

An Experimental Study on Fly Ash Based Self Compacting Geopolymer Concrete with Silica Fume as A Partial Replacement to Fly Ash

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Abstract—This Research Work Aimed to Investigate the Fresh Properties, mechanical Properties, and Durability Properties of Fly Ash Based Self Compacting Geopolymer Concrete with Silica Fume as a Partial Replacement to Fly Ash by 0%, 2.5%, 5%, 7.5% & 10% with constant GGBS content. Grade of concrete used in this research is M30. In this study, evaluate the effect of Silica fume, powder content, and PCE Superplasticizer on self-compacting geopolymer concrete. Five concrete mixes (SCGC-F₆₅-G₃₅-S₀, SCGC-F_{62.5}-G₃₅-S_{2.5}, SCGC-F₆₀-G₃₅-S₅, SCGC-F_{57.5}-G₃₅-S_{7.5}, and SCGC-F₅₅-G₃₅-S₁₀) were made by replacing fly ash with silica fume. The 12 M molarity of sodium hydroxide is used for all the mixes. Alkaline liquid to binder by mass is 0.43. The binder content can be further divided into fly ash and GGBFS. The fly ash content is on the higher side, the fly ash content is taken as 65% and the GGBFS is taken as 35%. Super plasticizer PCE of 6% is added to all the mixes to enhance the properties of concrete. Fresh properties of concrete mix were measured by slump flow test, T50cm slump flow, L-box test and U-box test and harden properties are measured by compressive strength, split tensile strength and flexural strength and NDT-test for concrete like UPV and rebound hammer test were done. The workability of self-compacting geopolymer concrete has been decreased in addition of silica fume with a partial replacement to fly ash by 2.5%, 5%, 7.5% & 10%. The compressive strength, splitting tensile strength and flexural strength for 0% replacement of silica fume with fly ash (SCGC-F₆₅-G₃₅-S₀) at 7, 14 and 28 days was found higher strength than other mixes.

Index Terms— Self compacting geopolymer concrete, Fly Ash, GGBFS, Silica Fume, Fresh properties, Harden properties, NDT

I. INTRODUCTION

Self-compacting geopolymer concrete (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 type of concrete that does not require vibration for placing it and can be produced by complete elimination of ordinary Portland cement. Self-compaction of SCC can be accomplished by limiting the substance and size of coarse aggregates while likewise utilizing superplasticizers (SP) to keep a lower water-to-powder proportion. On the other side, Geopolymer concrete (GPC) is profoundly viscous (high viscosity), or thick in nature due to this geopolymer concrete can fail if it is not properly compacted and is difficult mix hence workability is low. To conquer these issues, Geopolymer was associated with Self-Compacting concrete called self-compacting geopolymer Concrete (SCGC). As GPC and SCGC are new innovations, they need standard specifications like OPC-based concrete; thus, concentrated research and exploratory testing are expected to close the gap. The SCGC is manufactured through utilizing industrial by means of-products like Fly ash, GGBS, waste glass powder, silica fume and rice husk ash, materials containing extra alumina and silica can be used. These materials can be activated by adding an alkaline solution (Sodium Hydroxide and sodium silicate). By utilizing of superplasticizers like Viscosity modifying Agent (VMA), concrete can flow.

II. MATERIALS USED

A. Fly Ash

In this research, Class F fly ash is procured from mettur power plant. Fineness modulus of properties of fly ash is 7.86 and corresponding specific gravity of 2.21.

B. GGBFS

GGBFS is a by-product from iron industry. Specific gravity and fineness of GGBFS is 2.9 and 386 M²/kg.

C. Silica Fume

Densified silica fume is a mineral admixture produce as by-product from alloy silicon industry its specific gravity is 2.2.

D. Water

Portable water is available in a laboratory that has to be used for concrete mix around 12% of cement. The pH level of water is 7.3 and chloride is 210ml.

