INFLUENCE OF GGBS ON THE STRENGTH & DURABILITY PROPERTIES OF FLYASH BASED SELF COMPACTING GEOPOLYMER CONCRETE

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ABSTRACT

Geopolymer is a supplementary potential binder to Portland cement. The production of geopolymer concrete can be done by using supplementary cementitious alternatives like silica fume, flyash, rice husk ash, ground granulated blast furnace slag (GGBS), etc., Self compacting geopolymer concrete (SCGC) can be considered as an appreciable and inventive construction material and can be noticed as a revolutionary development in the field of concrete technology. It is an innovative type of concrete that can achieve the combined advantages of both geopolymer concrete (GPC) and self compacting concrete (SCC). As the name implies, it does not need any compacting efforts to achieve full compaction and SCGC that is produced by a polymeric reaction of alkaline activator solution with a SCM's as a binder for matrix formation and strength.In the present investigations, low calcium flyash based GPC replaced with GGBS in 20%, 40%, 60%, 80%, 100% proportions. The concrete specimens those are cured in oven curing as well as cured in ambient temperature will be investigated experimentally under different tests. The workability, mechanical& durability characteristics are studied for different mix replacements. The conclusions shown that the incorporation of GGBS in flyash based SCGC, accordingly it enhances the hardened properties in early age. The workability characteristics are decreased by the addition of GGBS with flyash as replacement & also the compressive strength increases with increase of binder content.The durability characteristics also shown that the SCGC specimens are more durable compared to specimens that are replaced when GGBS replaced with flyash.

INTRODUCTION

Concrete is the backbone for all the construction and development activities across the globe. Ordinary portland cement is the key component for the production of the concrete. The current concrete production practice can be considered as untenable to consume excessive quantities of natural sources such as stone, sand and water and about 3 billion tonnes of ordinary portland cement / year. The production of Portland Cement worldwide is increasing 13% annually, Portland cement production is under critical review due to high amount of corbondioxide (CO_2) gas released to the atmosphere and OPC is also one among the most energy – intensive construction material. The current contribution of green house gas emission from Portland cement production is about 1.5 billion tonnes annually (or) about 7% of total green house gas emission to atmosphere.Primarily, the environmental pollution is considered as an extensive issue facing bythe globe. But the manufacture of cement production leads to environmental pollution because of the corbondioxide emission during its manufacturing process. Majorly, the emission of CO_2 during production of cement would be done by two main sources: the ignition of non renewable energy to operate the rotary kiln is the largest cause and the other is the chemical action of calcining limestone to lime in the cement kiln also producescorbondioxide. In India, about 1.59 metric tonnes of CO_2 is emitted in the 2013. And also, the production of cement can be done by using the coarse materials like limestone, clay, and other minerals. Unearthening of these coarse minerals leads to environmental degeneration. To produce 1 tonnes of cement, about 1.6 tonnes of coarse materials are utilized and the time taken to form the limestone is much longer than the rate of which we use it [1].Geopolymer concretes are a type of Inorganic polymer compounds, to form an important construction and building products industry by replacing/supplementing the normal conventional concrete. The term 'Geopolymer' was firstly popularized by Davidovits 1970's to name the 3D alumino-silicates which is a binder produced from the chemical reaction of a source material or feedstock rich in silicon (Si) and Aluminum (Al) with a concentrated alkaline solutions. Geopolymers are chemically comparable to zeolite but has amorphous microstructure generally consists of Si and Al atoms. Unlike OPC/PC, geopolymers do not form calcium-silicate-hydrates (C-S-H) for matrix formation, strength & durability, but by employing the polycondensation of Si and Al precursors to gain structural strength & durability. Two main components of geopolymers are source materials and alkaline liquids. The source materials of alumino-silicate should be high composition in Si and Al. They could be supplementary materials such as silica fume, slag, rice-husk ash, fly ash, red mud, etc. Geopolymers are further exclusive in comparison to other aluminosilicate source materials e.g. aluminosilicate gels, zeolite and glasses. The combination of solids in geopolymerisation is superior to the zeolite synthesis or aluminosilicate gel [2-3].Self compacting geopolymer concrete (SCGC) can be considered as an appreciable and inventive construction material and can be noticed as a revolutionary development in the field of concrete technology. It is an innovative type of concrete that can achieve the combined advantages of both GPC and SCC. As the name implies, it does not need any compacting efforts to achieve full compaction and

