STUDY ON WORKABILITY AND DURABILITY CHARACTERISTICS OF SELF-COMPACTING GEOPOLYMER CONCRETE COMPOSITES

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ABSTRACT

Increase in production of cement causes the huge amount of carbon-dioxide emission, which results in global warming. In order to overcome this problem many researchers put their effects to achieve the optimum strength and durability of concrete by replacing the cement with fly ash and when it combines with the alkali activator solution it becomes geopolymer concrete. These concretes have the ability to fail due to lack of compaction. Self-compacting concrete is the innovative way of concreting; it can be compressed into every corner of formwork by means of its own weight. In order to trounce poor compaction and global warming; the new way of concreting is introduced as self-compacting geopolymer concrete. This concrete has two limitations such as delay in setting time and heat curing to gain strength. The present research intended to set right these limitations by replacing the fly ash by OPC up to 20% on a mass basis. Also an attempt to make to use of manufactured sand instead of using river sand due to scarcity of river sand and natural resource depletion. The durability of self-compacting geopolymer concrete composites is based on the tests conducted such as acid attack, sulphate attack, and Sorptivity.

Keywords : Acid Resistance, Geopolymer Concrete Composites, Self-Compaction, Sorptivity, Sulphate Attack.

I INTRODUCTION

Concrete is one of the most widely used construction material in the world and ordinary Portland cement is the main building material in concrete. During manufacturing of cement, there will be a release of large amount of carbon-dioxide gas into atmosphere, which results in global warming. The most effective way of reducing the CO_2 emission of cement industry is to substitute a proportion of cement with the other materials. These materials called supplementary cementitious material. Usually used supplementary cement materials are Fly ash, Slag, Silica fume and metakaolin [1].

Geopolymer concrete is an alkali activated concrete. In the past few decades it has emerged as one of the possible alternative to OPC binders due to their high early strength and resistance to acid and sulphate attack. Though geopolymers are manufactured from various source material, fly ash based geopolmer concrete [2] has more attractive than the other. Geopolymer binders might be a alternative acid resistant concrete since it relies the aluminum silicate rather than calcium silicate hydrate bonds for structural rigidity [3]. Geopolymersis is a type of inorganic polymeric composite that are produced and hardened even at ambient temperature under highly alkaline conditions. Polymerization takes place when reactive alumino silicates are rapidly dissolved and free SiO_4 and AlO_4 tetrahedral units are released in the solution. Fly ash based geopolymer concrete have better durability than Ordinary Portland Cement concrete due to that fly ash has very less CaO. Geopolymer concrete has a good resistance to acid and sulphate attack.

Concrete has considered as a brittle material because of its low tensile strain capacity. For long time concrete was considered as a very durable and required little maintenance. As a matter of fact that earlier concrete was prepared only by considering the compressive strength. It is now recognized that strength of concrete alone is not sufficient, durability of concrete is also equally important. Concrete is said to be durable when it have resistance to cavitations, good abrasion and impact.

SCC is a type of concrete, which can be compressed into every corner of the formwork purely by means of its own weight. SCC has been developed to ensure adequate compaction and facilitate placement of concrete and structures with congested reinforcement and in restricted areas. It is generally accepted that SCC was developed first in Japan in the late 1980s in response to the lack of skilled labour and the need for improved workability. According to Ouchi [4] the need for SCC was first identified by Okamura in 1986 and the first prototype was developed in 1988. SCC offers many benefits and advantages over traditional concrete.

Self-compacting geopolymer concrete composite (SCGC) is relatively a new concept and can be regarded as the most revolutionary development in the field of concrete technology. SCGC is an innovative and improved type of concrete that does not require vibration for placing it and can be produced by complete elimination of ordinary Portland cement. On the other hand, SCGC that is produced by a polymeric reaction of alkaline liquid with a byproduct material like low-calcium fly ash with total replacement of cement by fly ash have several limitation such as necessity of heat curing and delay in setting time [5]. In order to overcome these limitations effects have been taken in the present investigation to develop Self-compacting geopolymer concrete composites (SCGCC) with Fly Ash, Ordinary Portland cement, alkaline liquids.

