[b]	5.8	1.6
LWC	19.9	-	2.0		Grade A[b]	4.3	1.1

σ_{cu}, Compressive strength; σ_{spt}, split tensile strength; *SD*, standard deviation.

a IS: 1185 -Part I(C & M 8).

b IS:1185-Part 2 (C & M 9),+IS:15658 (C & M 19).

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