SCGC that is produced by a polymeric reaction of alkaline liquid with a by-product material utilizes Supplementary cementitious Materials such as Fly Ash, Ground Granulated Blast Furnace Slag, Silica Fume, Rich Husk Ash, Metakaolin, etc., together with alkaline solution and superplasticizer as a binder for matrix formation and strength.A significant progress of health and safety could also be achieved through reduction of CO_2 emission due to elimination of Portland cement production, suspending the use of vibrators and considerable minimization of environmental noise loading on and around a construction site .The sustainable production of self compacting geopolymer binder hinges on controlling the mix proportion, determining the right quantities of

Sodium Hydroxide (NaOH) (or) Potassium Hydroxide (KOH) and Sodium Silicate (Na_2SiO_3) (or) Potassium Silicate (K_2SiO_3) solution required to activate the source material and optimizing the superplasticizer dosage. The structure of SCGC mixes includes substantial proportions of fine-grained inorganic materials and this gives capabilities for utilization of mineral additives like slag, silica fume fly ash, etc., which arepresently waste products with no rational use and are costly to dispose-off.The alkaline activator solution (AAS) has a larger consequence on the compressive strength of activated concretes made using supplementary cementitious additives and the activator-to-binder ratio controls the compressive strengths of activated slag concretes to a higher degree [4, 5]. Relatively little attention has been given to the properties that would result from combining geopolymers as a matrix with high material greenness, with composite design for enhanced durability due to the suppression of brittleness in favour of more ductile behavior by composites of industrial by-products [6].The hardened properties of geopolymer concrete increases with increase in curing temperature upto a value of 100 °C and after that it decreases its strength. Modulus of elasticity and the Poisson's ratio of geopolymer concrete can carry to be equal to or even higher than that of the corresponding ordinary portland cement concrete, by the proper selection of total aggregate content (TAC) and ratio of FA to TAC[1, 7]. The effect of water-to-geopolymer solids ratio by mass on the hardened properties as compressive strength and the fresh properties as the workability of GPC and concluded that compressive strength of GPC decreases and also that the water-geopolymer solids by mass increases and certainly as the water- geopolymer ratio raised, the workability increased as the mixture consists of more water. The test results of [8] shown that the heat-cured low calcium fly-ash based GPC has an excellent resistance to sulphate attacks. The fresh & hardened properties of structural members casted of geopolymer concrete are similar to those observed in the case of ordinary portland cement concrete.The compressive strength of geopolymer concrete increases with increase in curing temperature upto a value of 100 °C and beyond which it decreases. Modulus of elasticity as well as the Poisson's ratio of geopolymer concrete can be brought equal to or even higher than that of the corresponding ordinary cement concrete, by the proper selection of total aggregate content and ratio of fine aggregate to total aggregate content [1, 7]. The effect of water-to- geopolymer solids ratio by mass on the compressive strength and the workability of GPC and concluded that compressive strength of GPC decreases and also that the water-geopolymer solids by mass increases and obviously as the water- geopolymer ratio increased, the workability increased as the mixture contained more water. The test results of [8] shown that the heat-cured low calcium fly-ash based GPC has an excellent resistance to sulphate attacks. 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.The chemical action of geopolymer concrete succeeds with the temperature usedfor the curing process. In the first 4 to 6 hours of heat curing, the specimens attain most of 70% of strength. Mostly the curing process that is done for geopolymer concrete is heat steam curing or normal heat curing in oven with in a temperature of 70℃-90℃ for 24 hours. Though a heat curing temperature of 70℃ is more adequate than other temperature or can be said is the optimal curing temperature [9-11].The influence of mineral admixtures on the workability, mechanical strength and durability aspects of self-compacting concrete are studied. The application of silica fume and GGBFS in concrete mixture has significantly increased and enhanced the properties ofthe concrete whether it is in wet stage or in harden condition. Silica fume is usable as a secondary mineral additive. By using the silica fume, it is greater in modulus value and from the mixes studied; it is recommended that not more than 5% silica fume can be replaced by mass. High performance self compacting concrete with GGBS and silica fumes illustrates superior attainment in compared to its flexure [12, 13]. Contraction of gelto powder ratio leads to improve compressive strength. Optimal quantity of chemical additive is 1.5-1.8%. Quantity of super plasticizer below 1.5% alters the workability, over dosage of SP implies setting time. Quantity of superplasticizers desires the maintenance of the self-compatibility of concrete, increased linearly by weight of supplementary cementitious additives. Consideration need at selecting the water content for self compacting concrete without adding viscosity modifying agent, since rheological behaviour is more responsive for water [14]. [15] presents an investigation into the durability of geopolymer concrete manufactured using class F fly ash and alkaline activators (NaOH and Na_2Sio_3) when exposed to sulphate and acidic environment and comparison was made with normal Ordinary Portland Cement (OPC) concrete and concluded that The least strength changes and weight loss were found in the sulphate solution. The OPC concrete more deterioratedin acid as well as in sulphate solution in compared with geopolymer concrete, thus geopolymer concrete is more durable than the OPC concrete [16]. The inclusion of extra water enhanced the workability attribute of concrete mixtures; however, the addition of water beyond the required limit results in bleeding and segregation of fresh concrete and decreased the compressive strength of the concrete. Sustained curing period enhances the geopolymerisation action resulting in greater compressive strength. The concentration of chemical composition of sodium hydroxide & sodium silicate had least influence on the fresh properties of self compacting geopolymer concrete [17, 18]. With the increase in NaOH molarity, the workability properties of fresh concrete was slightly decreased; Inspite of, the corresponding hardened properties are increased with increasing in the concentration of sodium hydroxide. Concrete specimens with NaOH concentration of 12 molarity give a greater compressive strength.