II EXPERIMENTAL PROGRAMME

2.1 Materials for Concrete Mixture

2.1.1 Fly Ash

In this research study, Low – calcium (ASTM Class F) Fly Ash conforming to IS 3812-2003[6] was used as a source material for the synthesis of Self-compacting geopolymer concrete. The fly ash was obtained from Thoothukudi Thermal Power Plant. The Physical properties of Fly Ash are given in the Table 1.The chemical composition of fly ash was tested at Department of Industries & Commerce, Regional Testing Laboratory, Madurai as shown in Table 2.

Table 1 Physical properties of Fly Ash

S.No	Physical Properties of Fly Ash	Test Results
1	Specific Gravity	2.36
2	Fineness	4%

Table 2 Chemical Composition of Fly Ash

S.No	Oxide	Percentage By Mass (%)
1	Silicon di (SiO_2) plus Aluminum Oxide(Al_2O_3)plus Iron Oxide)Fe_2O_3)	95.95
2	Silica (SiO_2)	59.71
3	Magnesium Oxide (MgO)	1.06
4	Total Sulphur As Sulphur trioxide (SO_3)	Nil
5	Available Alkalis As Sodium Oxide(Na_2O)	0.63
6	Loss on Ignition	0.71
7	Moisture	0.32
8	Calcium Oxide(CaO)	0.50

2.1.2 Aggregate

Fine aggregate used is manufactured sand [7]. Fine aggregate sieved using 4.75mm sieve to remove all the pebbles. Coarse aggregate of size used is 12.5mm. The physical properties of fine and coarse aggregate are given in Table 3 and Table 4 accordance with [8], [9].

Table 3 Physical Properties of Manufactured Sand (M-Sand)

S.No	Physical Properties	Test Results
1	Fineness modulus	2.72
2	Specific Gravity	2.71
3	Bulk Density(kg/m^3)- Loose State	1709.41
4	Zone Conformation	Zone-II

Table 4 Physical Properties of Coarse Aggregate

S.No	Tests For Coarse Aggregate	Results
1	Specific Gravity	2.78
2	Bulk density	1592.295 kg/m^3
3	Compaction Factor	0.921
4	Flakiness Index	12.162%
5	Elongation Index	28.72%

2.1.3 Alkaline Solution

In this study, a combination of sodium hydroxide and sodium silicate was chosen as an alkaline solution. Sodium based alkaline solutions were chosen because they are cheaper than potassium based solutions. Sodium hydroxide and sodium silicate are available commercially in flakes or pellets form. For the present study sodium hydroxide pellets with 98% purity were used for the preparation of alkaline solution with the concentration of 12M. The chemical composition of sodium silicate is Na_2O=14.7%, SiO_2=29.4% and water=55.9% by mass. Both the liquids were mixed together and alkaline solutions were prepared.

2.1.4 Super plasticizers

The chemical admixture based on Polycarboxylic ether, which is commercially known as Master Glenium SKY 8233 was used in producing SCC as a super plasticizer admixture.

2.1.5 Water

Specified amount of extra water was also used in the mix. The ordinary potable water available in the concrete laboratory was used for this purpose.

2.1.6 Cement

The SCGC mix has two limitations such as delay in setting time and necessity of heat curing to gain strength. In order to overcome these two limitations Ordinary Portland cement replace the fly ash up to 20% increasing in the order of 5% and the mix design was altered accordingly which results in self-compacting geopolymer concrete composites. Ordinary Portland cement conforming to IS 8112-1989[10], with the specific gravity of 3.15 was used.

2.2 Mix Proportion

In this study, Fly Ash based geopolymer and cement was used as a binder to produce concrete. The manufacture of SCGCC was carried out by using traditional trial and error concrete technology methods [11]. Table 5 shows the symbol of grade of concrete. The details of these mixtures are given in Table 6 & 7. The alkaline solution to Fly Ash ratio was kept constant at 0.5 where as the ratio of sodium silicate to sodium hydroxide solution was kept as 2.5.

