

Comparative Studies of Fresh Properties of Self-Compacting Geopolymers Concrete Using Waste Foundry Sand and Ordinary Self-Compacting Cement Concrete

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ABSTRACT

To resolve the problem of carbon emission and to reduce the labour cost in construction of concrete structures an innovative sustainable concreting technique named “self-compacting geopolymer concrete” is developed. The benefit of using this concreting technique over ordinary self-compacting concrete is that it solves the problem of disposal of waste foundry sand, fly ash and GGBFS and also it is environment-friendly. The present investigation is mainly focused on the comparison of fresh properties of self compacting concrete with self-compacting geopolymer concrete with 10 molarity of NaOH and using waste foundry sand as replacement of ordinary sand to make this a low-cost concreting technique. Test were performed such as slump flow, T_{50cm} , V-funnel and L-box were conducted to assess the fresh properties.

Keywords- self-compacting geopolymer concrete, Fly Ash, ground granulated blast furnace slag, waste foundry sand, and molarity of NaOH solution.

1. INTRODUCTION

Concrete is the primary material in construction industry. It consists of cement, coarse aggregate, fine aggregate, water and other admixtures. Generally Ordinary Portland cement is used in concreting but the production of OPC causes a huge amount of carbon emission and also it uses a huge amount of non-renewable natural resources. The concrete construction practice in use is considered as unsustainable because it consumes a huge quantity of sand, stone and water and 2.5 billion tons of OPC per year.

1.1. Self-Compacting Concrete

Self-compacting concrete is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling form work and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

Making concrete structures without compaction has been done in the past. Like placement of concrete under water by the use of tremie without compaction. Inaccessible areas were

concreted using such techniques. The production of such mixes often used expensive admixtures and very large quantity of cement. But such concrete was generally of lower strength and difficult to obtain. This leads to the development of self-compacting concrete (SCC) whose concept was first initiated by Japan in the mid of 1980s. The key properties of SCC are filling ability, passing ability and resistance to segregation. Filling ability help the concrete to flow through the formwork and completely fill the all spaces within it. Passing ability is the property by virtue of which the concrete flows without blocking. The benefit of resistance to segregation imparts the advantage to the concrete in maintaining a uniform composition hence the paste and aggregate bind together.

The main advantages of self-compacting concrete are as follows:

1. No vibration of fresh concrete is necessary.
2. Placement of concrete is easier.
3. Faster and more efficient placement of fresh concrete is achieved. Total concreting time is reduced.
4. Noise level on construction site is reduced. Thus the number of working hours on the construction site can be increased and the night shift in urban zone is enabled.
5. Energy consumption is reduced.
6. Required number of workers on construction site is reduced.
7. Safer and healthier working environment is obtained.

1.2. Self-Compacting Geopolymer Concrete

So to resolve the problem of emission of greenhouse gases Davidovits developed a innovative concreting technique named geopolymer concrete. Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and Aluminum (Al) in a source material of geological origin or in by-products materials such as Fly Ash (FA) and Rice Husk (RHA) to produce binders [1]. The two main constituents of geopolymer, namely the source materials and the alkaline liquids [1]. This could be natural mineral such as kaolinite, clays etc. Alternatively, by-products such as fly ash, silica fume, slag, rice husk, GGBS, red mud etc [1]. The material used as geo-polymer binders should be rich in silicon (Si) and Aluminium (Al). Both Fly Ash and GGBS in certain proportion were found to be geopolymer source materials to obtain sufficient strengths of geopolymer concrete [2]. Alkaline liquids are from soluble alkali metals that are usually sodium or potassium based [1]. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or Potassium Hydroxide (KOH) and Sodium Silicate or potassium silicate. Many of the GPC mixes earlier tested required the use of high temperature curing. Heat curing substantially assists the chemical reaction that occurs in the geo-polymer paste [1]. Both curing time and curing temperature influence the compressive strength of geopolymer

concrete [1]. However recent studies revealed that GPC mixes can be developed for ambient room temperature [5]. It was noticed that fresh GPC was highly viscous with low workability and hence, super plasticizer (SP) was found to be used to attain adequate workability [2].

