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Geopolymer Concrete with Fly Ash

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ABSTRACT

Geopolymer concrete results from the reaction of a source material that is rich in silica and alumina with alkaline liquid. A summary of the extensive studies conducted on fly ash-based geopolymer concrete is presented. Test data are used to identify the effects of salient factors that influence the properties of the geopolymer concrete and to propose a simple method for the design of geopolymer concrete mixtures. Test data of various short-term and long-term properties of the geopolymer concrete and the results of the tests conducted on large-scale reinforced geopolymer concrete members show that geopolymer concrete is well-suited to manufacture precast concrete products that can be used in infrastructure developments. The paper also includes brief details of some recent applications of geopolymer concrete.

INTRODUCTION

Davidovits [1988] proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders. Geopolymer concrete is concrete which does not utilize any Portland cement in its production. Geopolymer concrete is being studied extensively and shows promise as a substitute to Portland cement concrete. Research is shifting from the chemistry domain to engineering applications and commercial production of geopolymer concrete.

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials. The choice of the source materials for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide ($NaOH$) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

This paper is devoted to heat-cured low-calcium fly ash-based geopolymer concrete. Low-calcium (ASTM Class F) fly ash is preferred as a source material than high-calcium (ASTM Class C) fly ash. The presence of calcium in high amounts may interfere with the polymerization process and alter the microstructure [Gourley and Johnson, 2005].

GEOPOLYMER PRODUCTION

Mixture Proportions of Geopolymer Concrete

The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminium oxides in the low-calcium fly ash reacts with the alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, fine aggregates, and other un-reacted materials together to form the geopolymer concrete. As in the case of Portland cement concrete, the coarse and fine aggregates occupy about 75 to 80% of the mass of geopolymer concrete. The influence of aggregates, such as grading, angularity and strength, are considered to be the same as in the case of Portland cement concrete [Lloyd and Rangan, 2009]. Therefore, this component of geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete.

Studies have been carried out on fly ash-based geopolymer concrete. The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste. Research results [Hardjito and Rangan, 2005] have shown the following:

- Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of geopolymer concrete.
- Higher ratio of sodium silicate solution-to-sodium hydroxide solution ratio by mass, results in higher compressive strength of geopolymer concrete.
- The slump value of the fresh geopolymer concrete increases when the water content of the mixture increases. Superplasticizers may assist in improving workability.
- As the H_2O-to-Na_2O molar ratio increases, the compressive strength of geopolymer concrete decreases.

As can be seen from the above, the interaction of various parameters on the compressive strength and the workability of geopolymer concrete is complex. In order to assist the design of low-calcium fly ash-based geopolymer concrete mixtures, a single parameter called 'water-to-geopolymer solids ratio' by mass was devised. In this parameter, the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of water used in the making of the sodium hydroxide solution, and the mass of extra water, if any, present in the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids used to make the sodium hydroxide solution, and the mass of solids in the sodium silicate solution (i.e. the mass of Na_2O and SiO_2).

Tests were performed to establish the effect of water-to-geopolymer solids ratio by mass on the compressive strength and the workability of geopolymer concrete. The test specimens were 100x200 mm cylinders, heat-cured in an oven at various temperatures for 24 hours. The results of these tests, plotted in Figure 1, show that the compressive strength of geopolymer concrete decreases as the water-to-geopolymer solids ratio by mass increases [Hardjito and Rangan, 2005]. This test trend is analogous to the well-known effect of water-to-cement ratio on the compressive strength of Portland cement concrete. Obviously, as the water-to-geopolymer solids ratio increased, the workability increased as the mixtures contained more water. The test trend shown in Figure 1 is also observed by Siddiqui (2007] in the studies conducted on steam-cured reinforced geopolymer concrete culverts. The proportions of two different geopolymer concrete mixtures used in laboratory studies are given in Table 1 [Wallah and Rangan, 2006]. The details of numerous other mixtures are reported elsewhere.