Table 5 Designation of Grade of Concrete

S.NO	Grade of Concrete	Designation
1	M20	M1
2	M30	M2
3	0% of Cement	SCGCC
3	5% of Cement	SCGCC1
4	10% of Cement	SCGCC2

5	15% of Cement	SCGCC3
6	20% of Cement	SCGCC4

Table 6 Details of Mix Proportions for M1

Mix Id	Fly Ash (kg/m^3)	OPC (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	NaOH Solution (kg/m^3)	Na_2Sio_3 Solution (kg/m^3)	Extra Water (kg/m^3)	Super Plasticizer (kg/m^3)
SCGC	480	-	644.84	927.95	68.57	171.43	48	24
SCGCC1	456	24	644.84	927.95	68.57	171.43	57.6	24
SCGCC2	432	48	644.84	927.95	68.57	171.43	57.6	24
SCGCC3	408	72	644.84	927.95	68.57	171.43	67.2	24
SCGCC4	384	96	644.84	927.95	68.57	171.43	67.2	24

Table 7 Details of Mix Proportions for M2

Mix Id	Fly Ash (kg/m^3)	OPC (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	NaOH Solution (kg/m^3)	Na_2Sio_3 Solution (kg/m^3)	Extra Water (kg/m^3)	Super Plasticizer (kg/m^3)
SCGC	555	-	681	903	94	234	55.5	27.75
SCGCC1	527.25	27.75	681	903	94	234	66.6	27.75
SCGCC2	499.5	55.5	681	903	94	234	66.6	27.75
SCGCC3	472.5	82.5	681	903	94	234	77.7	27.75
SCGCC4	444	111	681	903	94	234	77.7	27.75

2.3 Mixing Procedure

Mixing was carried out in two stages. Initially, Fly ash, OPC, Fine Aggregate, Coarse Aggregate were mixed in a pan mixture for about 2-3 minutes. At the end of this mixing, the liquid component of the geopolymer concrete mixture comprising alkaline solution, super plasticizer and the extra water, was added to the dry mix and the wet mixing continued for another 3-4 minutes. The freshly prepared concrete mix was the assessed for the essential tests required for characterizing the self-compacting concrete. Tests such as V-funnel, J-Ring, L-Box, and V-funnel at T5 minutes were performed for this purpose.

2.4 Casting and Curing of Test Specimens

After assessing the necessary workability properties as guided by EFNARC [8], the fresh concrete was placed in steel moulds of 150mm side cubes and allowed to fill all the spaces of the moulds by its own weight. Three cubes were prepared for each test variable. After casting the specimens, without any delay, the SCGC specimens were kept in the oven at a specified period of time. At the end of the curing period, the moulds were taken out from the oven and left undisturbed for about 15 minutes. The SCGCC specimens were removed from the mould immediately after 24 hours since they set in a similar fashion that as conventional concrete. The plain SCC specimens were cured at water curing.

III DISCUSSION ON TEST RESULTS

3.1 Fresh Properties of SCGC & SCGCC

The properties of SCC differ significantly from that of conventional fresh concrete. There are three distinct fresh properties of SCC, which are basic requirements to its performance both in fresh and hardened state. According to EFNARC [5] a concrete mix can only classified as SCC if the requirements for all the workability properties are fulfilled. The three essential fresh properties required by SCC are Filling Ability, Passing Ability and Segregation resistance. To accomplish the workability properties, tests such as V-funnel, J-Ring, L-Box, V-funnel at T5 minutes were carried out. All the tests were performed by following the European Guidelines for SCC. The test results of fresh properties of SCGC and SCGCC are presented in Table 8& 9 and fig.1to 4.