**MATERIA
LS
FLYASH**

Flyash produced from Raichur thermal power plant, Karnataka was used. Flyash with specific gravity of 2.20 and surface area of 350 m^2/kg was used. The chemical compositions are given in table 1.

GGBS

Ground granulated blast furnace slag (GGBS) consists essential silicates and alumino silicates of calcium. GGBS obtained from JSW steel Ltd, Bellary. The specific gravity of 2.90 and surface area of 400 m^2/kg was used. The chemical compositions are given in table1.

AGGREGATES

Well graded locally available fine aggregates passing of 4.75 mm and coarse aggregate of passing 12.5 mm are used in the present work.

Table 1: Chemical Compositions

Oxide	Fly ash (%)	GGBS (%)
CaO	3.2	37.34
Al_2O_3	30.6	14.42
Fe_2O_3	1.5	1.11
SiO_3	61.12	37.73
MgO	0.75	8.71
Na_2O	1.35	----
LOI	0.79	1.41
MnO	----	0.02

ALKALINE ACTIVATOR SOLUTION

The preparation of alkaline activator solution plays a major role in Geopolymer concrete. The AAS is the combination of sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution. The solids must be dissolved in water to make a solution with the required concentration expressed in terms of molarity (M). The concentration of NaOH solution can vary in the range between 8M to 16M; however, 12M solution is adequate for most applications. The NaOH for 12M is 12x40 (Molecular weight) = 480gms should dissolve in 1 litre of water. After mixing the NaOH flakes in water its molecular weight reduces to 361gms for 12 Molarity. For 12M NaOH solution, for 1 litre of water we require 36.1% of NaOH flakes and 63.9% of water .It is recommended that the alkaline liquid is prepared at least 24 hours before to use.