E. Alkaline liquid

Alkaline liquid prepared by the addition of sodium silicate solution to the sodium hydroxide solution enhanced the reaction between the fly ash and GGBS and the solutions. Alkaline activator for the thesis work is prepared using commercially available sodium silicate liquid and sodium silicate pellets. Commercially available sodium silicate liquid contains Na₂O=14.61%, SiO₂=25.18% and H₂O=59.99%. The alkaline liquid is prepared with NaOH molar concentration 12M. The mass ratio of sodium silicate to sodium hydroxide was kept as 2.50.

F. Fine aggregate

M-sand was used as a fine aggregate in the present investigation were procured from local market. The properties such as specific gravity is 2.63, grading of sand is Zone III and fineness modulus is 3.98.

G. Coarse aggregate

Crushed stone aggregates of 10mm are procured from locally available crushed granite stone. The property such as specific gravity is 2.70 and fineness modulus is 7.30.

H. Polycarboxylate Ether

Polycarboxylate Ether (PCE) named as NOVAMIX 4000 is procured from chemtech concrete india pvt. Ltd. and its specific gravity is 1.092.(6% of cement)

III. MIX DESIGN

Self-compacting geopolymer concrete Mix Design for M30 grade using IS 10262-2019.

Grade	M30
Fly Ash	295.75 kg/m ³
GGBFS	159.25 kg/m ³
Fluid (Alkaline liquid)	200 kg/m ³
Fine Aggregate	788.23 kg/m ³
Coarse Aggregate	783 kg/m ³
Chemical Admixture	27.3 kg/m ³
Fluid / Binder Ratio	0.44
Powder Content	522 kg/m ³
Fluid / Powder Ratio	1.04

Table 3.1: Mix proportion for SCGC

IV. PREPARATION OF SCGC

The sodium hydroxide pellets are weighted and taken for the required quantity and it was mixed with the distilled water for the required quantity and mixing should do in a glass beaker. The NaOH pellets should be dissolved fully in the distilled water, during this process heat is generated by chemical reaction, care should be taken. And this solution is kept beside in a room temperature to fully cool. After the solution reaches cool then it was well mixed with the sodium silicate solution which is already weighted for the required quantity. Then this liquid kept for 24 hours, during this time the polymerization takes place. After 24 hours it is ready to mix to form SCGC. The use of alkaline liquids for making SCGC should not exceed 36 hours. The materials like fly ash, GGBFS, fine aggregate and course aggregate added in the mixer and the mixing time should be 3 to 5 minutes. Then the alkaline liquid was gradually added with the dry mix and mixed well. The time taken for wet mixing should be at least 3 minutes.



Fig 4.1: Mix proportion for SCGC

V. EXPERIMENTAL INVESTIGATION

5.1 Fresh Properties of Self Compacting Geopolymer Concrete.

The self-compacting fresh properties of fly-ash based self-compacting geopolymer concrete with silica fume as partial replacement to fly ash by 0%, 2.5%, 5%, 7.5% & 10% with constant GGBFS content. The fly ash content is 65% and GGBFS is 35%. Five concrete mixes (SCGC-F₆₅-G₃₅-S₀, SCGC-F_{62.5}-G₃₅-S_{2.5}, SCGC-F₆₀-G₃₅-S₅, SCGC-F_{57.5}-G₃₅-S_{7.5}, and SCGC-F₅₅-G₃₅-S₁₀) were made by replacing fly ash with silica fume.

The following self-compacting fresh property test were conducted,

- (a) Determination of consistency (slump flow test)
- (b) L- box test
- (c) J- ring test
- (d) U- box test

5.2 Hardened Properties of Self Compacting Geopolymer Concrete

The hardened properties of fly-ash based self-compacting geopolymer concrete with silica fume as partial replacement to fly ash by 0%, 2.5%, 5%, 7.5% & 10% with constant GGBFS content. The fly ash content is 65% and GGBFS is 35%. Five concrete mixes (SCGC-F₆₅-G₃₅-S₀, SCGC-F_{62.5}-G₃₅-S_{2.5}, SCGC-F₆₀-G₃₅-S₅, SCGC-F_{57.5}-G₃₅-S_{7.5}, SCGC-F₅₅-G₃₅-S₁₀) were made by replacing fly ash with silica fume.

