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Geopolymer

Geopolymer binder is formed when the dissolved Al2O3 and SiO2 minerals undergo geopolymerization to form a three-dimensional (3D) amorphous aluminosilicate network with strength similar or higher than that of OPC concrete.

From: Handbook of Low Carbon Concrete, 2017

Related terms:

Zeolite, Binders, Compressive
Strength, Sodium Silicate,
Activator, Geopolymerization,
Geopolymers, Metakaolin, Ordinary
Portland Cement, Portland Cement
Concrete

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The properties and durability of alkaliactivated masonry units

AhmariS. , ZhangL. , in Handbook of Alkali-Activated Cements, Mortars and Concretes, 2015

24.6 Summary and future trends

Geopolymer binder has been proven to possess excellent physical and mechanical properties and durability. Different applications of geopolymer binders, such as concrete, <u>coating material</u>, and <u>masonry</u> <u>units</u>, have been studied. Study of GMU from different types of waste materials indicates that GMU is a superior replacement for regular MU, especially considering the environmental impacts of solid wastes and the sustainability issues related to usage of natural materials and energy. For wide application of GMU, the major issue is the transition from research stage to <u>commercialization</u>. GMU standardization and public education are the main steps to achieve this goal. Further research is also needed to study the long-term durability of GMU and the environmental and economic benefits of utilizing waste materials to produce GMU.

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Bond Between Steel Reinforcement and Geopolymer Concrete

A. Castel, in Handbook of Low Carbon Concrete, 2017

14.2.1 GPC Mixes and Curing Regime

Two GPC mixes were used for this study. They were designed using the outcomes from both literature [15–21] and laboratory trials where different aluminosilicate materials proportions (FA and GGBFS), various activator concentration (8–14 M), and diverse activator-toaluminosilicate source ratio (0.42–0.6) were tested.

Three different sources of aluminosilicate materials have been used in this study: a low-calcium type (ASTM C 618 Class F) FA, sourced by Eraring Power Station in New South Wales, Australia; a special-grade (ultrafine) FA branded as Kaolite High-Performance Ash (HPA) sourced by Callide Power Station in Queensland, Australia; and a GGBFS supplied by Blue Circle Southern Cement Australia. All details related to those three aluminosilicate materials such as oxide compositions and grading curves are available in Ref. [22]. The alkaline solution was made from a mixture of 12 molar (M) <u>sodium</u> <u>hydroxide</u> (NaOH) solution and <u>sodium silicate</u> solution with Na₂O. The mass ratio of alkaline solution to aluminosilicate material was 0.55.

The two GPC mixes are presented in Table 14.1. The first GPC mix (labeled GPC-FA) contains only 15% GGBFS. It is a low-calcium GPC. The second GPC mix (labeled GPC-S) contains 75% GGBFS. It is a high-calcium GPC. All GPCs were compacted using a poker vibrator and demoded 24 h after casting. The low-calcium GPC, GPC-FA, required an intense heat curing to achieve an acceptable performance. Two types of heat curing conditions were adopted:

Table 14.1. Geopolymer concrete mixes

	GPC-FA (kg/m ³)	GPC-S (kg/m ³)	
FA	193.5	80	
Kaolite HPA	51.9		
GGBFS	42.5	240	
Crushed coarse aggregate 1/10 kg/m ³	1144.6	1215.2	
Sand 0/1 kg/m ³	710.4	714.8	
Free water, kg/m ³	59	25.5	
Sodium hydroxide solution (NaOH)	45.2	54.9	
Sodium silicate solution (Na2SiO3)	112.9	137.1	

- 2D-curing: After casting, specimens were sealed to prevent excessive loss of moisture, stored in an 80°C oven for 1 day, and then cured in an 80°C water bath for a further 1 day. Then, all specimens where transferred to a controlled room at 23°C and 65% relative humidity until the day of the test.
- 2. 7D-curing: After casting, specimens were sealed to prevent

Utilization of industrial by-products and natural ashes in mortar and concrete development of sustainable construction materials