VMA

In the present study Master Matrix 2, which is bought from BASF, Hyderabad was used. The advantage of using VMA in SCC is it reduces the sensitivity of self compacting concrete with variation in water content. It is used to avoid bleeding and segregation.

SUPERPLASTICIZER

Super plasticizer (SP) is an essential ingredient of SCC to provide adequate workability. In the present study, the SP used is Conplast SP 430 supplied by Fosroc constructive solutions, INDIA. Conplast SP430 is used where a high degree of workability .It facilitates production of high quality concrete. It is appeared in brown colored liquid instantly dispersible in water. The optimum dosage is determined by trails with the concrete mix which enables the effects of workability and strength measured.

EXPERIMENTAL PROGRAMMEOBJECTIVE

To develop flyash based self compacting geopolymer concrete and evaluating the optimummix proportions of SCGC with flyash replaced in various percentages of GGBS which achieved both workability and mechanical properties. Finally studying the effect of curing temperature and curing time on the properties of SCGC and also evaluating the durability characteristics of SCGC.

MIX DESIGN OF SCGC

Here, the mix design of SCGC is purely different to that of OPC concrete. The production of SCGC was carried out by using the trial and error method. In GPC, generallythe mass of combined aggregates may be taken to be between 70% to 80%. With regard to alkaline liquid to fly ash ratio by mass of flyash, values in range of 0.35 to 0.5 are recommended. In the beginning, a total number of 17 trial mixes of SCGC were produced to assess the workability characteristics and study the influence of various parameters on the compressive strength. Finally the ratio of alkaline liquid to flyash was kept 0.5 as constant and the ration of the sodium silicate solution to sodium hydroxide solution was kept 1 as constant for all mix proportions. The addition of extra water improved the workability characteristics of SCGC mixtures, however the addition of water beyond the limit results bleeding and segregation of fresh concrete & decreased the compressive strength of SCGC. Here, 12% of extra water by mass of flyash was taken. The details of mix proportions were given below in the table 2.Mixing, Casting, Curing: The components of SCGC i.e., fine aggregate; coarse aggregate, flyash, GGBS, were dry mixed in the pan mixer about 2 min. Then the dry mix followed by the wet mix where by the liquid part of the mixture i.e., sodium hydroxide solution, sodium silicate solution, AAS solution, SP, extra water mixed with VMA for another 2 min. After mixing, the fresh concrete was then filled into steel moulds and allowed to fill all the spaces of the moulds by its own self weight without any compacting efforts. After casting the specimens were put for curing. Here the curing methodology shown in figure. 1 is purely different that to curing of OPC concrete. After casting the specimens with mould kept for drying in both oven curing at 70℃ and ambient curing temperature.

Fig 1: Oven curing at 70℃

RESULTS & DISCUSSION TESTS ON FRESH PROPERTIES

The essential fresh properties required by SCGC are flowability or filling ability, passing ability and resistance to segregation. The tests performed on SCGC are Slump flow, T- 50cms flow, V- Funnel, L-Box satisfying the EFNARC guidelines.

Table 2: Details of Mix Proportions

S.No	Mix	CA (kg/m^3)	FA (kg/m^3)	Flyash (kg/m^3)	GGBS (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)
1	M1	935	829	424	---	106	106
2	M2	935	829	339.2	84.8	106	106
3	M3	935	829	254.4	169.6	106	106
4	M4	935	829	169.6	254.4	106	106
5	M5	935	829	84.8	339.2	106	106
6	M6	935	829	---	424	106	106