Table 8 Workability Test Results for M1

Workability Tests	Proportion Of Cement					
	PLAIN SCC	SCGC	SCGCC1	SCGCC2	SCGCC3	SCGCC4
V Funnel (Sec)	6	7	8.5	9	12	14
J Ring (Mm)	5.5	6	7	8.3	9	11
L Box (H_2/H_1)	0.8	0.84	0.87	0.93	0.98	1.1
V Funnel At T5 Minutes (Sec)	7	9	11	12.5	14.5	16

Table 9 Workability Test Results for M2

Workability Tests	Proportion Of Cement					
	PLAIN SCC	SCGC	SCGCC1	SCGCC2	SCGCC3	SCGCC4
V Funnel (Sec)	6	7	8.5	9	11	13
J Ring (Mm)	5	6.3	7	9	10	10.8
L Box (H_2/H_1)	0.7	0.81	0.91	0.95	0.98	1.03
V Funnel T5 Minutes (Sec)	7.5	10.5	11	12	14.5	15.5

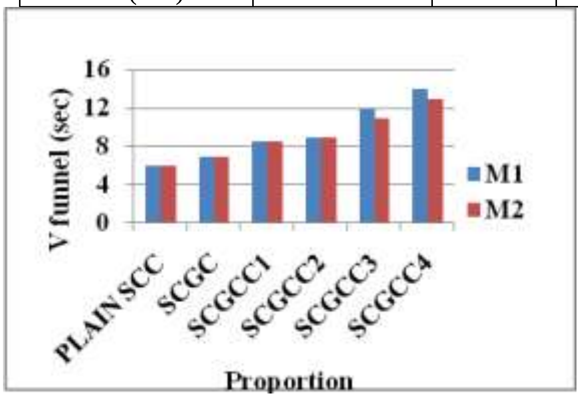

Fig 1.V funnel Test

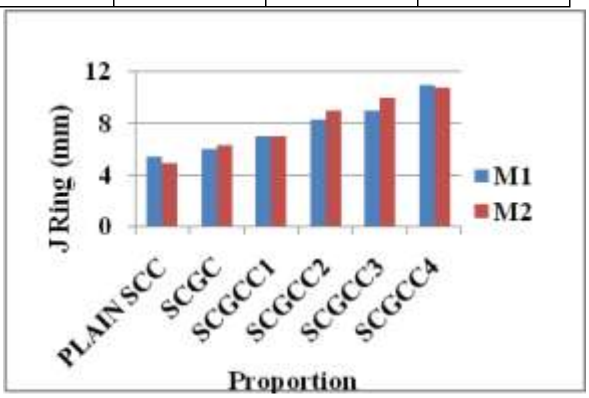

Fig 2. J Ring Test

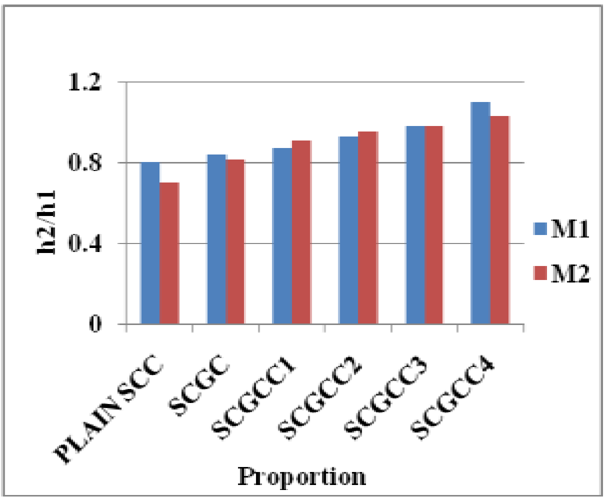

Fig 3. L Box Test

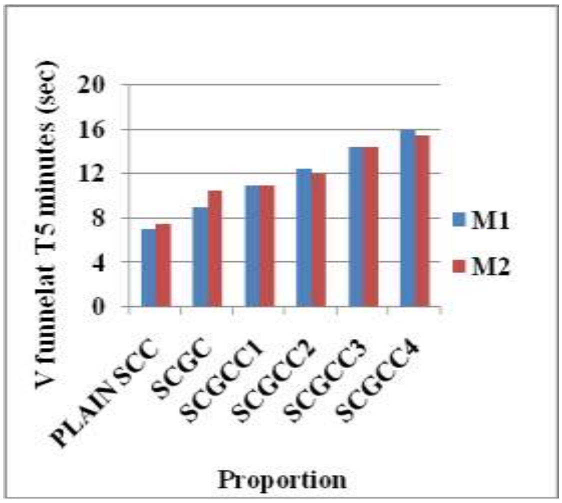

Fig 4. V funnel at T5 minutes Test

3.2 Durability Study

3.2.1 Acid Attack

In fact concrete is not fully resistant to acids. All acids will have impact on concrete. The rate of speed of action may differ but they finally disintegrate the concrete. Almost all the aggregates are susceptible to acid attack if they contain more calcareous content. The content like Ca and C-S-H are more susceptible to chemical attack. The intensity of disintegration of concrete caused by Hydrochloric (HCl) acid is more than the Sulphuric acid with an equal amount of concentration [3]. Because HCl has more calcareous content than sulphuric acid. The present experimental study has conducted on concrete of cube specimen of size 150x150x150 mm. The specimens are immersed in 5% HCl solution. The deterioration of specimen can be estimated by finding out the reduction in weight of the specimen and also the reduction in compressive strength of the specimen when they are immersed in chemical solution is identified. The results of acid attack are shown in Table 10.

