MultiCraft

International Journal of Engineering, Science and Technology
Vol. 9, No. 4, 2017, pp. 1-9

INTERNATIONAL
JOURNAL OF
ENGINEERING,
SCIENCE AND
TECHNOLOGY

www.ijest-ng.com
www.ajol.info/index.php/ijest

Durability studies on the high calcium flyash based GPC

R. Manickavasagam[1] and G. Mohankumar[2*]

[1]*PRIST University, Thanjavur-, Tamil Nadu, INDIA.*
[2]*Arunai Engineering College, Thiruvannamalai, Tamil Nadu, INDIA*
[*]*Corresponding Author: e-mail: parvathmohan@gmail.com; Tel; 04175 255101; Fax: 04175-237790*

Abstract

Geopolymer concrete is an environment friendly green concrete which is comparatively of lower carbon footprint. Most of the studies reported is about the development of low calcium flyash based GPC only and and that too mostly on achieving the compressive strength and not much on its durability related properties. In this study, the novel idea of using high calcium flyash based GPC is considered with Sodium based alkaline solution having different concentrations and cured in hot oven at 60^{o}C for 24 hours. Three different grades namely GM20, GM30 and GM40 are designed and common durability related properties like water absorption, acid resitance and corrosion resistance by constant voltage polarization test are determined using relevant concrete specimens and compared with similar grades of conventional concrete. High calcium flyash based GPC is observed to possess superior durability related properties over OPCC.

Keywords: Geopolymer concrete, high calcium flyash, durability, corrosion resistance, polarisation test.

DOI: http://dx.doi.org/10.4314/ijest.v9i4.1

---

1. Introduction

Ordinary Porland Cement Concrete (OPCC) is considered to be a highly durable material requiring a little or no maintenance. The assumption is largely true, expect when it is subjected to highly aggressive environments and durability of concrete is a subject of major concern in many countries. Durability problems can result in prematured failure. Durability aspect is one of the major revisions of IS 456-2000, in line with codes of practices of other countries, dealing with durability of reinforced and prestressed concrete structures. The durability of concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original from, quality, and serviceability when exposed to its environment. Flyash based Geopolymer concrete (GPC) is reported to have superior performance than conventional cement concrete. Common durability related properties include, Saturated water absorption (SWA), porosity,acid resistamce, alkaline resistance, sulphate resistance and corrosion resistance. But most of the works reported are concerned with low calcium flyash (LCFA) only, very few studies are reported about high calcium flyash (HCFA) based GPC. Even in the conventional cement concrete, the HCFA is not recommended by Indian specifications for reinforced concrete due its high calcium content which is expected to cause corrosion of the rebars. Comparatively, being more cementitious and less pozzolonic in nature, the HCFA can have potential applications in concrete industries if properly handled. Even though GPC has an arrival history starting from 1940 and has attributed significant academic research, it has yet to enter the mainstream of concrete construction. The high calcium flyash (HCFA) usage is not encouraged for even partial replacement of cement whereas the low calcium flyash upto 20% replacement is allowed for reinforced concrete as per Indian codes. As HCFA causes more problems, it has to be consumed usefully. Therefore, the novel idea of utilising HCFA for total cement replacement is considered.

2. Literature Survey

The name of Geopolymer was first coined in 1950s by Davidovits, investigating the metakaolin based aluminosilicate polymers (Davidovits, 1976). The prefix geo symbolize the constitutive relationship of the binders to geological materials like natural stone or minerals. Similar materials previously investigated by in the same period were termed as soil cement (Glukhovsky, 1965), thermally activated clay, ash, natural pozzolana and slag as activated binders, and alkaline activated slag (Talling and Brand, 1989), alkali-activated cement, inorganic polymer concrete and geocement (Duxson et al. 2007).

The solid is first partially dissolved by the alkaline activator, followed by the condensing of an aluminosilicate polymer in parallel. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a 3D polymeric chain and ring structure consisting of Si-O-Al-O bonds. Water is released during the formation of geopolymers unlike hydration of cement. This water plays no role in the chemical reaction but provides workability of the mixture during handling of geopolymers. The sustainable development in the geopolymers is best used by the development of GPC.

