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Use of Portland Cement to Improve the Properties of Self Compacting Geopolymer Concrete

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Abstract : Preparation of Self Compacting Geopolymer Concrete was proved to be tedious as enormous amount of Super plasticiser and heat curing regime hinders the commercial production of geopolymer concrete. Moreover compatibility of Super plasticiser is still an unknown element in the area of Self compacting geopolymer concrete. Here an attempt has been made to stabilise the properties of Self compacting geopolymer concrete by inclusion of Ordinary Portland cement in minimal quantities. Rheology and mechanical properties was studied by incorporating cement at the dosages of 0, 2, 4, 6, 8 % by mass of binder in Self compacting geopolymer concrete. Results showed tremendous change in fresh and hardened properties of concrete for an addition of Ordinary Portland cement in small amount say 5% of binding material. Curing regime was altered to normal external exposure curing which proved benefits of laying geopolymer concrete in tropical climatic conditions.
Keywords : Self compacting geopolymer concrete; Super plasticiser dosage; Mechanical properties; External exposure curing; Ordinary Portland cement.

1.0 Introduction

The fly ash generation from Coal based Thermal Power Plants in India has already crossed 200 million tonnes per year and is expected to increase for more than 300 million tonnes by the year 2017. The dumping and utilisation of such enormous quantity of fly ash is a formidable task which has to be performed within various environment protection laws. If this resource material is effectively utilised, these would result in conservation of scarce minerals, reduction of emitting green house gases and thereby sustainable construction practices can be adopted. Indian fly ashes are mainly utilised in making of fly ash bricks, Portland pozzolana cement, filling of low lying areas etc.. Use of fly ash in geopolymer is not much entertained because of economic aspects and complex in design problems. If geopolymers are introduced properly by taking care of its flaws and figures, 100 percent utilisation of fly ash can be entertained in concrete industry aiming for durability and green technology practices.

Geopolymers in concrete was evolved using industrial by products or siliceous materials (fly ash, ground granulated blast furnace slag, red mud, metakaolin etc.) and synthesising solutions (combination of sodium or potassium hydroxide and sodium or potassium silicates), which finally exhibits similar properties like cement. Due to the fact that geopolymerisation gets triggered on elevated temperatures, conventional methods of curing were avoided and heat curing was introduced for early strength purposes[1]. However later research also reveals that use of ambient curing conditions in geopolymer can also be accepted showing similar properties of normal concrete based on strength aspects[2]. Investigations have also been extended to achieve early strength of geopolymer concrete by utilisation of supplementary cementitious materials such as Ground granulated blast furnace slag (GGBS), Silica fume etc. to achieve strength without aids of temperature curing [3,4]. Introduction of Geopolymer in special concrete laid down methods for developing high performance as well as high strength concrete. Self compacting concrete is a special type of concrete which is mainly adopted in places where zero vibration for compaction is required and in areas of heavily congested reinforcement[5]. Geopolymer was also inculcated in Self compacting concrete employing fly ash as source material, super plasticisers (SP) and alkaline materials; comprising of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions. Tests were carried out by varying curing temperature, NaOH molar concentration, addition of extra water etc. in fresh as well as hardened properties of Self compacting geopolymer concrete (SCGC) [6]. Results proved that 12 molar concentrations of NaOH were found to be optimum for SCGC with 12% extra water of source material[7, 8.] Micro structural characterisation was also performed to analyse the geopolymer chemistry in SCGC by addition of superplasticisers[9]. Blending of source materials was also tried with the inclusion of GGBS and silica fume. Results proves, upto 40% replacement of GGBS with fly ash increases strength and flow properties whereas silica fume showed increase in strength upto 10% of replacement with fly ash [10,11] .Kalyana Rama et al. [12] investigated properties of SCGC made of 100 % GGBS, by varying sodium hydroxide molarity concentrations, and inferred that increase in molarity concentration of NaOH decreased the workability. However advantage of using GGBS and Silica fume in SCGC regarding curing regime was not pointed out in above research. From the literature survey it was found out that, investigations related to varying of curing regime is scant in the field of self compacting geopolymer.