Table 10 Effect of Acid Attack on SCC, SCGC & SCGCC

Concrete Grade	Concrete Type	Weight of Specimen Before Acid Immersion (Kg)	Weight of Specimen After Acid Immersion (Kg)	Compressive strength of Specimen Before Acid Immersion (N/mm^2)	Compressive strength of Specimen After Acid Immersion (N/mm^2)	Reduction in Compressive strength (N/mm^2)
M1	Plain SCC	8.130	8.063	27.07	25.81`	1.80
	SCGC	8.128	8.086	29.33	28.27	1.06
	SCGCC1	8.135	8.068	30.78	29.86	0.92
	SCGCC2	8.137	8.049	32.41	31.27	1.14
	SCGCC3	8.140	8.035	31.59	29.73	1.86
	SCGCC4	8.142	8.026	28.32	26.23	2.09
	Plain SCC	8.120	8.057	39	37.05	1.95

M2	SCGC	8.127	8.061	41.8	40.41	1.39
	SCGCC1	8.132	8.058	43.63	41.85	1.78
	SCGCC2	8.135	8.046	46.07	43.94	2.13
	SCGCC3	8.132	8.033	44.78	41.92	2.86
	SCGCC4	8.130	8.021	40.37	37.08	3.29

The acid resistance results show that the weight reduction and reduction in compressive strength for SCC, SCGC & SCGCC specimens. In that the reduction of weight &strength of SCGCC1 specimen have the better requirement than the other specimens for both grade of concrete.

3.2.2 Sulphate Attack

The sulphate attack testing procedure was conducted by immersing the cube specimen of size 150x150x150 mm in the 5% $MgSO_4$ solution over a period of time of 28 days. The deterioration of specimen can be estimated by finding out the reduction in weight of the specimen and also the reduction in compressive strength of the specimen when they are immersed in chemical solution is identified. The results of acid attack are shown in Table 11.