Rafat Siddique, ... Ankur Mehta, in Nonconventional and Vernacular Construction Materials (Second Edition), 2020

11.7.3.4 Summary

Geopolymer concrete can be seen as a more viable and sustainable solution to highly energy intensive conventional <u>Portland cement</u> <u>concrete</u>. The utilization of various industrial by-products such as fly ash, <u>GGBS</u>, <u>rice husk ash</u>, etc. as polymerized binder also alleviates their disposal problem as well. High early age <u>compressive strength</u> can be produced in geopolymer concrete. However, the major constraint of the use of GPC in is the requirement for hightemperature curing. Extensive research is still required to obtain standard design mixtures of geopolymer concrete as well as to mitigate the need for high-temperature curing.



Use of construction and demolition waste (CDW) for alkali-activated or geopolymer concrete

Vanchai Sata, Prinya Chindaprasirt, in Advances in Construction and Demolition Waste Recycling, 2020

19.3.2 Durability properties

Geopolymer concrete is more durable than Portland cement concrete, because the product obtained from the polymerization reaction is different from the cement hydration reaction, as mentioned in the previous section. Geopolymer concrete containing recycled concrete has higher permeable void volume, water absorption, and rate of sorptivity than the normal aggregate (crushed limestone)-based concrete for the same sodium hydroxide solution concentration (Nuaklong et al., 2016). The high porosity of old cement mortar in the recycled aggregate serves as a potential conduit for water transportation in concrete. Increased recycled aggregate content, pores at the microstructure interfacial transition zone (ITZ), and looser structure decrease the density of the matrix (Shi et al., 2012).

The rate of water absorption by concrete is a function of the pore system penetrability. Therefore, concrete with high porosity can absorb more water, resulting in higher chloride penetration. The boundaries of the chloride penetration depth by spraying silver nitrate (AgNO₃) on samples after immersion in a 3% NaCl solution of normal geopolymer concrete (GL) and recycled aggregate geopolymer concrete (GR), for different sodium hydroxide solution concentrations (8–16 Molars), at 30 and 120 day-long immersions, are shown in Fig. 19.2. Chloride can penetrate deeper into geopolymer concrete that contains recycled aggregates, compared with the normal aggregate geopolymer concrete. However, a mixture with a high sodium hydroxide solution concentration can reduce the chloride penetration for geopolymer concretes containing both aggregates (Nuaklong et al., 2016). The dissolution of Si and Al in the source material increases as the sodium hydroxide solution concentration increases. Further, the higher amounts of dissolved Si and Al yield a better polycondensation process in the geopolymer system and reduce porosity and chloride ingression (Mikuni et al., 2007; Chindaprasirt and Chalee, 2014; Gunasekara et al., 2019).



30 days immersion Sign in to download full-size image

excessive loss of moisture, stored in a 40°C oven for 1 day, and then cured in an 80°C water bath for a further 7 days. All specimens where then transferred to a controlled room at 23°C and 65% relative humidity until the day of the test.

The high-calcium geopolymer concrete GPC-S was ambient cured in a controlled environment ($T = 23^{\circ}$ C, RH =65%).



Coal combustion products in green building

L. Lemay, in Coal Combustion Products (CCP's), 2017

17.3.3 Geopolymers

Geopolymer concrete combines an alkaline liquid with a geological source material containing silicon and aluminum to form a binder that does not use any <u>Portland cement</u>. Because the chemical reaction that takes place is a polymerization process, the material is called a geopolymer. The geological source material can come from naturally occurring materials such as kaolites and clays or by-product materials such as fly ash, <u>silica fume</u>, slag, <u>rice-husk ash</u>, etc. Fly ash, being one of the most abundant source materials with the necessary properties, is the most commonly used source material for geopolymer concrete. The alkaline liquids come from soluble alkaline metals such as sodium or potassium such as combinations or <u>sodium hydroxide</u> and <u>potassium hydroxide</u> and <u>sodium silicate</u> or potassium silicate.