The strength properties are

- a Compressive strength test.
- b Split tensile strength test.
- c Flexural strength test.

The compression test strength on concrete was performed as per IS 516.1.1-2021 codal provisions. A test cube specimen of size 100mm x 100mm is placed horizontally between surfaces of compression testing machine. The size of cylinder is 500mm x 100mm for conduct splitting tensile strength. The flexural test is conducted on the specimen of size 500mm x 100mm x 100mm to find the cracking load of the concrete.

5.3 Non- Destructive Testing of Self compacting Geopolymer Concrete.

The following test were conducted

- 1. Ultrasonic pulse velocity testing

2. Rebound Hammer Test

VI. RESULTS AND DISCUSSIONS

6.1 Fresh Properties of Self Compacting Geopolymer Concrete.

MIX ID	SLUMP TEST (mm) (550 to 850) $SF = (d_1+d_2)/2$	T _{500mm} (sec) (2 – 5 Sec)
1. SCGC-F ₆₅ -G ₃₅ -S ₀	581 (SF 1)	8
2. SCGC-F _{62.5} -G ₃₅ -S _{2.5}	577 (SF 1)	12
3. SCGC-F ₆₀ -G ₃₅ -S ₅	564 (SF 1)	17
4. SCGC-F _{57.5} -G ₃₅ -S _{7.5}	552 (SF 1)	22
5. SCGC-F ₅₅ -G ₃₅ -S ₁₀	547 (SF 1)	34

Table 6.1.a: Slump flow test results



Fig 6.1: Slump flow test of SCGC-F₆₅-G₃₅-S₀



Fig 6.2: Slump flow test of SCGC-F₆₀-G₃₅-S₅

MIX ID	L- BOX , $P_L = H_2/H_1$ (0.8 – 1.0)
1. SCGC-F ₆₅ -G ₃₅ -S ₀	0.3
2. SCGC-F _{62.5} -G ₃₅ -S _{2.5}	0.3
3. SCGC-F ₆₀ -G ₃₅ -S ₅	0.5
4. SCGC-F _{57.5} -G ₃₅ -S _{7.5}	0
5. SCGC-F ₅₅ -G ₃₅ -S ₁₀	0

Table 6.1.b: L- box test results



Fig 6.3: L- box test of SCGC- F_{62.5}-G₃₅-S_{2.5}



Fig 6.4: L- box test of SCGC- F₅₅-G₃₅-S₁₀

MIX ID	J- RING (mm) (0 to 10)
1. SCGC-F ₆₅ -G ₃₅ -S ₀	8.5
2. SCGC-F _{62.5} -G ₃₅ -S _{2.5}	13
3. SCGC-F ₆₀ -G ₃₅ -S ₅	27
4. SCGC-F _{57.5} -G ₃₅ -S _{7.5}	48
5. SCGC-F ₅₅ -G ₃₅ -S ₁₀	62

Table 6.1.c: J-ring test results



Fig 6.5: J- ring test of SCGC- F_{62.5}-G₃₅-S_{2.5}



Fig 6.6: J- ring test of SCGC- F_{57.5}-G₃₅-S_{7.5}

MIX ID	U- BOX H_2-H_1 (mm) (30 mm Max.)
1. SCGC-F ₆₅ -G ₃₅ -S ₀	11
2. SCGC-F _{62.5} -G ₃₅ -S _{2.5}	22
3. SCGC-F ₆₀ -G ₃₅ -S ₅	31
4. SCGC-F _{57.5} -G ₃₅ -S _{7.5}	48
5. SCGC-F ₅₅ -G ₃₅ -S ₁₀	0

