ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 17, NO. 3(2016)
PAGES 277-288

PRELIMINARY STUDIES ON SELF COMPACTING GEOPOLYMER CONCRETE USING MANUFACTURED SAND

C. Sashidhar[1], J. Guru Jawahar[2*], C. Neelima[1] and D. Pavan Kumar[1]
[1]Department of Civil Engineering, Jawaharlal Nehru Technological University, Anantapur, India
[2]Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Tirupati, India

Received: 14 June 2015; **Accepted:** 20 September 2015

ABSTRACT

Self compacting geopolymer concrete (SCGC) is becoming an innovative sustainable engineered material in the construction industry that doesn't require both compaction and cement. In this study, SCGC mixes were manufactured using class F fly ash (FA) and ground granulated blast furnace slag (GGBS) in 50:50 proportions with 100% manufactured sand (MS). All mixes had a fixed water-to-geopolymer solids ratio of 0.4 by mass and a constant total binder content of 450 kg/m^3. The present investigation is mainly focused on the fresh and compressive strength properties of SCGC by varying the molarity of sodium hydroxide (NaOH) from 8 M to 12 M. Test methods such as slump flow, T_{50cm}, V-funnel and L-box were conducted to assess the fresh properties. Compressive strength of SCGC was determined after 7, 28, 56 and 90 days of curing at ambient room temperature. The contribution of GGBS helps the SCGC mixes to attain significant compressive strength development during all curing periods at ambient room temperature itself. Studies also revealed that the increase in NaOH molarity decreased the fresh properties, however it increased the compressive strength of SCGC.

Keywords: Self compacting geopolymer concrete, fly ash, ground granulated blast furnace slag, manufactured sand, ambient room temperature.

1. INTRODUCTION

Concrete is the backbone of all the construction and development activities around the world. Ordinary Portland cement (OPC) is the key ingredient of concrete. The current concrete construction practice can be considered unsustainable as it consumes enormous quantities of natural resources such as stone, sand, water, and 2-½ billion tones of OPC per year.

*E-mail address of the corresponding author: gurujawaharj@yahoo.co.in (J. Guru Jawahar)

From environment point of view, production of OPC is not an environmentally friendly aspect as it consumes large amount of natural resources and releases a significant amount of green-house gases [1]. The geopolymeric binders introduced by Davidovits shows promising area of research in construction industry as alternative binders to OPC. These geopolymers could be developed by a polymeric reaction of alkaline liquids with the silicon (Si) and aluminium (Al) source materials of naturally available resources or by-products such as fly ash (FA), ground granulated blast furnace slag (GGBS), rice husk ash (RHA) etc [2].

Naturally available Si-Al minerals, low calcium fly ash, metakaolin and combination of GGBS and metakaolin [3-5] have been studied as source materials. Both FA and GGBS in certain proportions were found to be geopolymer source materials to obtain sufficient strengths of geopolymer concrete (GPC).

Bhikshma et al. observed that a compressive strength of 30 MPa achieved in fly ash based GPC by providing alkaline solution to fly ash ratio of 0.5 at 16 molarity of sodium hydroxide (NaOH) [6]. Guru Jawahar and Mounika concluded that GGBS and FA blended GPC mixes attained enhanced mechanical properties at ambient room temperature itself [7]. Sujatha et al. concluded that geopolymer concrete columns exhibited high load carrying capacity, stiffness and ductility until failure [8]. Anuradha et al. pointed out that tensile strength of GPC made with river sand is higher than that of GPC made with manufactured sand [9]. Vijai et al. developed an expression to predict 28-day compressive strength, splitting tensile strength and flexural strength of steel fibre reinforced geopolymer concrete composites [10].

Many of the GPC mixes investigated earlier required the use of high temperature curing [11]. Palomo et al. concluded that the curing temperature significantly affected mechanical properties of the fly ash based GPC [4]. However, recent studies revealed that GPC mixes can be developed for ambient room temperature [12]. Hardjito et al. [13] noticed that fresh GPC was highly viscous with low workability and hence, superplasticizer (SP) was found to be used to attain adequate workability. Generally, the combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate solution can be considered as alkaline liquid in the geopolymer technology [3-5]. Increase in NaOH concentration and curing time resulted higher compressive strength values of fly ash based GPC mixes [11].