The mechanical properties of geopolymer concrete is similar to that of <u>Portland cement concrete</u>, and therefore can be used as a substitute for Portland cement. Geopolymer concrete gains strength similar to Portland cement concrete, is resistant to <u>sulfate attack</u>, has good acid resistance, and undergoes very little creep and <u>drying</u> <u>shrinkage</u>. It is ideal where durable concrete is a must. Structural tests on reinforced concrete elements such as beams and columns demonstrate similar behavior to ordinary Portland cement concrete.

One drawback is that the alkaline liquid is expensive to manufacture, and thus geopolymer concrete has not been commercialized to replace ordinary Portland cement concrete. However, some companies have commercialized it for specialty applications where high fire or chemical resistance is required. Obviously, if the process could be made more economical, it would provide an excellent opportunity to lower the <u>environmental footprint</u> of concrete construction.

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Biomass fly ash and biomass bottom ash

Francisco Agrela, ... Mazen Alshaaer, in New Trends in Eco-efficient and Recycled Concrete, 2019

2.4.6 Use of BA-based geopolymers for thermal and acoustic insulation

Geopolymer concrete leads to an excellent new material that will save operational energy due to its low density and relatively lower thermal conductivity than normal-weight concrete (Zhang et al., 2014). Moreover, Liu and his colleagues (Liu et al., 2014, 2016) have introduced the foamed technique into geopolymer materials to improve thermal insulation. In their initial investigation regarding the behaviour of palm oil-shell foamed geopolymer concrete utilising industrial wastes such as palm oil shell as lightweight coarse aggregate and POFA and coal FA as binder mix in concrete, they produced a geopolymer with densities between 1300 and 1700 kg/m³ due its higher porosity. Despite the fact of a reduction in compressive strength, they concluded that a thermal conductivity of about 0.47 W/m K was 22% and 48% lower than blocks and bricks as conventional materials for walls. Hence this geopolymer could be categorised as structural concrete Class I (compressive strength more than 15 MPa) and structural and insulating concrete Class II (compressive strength between 3.5 and 15 MPa and thermal conductivity less than 0.75 W/m K) according to the RILEM (1983) classification.

From the point of view of the acoustic properties of BA-based geopolymer, it is well-known that the sound absorption of a porous material is related to the loss of noise by friction in the wall of its pores (Park et al., 2005), so that geopolymer concrete which presents a high open voids ratio will have a greater sound absorption coefficient than less-porous concrete (Kim et al., 2012). Nevertheless, no study has been found in the literature regarding to the use of biomass ash in geopolymers with the purpose of enhancing its acoustic properties. The development and application of geopolymers manufactured with biomass ashes as insulated materials can contribute to the environmental impact on buildings reducing the energy demand both during the construction and use.

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Design and properties of fly ash, ground granulated blast furnace slag, silica fume and metakaolin geopolymeric based masonry blocks

Radhakrishna, in Eco-Efficient Masonry Bricks and Blocks, 2015

Fig. 19.2. The chloride penetration depth of geopolymer concrete at 30 and 120 day-long immersions.

Reproduced with permission from Nuaklong, P., Sata, V., Chindaprasirt, P., 2016. Influence of recycled aggregate on fly ash geopolymer concrete. J. Clean. Prod. 112, 2300–2307. Copyright © 2016, Elsevier.

In addition, Koushkbaghi et al. (2019) found that the increase in sodium silicate to sodium hydroxide solutions ratio from 2.0 to 3.0 (R2-R3) helped to decrease the deboning width at the ITZ between recycled aggregate and binder which improved the chloride resistance of recycled aggregate geopolymer concrete as shown in Fig. 19.3



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Fig. 19.3. Effect of sodium silicate to sodium hydroxide ratio (R2-R3) and 10%–30% recycled aggregate replacement (RCA10-30) on the chloride permeability of geopolymer concretes.

Reproduced with permission from Koushkbaghi, M., Alipour, P., Tahmouresi, B., Mohseni, E., Saradar, A., Sark, P.K., 2019. Influence of different monomer ratios and recycled concrete aggregate on mechanical properties and durability of geopolymer concretes. Constr. Build. Mater. 205, 519–528. Copyright © 2019, Elsevier.