One of the major problem faced in construction industry is the lack of skillful labors for concreting but to resolve this problem Japanese scientists Okamura et al and Ozawa et al proposed a new concreting technique named “self compacting concrete” in which the concrete compacts due to its self weight and can pass through congested reinforcement easily. Self compacting concrete has the follow properties: higher slump flow, high viscosity, passing ability and resistance to segregation [3]. Use of self compacting geopolymer concrete in construction industry can solve the problem of greenhouse gas emission as well as it reduces the problems faced due to lacking of skilful labour and using waste foundry sand as replacement of river sand can solve the problems of river mining, solves problems of disposal of waste foundry sand and reduces the cost of concreting. Studies reveals that the compressive strength of SCGC increases when thermal cured at 60-70 °C, but it decreases when temperature exceeds 70°C [7]. It is found that on increasing molarity of NaOH the fresh properties of concrete decreases [6]. It is observed that the alkaline solution, super plasticizer and extra water should be premixed before adding to the dry mix of concrete to get improved workability of SCGC [2-19]. In metal industries for various process in metal casting foundry sand is used. After the casting of metal the burnt fine-grained foundry sand can be re-used for various purposes in construction industry. It will reduce the cost of construction. But split tensile strength decreases on increasing the percentage of waste foundry sand [4].

In the present research we examined how self compacting geopolymer concrete using waste foundry sand as replacement is good over ordinary self-compacting concrete. Its Fresh properties are found by conducting tests such as slump flow, T50cm, V-funnel and L-box as per EFNARC [10].

2. EXPERIMENTAL STUDIES

Materials Used in preparation of self-compacting geopolymer concrete

2.1. Class F fly ash:

Nowadays fly ash is the material which is most extensively used in construction industry as a partial replacement of cement. The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 7% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime mixed with water to react and produce cementitious compounds. Alternatively, adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geopolymer.

We are using class F fly ash obtained from “Wanakbori Thermal Power Station, Gujarat, India”.

2.1.1. Ground Granulated Blast Furnace Slag:

It is obtained as a by-product of iron and steel-making from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. It is used as a partial replacement of cement, when it is used in certain proportion with fly ash it significantly helps in increasing the compressive strength. The main components of blast furnace slag are CaO (30-50%), SiO₂ (28-38%), Al₂O₃ (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag plasticity and an increase in compressive strength.

2.2. River Sand

Aggregate contains almost 75-80% of the concrete volume. While in SCGC for self compaction the fine aggregate content should be 40% of the mortar volume. Ordinary sand which pass through 4.75mm IS sieve and having no more than 5% coarser material are included in fine aggregate. River sand is obtained by river mining which is a non-renewable source. fine aggregate fills the voids and increases the workability of concrete.

2.1.1 Waste Foundry Sand

Mostly metal industries prefer sand casting system. In this system mould made of uniform size and uniform sand with high silica content is used. After the casting of metal foundries reuse and recycle the sand but after several time of using it the sand is discarded and it is called waste foundry sand. Its use in construction industry is economical and also solve the problems of its disposal.

2.3. Coarse Aggregate

The aggregate having size more than 4.75mm is termed as coarse aggregate. In order to achieve self compactability and passability of concrete through congested reinforcement coarse aggregate of two different sizes are used in SCGC. In SCGC the coarse aggregate content is 50% of the solid volume and coarse aggregate in two different size at 60:40 ratio can be used.

2.4. Super Plasticizer

Self-compacting concrete can be prepared by compounding admixture with high efficiency water reducing agent. According to requirement of performance of SCGC , climate conditions and the construction technology , combined with concrete raw materials performance, adaptability to cement and mix proportion and other factors, the species and dosage of admixture can be determined through the test.

2.5. Alkaline Solution

Generally sodium hydroxide or potassium hydroxide and sodium or potassium silicate is used as alkaline activators for formation of C-S-H gel. Studies reveal that only using sodium

hydroxide or sodium silicate is not much effective. So combination of sodium hydroxide and sodium silicate is used generally. Sodium hydroxide pellets is 97-8% purity is generally used and sodium silicate with Na₂O = 13.7%, SiO₂ = 29.4% and water = 55.9% is generally used. With the increase in concentration of solution in terms of molarity (M) the concrete becomes brittle with increased compressive strength. Cost of sodium hydroxide solids is high and preparation is very caustic. Generally sodium silicate-to-sodium hydroxide ratio of 2 to 2.5 is maintained in concrete casting which will help in gaining the strength after 24h of casting.