Table 11 Effect of Sulphate Attack on SCC, SCGC & SCGCC

Concrete Grade	Concrete Type	Weight of Specimen Before Acid Immersion (Kg)	Weight of Specimen After Acid Immersion (Kg)	Compressive strength of Specimen Before Acid Immersion (N/mm^2)	Compressive strength of Specimen After Acid Immersion (N/mm^2)	Reduction in Compressive strength (N/mm^2)
M1	Plain SCC	8.130	8.076	27.07	25.4	1.67
	SCGC	8.119	8.073	29.33	28.29	1.04
	SCGCC1	8.127	8.057	30.78	29.93	0.85
	SCGCC2	8.131	8.034	32.41	31.31	1.10
	SCGCC3	8.137	8.031	31.59	29.83	1.76
	SCGCC4	8.141	8.029	28.32	26.43	1.89
M2	Plain SCC	8.120	8.057	41.8	40.05	1.75
	SCGC	8.127	8.061	43.63	42.39	1.24
	SCGCC1	8.132	8.058	46.07	44.49	1.58
	SCGCC2	8.135	8.046	44.78	42.8	1.98
	SCGCC3	8.132	8.033	40.37	37.89	2.48
	SCGCC4	8.130	8.021	41.8	38.74	3.06

The sulphate attack results show that the weight reduction and reduction in compressive strength for SCC, SCGC & SCGCC specimens. In that the reduction of weight &strength of SCGCC1 specimen have the better requirement than the other specimens for both grade.

3.2.3 Sorptivity Test

Sorptivity test measures the rate of penetration of water into the pores of concrete by capillary suction. The cylindrical specimen of size 60 mm height and 100mm dia were cured in the respective curing type. After curing the SCC and SCGC &SCGCC specimens were kept in a oven for 110°C [12]. Then the side surface of the specimen was sealed with coating to allow the penetration of water into the concrete only from the bottom surface. The specimens are immersed in the container containing water and the specimens were supported on rods that was submerged about 10mm. The quantity of water absorbed in the period of 30 minutes was weighed using weighing balance. Surface water of the specimen was wiped with the disuse and each weighing operation was completed within 30 seconds. The cumulative volume of water that has penetrated per unit surface area of exposure plotted against the square root of the time elapsed. The results of sorptivity are shown in Table 12

The sorptivity was computed by,

$$S = I/\sqrt{t}$$

Where,

S = Sorptivity (mm/min$^{0.5}$),

I = ΔW/Ad,

ΔW = Change in Weight = $W_2 - W_1$,

W_1 = Oven dry weight (grams),

W_2 = Weight of specimen after 30 minutes penetration of water (grams),

A = Surface Area through which water penetrated (mm^2),

d = Density of water,

t= time elapsed (min)

Table 12 Effect of Sorptivity on SCC, SCGC & SCGCC

Concrete Grade	Concrete Type	Dry weight of specimen (W_1) (gram)	Wet weight of specimen(W_2) (gram)	Sorptivity Value in 10^{-5} (mm/min$^{0.5}$)
M1	Plain SCC	1306.5	1307.85	0.08717
	SCGC	1230.7	1231.5	0.05166

	SCGCC1	1247.6	1249.25	0.10654
	SCGCC2	1248.5	1250.21	0.11042
	SCGCC3	1248.7	1250.87	0.13792
	SCGCC4	1249.3	1251.24	0.16780
M2	Plain SCC	1286.8	1287.98	0.07619
	SCGC	1251.5	1252.67	0.07555
	SCGCC1	1256.53	1258.03	0.09685
	SCGCC2	1267.47	1269.19	0.11106
	SCGCC3	1270	1271.85	0.11946
	SCGCC4	1273.35	1275.37	0.13043

IV **CONCLUSION**

Based on the experimental investigation the following observations are made regarding the durability study as replacement of fly ash by cement up to 20% for M1and M2 grade concrete.

1. The workability properties for M1 & M2 mixes are satisfies the EFNARC guidelines; give the best replacement percentage of fly ash by cement was SCGCC2 and for SCGCC4 specimen slightly beyond the requirements of EFNARC guidelines.
2. The test results of acid attack & sulphate attack of the concrete shows at SCGCC1 specimen have lower disintegration than the other type of concrete because SCGCC2, SCGCC3 & SCGCC4 have the higher Ca and C-S-H content than SCGCC1.
3. The sorptivity of the concrete also shows lower water penetration for SCGCC1 specimen than the others.

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