The durability related properties of LCFA based GPC is studied by many authors. The long term properties of LCFA based GPC was studied by Wallah and Rangan (2006) and reported that compared to conventional concrete, the GPC has less creep coefficient. Cheema (2012) reported that the physical properties and micro structure and pore structure related properties of GPC found to be more mechanically stable than the OPCC. Rajamane *et al.* (2011) conducted accelerated corrosion test on embedded steel and reported that the performance is almost similar to OPCC. Reddy, et al (2011) reported that excellent resistance to chloride attack, with longer time to corrosion cracking are observed for GPC compared to OPCC.

Farhana *et al.* (2013) reviewed and reported that rebar embedded in GPC had good corrosion performance and low corrosion rate compared to rebar embedded in OPCC, because of the strong and adherent silicate membrane coating around the rebars. Shaikh (2014) studied the effects of alkali solutions on corrosion durability of GPC to cyclic wetting and drying regime and reported that, the GPC exhibited lower Sorptivity and chloride penetration depth and better corrosion resistance than that of OPCC. Salmabanu and Urvashi (2015) found that the weight loss after three months of acid immersion of GPC is less compared to OPCC.

There are only few studies reported about the durability related properties of HCFA based GPC. The calcium content in flyash played a significant role in the development of strength particularly in the final compressive strength and higher the calcium content resulted in faster strength development as well as higher compressive strength (van Jaarsveld *et al.* (2002, 2003). Sanni and Khadiranaikar (2012) presented the experimental investigation made on the performance of HCFA based GPC subjected to severe environmental conditions and compared with conventional concrete of M30, M40, M50 and M60 grades. Sodium hydroxide solution of molarity 8M and 12M and sodium silicate with liquid ratio of 2.5 and 3.5 were used. The test results indicated that the heat-cured (60°C for 24 hours) flyash-based GPC had an excellent resistance to Sulphuric acid and magnesium sulphate attack when compared to conventional concrete. Better microstructure for geopolymer pastes and mortars made of HCFA at mass ratios of water-to-flyash from 0.30 to 0.35 was reported by Li *et al.* (2013).

Chindaprasirt *et al.* (2013) studied the curing effect of 90-W microwave radiation for 5 minutes followed by a shortened heat curing of class C flyash based GPC. Results showed that microwave radiation contributed to the dissolution of flyash in the alkaline solution. Numerous gel formations were observed in microscopic scale. This resulted in a dense composite and strong bonding between the flyash and the geopolymer matrix leading to high strength gain compared to those of the control pastes cured at 65°C for 24 hours.

3. Experimentation

Three different grades of GPC designated as GM20, GM30 and GM40and equivalent to OPCC grades of M20, M30 and M40 are considered for the study and based on the literature survey (Mohankumar and Manickavasagam, 2017), the proportions are designed and chosen as detailed in Table 1.The liquid ratio is taken as 2.5 uniformly for all the three grades of GPC but the molarity of NaOH is varied as 8M, 10M and 12M respectively for the three grades of GPC in the order. The mix proportions of constituents of concrete and the corresponding compressive strength are shown in Figure 1.

The dry materials (HCFA and aggregates) are mixed for about three minutes and the activating solution premixed with admixture is added, and mixing again continued for another three minutes. 100mm cubes are cast by using multiple wooden moulds. The concrete is poured into the cube moulds in layers and compacted by placing on the table vibrator. After finishing, the specimens are wrapped by placing a lid on the mould. The specimens are kept for a rest period of one day and then cured in hot oven for 24 hours at 60°C. The views of GPC specimens cast and curing in hot oven are shown in Figure 2.