2.6. Water

Water plays an important role in concrete while in self compacting geopolymer concrete water does not play any important role in gaining strength rather it helps in improving the workability. As studies reveals that geopolymer mix is less workable so to attain self compact ability extra water is needed to add in the mix.

2.7. Materials Used In The Preparation Self-Compacting Cement Concrete(SCC)

- 2.7.1. Cement: Ordinary Portland Cement (OPC) of 53grade conforming IS 12296 is used in this mix. This is used in 70% of binder content.
- 2.7.2. Fly Ash: Class F Fly Ash conforming ASTM is used as a replacement of OPC up to 30%.
- 2.7.3. Coarse Aggregate: Coarse aggregate of maximum nominal size 12.5 mm is used for preparation of mix is used.
- 2.7.4. Fine Aggregate: ordinary river sand sieved with 4.75mm sieve is used as fine aggregate.
- 2.7.5. Super plasticizer: masterglenium polyheed SKY8630 is used as plasticizer which is blended version of super plasticizer and viscosity modifying agent.

TABLE - I

CHEMICAL COMPOSITIONS OF FLY ASH AND GGBFS

Particulars	Class F Fly Ash	Ground Granulated Blast Furnace Slag.
Chemical Compositions	High Fe	
%Silica(SiO ₂)	47	30.61
% Alumina(Al ₂ O ₃)	23	16.24
% Iron Oxide(Fe ₂ O ₃)	15	0.584
% Lime (CaO)	2.3	34.48

%Magnesia(MgO)	0.8	6.79
%Titanium Oxide(TiO ₂)	1	-
% Sulphur Oxide(SO ₃)	0.5	1.85
Loss on Ignition	0.37	2.1
Physical Compositions		
Specific Gravity	2.11	2.9
Fineness(m ² /kg)	330	400

TABLE - II

CHEMICAL COMPOSITION OF WASTE FOUNDRY SAND

Constituent	Value (%)
Silica(SiO ₂)	87.91
Alumina(Al ₂ O ₃)	4.7
Iron Oxide(Fe ₂ O ₃)	0.94
Lime (CaO)	0.14
Magnesia (MgO)	0.3
Sulphur Oxide (Na ₂ O)	0.19
Potassium Oxide (K ₂ O)	0.25

TABLE - III

PROPERTIES OF ADMIXTURES

Chemical Admixture	Relative Density	pH	Chloride Content (%)	Main Component
SKY8630	1.08	≥6	<0.2%	Polycarboxylate Ether

2.8. Mix Proportions**TABLE - IV**

MIX DESIGNATIONS OF SCGC

Mix	AS/B	Binder	CA	FA	WFS	NaOH
M1	0.45	450	712	984	0	58
M2	0.45	450	712	689	295	58
M3	0.45	450	712	394	590	58
M4	0.45	450	712	0	984	58

TABLE - V

MIX DESIGNATIONS OF SCGC

Mix	Na ₂ SiO ₃	Extra Water (%)	SP (%)	W/B
M1	145	20	3	0.4
M2	145	20	3	0.4
M3	145	20	3	0.4
M4	145	20	3	0.4