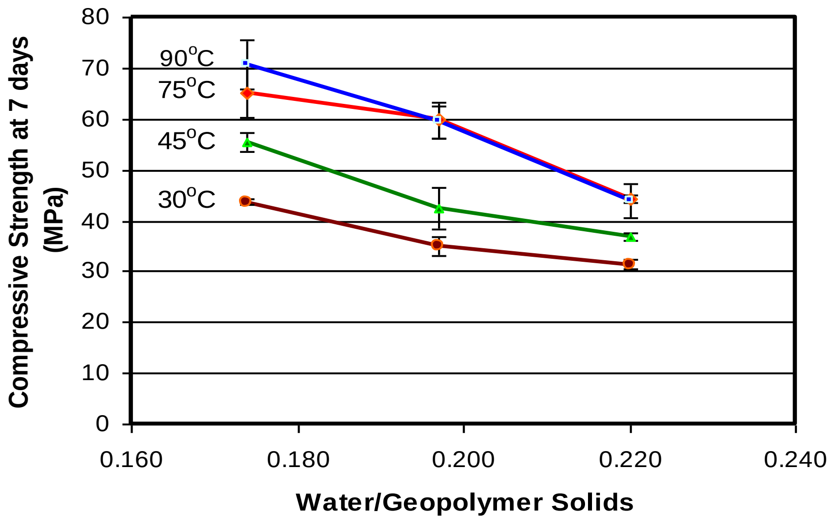

Fig. 1. Effect of Water-to-Geopolymer Solids on Compressive Strength

Table 1. Geopolymer Concrete Mixture Proportions

Materials		Mass (kg/m3)	
		Mixture-1	Mixture-2
Coarse aggregates:	20 mm	277	277
	14 mm	370	370
	7 mm	647	647
Fine sand		554	554
Fly ash (low-calcium ASTM Class F)		408	408
Sodium silicate solution($SiO_2/Na_2O=2$)		103	103
Sodium hydroxide solution		41(8 Molar)	41(14 Molar)
Super Plasticizer		6	6
Extra water		None	22.5

Mixing, Casting, and Compaction of Geopolymer Concrete

Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry in 80-litre capacity pan mixer for about three minutes. The aggregates were prepared in saturated-surface-dry (SSD) condition. The alkaline liquid was mixed with the super plasticizer and the extra water, if any. The liquid component of the mixture was then added to the dry materials and the mixing continued usually 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 compressive strength. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete. Fresh fly ash-based geopolymer concrete was usually cohesive. The workability of the fresh concrete was measured by means of the conventional slump test. The compressive strength of geopolymer concrete is influenced by the wet-mixing time. Test results show that the compressive strength increased as the wet-mixing time increased [Hardjito and Rangan, 2005].

Curing of Geopolymer Concrete

Heat-curing of low-calcium fly ash-based geopolymer concrete is generally recommended. Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste. Both curing time and curing temperature influence the compressive strength of geopolymer concrete. The effect of curing time is illustrated in Figure 2 [Hardjito and Rangan, 2005]. The test specimens were 100x200 mm cylinders heat-cured at 60^{o}C in an oven. The curing time varied from 4 hours to 96 hours (4 days). Longer curing time improved the polymerization process resulting in higher compressive strength. The rate of increase in strength was rapid up to 24 hours of curing time; beyond 24 hours, the gain in strength is only moderate. Therefore, heat-curing time need not be more than 24 hours in practical applications.

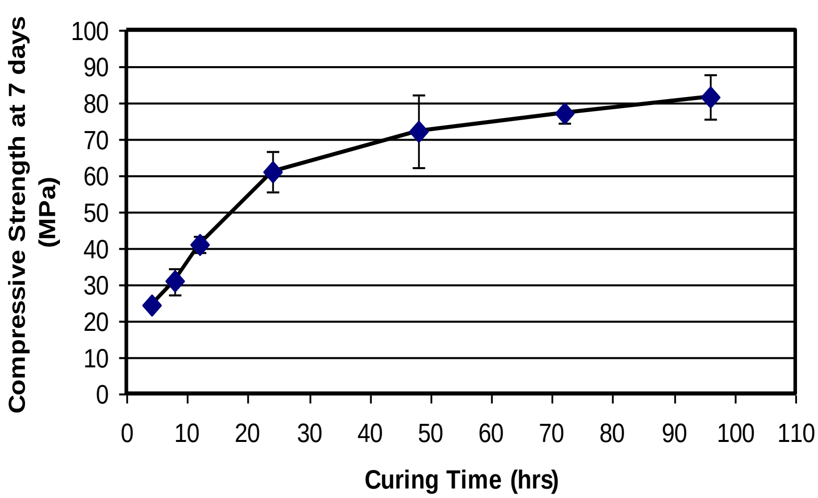

Fig. 2. Effect of Curing Time on Compressive Strength

Heat-curing can be achieved by either steam-curing or dry-curing. Test data show that the compressive strength of dry-cured geopolymer concrete is approximately 15% larger than that of steam-cured geopolymer concrete [Hardjito and Rangan, 2005]. The temperature required for heat-curing can be as low as 30 ^{o}C (Figure 1). In tropical climates, this range of temperature can be provided by the ambient conditions.

