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Zero Cement Concrete with Self-Curing Technology: An Overview

N. Anuja[1] and A. Mohammed Yasar[2]
[1]Assistant Professor, [2]PG Student
[1&2]Department of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu, India
E-mail: anu_priya1031@yahoo.com, yasar96mohammad_ci@mepcoeng.ac.in

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***Abstract* - Geopolymer concrete is the concept of environmental friendly construction material which helps in reducing the greenhouse gas emission, however it cannot be applied directly on field due to its steam curing process. To overcome this defect various researcher have found self-curing or ambient curing process to achieve same strength as in steam curing process for geopolymer. This paper presents an over review about self-cured or ambient cured geopolymer concrete produced by various methods.**
***Keywords:* Geopolymer, Fly Ash, Thermal, Compressive Strength, Flexural Strength**

I. INTRODUCTION

Ordinary Portland cement (OPC) is the most commonly used construction material all over the world. Concrete becomes a major component for the development of our infrastructure in which Portland cement plays a dominant role in concrete for construction (Anuja Narayanan, Prabavathy Shanmugasundaram., 2018). The production of cement involved different processes that consumed lot of energy which in-turn released tons of carbon-dioxide (CO_2) into the atmosphere (Pitiwat Wattanachai *et al.,* 2017). Portland cement manufacturing is an energy intensive process and releases very large amount of greenhouse gas to atmosphere, and alternative cementitious systems have been studying to totally or partially replace the Ordinary Portland Cement (OPC) (Pradip Nath *et al.,* 2015).

Alumina–silicate materials, especially fly ash and other pozzolanic industrial wastes have been identified as starting materials to produce OPC-less cementitious material, called Geopolymer Cement. The chemical composition of geopolymer is similar to that zeolite, but it shows an amorphous microstructure (Yun Young Kim,. 2014). Geopolymer mortar of reasonable workability and strength can be produced by activating locally available fly ash with sodium hydroxide and sodium silicate solution (Anupam Bhowmick, *et al.,* 2012). Geopolymer is a lightweight inorganic aluminosilicate polymer in which the alkaline liquid reacts with the source material which is rich in silicon and aluminium. Geopolymer has two main constituents such as a source material and an alkaline liquid (Anuja Narayanan Prabavathy Shanmugasundaram, 2019). The production of alumina–silicate based geopolymer cement commonly use alkaline solutions, such as sodium or potassium silicate (Na_2SiO_3/K_2SiO_3) and potassium or sodium hydroxide (KOH or NaOH) mixed with raw materials to form homogenous slurry. Geopolymer reaction starting at room temperature is extended by subjecting it to heat treatment in an oven or in a steam chamber between the temperatures of 60°C and 120°C after achieving the desired mixture. Thus, the properties of the desired material are improved. Alkaline activators have an important role in the dissolution of Al and Si oxides in the raw material structure which will be activated. Hence, sodium hydroxide (NaOH) or potassium hydroxide (KOH), potassium silicate or sodium silicate are the most widely used activators for the synthesis of alumina silicate reactive material in the activation process (A. M. Kaja *et al.,* 2018). Even though geopolymer has improved properties when compared to normal cement concrete, its mix design is not yet been a standardized procedure to be followed for precast works (Anuja Narayanan, Prabavathy Shanmugasundram, 2019).

Geopolymer concrete mortar produces high shear bond and bending strength in repair material compared to concrete made from OPC (Tanakorn Phoo-ngernkham , *et al.,* 2015). Heat curing process led to high cost and in-situ practical issues thereby preventing the large scale application of geopolymers (A. Karthik., *et al.,* 2019). However, the requirement of heating for the curing process of the geopolymer has a significant implication for on-site operation of construction and energy consumption. The typical fly ash-based geopolymer paste cannot set within 24 hr in ambient temperature, although adding some of additive source can shorten the setting time of geo paste and give self-curing nature by producing internal heat through reaction.

II. MATERIALS

A. Calcium Aluminates Cement (CAC)

There are different types of CAC with different amounts of alumina (40–80%). Normally CACs with 40–50% alumina can be used in a wide range of applications, such as self-levelling floor or non-shrink grouts. CACs with 70–80% alumina, such as Secar 71, are primarily employed for high duty refractory mortars and concretes. High alumina CAC are designed to be used at temperatures greater than 1400°C which might promote geopolymerization for strength development.(Yi-Fang Cao *et al.,* 2018). The inclusion of CAC in the fly ash-based geopolymer mixture can greatly promote the strength development at ambient conditions. Thus, this type of geopolymer concrete is suitable for in situ construction by eliminating the need for heat curing.