Table 1. Mix details of OPCC and GPC

No	Concrete grades	Mix Ratio	w/c or Alkaline/FA	Water or Activator kg/m^3	Compressive strength (MPa)
1	M20	1:2.40:3.50	0.5	170	27.8

Table 1 (cont'd). Mix details of OPCC and GPC

No	Concrete grades	Mix Ratio	w/c or Alkaline/FA	Water or Activator kg/m^3	Compressive strength (MPa)
2	M30	1:2.11:3.30	0.45	162	39.2
3	M40	1:2.01:3.13	0.4	152	48.7
4	GM20(8M)	1:2.65: 6.18	0.56	129.2	29.3
5	GM30(10M)	1:1.94 :4.54	0.62	183.7	40.1
6	GM40(12M)	1:1.49 :3.47	0.65	236.4	51.2

(a) Sodium hydroxide (b) Sodium silicate

(c)HCFA (d) River sand (e) Granite jelly (f) SP

Figure 1. View of constituents of GPC

Figure 2. Views of GPC specimens cast and curing in hot oven

3.1 Saturated water absorption

The water absorption of concrete is determined as per ASTM C 642 standards using 100mm cubes. The concrete cubes after immersing in water for appropriate days (90, 180 and 360 days) are weighed for their water saturated weight (Ws). The samples are then oven dried at a temperature of 105°C for 24 hours and the process is maintained until the difference in mass between two successive measurements agreed closely. These oven dried specimens are again weighed (Wd) after cooling to room temperature. The saturated water absorption (SWA) is arrived from Equation (1) and the results are presented in Table 2. The view of water immersion is shown in Figure 3(a).

$$SWA = \frac{W_s - W_d}{W_d} \times 100\% \qquad (1)$$

3.2 Sulphuric acid resistance

Sulphuric acid is one type of acid solution that is frequently used to simulate the acid attack in sewer pipe systems as generated bacterially from hydrogen sulphide. Acid resistance of geopolymer concrete is tested by exposing to Sulphuric acid solution (Hime, 2003; Gourley and Johnson, 2005) and 2% concentrated Sulphuric acid is used (Li and_Zhao, 2003). The ratio of the volume of the acid solution to that of the specimens is four and the solution is replaced in 30 days of interval. After 360 days of immersion, the specimens are surface cleaned and the loose materials removed. Then, the specimens are surface dried and the weight loss and compressive strength are determined. The view of acid immersion of concrete cubes is shown in figure 3(b). The results of acid test are presented in Table 3.

Table 2. Saturated water absorption of OPCC and GPC

No	Concrete type and Grade	Curing type	Saturated water absorption (%) in		
			90days	180 days	360 days
1	M20	PC	4.110	3.890	3.174
2	GM20 (8M)	HC	3.995	3.391	2.898
3	% less than M20	-	2.8%	12.8	8.7
4	M30	PC	3.821	3.191	2.798
5	GM30 (10M)	HC	3.268	2.779	2.682
6	% less than M30	-	14.5	12.9	11.6
7	M40	PC	3.258	3.102	2.884
8	GM40 (12M)	HC	3.021	2.405	2.145
9	% less than M40	-	7.3	22.5	25.6

(a) SWA Test (b) Immersion in Acid

Figure 3. Views of Durability test under progress in day one

Table 3. Results of acid attack on the compressive strength OPCC and GPC

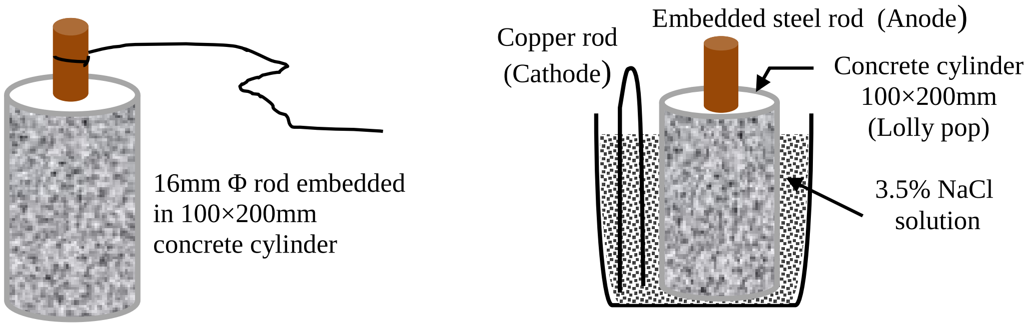
No	GPC Grade	Curing type	by % loss in compressive strength		
			90days	180 days	360 days
1	M20	PC	10.125	11.303	15.615
2	GM20 (8M)	HC	9.871	10.455	13.504
3	% less than M20	-	2.5	7.5	13.5
4	M30	PC	9.684	10.095	14.133
5	GM30(10M)	HC	8.680	9.225	12.120
6	% less than M30	-	10.4	8.6	14.2