Geopolymeric materials have become the focus of interest and received the considerable attention because of the environmental benefits, such as the reduction in consumption of natural resources and the decrease in production of CO_2. Geopolymers does not require a high level of energy consumption than Portland cement [14 & 15]. Therefore, the use of geopolymer concrete technology not only significantly reduces CO_2 emissions but also utilizes the industrial waste and/or by-product, converting a potentially hazardous material to a valuable construction material. To sustain the environment from sand mining in rivers, manufactured sand (MS) is being used as an alternative to sand as the demand and cost of river sand is becoming high. To overcome the problems encountered in conventional concrete (CC), recently, self compacting concrete (SCC) has been encouraged in the construction industry as it fills each and every corner of the structural element under its own weight without any segregation or bleeding. This makes self compacting concrete (SCC) particularly useful wherever placing is required in heavily reinforced concrete members or in complicated formworks [16].

Self compacting geopolymer concrete (SCGC) is an innovative concept in the field of concrete technology that addresses two fold problems such as placing the concrete in complicated structural formworks and utilizing the industrial wastes. Memon et al. studied effect of curing temperature on strength of fly ash based SCGC and concluded that compressive strength of SCGC was increased with the increase in temperature from 60^0C to 70^0C, but beyond 70^0C strength was decreased [17]. Memon et al. concluded that compressive strength of fly ash based SCGC increased with the increase in molarity of NaOH from 8 M to 12 M, but further increase in moloarity (14 M) decreased the strength of SCGC. They also concluded that the increase in molarity decreased the fresh properties of SCGC [18]. Nuruddin et al. observed that the alkaline solution, superplasticizer and extra water should be premixed before adding to the dry mix of concrete to get improved workability of SCGC [19].

The present research examined the potential of SCGC made with the available constituent materials by examining its basic fresh and strength properties. The present work is investigated SCGC properties by varying the molarity of sodium hydroxide (NaOH) from 8 M to 12 M. In this study, class F fly ash (FA) and ground granulated blast furnace slag (GGBS) were blended equally at 50% replacement level (FA50-GGBS50). Manufactured sand (MS) was used as fine aggregate. As per EFNARC [16], test methods such as slump flow, T_{50cm} Slump flow**,** V-funnel and L-box were used to assess the fresh properties of SCGC. Compressive strength of SCGC was determined after 7, 28, 56 and 90 days of curing at ambient room temperature.

2. EXPERIMENTAL STUDY

2.1 Materials

The materials used in this study were class F fly ash (FA), GGBS, MS and coarse aggregate, superplasticizer, alkaline solution and water. Class F fly ash (ASTM 618) [20] obtained from Rayalaseema Thermal Power Plant (RTPP), Muddanur, A.P and GGBS produced from the Vizag steel plant, A.P were used in the manufacturing of SCGC. The chemical and physical properties of binders (FA and GGBS) are shown in Table 1. Locally available crushed coarse aggregate (CA) of maximum size 14 mm having specific gravity of 2.66 was used for all mixes. The coarse aggregate was used in saturated surface dry (SSD) condition. Manufactured sand (MS) having specific gravity of 2.61 and the fineness modulus of 2.69 was used as fine aggregate.

Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution was used as alkaline solution. The sodium silicate solution (Na_2O= 13.7%, SiO_2=29.4%, and water=55.9% by mass) was purchased from a local supplier. The sodium hydroxide (NaOH) in flakes or pellets from with 97%-98% purity was also purchased from a local supplier. NaOH solution concentration was varied from 8 M to 12 M. The mass of NaOH solids in a solution varied depending on the concentration of the solution. The alkaline solution was prepared 24 hrs before to use. To attain higher workability of the fresh concrete, commercially available superplasticizer (SKY 8630) was used. It is a blended version of both superplasticizer (SP) and viscosity modifying agent (VMA). A specified amount of extra water (other than the water used for the preparation of sodium hydroxide solution) was also used in the preparation of SCGC. The properties of the chemical admixture as obtained from the manufacturer are presented in the Table 2.