The required heat-curing regime can be manipulated to fit the needs of practical applications. In laboratory trials [Hardjito and Rangan, 2005] precast concrete products were manufactured using geopolymer concrete; the design specifications required steam-curing at 60^{o}C for 24 hours. In order to optimize the usage of formwork, the products were cast and steam-cured initially for about 4 hours. The steam-curing was then stopped for some time to allow the release of the products from the formwork. The steam-curing of the products then continued for another 21 hours. This two-stage steam-curing regime did not produce any degradation in the strength of the products. A two-stage steam-curing regime was also used by Siddiqui [2007] in the manufacture of prototype reinforced geopolymer concrete box culverts in a precast concrete plant. It was found that steam curing at 80 ˚C for a period of 4 hours provided enough strength for de-moulding of the culverts; this was then followed by steam curing further for another 20 hours at 80 ˚C to attain the required design compressive strength.

Also, the start of heat-curing of geopolymer concrete can be delayed for several days. Tests have shown that a delay in the start of heat-curing up to five days did not produce any degradation in the compressive strength. In fact, such a delay in the start of heat-curing substantially increased the compressive strength of geopolymer concrete [Hardjito and Rangan, 2005]. This may be due to the geopolymerisation that occurs prior to the start of heat-curing.

The above flexibilities in the heat-curing regime of geopolymer concrete can be exploited in practical applications and prototype products can be manufactured ready for use within 24 hours after casting.

DESIGN OF GEOPOLYMER CONCRETE MIXTURES

Concrete mixture design process is vast and generally based on performance criteria. Based on the information given in above, some simple guidelines for the design of heat-cured low-calcium fly ash-based geopolymer concrete have been proposed [Hardjito et al, 2004; Rangan, 2008; Sumajouw, 2007]. The performance criteria of a geopolymer concrete mixture depend on the application. For simplicity, the compressive strength of hardened concrete and the workability of fresh concrete are selected as the performance criteria. In order to meet these performance criteria, the alkaline liquid-to-fly ash ratio by mass, water-to-geopolymer solids ratio by mass, the wet-mixing time, the heat-curing temperature, and the heat-curing time are selected as parameters.

With regard to alkaline liquid-to-fly ash ratio by mass, values in the range of 0.30 and 0.45 are recommended. Based on the results obtained from numerous mixtures made in the laboratory over a period of six years, the data given in Table 2 are proposed for the design of low-calcium fly ash-based geopolymer concrete. Note that wet-mixing time of 4 minutes, and steam-curing at 60^{o}C for 24 hours after casting are proposed. Increased wet mixing time increased the compressive strength by 30%. The data given in Figures 1 and 2 may be used as guides to choose other curing temperature, and curing time.

The design data given in Table 2 assumes that the aggregates are in saturated-surface-dry (SSD) condition. In other words, the coarse and fine aggregates in a geopolymer concrete mixture must neither be too dry to absorb water from the mixture nor too wet to add water to the mixture. In practical applications, aggregates may contain water over and above the SSD condition. Therefore, the extra water in the aggregates above the SSD condition must be estimated and included in the calculation of water-to-geopolymer solids ratio given in Table 2. Mixes with aggregates not prepared to SSD condition have been found to produce geopolymer with high compressive strength and good workability [Lloyd and Rangan, 2009].

Table 2: Data for Design of Low-Calcium Fly Ash-Based Geopolymer Concrete

Water-to-geopolymer solids ratio, by mass	Workability	Design compressive strength (MPa)
0.16	Very Stiff	60
0.18	Stiff	50
0.20	Moderate	40
0.22	High	35
0.24	High	30

The mixture design process is illustrated by the following Example: Mixture proportion of heat-cured low-calcium fly ash-based geopolymer concrete with design compressive strength of 45 MPa is needed for precast concrete products.

Assume that normal-density aggregates in SSD condition are to be used and the unit-weight of concrete is 2400 kg/m^3. Take the mass of combined aggregates as 77% of the mass of concrete, i.e. 0.77x2400= 1848 kg/m^3. The combined aggregates may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. For instance, the aggregates may comprise 277 kg/m^3 (15%) of 20mm aggregates, 370 kg/m^3 (20%) of 14 mm aggregates, 647 kg/m^3 (35%) of 7 mm aggregates, and 554 kg/m^3 (30%) of fine sand to meet the requirements of standard grading curves. The fineness modulus of the combined aggregates is approximately 5.0.