Table 6.1.d: U- box test results



Fig 6.7: U- box test of SCGC- F₆₅-G₃₅-S₀



Fig 6.8: U- box test of SCGC- F₅₅-G₃₅-S₁₀

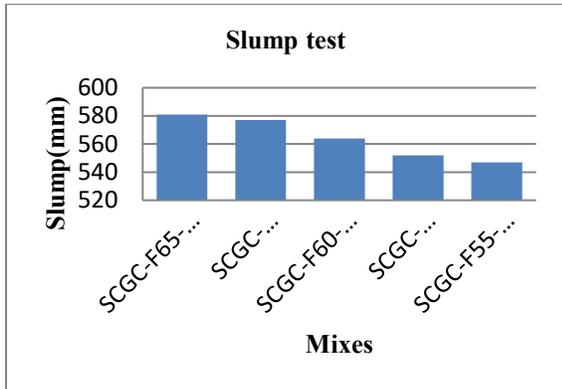


Fig 6.9: Slump test

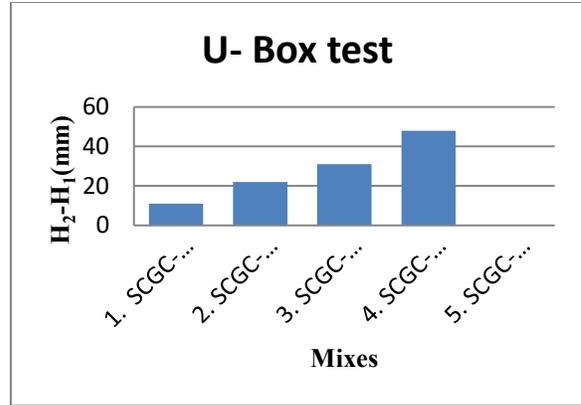


Fig 6.13: U-box test

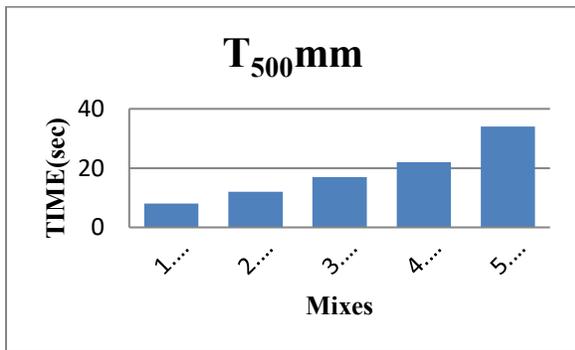


Fig 6.10: T₅₀₀ mm test

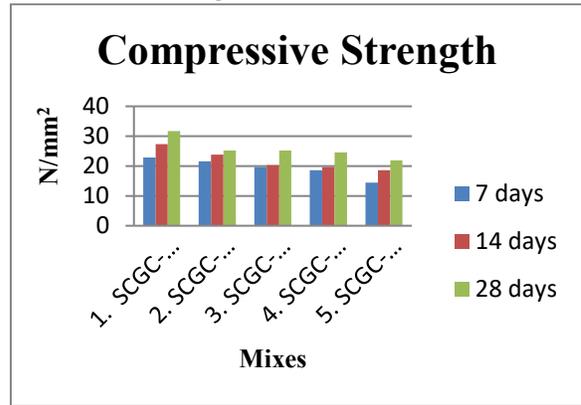


Fig 6.14: Compressive strength

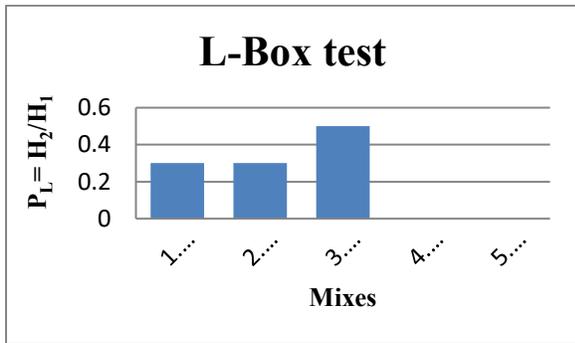


Fig 6.11: L-box test

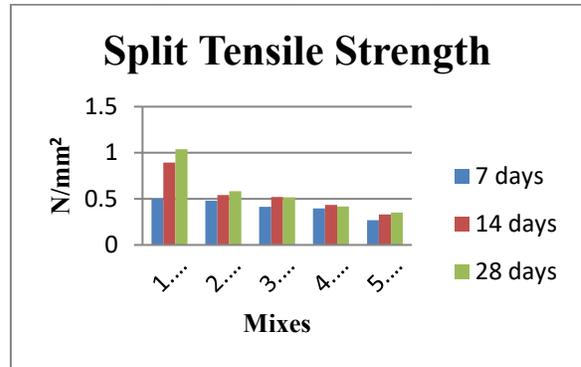


Fig 6.15: Splitting tensile strength

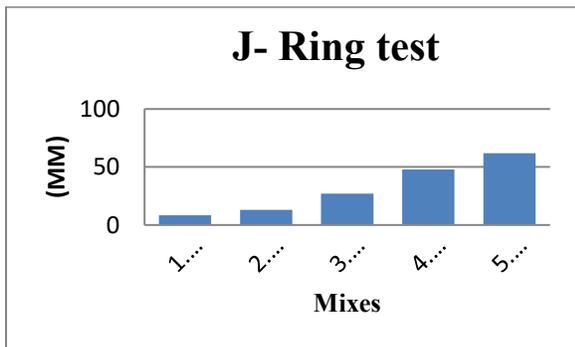


Fig 6.12: J-ring test

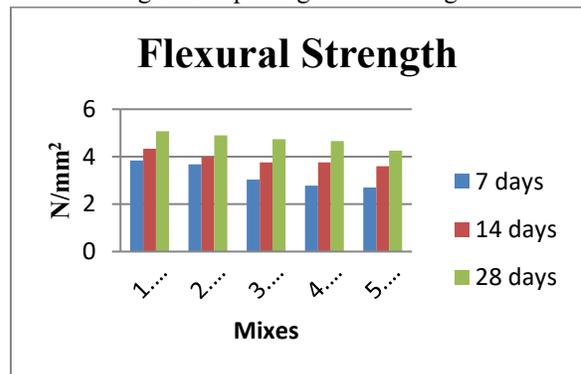


Fig 6.16: Flexural strength

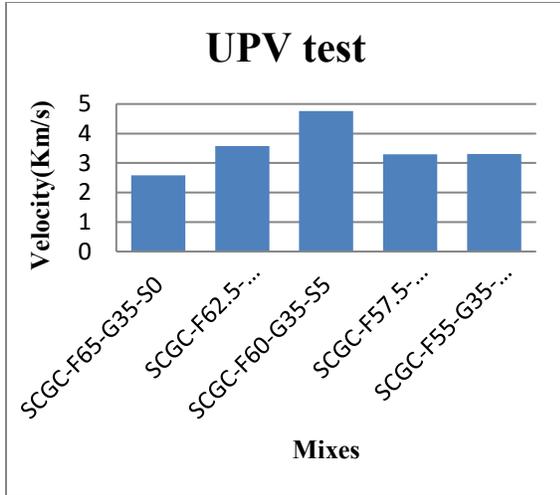


Fig 6.17: UPV test

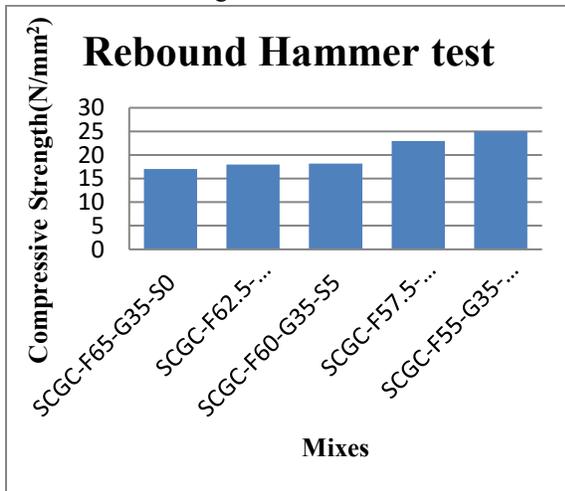


Fig 6.18: Rebound hammer test

VII. CONCLUSION

- The workability of self-compacting geopolymer concrete has been decreased in addition of silica fume with a partial replacement to fly ash by 2.5%, 5%, 7.5% & 10%.
- Mixes SCGC-F65-G35-S0 , SCGC-F62.5-G35-S2.5 , SCGC-F60-G35-S5 & SCGC-F57.5-G35-S7.5 has satisfies the slump flow test and conforming to SF1 which is suitable for housing slab, tunnel linings, piles and deep foundation.
- Mix SCGC-F55-G35-S10 has been failed in the slump flow test.
- Due to high viscosity and yield values too high, mixes SCGC-F65-G35-S0, SCGC-F62.5-G35-S2.5, SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 were failed in T-500mm test.