TABLE I CHEMICAL COMPOSITION OF CALCIUM ALUMINATE CEMENT (YI-FANG CAO *et al.*, 2018).

Compounds	Percentage
Al_2O_3	75.3
SiO2	0.1
Fe_2O_3	0.3
CaO	20.9
MgO	2.1
SO_3	0.2
K_2O	0.1
Na_2O	1.0

B. Ordinary Portland Cement

Portland cement is the most common type of cement in general use around the world as a basic ingredient of concrete, mortar, stucco, and non-specialty grout. The impact of calcium ions in hybrid systems is assigned to the provision of nucleation sites for the precipitation of products, thus leading to an accelerated hardening (A.M.Kaja *et al.*, 2018). It was found that the inclusion of OPC in geopolymer mixes reduced the workability and setting time but significantly increased the early age and ultimate compressive strength due to the quick reaction of OPC with alkali activators (Mahya Askarian, *et al.*, 2018). The presence of a calcium source has also been proved to influence considerably the setting time of alkali-activated materials, but from SEM image, it is found that densification of the structure increasing cement content. It was observed that at the early ages of activation, C-S-H and N-A-S-H gels are formed simultaneously in the systems with the addition of extra calcium source. After longer periods, C-S-H gel transforms into C-A-S-H gel (Pradip Nath *et al.*, 2015). Setting time of alkali activated hybrid fly ash – cement systems is considerably accelerated due to the presence of cement (5–10 wt %) and can be tailored by modifying the cement dosage and activator modulus. (Pradip Nath *et al.*, 2015). The internal heat accumulated inside the Geopolymer and Portland Cement samples was mainly induced by the OPC hydration which could promote more appropriate curing condition (Teewara Suwan, *et al.*, 2016).

TABLE II CHEMICAL COMPOSITION ORDINARY PORTLAND CEMENT (PRADIP NATH *et al.*, 2015)

Compounds	Percentage
CaO	63.1
SiO_2	20.27
Al_2O_3	4.8
Fe_2O_3	3.43
MgO	1.58
SO_3	2.91
K_2O	0.53
Na_2O	0.26
TiO_2	-
Mn_3O_4	-
P_2O_5	-
LOI	2.51

C. Silica Fume

Silica fume, also known as micro silica, is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field application is as pozzolanic material for high performance concrete (Lateef Assi *et al.*, 2016). The silica fume-bearing mortars showed the highest compressive strength values. (Ali Mardani-Aghabaglou *et al.*, 2014).

TABLE III CHEMICAL COMPOSITION OF SILICA FUME (LATEEF ASSI *et al.*, 2016)

Compounds	Percentage
SiO_2	85–97
Al_2O_3	-
Fe_2O_3	-
CaO	< 1
MgO	2.5
SO_3	1.7

An alternative activating solution, a combination of silica fume and sodium hydroxide were used in all mixtures. The term of Fly ash-based Geopolymer Concrete-silica fume [FGC-silica fume] is used to differentiate the activating solution from the more common one. In addition, the effects of partial Portland cement replacement on the early and final compressive strength, density, and permeable voids ratio were investigated. However silica fume is used only as activating solution; for self-curing or self-heating only OPC is used. FGC-silica fume has similar or less volume of permeable pores in comparison to conventional concrete. (Lateef Assi *et al.*, 2016).

D. Metakaolin

Metakaolin is a pozzolan, probably the most effective pozzolanic material for use in concrete. It is a product that is manufactured for use rather than a by-product and is formed when china clay, the mineral kaolin, is heated to a temperature between 600 and 800ºC. Its quality is controlled during manufacture, resulting in a much less variable material than industrial pozzolans that are by-products. Metakaolin is used in geopolymer concrete but not as self-curing agent, because it doesn't contain calcium content in it. But it shows high flexural strength (17.6 MPa). Flyash and metakaolin-based geopolymers, show the potential of geopolymer cement development for the construction industry .The results obtained have revealed high compressive strength of around 60-65 MPa at 28 days which can achieve up to 73 MPa at 90 days (Raul Arellano-Aguilar *et al.*, 2014). The compressive strength of the mortar mixtures containing metakaolin and silica fume were higher than that of the plain mixtures at all ages (Ali Mardani-Aghabaglou *et al.*, 2014).