Table 3. Results (cont'd) of acid attack on the compressive strength OPCC and GPC

No	GPC Grade	Curing type	by % loss in compressive strength		
			90days	180 days	360 days
7	M40	PC	9.122	9.865	12.892
8	GM40(12M)	HC	7.840	8.792	11.020
9	% less than M40	-	14.1	10.9	14.5

3.3 Corrosion resistance by polarization test

Two specimens are cast for each grade of concrete of for polarization test. The specimen known as lolly pop specimen for polarization test is shown in Figure 4(a). It is a cylinder with a 16mm rebar embedded partly with a 30mm projection. The polarization test set up as galvanic cells is shown in Figure 4(b).



(a) Details of lolly pop Specimen and NaCl tub

(b) Polarisation set up (c) The cracked specimens

Figure. 4 Details of polarization test

Three specimens are considered simultaneously one from each set consisting of specimens from three grades of GPC or OPCC respectively. Two specimens of each category is considered (Trial 1 and 2) and the average value is taken as the result. All the embedded rods of the concrete specimens are connected as anodes to the positive terminal and a cathode made of 8mm copper rod being the metal on the higher electro potential range, to the negative terminal of a constant power supply unit in each cell. The anode and the cathode are put up in a tub containing 3.5% NaCl solution. A constant potential of 12 volts is given for polarization study. For the impressed potential of 12V, the current response is monitored periodically. This is continued up to the cracking of the cylindrical specimen. The specimens are watched continuously for the appearance of brown rust colour which is an indication of oozing out of rust formed over the corroded rebar embedded. The tested samples after cracking are shown in Figure 4(c).The cracking time for all the specimens is noted and the results are presented in Table 4.

Table 4. Results of Polarisation study of GPC and OPCC

Details	Corrosion resistance of OPCC and GPC by cracking time (Hours)					
	M20	GM20	M30	GM30	M40	GM40
Trial 1	74	92	81	96	92	109
Trial 2	78	97	77	94	94	107
Average of 1 & 2	76	94.5	79	95	93	108
More than OPCC	-	24.3%	-	20.3%	-	16.1%

4. Discussion of Results

The design mix proposed for the three grades of GPC resulted in the expected compressive strength after curing and even by slightly more than the target strength similar to OPCC. The comparison of SWA for GPC and OPCC are shown in figure 5. The SWA of GPC is always less compared to OPCC for all the three grades of concrete respectively. The SWA of GM20 grade GPC is less compared to OPCC and varies from 2.8% to 12.8%. The difference in the % increase is not uniform. For GM30 grade GPC, the SWA is less compared to OPCC and varies from 14.5% to11.6%. For increase of immersion days, the SWA decreases uniformly. The SWA of GM40 grade GPC is less compared to OPCC and varies from 7.3% to 25.6%. The SWA increases as the immersion days increases but the rate of decrement is not uniform. The comparison of strength loss in acid immersion for 90 days, 180 days and 360 days for GPC and OPCC are shown in figure 6. In general, the strength loss of GPC is always less compared to OPCC for all the three grades of concrete. The strength loss of GM20 grade GPC is less compared to OPCC and varies from 2.5% for 90 days of immersion to 13.5% for 360 days of immersion uniformly. For GM30 grade GPC, the strength loss is less compared to OPCC and varies from 8.6% to14.2% but not uniformly. The strength loss of GM40 grade GPC is less compared to OPCC and varies from 10.9% to 14.5% but not uniformly.

The comparison of corrosion resistance by means of cracking period by polarization test is shown in figure 7. In general, the corrosion resistance of GPC is always more compared to OPCC with respect to the corresponding three grades of concrete. The cracking period of GM20 grade GPC is more by 24.3% than OPCC. For GM30 grade GPC, the corrosion resistance is 20.3% more compared to OPCC. The corrosion resistance of GM40 grade GPC is 16.1% more compared to OPCC. Higher the grades of concrete lower are the difference between the cracking time of GPC and OPCC. The basic compressive strength of the material is the mere indication of the quality of concrete, and the high calcium flyash based geopolymer concrete without conventional cement not only promotes the green technology but also results in cost effective nature.