Geopolymer in self compacting concrete was proved to be advantageous as the setting of geopolymer was found out to be delayed comparing to normal cement. Self compacting behaviour in concrete is achieved by various methods such as, a) Reducing size of coarse aggregate b) Inclusion of super plasticiser and c) Increasing amount of fines. However to balance the setting time and flowability, lots of laboratory trials were carried out to get good and even mix. Eventhough geopolymer retards setting time, flowability is an important issue which makes use of enormous amount of super plasticiser in SCGC. In SCGC, it was considered that first two days of initial strength plays crucial role in geopolymerisation processes. Use of Retarders in SCGC for self compacting behaviour affects the strength detrimentally due to prolonged setting time. This drawback was stabilised by heat curing regime and thereby 28 days strength was achieved in 2 days elevated curing conditions[13]. Recently, research work was also carried out incorporating OPC in normal geopolymer concrete to evaluate the reduction of setting time and strength. Pradip Nath et al. [14]proposed that addition of 5% OPC in geopolymer concrete under ambient curing conditions increased strength and workability tremendously. Similar results were also noted down in an experimental work on geopolymer mortar, developed using Class C fly ash and OPC as additive[15]. Present study is mainly intended to rectify the drawbacks of using SCGC in normal curing conditions and hence paving the way for cast-in-situ commercial production. Addition of OPC in small amounts to SCGC was found to be effective in reducing amount of super plasticiser and setting time, thereby altering curing conditions to external exposure techniques.

2.0 Experimental Observations

2.1. Materials

Fly Ash

Dry Fly ash of grade Class F procured from Mettur Power Plant, Tamilnadu was used as source material for the study. The chemical composition of fly ash is given in Table 1. Referring to the given values it was inferred that fly ash is conforming to IS: 3812 (2003) specifications. Specific gravity of fly ash was noted as 2.2.

Table 1. Chemical composition of Class F Fly Ash

Maximum Range (%)	Chemical Properties (% By Mass)
58	SiO_2
3.6	CaO
1.8	SO_3
2	Na_2O
1.91	MgO
2	Loss on ignition

Aggregates

Locally available coarse aggregate of size below 14mm and of specific gravity 2.72 was used for the experimental work. Fine aggregate was conforming to zone 2 river sand with specific gravity 2.68. Both coarse and fine aggregate were complying to IS: 383(1970) specifications.

Alkaline solutions

Synthesising chemicals used for geopolymerisation are sodium hydroxide (available in pellets) and sodium silicate solution. Sodium hydroxide pellets of minimum assay-97 %, Carbonate-2%, Chloride-0.01 %, Sulphate-0.05 %, Potassium-0.1 %, Silicate-0.05 %, Zinc-0.02 %, Heavy metals-0.002 % and Iron-0.002 % was mixed in water in order to achieve the required molarity in solution. The concentration of NaOH was maintained as 12 M prepared by dissolving 36.1% solids into 1 litre solution [8]. Aqueous Sodium silicate of approximate N_2O-14.7%, SiO_2-29.4%, H_2O-55.7% was taken for the preparation of alkaline solutions. Specify gravity of NaOH and Na_2SiO_3 are noted as 1.47 and 1.6 respectively.

Cement

Ordinary Portland Cement (OPC) of 53 grade conforming to IS: 12269 (2013) was used for the study.

2.2 Mix design

Even though there are many methods explaining design of SCC, proper standardised method was not available till date. Taking account of previous research, SCGC was designed using EFNARC guidelines and various laboratory trials were performed to achieve a better mix. EFNARC guidelines stipulates various considerations such as limiting coarse aggregate content upto 35% of total aggregates and variation of binder content from 400 to 600 kg/m^3[16]. Considering these points, trials were made by varying fly ash content as 400 kg/m^3, 450 kg/m^3 and 500 kg/m^3 and finally binder content was fixed to 500 kg/m^3. Alkaline solution to fly ash ratio was fixed as 0.5 and extra water was limited to 12% of binder content [7]. Na_2SiO_3/NaOH solution ratio was taken as 2 based on trials to get better flowability properties. Mix Proportions of trial mix design are given in Table 2. For the present examination varying factors decided are 1) checking dosage of SP in first phase 2) altering curing conditions and 3) checking for OPC additions in the next phase.