Table 1: Chemical Composition and Physical Properties Geopolymer Binders

Particulars	Class F fly ash	GGBS
Chemical composition		
% Silica(SiO_2)	65.6	30.61
% Alumina(Al_2O_3)	28.0	16.24
% Iron Oxide(Fe_2O_3)	3.0	0.584
% Lime(CaO)	1.0	34.48
% Magnesia(MgO)	1.0	6.79
% Titanium Oxide (TiO_2)	0.5	-
% Sulphur Trioxide (SO_3)	0.2	1.85
Loss on Ignition	0.29	2.1
Physical properties		
Specific gravity	2.13	2.90
Fineness (m^2/Kg)	360	400

Table 2: Properties of chemical admixture

Chemical Admixture	Relative density	pH	Chloride content (%)	Main component
SKY 8630	1.08	≥ 6	<0.2%	Polycarboxylate ether

2.2 Mix proportions

In this experimental work, three different mixtures with the same binder (FA+GGBS) content of 450 kg/m^3 were prepared to study the influence of sodium hydroxide concentration on fresh properties and compressive strength of SCGC. The NaOH solution was varied from 8 M to 12 M. The alkaline solution-to-binder ratio (AS/B) was kept constant at 0.45. All mixes had a fixed water-to-geopolymer solids ratio of 0.4 by mass, whereas the ratio of sodium silicate to sodium hydroxide was kept at 2.5. As per SCC guidelines, coarse aggregate (CA) content was maintained at 30% of concrete volume [16]. In order to obtain the required fresh properties of SCGC, a water content of 25% and superplasticizer dosage of 3% by mass of the binder were also used.The SCGC mix designations and details are given in Tables 3 and 4 respectively.

Table 3: SCGC mix designations

Mix	AS/B	Binder Kg/m3	CA Kg/m^3	MS Kg/m^3	NaOH Solution Kg/m^3	Molarity	Na_2SiO_3 Solution Kg/m^3	Extra Water (%)	SP (%)
M1	0.45	450	790	960	58	8	145	25	3
M2	0.45	450	790	960	58	10	145	25	3
M3	0.45	450	790	960	58	12	145	25	3

Table 4: SCGC mix details

Material	Content
Class F fly ash (kg/m^3)	225
GGBS (kg/m^3)	225
Coarse aggregate (kg/m^3)	790
Manufactured sand (kg/m^3)	960
Sodium silicate solution (kg/m^3)	145
Sodium hydroxide solution (kg/m^3)	58 (8M, 10M, 12M)
Superplasticizer (%)	3
Extra water (%)	25
Na_2SiO_3/ NaOH by mass	2.5
Alkaline solution/ binders	0.45
Water/ geopolymer solids (by weight)	0.4

2.3 Mixing, testing, casting and curing of SCGC

Mixing process was done in two stages. Initially, manufactured sand, coarse aggregate in saturated surface dry condition and binder (FA+GGBS) were mixed together in 100 liter capacity concrete mixer for 2.5 minutes. At the end of this dry mixing, a well-shaked and premixed alkaline solution, super plasticizer and extra water was added in the concrete mixer and the wet mixing was continued for another 3 minutes [19]. To ensure the good homogeneity in the mix fresh concrete was mixed for another 2 to 3 minutes. To assess the characteristics of SCGC, a freshly prepared wet mix was used to test the workability. As per EFNARC [16], test methods such as slump flow, T_{50cm} Slump flow**,** V-funnel and L-box were carried out to assess the fresh properties of SCGC. The fresh concrete mixture was then cast in 150 mm x 150 mm x 150 mm cube moulds. After demoulding, the specimens were kept at ambient curing for various curing periods. The specimens were tested for compressive strength as per IS 516 [21] after 7, 28, 56 and 90 days of curing.

3. RESULTS AND DISCUSSION

This section discusses the effect of sodium hydroxide concentration on the fresh properties and compressive strength of SCGC.

3.1 Effect of sodium hydroxide concentration on SCGC fresh properties

The fresh properties of SCGC were tested by as per SCC guidelines [16]. The experimental results of various fresh properties are presented in Table 5.