- Due to high viscosity, yield values too high and blockage, mixes SCGC-F65-G35-S0, SCGC-F62.5-G35-S2.5, SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 were failed in L- Box test.
- Due to high viscosity, yield values too high and blockage, mixes SCGC-F65-G35-S0, SCGC-F62.5-G35-S2.5, SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 were failed in J- Ring test.
- Mixes SCGC-F65-G35-S0 , SCGC-F62.5-G35-S2.5 were satisfied the U- Box test.
- Due to high viscosity, yield values too high and blockage, mixes SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 were failed in U- Box test.
- The compressive strength, splitting tensile strength and flexural strength for 0% replacement of silica fume with fly ash (SCGC-F65-G35-S0) at 7, 14 and 28 days was found higher strength than other mixes.
- Mixes SCGC-F62.5-G35-S2.5, SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 at 7, 14 and 28 days was found lower strength than mixes SCGC-F62.5-G35-S2.5 at 7, 14 and 28 days, this may due to uneven distribution of silica fume, not proper mixing of concrete, no reaction take place in the concrete in order to addition of silica fume or may reduce the polymerization reaction of self-compacting geopolymer concrete.
- The flexural strength failure of mixes SCGC-F65-G35-S0, SCGC-F62.5-G35-S2.5, SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 at 7, 14 and 28 days were failed under A- Type failure and where the 'a' value of all mixes were greater than 133.33mm.