Table 2. Proportion of materials taken for trial mix design

Fly ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Sodium hydroxide (kg/m^3)	Sodium Silicate Solution (kg/m^3)	Water (%)
500	650	900	83	167	12

2.3 Mixing and mix proportioning

It was detected during trials that $Na_2SiO_3$when mixed with NaOH forms a viscous solution as time advances, thereby restricting flowability aspects required for self compacting concrete. Hence blending of alkaline solutions was performed 1 hour prior to concreting process. Alkaline solutions thus prepared are poured into aggregates along with super plasticisers and extra water. Aggregates used are taken in saturated surface dry condition and all dry materials are mixed together for 5 min before alkaline solutions are poured. Mixing was performed by manual methods to avoid wastage and other corrections.

2.4 Curing

In the first set of observations regarding selection of apt dosage of super plasticiser, two curing methods were made for comparison viz; Room temperature curing (25º) and external exposure curing (day temperature for an average of 36º). Curing method for OPC additions was decided using superior properties taken from trials of SP dosage ie. curing was altered to external exposure curing conditions for identifying the behaviour on strength aspects. The present study was mainly conducted to modify the conventional curing method of SCGC to normal procedure resembling onsite curing conditions of tropical regions. Care has to be taken to protect specimens from rain and extreme weather conditions for atleast 7 days. It was experienced that if covering was not done properly, shrinkage cracks appeared after 3 days of curing. The external exposure curing is shown in Figure 1.

Figure 1. External Exposure Curing

2.5 Tests for evaluating the dosage of SP

As a preliminary investigation, different types of SP available in market are tested for SCGC to find out compatibility with geopolymer. Sulphonated naphthalene formaldehyde (SNF) based SP and Modified polycarboxyl ether (MPCE) based SP (G 3, V 3 and V 20) was used for the experimental work. SNF based SP and G 3 was taken from a different chemical company whereas V 3 and V 20 are two products of same chemical company but with different percentiles of added Viscosity modifying agents (VMA). Dosage of SP and specific gravity given in manufacturer's manual are depicted in Table 3. To find out the saturation dosage, tests were performed using marsh cone test as specified in EFNARC guidelines and results are noted down. The Marsh cone test is a simple approach to get some data about cement pastes rheological behaviour which is shown in Figure 2. It has already been used in cement based materials mix design in order to define the super plasticizer saturation point, i.e. the dosage beyond which the flow time does not decrease appreciably**.** Even though marsh cone test is a standard test used for cement paste, testing of geopolymer paste also showed positive results. Variation for different types of SP on SCGC regarding dosage and strength are stipulated in Figure 3 and 4 respectively. It was inferred that MPCE based super plasticiser was found to be superior than SNF based SP. Compressive strength of cubes at the age of 28 days was also tested with optimum content of SP using proposed mix design and it was found that V 20 showed better results. So V20 was used for further investigations. Temperature of curing was maintained to 25° up to 28 days.

Table 3. Dosage and Specific gravity*of different Super plasticisers used for the trial design

Type of SP	Construction Or Dosage	Specific Gravity
SNF	0.6 - 1.5 lit/100 g cement	1.19 - 1.24
G 3	500 ml to 1500ml per 100kg	1.09
V 3	0.6 - 2% by weight of cement	1.09
V20	1%- 2% by weight of cement	1.08