Table 5: Fresh properties of trial mixes

Mix No.	Molarity (M)	Slump flow (mm)	T_{50cm} slump flow(sec)	V-funnel (sec)	V-funnel at T_{5min} (sec)	L-box ratio (h_2/h_1)
M1	8	690	3.5	9.5	10	1.00
M2	10	690	3.5	10	10.5	0.92
M3	12	670	4.0	11	12	0.90

SCC acceptance criteria as per EFNARC [16]					
Minimum	650	2	6	9	0.8
Maximum	800	5	12	15	1

It is seen from the Table 5 that the three mixes M1 (8M), M2 (10M) and M3 (12M) have met the SCGC acceptance criteria [16]. From the results it is observed that the mix M1 with 8M of NaOH has attained excellent fresh properties when compared to those of the other two mixes. It is noted that the increase in molarity of NaOH increased the viscosity of the mix and thus caused in the reduction of SCGC fresh properties. This trend is in line with the results obtained in the earlier investigations [18 & 22]. Hence, it is concluded that the increase in NaOH molarity in the mix decreased the fresh properties of SCGC. Various tests conducted on SCGC mixes are shown in Figs. 1, 2 and 3.

Figure 1. V-funnel test

Figure 2. L-box test

Figure 3. Slump flow test

Slump flow test is the most commonly used test that assesses the horizontal free flow of fresh concrete. The results of the slump flow test are shown in Fig. 4. It is seen that slump flow results of all mixes were within the EFNARC range of 650-800 mm [16]. A maximum slump flow value of 690 mm was observed for the mix with 8 M. With the increase in molarity from 8 M to 12 M, the slump flow value was decreased from 690 mm to 670 mm. This reduction is mainly due to the increase in the viscosity of mix [19].

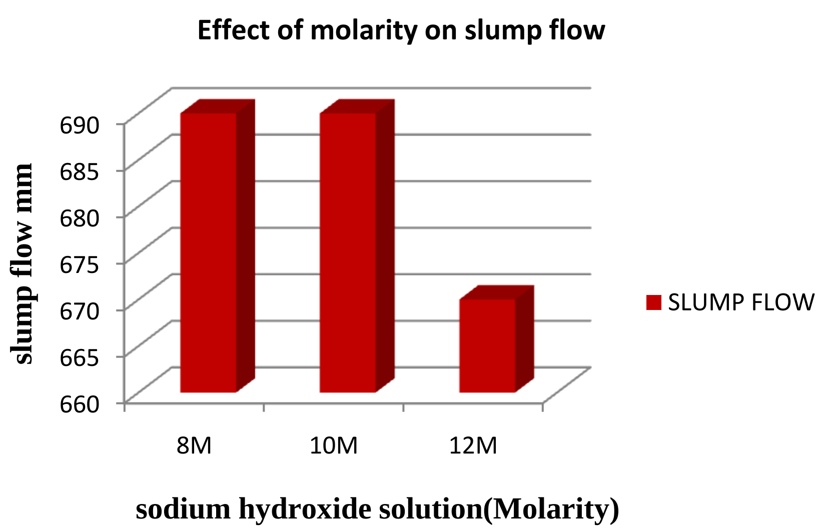

Figure 4. Slump flow test results of SCGC mixes

Fig. 5 shows the results of the T_{50cm} slump flow. It gives an indication of the relative viscosity and provides a relative assessment of the unconfined flow rate of the SCGC mixes.