The mass of low-calcium fly ash and the alkaline liquid = 2400 – 1848 = 552 kg/m^3. Take the alkaline liquid-to-fly ash ratio by mass as 0.35; the mass of fly ash = 552/ (1+0.35) = 408 kg/m^3 and the mass of alkaline liquid = 552 – 408 = 144 kg/m^3. Take the ratio of sodium silicate solution-to-sodium hydroxide solution by mass as 2.5; the mass of sodium hydroxide solution = 144/ (1+2.5) = 41 kg/m^3; the mass of sodium silicate solution = 144 – 41 =103 kg/m^3.

Therefore, the trial mixture proportion is as follow: combined aggregates = 1848 kg/m^3, low-calcium fly ash = 408 kg/m^3, sodium silicate solution = 103 kg /m^3, and sodium hydroxide solution = 41 kg/m^3.

To manufacture the geopolymer concrete mixture, commercially available sodium silicate solution A53 with SiO2-to-Na2O ratio by mass of approximately 2, i.e., Na2O = 14.7%, SiO2 = 29.4%, and water = 55.9% by mass, is selected. The sodium hydroxide solids (NaOH) with 97-98% purity is purchased from commercial sources, and mixed with water to make a solution with a concentration of 8 Molar. This solution comprises 26% of NaOH solids and 74% water, by mass.

For the trial mixture, water-to-geopolymer solids ratio by mass is calculated as follows: In sodium silicate solution, water = 0.559x103 = 58 kg, and solids = 103 – 58 = 45 kg. In sodium hydroxide solution, solids = 0.26x41 = 11 kg, and water = 41 – 11 = 30 kg. Therefore, total mass of water = 58+30 = 88 kg, and the mass of geopolymer solids = 408 (i.e. mass of fly ash) +45+11 = 464 kg. Hence the water-to-geopolymer solids ratio by mass = 88/464 = 0.19. Using the data given in Table 2, for water-to-geopolymer solids ratio by mass of 0.19, the design compressive strength is approximately 45 MPa, as needed. The geopolymer concrete mixture proportion is therefore as follows:

20 mm aggregates = 277 kg/m^3, 14 mm aggregates = 370 kg/m^3, 7 mm aggregates = 647 kg/m^3, fine sand = 554 kg/m^3, low-calcium fly ash (ASTM Class F) = 408 kg/m^3, sodium silicate solution (Na2O = 14.7%, SiO2 = 29.4%, and water = 55.9% by mass) = 103 kg/m^3, and sodium hydroxide solution (8 Molar) = 41 kg/m^3 (Note that the 8 Molar sodium hydroxide solution is made by mixing 11 kg of sodium hydroxide solids with 97-98% purity in 30 kg of water).

The geopolymer concrete must be wet-mixed at least for four minutes and steam-cured at 60^{o}C for 24 hours after casting. The workability of fresh geopolymer concrete is expected to be moderate. If needed, commercially available super plasticizer of about 1.5% of mass of fly ash, i.e. 408x (1.5/100) = 6 kg/m^3 may be added to the mixture to facilitate ease of placement of fresh concrete.

Numerous batches of the Example geopolymer concrete mixture have been manufactured and tested in the laboratory over a period of six years. These test results have shown that the mean 7th day compressive strength was 56 MPa with a standard deviation of 3 MPa (see Mixture-1 in Table 1). The mean slump of the fresh geopolymer concrete was about 100 mm.

GEOPOLYMER CONCRETE PROPERTIES

The elastic properties of hardened geopolymer concrete and the behavior and strength of reinforced geopolymer concrete structural members are similar to those observed in the case of Portland cement concrete [Sofi et al, 2007; Chang, 2009]. Heat-cured low-calcium fly ash-based geopolymer concrete also shows excellent resistance to sulfate attack, good acid resistance, undergoes low creep, and suffers very little drying shrinkage [Wallah and Rangan, 2006].

The behaviour and failure modes of reinforced geopolymer concrete columns and beams were similar to those observed in the case of reinforced Portland cement concrete columns [Sumajouw and Rangan, 2006; Sumajouw et al, 2007]. Test results demonstrated that the methods of calculations used in the case of reinforced Portland cement concrete columns and beams are applicable for reinforced geopolymer concrete columns. Mid-span deflection at service load of reinforced geopolymer concrete beams was calculated using the elastic bending theory and the serviceability design provisions given in Standards. Good correlation of test and calculated deflections at service load was observed.