TABLE IV CHEMICAL COMPOSITION OF METAKAOLIN (ALI MARDANI-AGHABAGLOU *et al.*, 2014)

Compounds	Percentage
Al_2O_3	45.2
SiO_2	53.4
Fe_2O_3	0.43
CaO	0.03
K_2O	0.41
Na_2O	-
MgO	0.01

E. Ground Granulated Blast Furnace Slag

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The inclusion of GGBFS in fly-ash-based geopolymer concrete resulted in quicker setting times and higher strength, resulting in creating a concrete suitable for ambient curing conditions (Farhad Aslani *et al.*, 2019).

TABLE V CHEMICAL COMPOSITION OF GROUND GRANULATED BLAST FURNACE SLAG (FARHAD ASLANI *et al.*, 2019)

Compounds	Percentage
CaO	42%
SiO_2	31%
S	0.40%
SO_3	2.40%
MgO	5.70%
Al_2O_3	12.70%
FeO	0.80%
MnO	0.10%

F. Lime Powder

Lime (calcium oxide) is a white solid with strongly basic properties. Lime reacts readily with water to produce slaked lime, which is the chemical compound calcium hydroxide. A considerable amount of heat energy is released during this reaction.

TABLE VI CHEMICAL COMPOSITION OF LIME POWDER

Compounds	Percentage
CaO	≥ 83.3
SiO_2	≤ 2.5
Al_2O_3	≤ 1.5
Fe_2O_3	≤ 3.43
MgO	≤ 0.5
SO_3	≤ 0.5
CO_2	≤ 5
Na_2O	0.4-0.5
Specific Gravity	2

$CaCO_3$(s) limestone → CaO(s) lime + CO_2 (g) carbon dioxide

Calcium hydroxide is sparingly soluble in water producing an alkaline solution known as limewater. When carbon dioxide gas is passed through or over limewater, it turns milky due to the formation of calcium carbonate.

III. EXPERIMENTAL TESTING

A. Thermal Stability Test

Mixtures were prepared to study the thermal stability of geopolymer mortar, especially on the compressive strength. Geopolymer mortar specimens placed in furnace at the age of 7th day for three hours under 400^{o}C, 600^{o}C and 800^{o}C respectively. From Figure 1, it is observed that geopolymer mortar specimens exposed to 400°C yielded the highest compressive strength of 81 MPa.

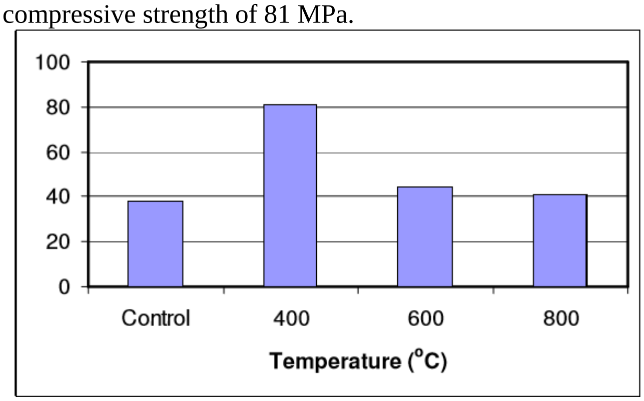

Fig. 1 Variation in Strength with respect to temperature (Djwanto Hardjito., 2008)

With the increase of high temperature exposure upto 800^{o}C, Figure 1 shows steady loss in strength with an increase in temperature; however it remains higher than those of control mixture. These facts confirm the excellent fire resistance of geopolymer mortar (Cheng and Chiu., 2003). Usually when compared to traditional concrete, flyash based geopolymer has good insulating property (Anuja N, Prabavathy S, 2016).

When exposed to temperature of 400^{o}C for three hours, the compressive strength doubled than the one of control mixture. This indicates that the geopolymerisation process continues when geopolymer mortar exposed to high temperature, at least up to 400^{o}C, resulted in very high strength gain. From then on, with the increase in temperature, the compressive strength starts to decrease. Compressive Strength of Geopolymer Mortar at High Temperature Geopolymer mortar possess excellent fire resistance at least up to 800°C exposure for three hour (Djwanto Hardjito, 2008).