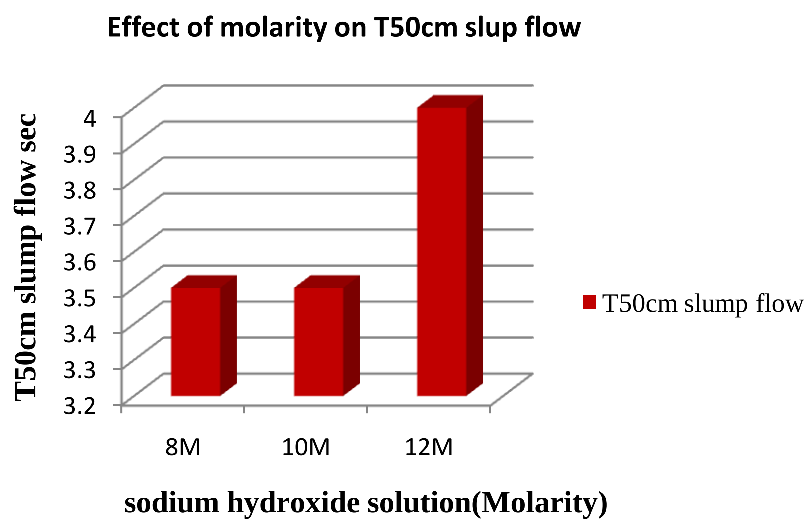

Figure 5. T_{50cm} slump flow test results of SCGC mixes

Test results of T_{50cm} slump flow shows that all the three mixes were qualified the permissible limits (2-5seconds) given by EFNARC [16]. An increase in the quantity of NaOH increased the viscosity and reduced the fluidity of concrete which in turn increased the T_{50cm} value. V-funnel test is primarily used to measure the filling ability (flowability) of SCC. Fig. 6 illustrates the V-funnel test results. All the results were within the permissible limits as shown in Table 5. With the increase in NaOH molarity, the filling ability was decreased and consequently V-funnel time was increased.

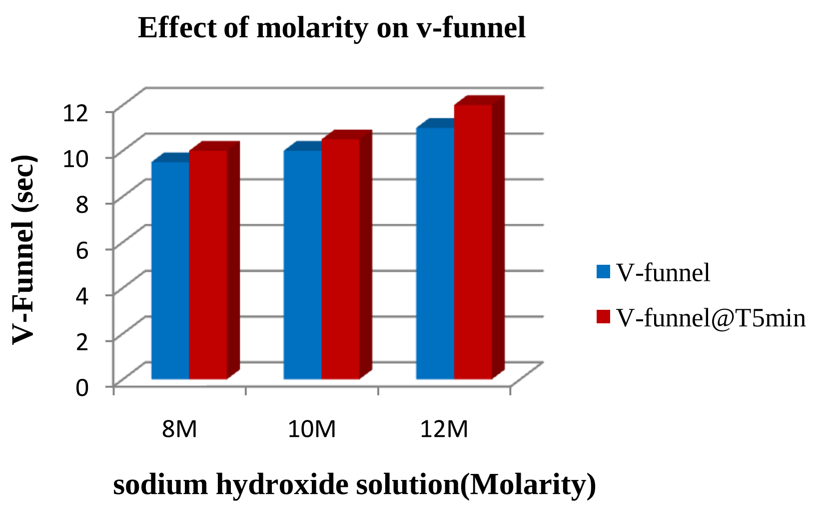

Figure 6. V-funnel test results of SCGC mixes

L-box test is used to assess the filling and passing ability of SCGC. Fig. 7 shows L-box test results. All the results were within the permissible limits as shown in Table 5. With the increase in NaOH molarity, the blocking ratio (h_2/h_1) was decreased.

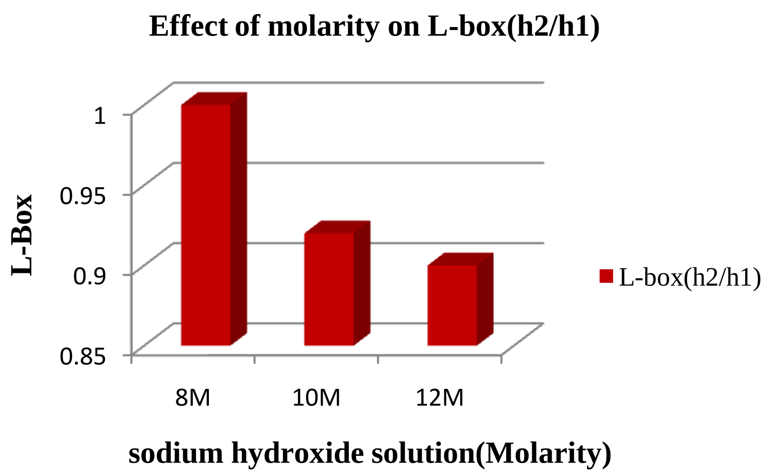

Figure 7. L-box test results of SCGC mixes

From the above results, it can also be concluded that for the given coarse aggregate content of 30%, the paste content of 36.4% can be considered as adequate paste content to attain successful SCGC mixes.

3.2 Effect of sodium hydroxide concentration on SCGC compressive strength

From the results obtained in the fresh properties of SCGC as shown in Table 5, the mixes were considered as successful SCGC mixes. Compressive strength results of SCGC mixes after 7, 28, 56 and 90 days of curing at ambient room temperature are presented in the Table 6 and their comparisons in their molarity are shown in Fig. 8.