TABLE - VI

MIX DESIGNATION OF SELF COMPACTING CONCRETE

Mix	W/P	Cement	Fly Ash	CA
M1	0.36	315	135	712

TABLE - VII

MIX DESIGNATION OF SELF COMPACTING CONCRETE

Mix	FA	Water (kg/m ³)	SP%
M1	984	165	3

3. PREPARATION OF SCGC: ITS MIXING, CASTING AND TESTING.

In this study we used Class F Fly Ash and Ground Granulated Blast Furnace Slag (GGBFS) in ratio of 70:30 as binder materials. In the first study we conducted fresh property test with 0% replacement of river sand and then we have conducted fresh property test by replacing river sand with waste foundry sand in an amount of 30%, 60% and 100%. We used Coarse Aggregate passing through 12.5 mm sieve and retaining on 10mm sieve. We have used sodium silicate (40% solids) and sodium hydroxide (97-98% purity) as alkaline solution in ratio of sodium silicate-to- sodium hydroxide is 2.5. To attain higher workability we used masterglenium SKY8630 as super plasticizer which is a blended version of Super Plasticizer (SP) and Viscosity Modifying Agent (VMA). Alkaline solution is prepared 24 hours before the practical to be performed. A specified amount of extra water (other than water used in preparation of alkaline solution) is added to attain higher workability because geopolymer mix is having less workability (dry mix). Mix is prepared in two stages. In first stage coarse aggregate, fine aggregate, fly ash and ground granulated blast furnace slag are dry mixed for 3-4 minutes. In the second stage the alkaline solution, super plasticizer and water is mixed properly and

then mixed with the dry mixed materials for 3 minutes. To ensure homogeneity of concrete the materials are allowed to mix for 2-3 minutes more. To access the fresh properties of self compacting geo-polymer concrete test such slump flow, T_{50cm}, V funnel and L-box were conducted as mentioned by EFNARC. The fresh concrete mixtures are then filled into cubes of 150mm x 150mm x 150mm and cylinders of 150mm diameter and 300mm height.

4. PREPARATION OF SCC: ITS MIXING, CASTING AND TESTING

We have used cement and fly ash as binder material in 70:30 ratios. Total 450kg/m³ binder material is used in mix. We used coarse aggregate passing through 12.5mm sieve and retaining on 10mm sieve. We used fine aggregate passing through 4.75mm sieve and masterglenium polyheed SKY8630 as super plasticizer at 3% of mass of binder material. This mix is also prepared in two stages, in first stage cement, fly ash, sand and aggregate is allowed to mix for 3-4 minutes. In the second stage mixture of water and plasticizer is mixed with the dry mixed material for 2.5-3 minutes. Fr homogeneity it is allowed to mix for 2-3 minutes more. Then the tests for fresh properties such as slum flow, T50cm, V-funnel and L-box were conducted.