The bond characteristics of reinforcing bar in geopolymer concrete have been researched and determined to be comparable or superior to Portland cement concrete [Sofi et al, 2007; Sarker et al, 2007; Chang, 2009]. The shear and bond strength of reinforced fly ash-based geopolymer concrete beams can be calculated using the design provisions currently available in building codes and standards.

Therefore, the design provisions contained in the current Standards and Codes can be used to design reinforced low-calcium fly ash-based geopolymer concrete structural members. The mechanical properties offered by geopolymer concrete also suggest its use in structural applications is beneficial from an enhanced durability and fire resistance perspective. Its high strength gain at elevated curing temperatures lends geopolymer concrete to precast structural applications.

GEOPOLYMER PRECAST CONCRETE PRODUCTS

High-early strength gain is a characteristic of geopolymer concrete when dry-heat or steam cured, although ambient temperature curing is possible for geopolymer concrete. It has been used to produce precast railway sleepers, sewer pipes, and other prestressed concrete building components. The early-age strength gain is a characteristic that can best be exploited in the precast industry where steam curing or heated bed curing is common practice and is used to maximize the rate of production of elements. Recently, geopolymer concrete has been tried in the production of precast box culverts with successful production in a commercial precast yard with steam curing [Siddiqui, 2007; Cheema et al, 2009].

Geopolymer concrete has excellent resistance to chemical attack and shows promise in the use of aggressive environments where the durability of Portland cement concrete may be of concern. This is particularly applicable in aggressive marine environments, environments with high carbon dioxide or sulphate rich soils. Similarly in highly acidic conditions, geopolymer concrete has shown to have superior acid resistance and may be suitable for applications such as mining, some manufacturing industries and sewer systems. Current research at Curtin University of Technology is examining the durability of precast box culverts manufactured from geopolymer concrete which are exposed to a highly aggressive environment with wet-dry cycling in sulphate rich soils.

Gourley and Johnson [2005] have reported the details of geopolymer precast concrete products on a commercial scale. The products included sewer pipes, railway sleepers, and wall panels. Reinforced geopolymer concrete sewer pipes with diameters in the range from 375 mm to 1800 mm have been manufactured using the facilities currently available to make similar pipes using Portland cement concrete. Tests performed in a simulated aggressive sewer environment have shown that geopolymer concrete sewer pipes outperformed comparable Portland cement concrete pipes by many folds. Gourley and Johnson [2005] also reported the good performance of reinforced geopolymer concrete railway sleepers in mainline tracks and excellent resistance of geopolymer mortar wall panels to fire.

Siddiqui [2007] and Cheema et al [2009] demonstrated the manufacture of reinforced geopolymer concrete culverts on a commercial scale. Tests have shown that the culverts performed well and met the specification requirements of such products. Reinforced geopolymer concrete box culverts of 1200 mm (length) x600 mm (depth) x1200 mm (width) and compressive cylinders were manufactured in a commercial precast concrete plant located in Perth, Western Australia. The dry materials were mixed for about 3 minutes. The liquid component of the mixture was then added, and the mixing continued for another 4 minutes. The geopolymer concrete was transferred into a kibble from where it was then cast into the culvert moulds (one mould for two box culverts) as shown in Figure 3. The culverts were compacted on a vibrating table and using a hand -held vibrator. The cylinders were cast in 2 layers with each layer compacted on a vibrating table for 15 seconds. The slump of every batch of fresh geopolymer concrete was also measured in order to observe the consistency of the mixtures.

After casting, the cylinders were covered with plastic bags and placed under the culvert moulds. A plastic cover was placed over the culvert mould and the steam tube was inserted inside the cover. The culverts and the cylinders were steam-cured for 24 hours. Initially, the specimens were steam-cured for about 4 hours; the strength at that stage was adequate for the specimens to be released from the moulds. The culverts and the remaining cylinders were steam-cured for another 20 hours. The operation of the precast plant was such that the 20 hours of steam-curing has to be split into two parts. That is, the steam-curing was shut down at 11 p.m. and restarted at 6 a.m. next day. In all, the total time taken for steam-curing was 24 hours.