Table 6: Compressive strength values of SCGC

Mechanical property	**Age (days)**	**Molarity (M)**		
		8M	**10M**	**12M**
Compressive strength, f'$_c$ (MPa)	7	35.445	37.334	40.595
	28	40.352	43.045	45.667
	56	46.155	49.615	51.177
	90	49.235	54.326	56.014

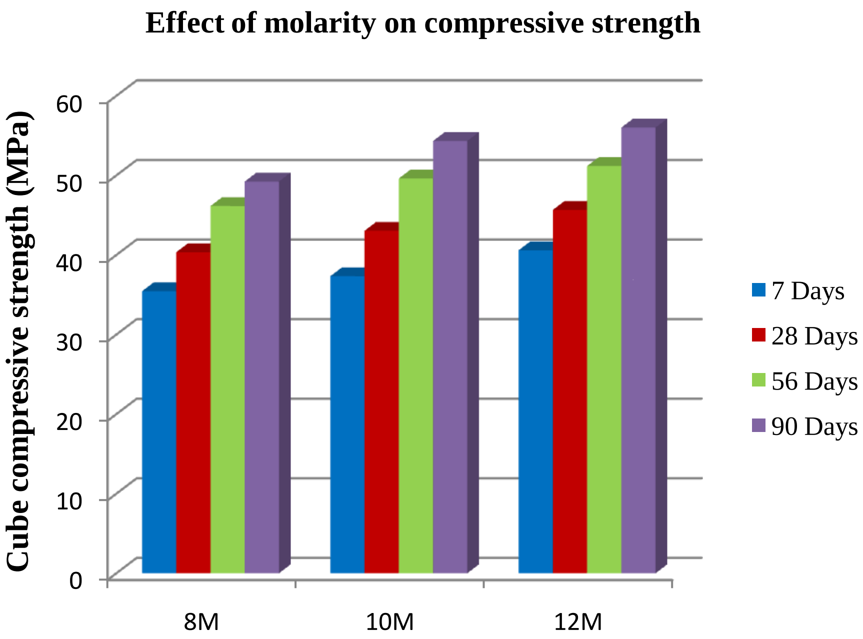

Figure 8. Compressive strength results of SCGC mixes

Fig. 8 illustrates the effect of NaOH molarity on the compressive strength of SCGC mixes. Test results shown that the increase in molarity increased the compressive strength of SCGC. It is due to the better geopolymer synthesis. The increase in NaOH molarity increases the dissolution of initial solid materials and increases the geopolymerization reaction. This improves the micro structure of the mix and increases the compressive strength [23-25]. That is why all mixes have attained excellent values of compressive strength at all curing periods at ambient room temperature. Another reason is also due to 50%-50% blending proportions of FA and GGBS. The contribution of GGBS helps the mix to attain early and rapid strength development at ambient room temperature curing.

From the results, it is revealed that the increase in NaOH molarity decreased the fresh properties, but however it enhanced the strength properties of SCGC. No adverse effects have been observed when SCGC mixes prepared with manufactured sand (MS). Thus, successful SCGC mixes can be achieved using MS and there by natural resources can be saved.

4. CONCLUSIONS

Based on the results of this experimental investigation, the following conclusions can be drawn:

1. The increase in the concentration of sodium hydroxide from 8 M to 12M increased the viscosity and reduced the fresh properties of SCGC mixes, nevertheless, all the three mixes still met the requirements of SCC suggested by EFNARC.
2. The increase in the NaOH molarity increased the compressive strength of SCGC.
3. The contribution of GGBS helps the mix to attain early and rapid strength development at ambient room temperature curing.
4. No adverse effects have been observed when SCGC mixes prepared with manufactured sand (MS).
5. For the given coarse aggregate content of 30%, the paste content of 36.4% can be considered as adequate paste content to attain successful SCGC mixes.