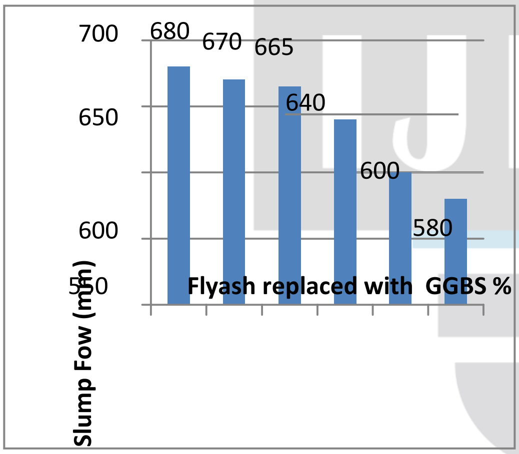
Table 3: Fresh properties of SCGC

% of GGBS replaced with flyash	Mix Designation	Slump flowin mm	T-50cms in sec	V-Funnel in sec	L-Box
0	M1	680	3	12	0.92
20	M2	670	4	14	0.89
40	M3	665	6	15	0.86
60	M4	640	6	18	0.85
80	M5	600	7	22	0.77
100	M6	580	8	24	0.74

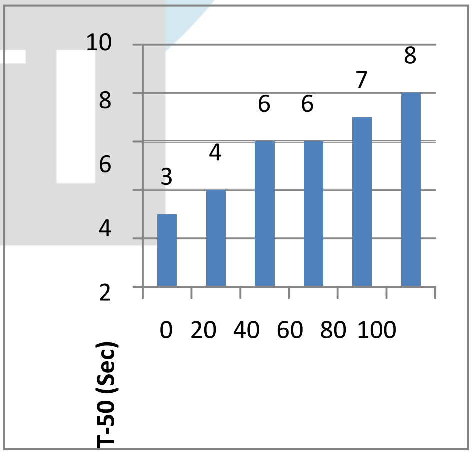
Figure 2: Test setups for fresh concrete

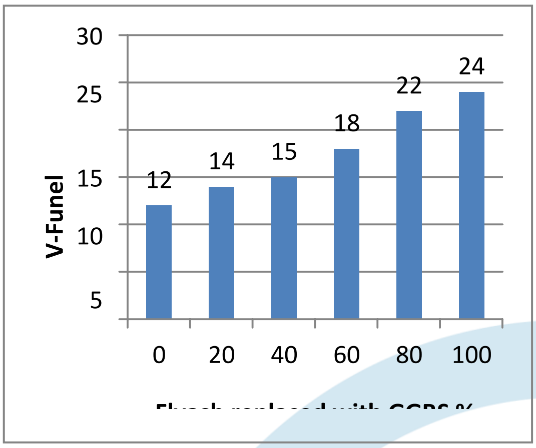
The test setups are shown in the above figure 2. The values are tabulated in the table 3 and shown in figures 3 (a), (b), (c), (d). The figure 3 (a) shown that the flowability (in mm) in the slump flow is gradually decreased from 680mm, when the flyash replaced with 0% of GGBS to 580 mm, when the flyash replaced with 100% of GGBS. The figure 3 (b) shows that the flow time, termed as T_{50cm} slump flow, gives an indication of the relative viscosity and provides a relative assessment of the confined flow rate of the SCGC mixture. A lowertime indicates greater flow ability. The figure 3 (c) shown that the period of flowability (in sec) in the V-Funnel is gradually increased from 12 sec, when the flyash replaced with 0% of GGBS to 24 sec, when the flyash replaced with 100% of GGBS. When the concrete stop flowing, the height of the concrete at the end of horizontal section (H_2) and in the vertical section (H_1) are measured to compute the blocking ratio (H_2/H_1) to 1, the better will be the flow of the SCGC. Various sources set different values for (H_2/H_1) ratio but values between 0.8 to 1 are generally recommended.