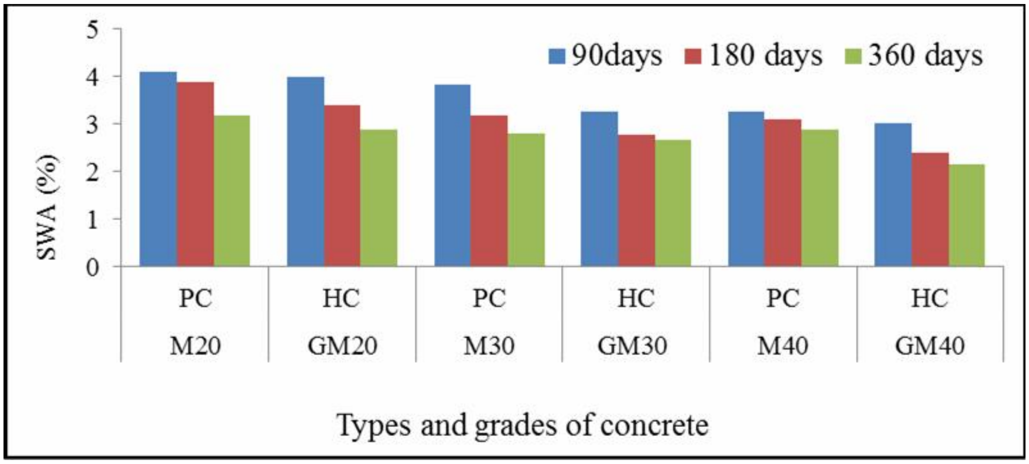


Figure 5. Comparison of SWA of GPC and OPCC

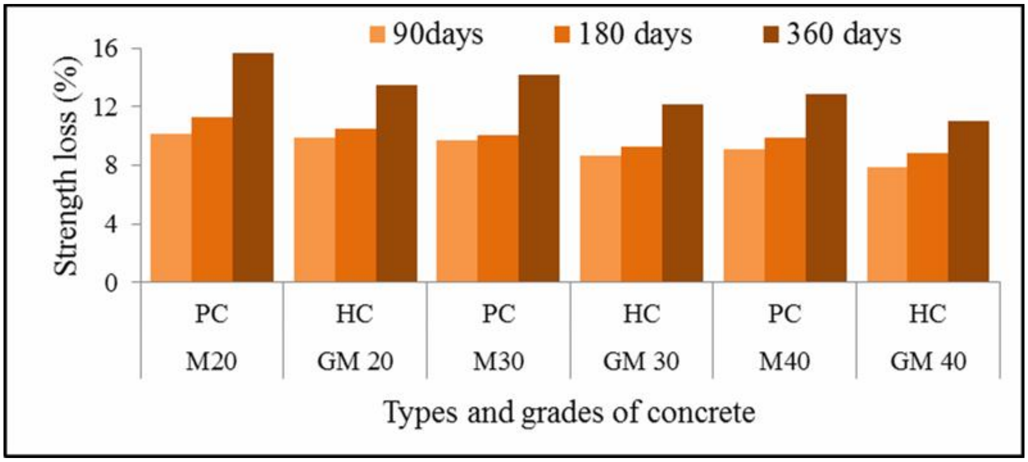


Figure 6. Comparison of Strength loss on Acid immersion of GPC and OPCC

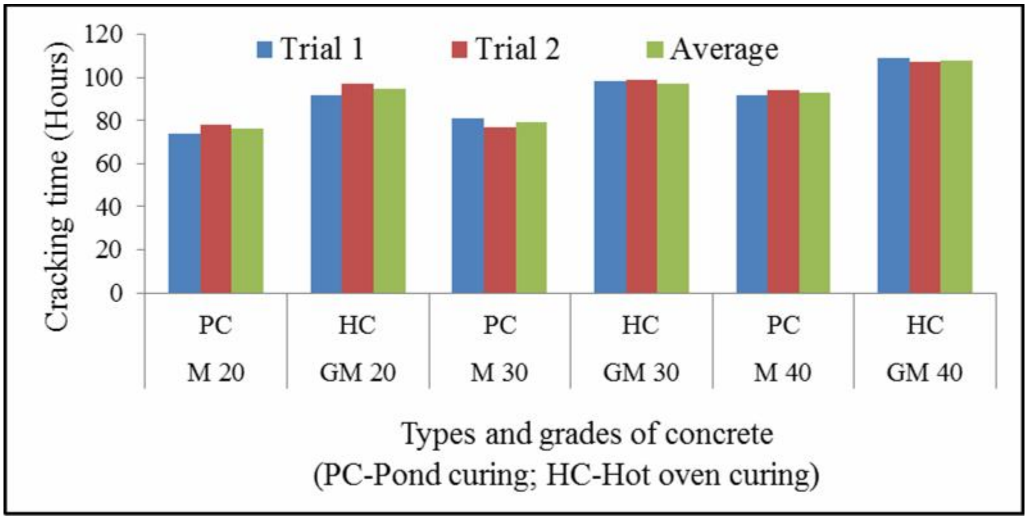


Figure 7. Comparison of corrosion resistance of GPC and OPCC

Compared to OPCC, the durability related properties are superior for GPC. Similar to LCFA based GPC, HCFA can also be used for making GPC. Comparatively, the quick setting characteristics of HCFA over LCFA are the real advantage. Durability properties of HCFA based GPC are determined, compared and found superior to OPCC. Encouraging result is the major strength of the study.

5. Conclusions

Confined to the present study on the development of durable Geopolymer concrete the following conclusions are made:

- High calcium flyash can be used as source material for making GPC similar to low calcium flyash for developing the required design strength.
- High calcium flyash has compatibility with the alkaline solution and other constituents.
- The durability characteristics of GPC of normal grades is superior to the equivalent grades of OPCC.
- Polarization test can be the simple and opt test for measuring the corrosion inhibiting characteristics.
- The corrosion resistance of GPC is 16% to 24% higher than the OPCC.

Based on the experimental investigations the following recommendations are made:

- High calcium flyash can be used as source material for making GPC.
- Mix design detailed in Table 1 can be adopted for normal grades of GPC equivalent to M20, M30 and M40 and the concentration of Sodium hydroxide can be chosen as 8M, 10M and 12M respectively.
- The ratio of sodium silicate to sodium hydroxide can be kept constantly as 2.5.