*As per manufacturer's Manual

Figure 2. Marsh Cone Test

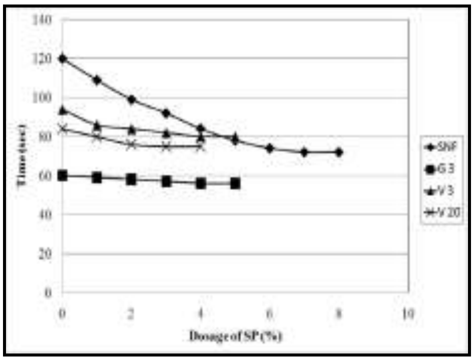

Figure 3. Saturation dosage for different types of SP in SCGC

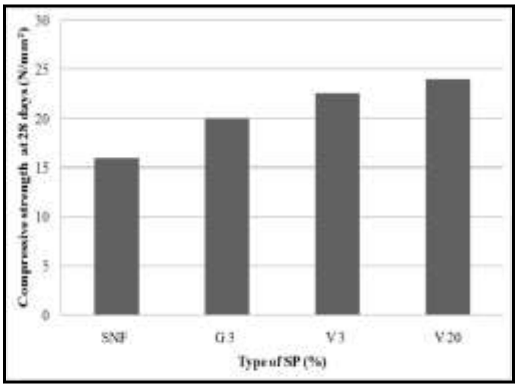

Figure 4. Compressive strength for different types of SP in SCGC

2.6 Testing of SCGC with OPC as additive

2.6.1 Selection of SP Dosage

SCGC has a drawback that its performance is weak in low temperature curing conditions. Previous Research suggests increased temperature curing for attaining high strengths. However this aspect withdraws attention of cast in situ industry and thereby economic aspect cannot be considered in case of SCGC other than sustainability. Hence an attempt has been made to bring down curing temperature by addition of OPC. Tests were repeated to find out dosage of SP with a minimum amount of OPC say 5% of source material and addition of SP was tried on each increment of 1% in SCGC. Fresh properties suggested in EFNARC guidelines such as T_{500mm} slump flow, Abrams slump flow, L Box Test and U Box Test were performed to study the characteristics of filling ability, passing ability and segregation resistance in SCGC. The fresh properties were shown in Figure 5, 6 and 7 respectively. Hardened properties were investigated in terms of compressive strength and results are plotted. Interestingly flowability increased for an addition of SP in just 2% of binder which proves OPC stabilises the use of SP in SCGC. This is slightly different to previous observations which started showing appreciable flowable properties in 4% of SP. Details of fresh properties are shown in Table 4 and compressive strength for an age of 28 days are plotted in Figure 8. Curing method was varied which shows a steady increase in strength for external exposure curing conditions.

Figure 5. T_{500mm} Slump Flow and Abrams and Slump Flow

Figure 6. L Box Test

Figure 7. U Box Test

Table 4. Fresh Properties of SCGC for varying dosage of SP

Dosage of SP (%)	T_{500mm} Slump flow (sec)	Slump flow dia. (mm)	L - Box Ratio	U - Box value (mm)
1	8	630	0.8	32
2	5	680	0.9	26
3	4	750	0.96	23
4	5	720	0.92	24
5	8	620	0.8	30
Range as per EFNARC guidelines	2-5	650-800	0.8-1	30 mm max.

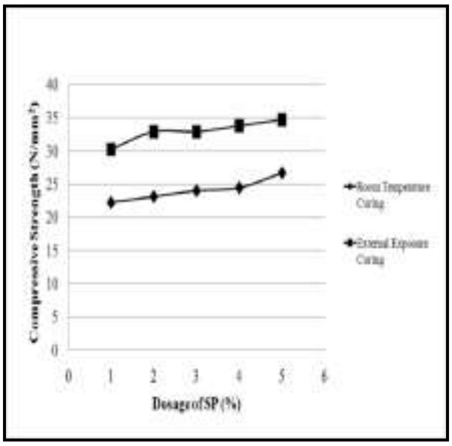

Figure 8. 28 days Compressive strength of SCGC for different dosages of SP Slump flow

2.6.2 Setting time of geopolymer paste in SCGC

Initial and final setting time of geopolymer paste in SCGC was found out using standard methods for initial and final setting time [17]. 500 g of Fly ash was taken to prepare geopolymer paste maintaining 2% SP, 12% extra water and fly ash to alkaline solution ratio as 0.5. Investigation was made using Vicat's apparatus to identify whether there are any effects for addition of OPC in SCGC based on curing conditions. Dosage of cement was taken as 0 and 5% of binder for room temperature curing and external exposure curing methods. Results are shown in Table 5 and proved that addition of OPC decreased the amount of initial and final setting time tremendously in both curing conditions.