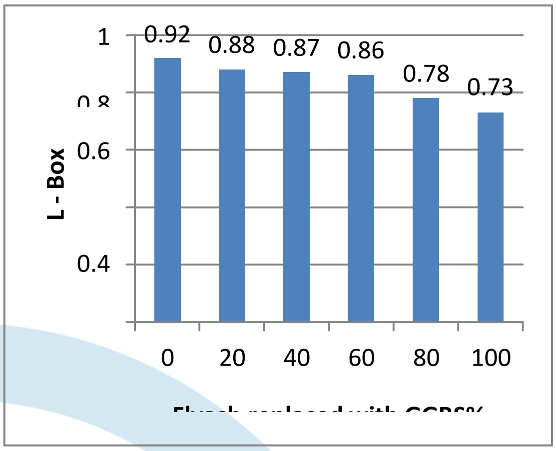
(a). Slump Flow values in mm



(b). T50 cms values







(c). V- Funnel Values **(d)** L-Box values

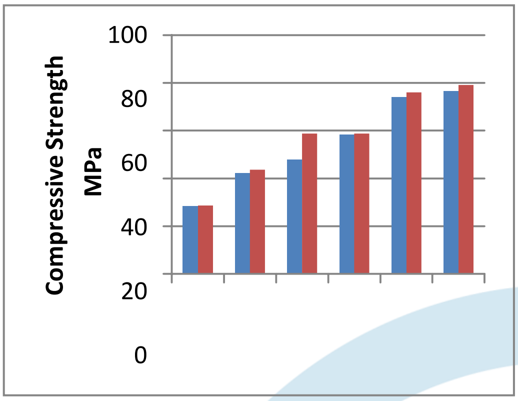
Figure 3:- Fresh Properties of SCGC.

HARDENED PROPERTIES

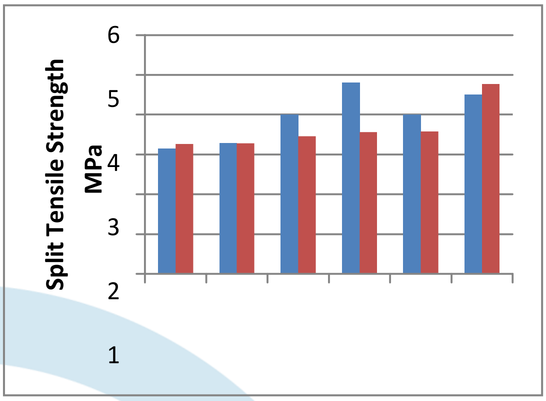
The hardened properties for the specimens cured in both heat curing & ambient temperature curing are assessed by compressive strength, split tensile strength, flexural strength by using test methods. Red colour bars show the ambient temperature curing specimen's strength and blue colour bars shows that the oven curing specimen's strength. The values are tabulated in table 4 and shown in figures 4(a), (b) and (c).The Figure 4 (a), (b), (c) shows that the strength obtained for the specimens cured by using oven curing at 70°C is nearer to the strength obtained for the specimens cured by ambient temperature for 28 days. Hence after evaluating the hardened properties it is permitted to using the ambient temperature curing process for the SCGC.

Table 4:- Hardened properties of SCGC specimens.

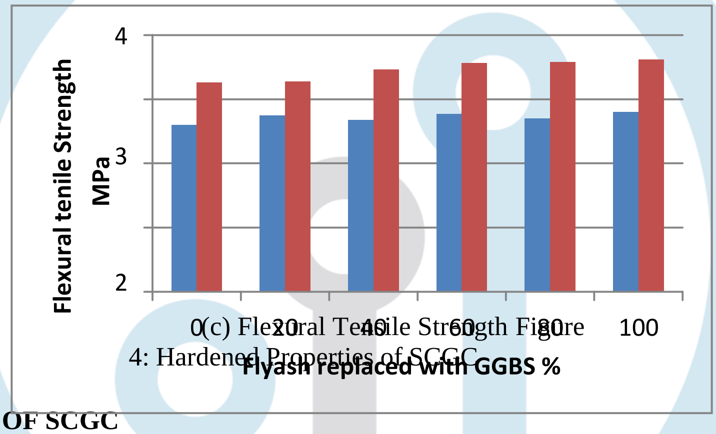
% of GGBS replaced with flyash	Comp. Strength (N/mm^2)		Split Tensile Strength (N/mm^2)		Flexural Strength (N/mm^2)	
	Ambient Curing	Heat Curing	Ambient Curing	Heat Curing	Ambient Curing	Heat Curing
0	28.22	28.55	3.15	3.26	2.6	3.26
20	42.22	43.50	3.29	3.28	2.75	3.28
40	47.88	58.66	4.00	3.46	2.68	3.46
60	58.22	58.66	4.81	3.56	2.77	3.56
80	74.00	76.00	4.00	3.58	2.70	3.58
100	76.50	79.00	4.50	4.77	2.80	3.62