- As HCFA sets more quickly, hot oven curing at 60^{o}C for 24 hours is adequate.
- Further research is a must to establish for high strength GPC.

Acknowledgement

The authors wish to thank Dr. R.M. Senthamarai, Head of the department of Structural Engineering, Annamalai University for the encouragement given. The help rendered by the staff of Civil Engineering department, Arunai Engineering College, Tiruvannamalai is also gratefully acknowledged.

References

ASTM C 642-2006. Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, West Conshohocken, PA, 2004, www.astm.org.

Cheema D.S., Lloyd, N.A and Rangan, B.V., 2009, Durability of geopolymer concrete box culverts- A Green alternative, *Proceedings, 34th Conference on Our World in Concrete and Structures*, Singapore, pp. 85-92.

Cheema D.S., 2012, Low calcium flyash geopolymer concrete –A promising sustainable alternative for rigid concrete road furniture, Proceedings, 25th ARRB Conference – Shaping the future: Linking policy, research and outcomes, Perth, Australia, pp. 1-12.

Chindaprasirt P., Rattanasak U. and Taebuanhuad S., 2013, Resistance to acid and sulphate solutions of microwave-assisted high calcium flyash geopolymer, *Materials and Structures*, Vol. 46, No. 3, pp. 375-381.

Davidovits J., 1976, Solid phase of a mineral block polymer by low temperature polycondensation of Aluminosilicate polymers. *Proceedings, I.U.P.A.C International Symposium on Macromolecules*, Topic III: New polymers of high stability, September 1976, Stock-holm.

Duxson P., Fernández-Jiménez A., Provis J.L., Lukey G.C., Palomo A and van Deventer J., 2007, *Geopolymer Technology: The Current State of The Art, Journal of Materials Science*, Vol. 42, pp. 2917-2933.