- From compressive strength test some of the specimens at 7, 14 and 28 days of mixes SCGC-F65-G35-S0, SCGC-F62.5-G35-S2.5, SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 were failed under tensile cracks.
- From splitting tensile strength test some of the specimens at 7, 14 and 28 days of mixes SCGC-F65-G35-S0, SCGC-F62.5-G35-S2.5, SCGC-F60-G35-S5, SCGC-F57.5-G35-S7.5 & SCGC-F55-G35-S10 were found unsatisfied failure types of cracks or splitting.
- The quality of concrete tested by NDT-UPV test of mix SCGC-F60-G35-S5 was excellent when

compared to other mixes SCGC-F₆₅-G₃₅-S₀, SCGC-F_{62.5}-G₃₅-S_{2.5}, SCGC-F_{57.5}-G₃₅-S_{7.5} & SCGC-F₅₅-G₃₅-S₁₀ at 7, 14 and 28 days were doubtful and poor, and this may be due to not denser or may be due to high porosity in concrete.

- The quality of concrete tested by NDT-Rebound hammer test of mixes SCGC-F₆₅-G₃₅-S₀, SCGC-F_{62.5}-G₃₅-S_{2.5}, SCGC-F₆₀-G₃₅-S₅, SCGC-F_{57.5}-G₃₅-S_{7.5} & SCGC-F₅₅-G₃₅-S₁₀ at 7, 14 and 28 days the compressive strength were very low and below 25 N/mm².
- Severe segregation and minor segregation is not occurred in the flow. The coarse aggregate with the paste as spread evenly.
- During casting of specimen in mould compacting is done for mixes SCGC-F_{57.5}-G₃₅-S_{7.5} & SCGC-F₅₅-G₃₅-S₁₀ due to less workability induced by silica fume.
- Smooth surface is appeared in the specimen after demoulding.

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