(a). Compressive Strength



(b) Split Tensile Strength



(c) Flexural Tensile Strength Figure 4: Hardened Properties of SCGC

DURABILITY PROPERTIES OF SCGC

In the present experimental investigations, tests were performed on concrete cube specimens of size 70.6 mm^3. The SCGC specimens are immersed in 5% HCL and 5% H_2SO_4 solutions. The deterioration of SCGC specimens can be estimated by finding out the appearance of the specimen, weight loss of the specimen and also the reduction in compressive strength of the specimens when they are kept in HCL and H_2SO_4 solution were identified for 28 days respectively. The appearance of the specimens before and after immersion in HCL & H_2SO_4 solutions are shown in figure 5(a) & 5(b). The weight loss of SCGC specimens of different mixes in HCL solution H_2SO_4 solution are shown in table 5. The Compressive strength loss of SCGPC specimens of different mixes in HCL solution H_2SO_4 solution are shown in table 6.

Figure 4(a): Specimens before immersion in chemicals

Figure 4(b): Specimens after immersion in HCL and H_2SO_4 solutions

Table 5:- Weight loss of SCGC specimens

MIXES	weight of specimens beforeacid immersion in gms (28 days)		weight of specimens afteracid immersion in gms (28 days)		Weight loss in gms (28 days)	
	HCL	H_2SO_4	HCL	H_2SO_4	HCL	H_2SO_4
M1	868	859	830	816	38	43
M2	913	902	886	869	33	33
M3	893	886	874	862	19	24
M4	855	855	838	834	17	21
M5	882	895	871	882	11	13
M6	865	886	861	879	4	7

Table 6:- Compressive Strength loss of SCGC specimens

MIXES	Compressive strength of specimens before acid immersion in N/mm^2 (28 days)		Compressive strength of specimens after acid immersion in N/mm^2 (28 days)		Compressive strengthloss in N/mm^2 (28 days)	
	HCL	H_2SO_4	HCL	H_2SO_4	HCL	H_2SO_4
M1	29.01	30.01	27.01	27.01	2	3
M2	36.01	35.01	34.01	33.01	2	2
M3	48.01	48.01	47.01	46.01	1	2
M4	59.01	59.01	58.01	58.01	1	1
M5	60.01	56.02	60.01	55.03	0	0.99
M6	66.02	67.02	66.01	67.02	0	0

CONCLUSION

In this present study, the fresh & hardened properties of Low-calcium flyash based SCGC assessed with different replacements of GGBS. From experimental results, the following conclusions are drawn as follows:Economical benefits are achieved by elimination of curing cost and labour cost for compaction efforts.In fresh properties, by replacement of GGBS to flyash based SCGC, the workability was reduced.In hardened properties, by replacement of GGBS to flyash based SCGC, the strength was increased.By considering the self compacting properties and strength criteria, Mix 4 at 60% replacement of GGBS to flyash based SCGC was appropriate mix for application of structural elements.SCGC is more durable for chemical attacks as well as strength criteria.