Farhana Z.F., Kamarudin H., Rahmat A., Mustafa Al-Bakri A.M and Norainiza S., 2013, Corrosion performance of reinforcement bar in geopolymer concrete compared with its performance in ordinary Portland cement concrete: A short review, The 2nd *International Conference on Sustainable Materials Engineering (ICoSM2013)*, 26-27 March, pp. 510-513.

Gourley, J.T and Johnson G.B., 2005, Developments in geopolymer precast concrete, Proceedings, *International Workshop on Geopolymers and Geopolymer Concrete*, Perth, Australia, 2005.

Glukhovsky V.D., 1965, Soil silicates, Their Properties, Technology and Manufacturing and Fields of Application, *Doct Tech Sc. Degree Thesis*. Civil Engineering Institute, Kiev, Ukraine (former USSR).

Hime W.G., 2003, Comments on Geopolymer Concrete, Private Communication.

IS 456-2000. Plain and Reinforced Concrete - Bureau of Indian Standards, New Delhi, India.

Li G. and Zhao X., 2003, Properties of concrete incorporating flyash and ground granulated blast-furnace slag. *Cement & Concrete Composites*, Vol. 25, No. 3, pp. 293-299.

Li X., Ma X., Zhang S. and Zheng E., 2013, Mechanical properties and microstructure of class C flyash based geopolymer paste and mortar, *Materials*, Vol. 6, pp. 1485-1495.

Mohankumar,G and Manickavasagam R., 2017. Study on the development of class c flyash based GPC by ambient curing, *International Journal of Applied Engineering Research*, Vol. 12, No. 7, pp. 1227-1231.

Rajamane, N.P., Nataraja, M.C., Lakshmanan, N and Dattatreya, J.K., 2011, Accelerated test for corrosion of steel in geopolymer concretes, *ICI Journal*, October- December, pp.7-15.

Reddy, D.V., Edouard, J.B., Sobhan, K and Rajpathak, S.S., 2011, Durability of reinforced flyash based geopolymer concrete in the marine environment, *Proceedings, 36th Conference on Our World in Concrete & Structures*, Singapore, August 14-16, 2011.

Salmabanu Luhar and Urvashi Khandelwal (2015). Durability Studies of Flyash Based Geopolymer Concrete, *International Journal of Engineering Research and Applications*, Vol. 5, No. (8-4), pp. 17-32.

Sanni S.H. and Khadiranaikar R.B., 2012, Performance of geopolymer concrete under severe environmental conditions, *International Journal of Civil and Structural Engineering*, Vol. 3, No. 2, pp. 396-407.

Shaikh F., 2014, Effects of alkali solutions on corrosion durability of geopolymer concrete, *Advances in Concrete Construction*, Vol. 2, No. 2, pp. 109-123.

Talling, B and Stetr B., 1989, Present state and future of Alkali-activated slag concretes, *Proceedings, 3rd International Conference on Flyash, Silica fume, slag and Natural pozzolans in concrete*, pp.1519-1545.

van Jaarsveld J.G.S., Jannie S.J., van Deventer and Lukey G.C., 2003, The characterisation of source materials in flyash based geopolymers, *Materials Letters*, Vol. 57, No. 7, pp. 1272-1280.

Wallah S.E. and Rangan B.V., 2006, Low-calcium flyash-based geopolymer concrete: long-term properties, Research Report GC2, *Faculty of Engineering*, Curtin University of Technology, Perth.

Biographical notes

R. Manickavasagam received his M.Tech Degree in Structural Engineering in PRIST University, Thanjavur, India in 2011 and presently pursuing his doctoral programme with the same University. He is working as an executive Engineer, Public Works Department, Puducherry, India. His interest includes new concrete, repair and rehabilitation of structures. He has contributed much in the construction of Bridges and group housing projects.

Dr. G. Mohankumar is presently, a senior Professor in the Department of Civil Engineering and Principal, Arunai Engineering College, Tiruvannamalai, India. He has more than 37 years of experience in teaching and research. His area of research includes Prestressed concrete, Green concrete, Non destructive testing, Damage Assessments of Reinforced and Prestressed concrete structures and Retrofitting of Structures. He has published more than sixty research papers in referred international and national journals and has also presented more than eighty research articles in national and international conferences and workshops.

Received May 2017
Accepted June 2017
Final acceptance in revised form June 2017