REFERENCES

1. McCaffrey R. Climate Change and the Cement Industry, *Global Cement and Lime Magazine (Environmental Special Issue)*, (2002) 15-9.
2. Davidovits J. Geopolymers: Inorganic Polymeric New Materials, *Journal of Thermal Analysis*, **37**(1991) 1633-56.
3. Xu H, Van Deventer JSJ. The geopolymerisation of aluminosilicate minerals, *International Journal of Mineral Processing*, **59**(2000) 247-66.
4. Palomo SA, Grutzeck MW, Blanco MT. Alkali-activated fly ashes – A cement for the future, *Cement and Concrete Research*, **29**(1999) 1323-9.
5. Davidovits J, Chemistry of geopolymeric systems, terminology, *Proceeding of Geopolymer International Conference, Saint-Quentin, France*, 1999.

6. Bhikshma V, Koti reddy M, Srinivas Rao T. An experimental investigation on properties of geopolymer concrete (no cement concrete), *Asian Journal of Civil Engineering*, **13**(2012) 841-53.
7. Guru Jawahar J, Mounika G. Strength properties of fly ash and GGBS based geopolymer concrete, *Asian Journal of Civil Engineering*, **17**(2016) 127-35.
8. Sujatha T, Kannapiran K, Nagan S. Strength assessment of heat cured geopolymer concrete slender column, *Asian Journal of Civil Engineering*, **13**(2012) 635-46.
9. Anuradha R, Sreevidya V, Venkatasubramani R, Rangan BV. Modified guidelines for geopolymer concrete mix design using Indian standard, *Asian Journal of Civil Engineering*, **13**(2012) 353-64.
10. Vijai K, Kumutha R, Vishnuram BG. Effect of inclusion of steel fibres on the properties of geopolymer concrete composites, *Asian Journal of Civil engineering*, **13**(2012) 377-85.
11. Hardjito D, Rangan BV. Development and properties of low-calcium fly ash-based geopolymer concrete, *Research Report GC1, Perth, Australia: Faculty of Engineering, Curtin University of Technology*, 2005.
12. Rajamane NP, Nataraja MC, Lakshmanan N, Ambily PS. Geopolymer concrete - An ecofriendly concrete, *The Masterbuilder*, *November*, **11**(2009) 200-6.
13. Hardjito D, Wallah SE, Rangan BV. Study on engineering properties of fly ash-based geopolymer concrete, *Journal of the Australasian Ceramic Society*, **38**(2002) 44-7.
14. Temuujin J, van Riessen A, MacKenzie KJD. Preparation and characterisation of fly ash based geopolymer mortars, *Construction and Building Materials*, **24**(2010) 1906-10.
15. Gourley JT. Geopolymers; Opportunities for environmentally friendly construction materials, *Paper Presented at the Materials 2003 Conference: Adaptive Materials for a Modern Society*, Sydney, 2003.
16. EFNARC. Specification and Guidelines for Self-compacting Concrete, 2002.
17. Memon FA, Nuruddin MF, Samuel D, Shafiq N. Effect of curing conditions on strength of fly ash-based self-compacting geopolymer concrete, *International Journal of Civil and Environmental Engineering*, **3**(2011) 183-6.
18. Memon FA, Nuruddin MF, Khan S, Shafiq N, Ayub T. Effect of sodium hydroxide solution and compressive strength of self-compacting geopolymer concrete, *Journal of Engineering Science and Technology*, **8**(2013) 44-56.
19. Nuruddin MF, Samuel D, Shafiq N. Effect of mix composition on workability and compressive strength of self-compacting geopolymer concrete, *Canadian Journal of Civil Engineering*, **38**(2011) 1-8.
20. ASTM C 618. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete, 2003.
21. IS 516. Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, India, 1991.

22. Siva Konda Reddy B, Varaprasad J, Naveen Kumar Reddy K. Strength and workability of low lime fly-ash based geopolymer concrete, *Indian Journal of Science and Technology*, **3**(2010) 1188-9.
23. Somna K, Jaturapitakkul C, Kajitvichyanukul P, Chindaprasirt P. NaOH-activated ground fly ash geopolymer cured at ambient temperature, *Fuel*, **90**(2011) 2118-24.
24. Panias D, Giannopoulou IP, Perraki T. Effect of synthesis parameters on the mechanical properties of fly ash-based geopolymers, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **301**(2007) 246-54.
25. Temuujin J, Williams RP, van Riessen A. Effect of mechanical activation of fly ash on the properties of geopolymer cured at ambient temperature, *Journal of Materials Processing Technology*, **209**(2009) 5276-80.