REFERENCES

1. Aaron Richard Sakulich" Reinforced geopolymer composites for enhancedmaterial greenness and Durability" Elsevier Sustainable Cities and Society 1 (2011) 195– 210 IN 2011
2. Aravinth S. N." Development of High Strength Self Compacting Concrete Using Mineral And Chemical Admixture" Journal of Civil Engineering and Environmental Technology Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 1, Number 4 ; August, 2014 pp. 8 – 13
3. Benny Joseph , George Mathew "Influence of aggregate content on the behavior of fly ash based geopolymer concrete " Elsevier Scientia Iranica A (2012) 19 (5), 1188–1194.
4. B. Vijaya Rangan "Geopolymer concrete for environmental protection" The Indian Concrete Journal, April 2014, Vol. 88, Issue 4, pp. 41-48, 50-59.
5. D B Raijiwala, H S Patil, I U Kundan" Effect of alkaline activator on the strength and durability of geopolymer concrete " Journal of Engineering Research andStudies E-ISSN: 0976-7916, March 2012.
6. Deepak Ravikumar, Sulapha Peethamparan, Narayanan Neithalath "Structure and strength of NaOH activated concretes containing fly ash or GGBFS as the sole binder" (March 2010) Elsevier Cement & Concrete Composites 32 (2010) 399– 410.
7. Karthik Poovaiah D "Durability and Strength Properties on High Performance Self Compacting Concrete with GGBS and Silica Fumes" Journal of Engineering Research and Applications www.ijera.com ISSN: 2248-9622, Vol. 4, Issue 6(Version 6), June 2014, pp.12-19.
8. Madheswaran C. K, Gnanasundar G, Gopalakrishnan. N "Effect of molarity in geopolymer concrete" International journal of civil and structural engineering volume 4, no 2, 2013, pp. 106-115.
9. Monu Malviya, Prof. H.S. Goliya "Durability of Fly ash based Geopolymer Concrete using Alkaline Solutions" International Journal of Emerging Trends in Engineering and Development Issue 4, Vol.6 (Oct. -Nov. 2014).
10. M. Fareed Ahmed, M. Fadhil Nuruddin, "Compressive Strength and Workability Characteristics of Low-Calcium Fly ash-based Self-Compacting Geopolymer Concrete" International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:5, No:2, 2011.
11. M. Fareed Ahmed, M. Fadhil Nuruddin "Effect of sodium hydroxide concentration on fresh properties and compressive strength of SCGC " Journal of Engineering Science and Technology, Vol. 8, No. 1 (2013) 44 – 56.
12. Monu Malviya, Prof. H.S. Goliya "Durability of Fly ash based Geopolymer Concrete using Alkaline Solutions" International Journal of Emerging Trends in Engineering and Development Issue 4, Vol.6 (Oct. -Nov. 2014).
13. Mucteba Uysal, Mansur Sumer" Performance of self-compacting concrete containing different mineral admixtures" Elsevier Construction and Building Materials 25 (2011) 4112–4120.
14. Ping Duan, Chunjie Yan, Wei Zhou "An investigation of the microstructure and durability of a fluidized bed fly ash-metakaoline geopolymer after heat and acid exposure "Materials and Design S0261-3069(15)00092-8, 7 March 2015.
15. Pradip Nath , Prabir Kumar Sarker "Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition" Elsevier Construction and Building Materials 66 (2014) 163–171.
16. Pradip Nath , Prabir Kumar Sarker, Vijaya B Rangan "Early age properties of low- calcium fly ash geopolymer concrete suitable for ambient curing "ELSEVIER Procedia Engineering 125 (2015) 601 – 607.12.
17. Prof Joseph Davidovits "Geopolymer Cement" web: www.geopolymer.org,January 2013.
18. Prof Joseph Davidovits " Properties of Geopolymer Cements" International Conference on Alkaline Cements & Concrete, Scientific Research Institute on Binders & Materials, Kiev State Technical University, Ukraine, 1994, pp.131-149.
19. Sourav Kr. Das, Amarendra Kr. Mohapatra and A.K. Rath "Geo-polymer Concrete–Green Concrete for the Future—A Review " International Journal of Civil Engineering Research. ISSN 2278-3652 Volume 5, Number 1 (2014), pp. 21- 2