Table 5. Initial and Final Setting time of SCGC

Cement Addition (%)	Room temperature curing		External exposure curing	
	Initial setting time	Final setting time	Initial setting time	Final setting time
0	3 days 12 hours	7 days	3 days	5 days
5	2 days 12 hours	5 days	1 day	1 day 10 hours

2.6.3 Fresh and Hardened Properties of SCGC incorporating OPC

Mix design was finally decided using above investigations on Super plasticisers and 2% of SP was selected for further trials. Next phase of investigation was made by varying the cement additions on SCGC to identify the variation in mechanical properties of SCGC. OPC additions in range of 2, 4, 6, 8% was replaced in fly ash and fresh as well as hardened properties was noted down. Ratios of various contents taken for mix were given in Table 6. Fresh properties in terms of workability as specified in EFNARC guidelines was carried out. T_{500mm} slump flow, Abrams slump flow test, L box test U box test etc. were checked for SCGC. Hardened properties such as cube compressive strength, Splitting tensile strength and Beam flexural strength was carried to evaluate the variation of strength parameters [18]. Cube specimens of size 150 × 150 × 150 mm, cylinders of size 150 × 300 mm, prism beams of size 500×100×100 mm were made for testing of compressive strength, split tensile strength and flexural strength respectively. Type of curing adopted here was external exposure curing conditions. 7 day and 28 days strength of specimens were performed to identify the variation in initial strength developments.

Table 6. Mix proportions of SCGC incorporating OPC

Fly ash (kg/m^3)	OPC (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Sodium Hydroxide (kg/m^3)	Sodium Silicate (kg/m^3)	Extra Water (kg/m^3)	S.P. Dosage (kg/m^3)
500	0	900	650	83	167	60	10
490	10	900	650	83	167	60	10
480	20	900	650	83	167	60	10
470	30	900	650	83	167	60	10
460	40	900	650	83	167	60	10

3.0 Results

Experimentation regarding dosage of different types of SP clearly indicates that use of MPCE based SP improved the flowability and strength. From Figure 1 it was also evident that SNF based SP showed saturation point only at 7% and MPCE based at 4-5%. 28 days Compressive strength shown in Figure 2 clearly shows increase in strength for V 20 than other SP's at the saturation dosage of 4%.

The Second set of observations was made on SCGC with addition of OPC and its effect of dosage of SP. Here for each increment of SP, workability and compressive strength was tested which shows steady increase in workability upto 4% additions of SP. In 5% additions, workability started reducing which shows clear case of saturation point. Compressive strength was tested for both curing conditions showing increased strength upto 5% additions. Workability tests and strength tests of SCGC with OPC as additive was carried out to check variation in properties regarding dosage. Workability properties in terms of T_{500mm} slump flow, Abrams Slump Test, L-Box Test and U- box test are performed and elaborated in Table 7. It was identified that flowability started reducing after increasing the amount of OPC in 6% . Variation of Compressive strength for OPC additions is shown in Figure 9 and was found to be increasing for 8% additions. Splitting tensile strength and flexural properties were plotted in Figure 10 and 11 which showed similar trends based on Compressive strength.

Table 7. Workability properties of SCGC for varying percentage of OPC

Dosage of cement (%)	T_{500mm} (sec)	Slump flow dia. (mm)	L Box (mm)	U Box (mm)
0	9	600	0.8	31
2	7	680	0.9	26
4	6	690	0.9	26
6	5	720	0.87	28
8	8	640	0.81	30