In general, the deterioration under the acid attack of Portland cement-based materials is primarily a reaction between calcium hydroxide [Ca(OH)₂] and an acid solution that causes tensile stress, cracking, and scaling of the cement matrix. The excellence in sulfuric acid resistance of geopolymer-based binders is caused by a low water absorption and calcium hydroxide content, which creates less soluble products (Pacheco-Torgal and Jalali, 2011). The main components of the geopolymer binders are Si, Al, O, and Na, which have better resistance than those of Portland cement systems. The resistance of the geopolymer matrix in magnesium sulfate solution and sulfuric acid was better than that of the Portland cement mortar (Sata et al., 2011; Elyamany et al., 2018).

The weight loss of geopolymer concrete increases significantly with immersion time after 14 days of sulfuric acid immersion, as shown in Fig. 19.4. The aggregate particles are damaged owing to the sulfuric acid reacting with calcium compounds in crushed limestone, which results in the destruction of its particle. The weight loss after 28 days of limestone aggregate geopolymer is related to the concentration of sodium hydroxide solution, and the resistance increases as the sodium hydroxide solution concentration increases. At the same concentration, recycled aggregate geopolymer concrete exhibits lower acid resistance than normal aggregate geopolymer concrete. This occurs owing to the higher water absorption, permeable void volume, and sorptivity of recycled aggregates. In addition, calcium compounds in the old mortar (cement mortar) react with the acid solution and cause more deterioration.



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Fig. 19.4. Weight loss after immersion in a 3% sulfuric acid of limestone aggregate (GL) and recycled aggregate (GR) geopolymer concretes, for different sodium hydroxide solution concentrations. Reproduced with permission from Nuaklong, P., Sata, V., Chindaprasirt, P., 2016. Influence of recycled aggregate on fly ash geopolymer concrete. J. Clean. Prod. 112, 2300–2307. Copyright © 2016, Elsevier.

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Engineering properties of geopolymer concrete

B.V. Rangan, in Geopolymers, 2009

11.3.2 Production

Geopolymer concrete can be produced by adopting the conventional techniques used in the manufacture of <u>Portland cement concrete</u>. In the laboratory, the fly ash and the aggregates were first mixed together dry in an 80-litre capacity pan mixer for about three minutes. The alkaline liquid was mixed with the super plasticiser and the extra water, if any. The liquid component of the mixture was then added to the dry materials and the mixing continued for another four minutes. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the <u>compressive</u> strength. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete (Hardjito and Rangan, 2005; Wallah and Rangan, 2006; Sumajouw and Rangan, 2006). The compressive strength and workability of geopolymer concrete are also influenced by the wet-mixing time (Hardjito and Rangan, 2005). As the wet-mixing time increased, the compressive strength of hardened geopolymer concrete increased with a slight loss in the workability of the fresh concrete.

15.1 Introduction

<u>Geopolymer</u> is the name given to a wide range of alkali or silicateactivated <u>aluminosilicate</u> binders. Since the chemical reaction that takes place in this case is a <u>polymerization process</u>, Davidovits (1994, p. 9, 1999) coined the term 'geopolymer' to represent these binders. The dominant <u>aluminosilicates</u> 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 <u>geopolymer</u> 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 <u>colloid</u> 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, shortterm 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 <u>multi-objective</u> 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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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 siliconaluminum 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 (I/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	Molar ratios				
Mix ID	Binder	proportion (B:S:CA)	H ₂ O/Na ₂ O	SiO ₂ /Na ₂ O	SiO ₂ /Al ₂ O 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	_				
CC2	ODC	1.1 40.2 15					

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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 μ m/m for GPCCs, which is higher than that for CCs (around 2700 microstrains). The strain at failure ranged up to 6000 μ m/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				Grade	Average value of	
	σ _{cu} (MPa)	σ _{spt} (MPa)	SD (MPa)	Suitable application	designation uitable as per IS oplication code	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	0.45
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.

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