(a) As Cast **(b) Finished Box culverts**

Fig. 3. Manufacture of Test Culverts and Cylinders

The box culvert made of geopolymer concrete mix 4 (Table 4) was tested for load bearing strength in a load testing machine which had a capacity of 370 kN and operated to Australian Standards, AS 1597.1-1974. The culvert was positioned with the legs firmly inside the channel supports. Load was then applied and increased continuously so that the proof load of 125 kN was reached in 5 minutes. After the application of the proof load, the culvert was examined for cracks using a crack-measuring gauge. The measured width of cracks did not exceed 0.08 mm.

The load was then increased to 220 kN and a crack of width 0.15 mm appeared underside the crown. As the load increased to about 300 kN, a crack of 0.4 mm width appeared in the leg of the culvert. The load was then released to examine to see whether all cracks had closed. No crack was observed after the removal of the load.

According to Australian Standard AS 1597, a reinforced concrete culvert should carry the proof load without developing a crack greater than 0.15 mm and on removal of the load; no crack should be greater than 0.08 mm. The test demonstrated that geopolymer concrete box culvert met these requirements [14, 15]. Further test work is in progress.

Table 4. Geopolymer Concrete Mixture Proportions for Box Culverts

Materials		Mass (kg/m3)					
		Mix 1	Mix2	Mix3	Mix4	Mix5	Mix6
Coarse Aggregates							
	14mm	554	554	554	554	554	554
	10mm	702	702	702	702	702	702
Fine Sand		591	591	591	591	591	591
Fly Ash (Low Calcium ASTM Class F)		409	409	409	409	409	409
Sodium Silicate Solution (SiO_2/Na_2O =2)		102	102	102	102	102	102
Sodium Hydroxide Solution		41	41	41	41	41	41
Super Plasticizer (SP)		6	6	6	6	6	6
Extra water in aggregates		22.5	22.5	35	34	19	33

CONTRIBUTIONS OF GEOPOLYMER CONCRETE TOWARDS SUSTAINABLE DEVELOPMENT

Coal is often used in the generation of a major proportion of the power not only in in many parts of the world such as India, China, Australia, and the USA. The huge reserves of good quality coal available worldwide and the low cost of power produced from these resources cannot be ignored. Coal-burning power stations generate huge volumes of fly ash; most of the fly ash is not effectively used. As the need for power increases, the volume of fly ash would increase if we continue to largely rely on coal-fired power generation. On the other hand, concrete usage around the globe is on the increase to meet infrastructure developments. An important ingredient in the conventional concrete is the Portland cement. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. Moreover, cement production is not only highly energy-intensive, next to steel and aluminium, but also consumes significant amount of natural resources.

For sustainable development, the concrete industry needs an alternative binder to the Portland cement. Such an alternative is offered by the fly ash-based geopolymer concrete, as this concrete uses no Portland cement; instead, utilizes the fly ash from coal-burning power stations to make the binder necessary to manufacture concrete. The use of fly ash-based Geopolymer Concrete contributes through the process of Carbon Reduction Scheme between the Power Generators, Coal Producers, the Government Agencies, and other industries including the cement producers.

ECONOMIC BENEFITS OF GEOPOLYMER CONCRETE

Heat-cured low-calcium fly ash-based geopolymer concrete offers several economic benefits over Portland cement concrete. The price of one ton of fly ash is only a small fraction of the price of one ton of Portland cement. Therefore, after allowing for the price of alkaline liquids needed to the make the geopolymer concrete, the price of fly ash-based geopolymer concrete is estimated to be about 10 to 30 percent cheaper than that of Portland cement concrete. In addition, the appropriate usage of one ton of fly ash earns approximately one carbon-credit that has a significant redemption value. One ton low-calcium fly ash can be utilized to manufacture approximately three cubic meters of high quality fly ash-based geopolymer concrete, and hence earn monetary benefits through carbon-credit trade. Furthermore, the very little drying shrinkage, the low creep, the excellent resistance to sulfate attack, and good acid resistance offered by the heat-cured low-calcium fly ash-based geopolymer concrete may yield additional economic benefits when it is utilized in infrastructure applications.

CONCLUDING REMARKS

The paper presented brief details of fly ash-based geopolymer concrete. A simple method to design geopolymer concrete mixtures has been described and illustrated by an example. Geopolymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster. The economic benefits and contributions of geopolymer concrete to sustainable development have also outlined. To ensure further uptake of geopolymer technology within the concrete industry, research is needed in the critical area of durability. Current research is focusing on the durability of geopolymer in aggressive soil conditions and marine environments.

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