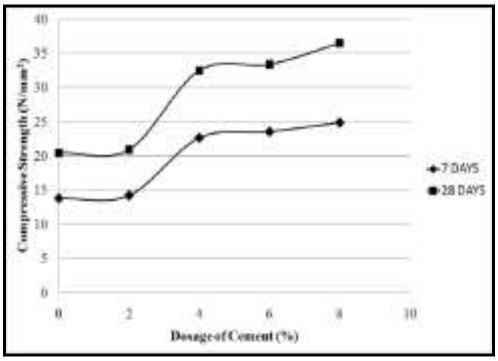

Figure 9. Compressive Strength of SCGC for varying percentage of OPC

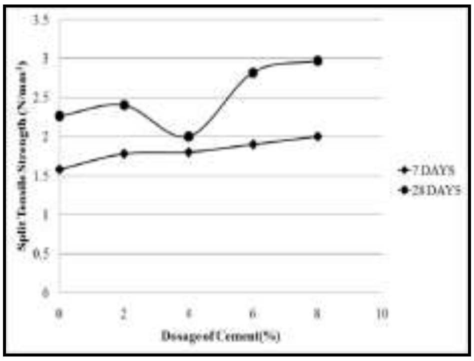

Figure 10. Splitting Tensile Strength of SCGC for varying percentage of OPC

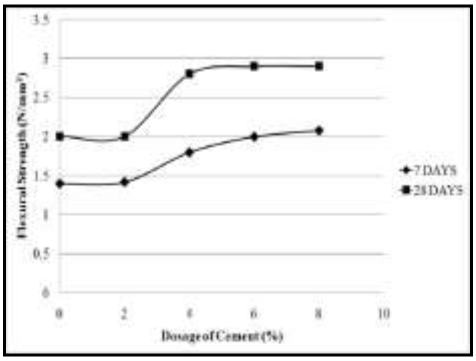

Figure 11. Flexural Strength of SCGC for varying percentage of OPC

4.0 Discussion

In the first set of observations it was proved that third generation SP with increased amount of VMA improved the strength characteristics of SCGC. It was interesting to note down that flow time of G3 was less showing good flowability characteristics. However G3 was eliminated in further tests as strength was not much appreciable than V 20. This result was used in next set of experiments incorporating cement to check the most viable dosage regarding economy. From the trials 2% of SP showed preferred properties to meet the requirements of SCGC. For 4% additions workability increased tremendously. However further increase is restricted so as to decrease the cost and not much difference in strength is noted down for 4% additions. For 5% of SP, workability decreased considerably and which proved to be contradictory with the previous findings. This change was experienced because of introducing Modified Polycarboxyl Ether in SP, which is slightly different from normal PCE based SP as it comes with added VMA. Alkaline Solutions taking part in geopolymerisation processes provides necessary viscosity to SCGC so that VMA was avoided in previous Research. But the inclusion of VMA in MPCE and unavailability of PCE based SP in market made the investigation even more tedious as dosage has to be limited. It was experienced that if correct dosage was not applied, the whole mix will get viscous within 30 min of addition. So 2% of SP was fixed for further investigations. Curing regime was fixed to external exposure conditions giving good results based on strength aspects. This must be carefully planned in such a way that low temperature has to avoided upto final setting time for better geopolymerisation processes.

Diagnosis of setting time for SCGC with/without OPC by varying curing conditions recommends the use of OPC to reduce the time of hardening process. It was proved that final setting time reduced to 1day 10 hours in case of 5% addition of OPC in SCGC for exposed curing conditions. This helps in early geopolymerisation processes without aids of elevated curing conditions.

Investigations on OPC added SCGC depicts steady increase in compressive strength, splitting tensile strength and Flexural properties. Workability tests were also satisfied according to EFNARC guidelines. But optimum amount of OPC additions was limited to 5% because of flowability issues which is considered as major aspect in case of SCGC. It can be seen that 7 days and 28 days strength followed the same tendency as that of normal concrete achieving 99% strength in 28 days period.

5.0 Conclusion

Addition of OPC in SCGC helped in reducing amount of SP and decreasing of setting time. It was inferred that OPC helps SCGC in adjusting the rheological properties which helped in reduction of SP by 2% of binder. However optimum dosage was not considered in this case as the main aim was to conceive the disparity of SP performance in geopolymer paste. Fresh properties of SCGC were satisfied according to EFNARC guidelines and variation of hardened properties was also investigated. From the results, it was found out that optimum amount of cement to be used as additive comes around between 4 - 6% of powder content, to get better workability and strength properties in SCGC. SCGC of strength 33 N/mm^2 was achieved for optimum results without aids of elevated curing. Curing was altered to external exposure curing regime because OPC reduces setting time in substantial amounts. It was inferred that SCGC can be adopted for cast-in-situ structural applications especially in tropical climatic conditions. Detailed investigation on rheology of SP has to be performed so that exact dosage can be applied for SCGC. Further studies have to be extended in the field of SCGC regarding micro structural characterisation to understand the interstitial bonding of geopolymer, OPC and aggregates. Generally geopolymer is considered to be highly durable than normal concrete. Hence a detailed examination to assess the effects on durability by addition of OPC in SCGC also has to be carried out.

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