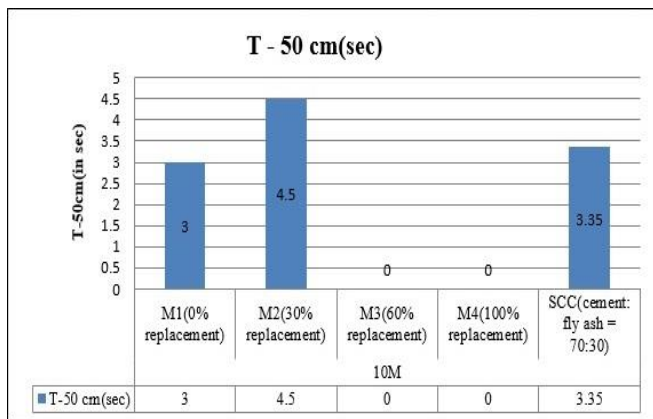


Fig-1: Comparison of T-50sec with 10M

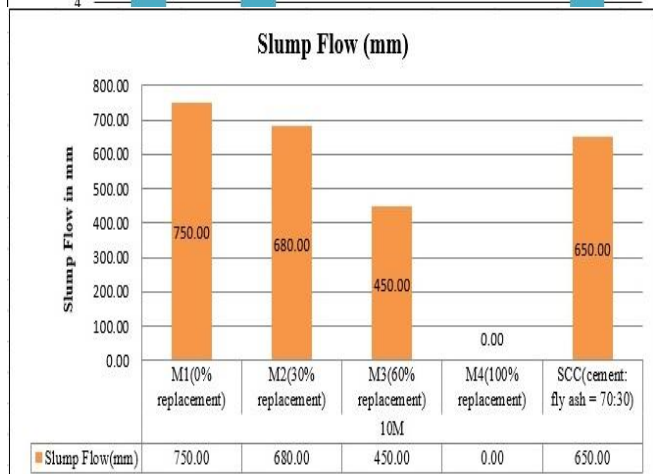
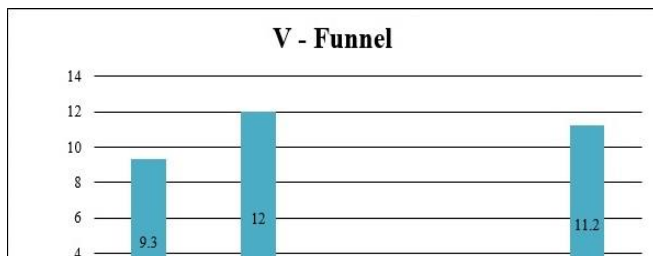
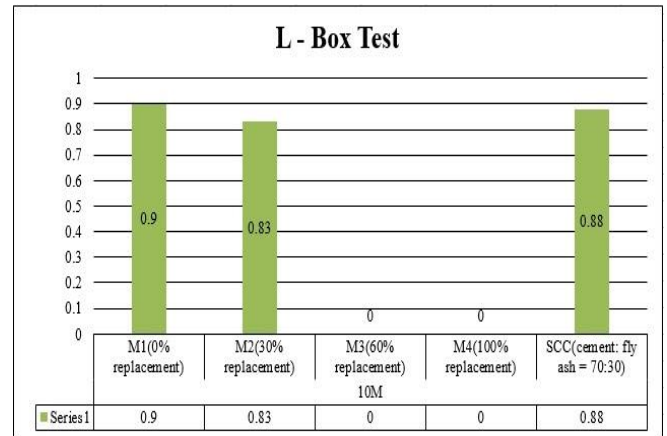


Fig-2: Comparison of V-Funnel with 10M

Fig-3: Comparison of Slump Flow with 10M

Fig-4: Comparison of L-Box Test with 10M

5. RESULT



This section discusses the effect on fresh properties of self compacting geo-polymer concrete due to replacement of sand by certain amount with waste foundry sand.

TABLE - VIII

FRESH PROPERTIES TEST RESULT FOR SCGC

Mix NO	Description	Slump Flow (mm)	T _{50cm}	L-box H ₂ /H ₁	V funnel (seconds)
M1	0% replacement of FA	750mm	3	0.9	9.3
M2	30% replacement of FA	670mm	4.5	0.83	12
M3	60% replacement of FA	450mm	Fail	Fail	Fail
M4	100% replacement of FA	Fail	Fail	Fail	Fail

TABLE - IX

FRESH PROPERTIES TEST RESULT FOR SELF COMPACTING CEMENT CONCRETE (SCC)

Mix	Description	Slump	T _{50cm}	L-box	V-funnel
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		flow (mm)	test (H ₂ /H ₁)	test (seconds)
M5	SCC (cement: fly ash = 70:30)	660	3.35	0.88
				11.20

TABLE – X

AS RECOMMENDED BY EFNARC[10] FOR
SELF-COMPACTING CONCRETE

	Slump Flow	T _{50cm}	L- box	V- funnel
Minimum	650mm	2	0.8	9
Maximum	800mm	5	1	15

6. CONCLUSION

1. On using Fly Ash and GGBFS as binder material for self-compacting geo polymer concrete can help in reducing CO₂ emission from concrete structures.
2. On replacing river sand with waste foundry sand by certain amount can solve the problems of river mining and reduce the cost of concreting.
3. On replacing sand up to 30% with ordinary sand give quite good self-compacting properties such as flow ability, pass ability, segregation resistance-stability and viscosity.
4. While replacing 60% ordinary sand with waste foundry sand the self-compactability of the concrete decreases and test for self-compacting concrete fails in attaining the values recommended by EFNARC and at 100% replacement the concrete does not show flow ability, pass ability, segregation resistance and viscosity hence fails every criteria for self-compacting concrete by EFNARC.
5. The results reveals that on keeping the same binder ratio as kept for SCC , SCGC with 0% replacement of sand and 30% replacement of sand both mix yields better result in slump flow .
6. While replacing 60% sand with waste foundry sand gives poor result in slump flow.
7. While there is a minor difference in results for T50cm, L-box and V funnel test between SCC and SCGC with (0% and 30% replacement of sand) but it is within the values recommended by EFNARC.
8. The mix designed with aggregate size ranging from 10-12.5 mm gives better fresh properties.
9. Problems of disposal of Fly Ash and Ground Granulated Blast Furnace Slag is resolved.
10. This type of concreting is good for casting precast concrete members.

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