B. Compressive Strength Test

Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, and quality control during production of concrete etc. But here the concrete or mortar is not prepared with cement. The compressive strength of the geopolymer concrete increases with increase of concentration in terms of molarities of sodium hydroxide. The compressive strength of the geopolymer concrete increases with increase in the curing time. However, the increase in strength beyond 24 hours is not much significant (Ernesto J. Guades *et al.,* 2016).

The compressive strength of the geopolymer concrete increases with increase in the curing time. Compressive strength of the geopolymer concrete decreases with increase in the ratio of water to geopolymer solids by mass (Pradip Nath et *al.,*). And it has been observed that as the Molarity increases, compressive strength increases (C. D. Budh., *et al.*, 2014). The increase of strength was significant when no extra water was added with alkaline activator. The mixtures containing 35% alkaline activator, exceptA35 S00, showed relatively lower strength than those containing 40% alkaline activator and similar additive contents. This is because of the addition of extra water along with Superplasticiser in the mixtures containing less activator liquid (Pradip Nath *et al.*,).

Compressive strength of geopolymer mortars indicated the increase of geopolymer strengths with the increase of temperature from 55 C to 95^{o}C (Violet nikolic *et al.,* 2015). Compressive strength of geopolymer concrete is higher than ordinary concrete. The average compressive strength of ordinary concrete cylinders is 24 MPa. The average compressive strength of geopolymer concrete cylinders is 31 MPa. Compressive strength of geopolymer concrete is 26.78% higher than ordinary concrete (Nindyawati *et al.,* 2016). It is clear that the 28-day compressive strength increased by the inclusion of GGBFS, OPC or CH with fly ash. Figure 2 represents the compressive strength setup.

Compressive Strength (MPa) = Load / Cross-sectional Area

Fig. 2 Compression test set up (Ernesto J. Guades *et al.,* 2016)

C. Flexural Strength

Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test. Flexural strength of GPC cured in ambient temperature mostly followed similar development trend as that of compressive strength. It can be seen that flexural strength increased when GGBFS, OPC or calcium hydroxide was used with fly ash. However, when the amount of additives increased after certain limit, flexural strength tended to decline, although was higher than control. (A. Karthik *et al.,* 2017).

Flexural strength of GPC cured in ambient temperature mostly followed similar development trend as compressive strength. Inclusion of up to 10% GGBFS, 6% OPC and 2% CH enhanced flexural strength as compared to the mixture without any additive. Geopolymer concretes exhibited higher flexural strength than OPC concrete of similar compressive strength (Pradip Nath *et al.,*). It has been found that the bond strength between geopolymer concrete and rebar is more than that of conventional concrete (G. S. Manjunatha, *et al.,* 2014).Ordinary Concrete beam has higher flexural strength than geopolymer concrete beams. This result is little bit different from author expectation, geopolymer beams expected to higher flexural strength than ordinary concrete due to its high compressive strength. This unexpected result occurs because geopolymer concrete beams are more brittle than ordinary concrete beams (Nindyawati *et al.,* 2016). Figure 3 shows the flexural strength test

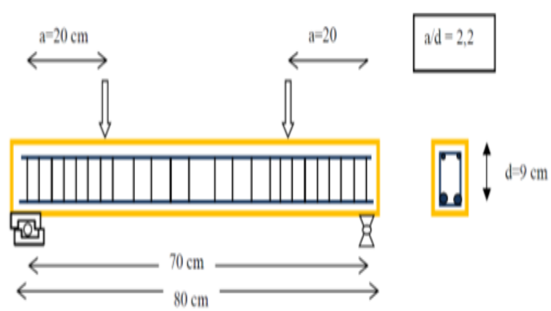

Fig. 3 Flexural Strength Test (Nindyawat *et al.,* 2016)

IV. CONCLUSION

This paper presents an over review of ambient self-cured geopolymer concrete. Various researchers found that ambient cured geopolymer concrete produces good mechanical property than the conventional concrete and it can also overcome the major drawback of steam curing condition which consumes large amount of energy, and it can be applied easily on site work. This in turn reduces the energy consumption through heating process.

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