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Development of Fly Ash-GGBS based Self Compacting Geo-Polymer Concrete with and without Steel Fibres

B. Narendra Kumar[1*], G. Vinod Kumar[2], V. Rajesh[2]

1. Professor, Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India
2. PG Student, Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India

Corresponding author: *narendrakumar_b@vnrvjiet.in*

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ABSTRACT

The present work is focussed on the optimization of mix proportions to satisfy the self-compatibility requirements as per EFNARC [march 2006] guidelines and to assess the mechanical properties of concrete made out from these industrial by-products adding partially with GGBS in cement called self compacting concrete (SCC) and concrete made with (GGBS+Fly ash) named as Self Compacting Geo-polymer Concrete (SCGPC) and concrete made with incorporation of steel fibers for the optimized SCGPC mix named as Self-Compacting Geo-Polymer Fibre Reinforced Concrete (SCGPFRC) mixes were prepared. The fresh properties, as well as the hardened properties, were studied. The physical durability was also studied with the abrasion resistance test. The fresh properties of SCGPC were better than SCC and SCGPFRC. Although there is a slight decrease in strength for SCGPC, when compared to conventional concrete(100% cement) and SCC, but it fulfill the strength requirements by achieving the target strength. With the introduction of fibres to the SCGPC, the flexural strength and split tensile strength of SCGPFRC is significantly increased when compared to SCGPC mixes. It can be inferred that at fiber content of 1.5% (SCGPFRC2) the value of flexural strength and split tensile strength was found to be increased by 15.73% and 40.72% respectively.

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1. Introduction

The name Geopolymer was pronounced by a French professor whose name is Davidovits in the year 1978. The binding property of geopolymers depends upon thermally activated natural materials like industrial by-products such as fly ash in thermal power plants or slag in iron industries, to provide a source of aluminium and silica. By dissolving these silicon and aluminium in an alkaline activating solution, it subsequently forms molecular chains through polymerization and becomes a binder. Thermal industries produce a waste called fly ash, which is simply dumped over the earth, which occupies large areas. Fly ash reacts with the aqueous solution which contains both Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) in their respective mass ratio, which results in a new material having a three-dimensional polymeric chain and ring structures throughout and consisting of Si-O-Al-O bonds.

Ground Granulated Blast Furnace Slag (GGBS) is a by-product from the iron manufacturing industries. By blending these two by-products (Fly ash+GGBS) and incorporating an alkali activator and by adopting proper mix guidelines a new concrete called Geopolymer Concrete will develop. Combining Self compatibility with Geopolymer concrete and reinforcing with fibres to develop a new concrete which possess high workability, high strength and high durability. But developing this concrete at ambient curing conditions is still in research phase only. Hence, in this project we have experimentally discussed the rheological properties and mechanical properties of Self Compacting Geo-polymer Fibre Reinforced Concrete.

The experimental investigation is aimed for developing M40 grade Self-Compacting geopolymer Fibre Reinforced Concrete in three phases. In first phase determination of properties of various constituent materials such as Specific gravity of cement, Fineness of cement, Normal Consistency, Setting time, Fineness Modulus, Specific gravity, Bulking, Bulk Density of the fine aggregate and Coarse aggregate etc. In the second phase, mix design was done for Conventional Concrete (Control Concrete), Self-Compacting Concrete (SCC), Self-Compacting geo-polymer Concrete (SCGPC), and Self-Compacting Geopolymer Fibre Reinforced Concrete (SCGPFRC), and then several trial mixes were done and the fresh properties were tested as per guidelines given in EFNARC [march 2006].

The design of Mixes for SCC was done as per the Nan-Su method of mix design. Nan-Su method of mix design based on target strength and it reduces the number of trail mixes, helps in attaining the perfect proportion. The fresh properties were checked as per EFNARC [march 2006] guidelines. In the third phase the hardened properties of the developed mixes were determined and also the physical durability of SCC and SCGPC was determined through abrasion test. The abrasion resistance of concrete depends upon the hardness of paste, aggregate and bond between the paste/aggregate. Abrasion test measures the resistance of material surface being worn out by rubbing and friction.There are many test methods are available to measure the abrasion of concrete for specific condition. It is well known that no single test method which measures the abrasion resistance of concrete in all conditions. In the present study abrasion resistance of concrete is determined by using under water methods according to the code (ASTM C 1138, 1997).

2. Literature review

The experimental results show that it is possible to develop SCGC possessing good strength using GGBS and Rice Husk Ash (RHA). The mechanical properties of GGBS based SCGC improved with the inclusion of RHA up to 5% RHA replacement at ambient curing and 15% RHA replacement at temperature curing[1]. For any self-compacting Geo-polymer concrete mix the workability increases with an increase in water to Geopolymer solids ratios. Compressive strength increases with decrease in water to geopolymer solids ratios [2]. Utilizing fly ash contents in (SCGC) mixtures from 400 Kg/m3 to 500 Kg/m3, enhanced the compressive strength of self-compacting geopolymer concrete (SCGC) especially when superplasticizer dosages increased, Longer curing time between 24 to 72 hours at a temperature of 70°C enhances the Geopolymerization procedure bringing about higher compressive strength at early ages [3]. When fibres are added to concrete, the mix becomes stiff. So the workability of Geopolymer concrete is decreased with addition of fibres. Addition of fibres improved the mechanical properties of Geopolymer concrete. Percentage increase in compressive strength of SFRGPC was 11%when compared to GPC and 5% compared to HFRGPC [4]. Mehta (2020) studied the influence of GGBS incorporation partially in fly ash based Geopolymer concrete. GGBS incorporated at 5-20% with 5% increment, at 20% GGBS in fly ash based Geopolymer shows good strength, durability and microstructural properties. Adding GGBS calcium based hydration products forms along with polymerization of alumina-silicate bond results inn compact and dense concrete [5]. Subhashree (2018) studied the mechanical and microstructural behaviour of fly-GGBS based Geopolymer concrete by experimenting different percentage replacement of GGBS in Fly Geopolymer concrete. At 60% replacement with GGBS shows good mechanical properties and also conducted experiment with different combination of NaOH concentration combination. As the concentration increases the strength increases up to 8M after that strength starts deceases [6]. Adding steel fibers to the Geopolymer concrete increases the ultimate flexural strength and nominal increment of compressive strength, whereas it is obvious that flow properties decreases. As the length and fiber content increases and diameter decreases could increases compressive and ultimate flexural strength of concrete [7].

3. Materials used

In the present work the material used are OPC 53 grade cement (ultra tech) of specific gravity 3.10 conforming to IS 12269-1987 [8]. Ground granulated blast furnance slag (GGBS) are purchased from JSW industry, which are of specific surface area and specific gravity are 350m^2/kg, 2.9 respectively. Class F-Fly Ash collected from the Ramagundam thermal power plant, India of size and specific gravity are 10mirco meters, 1.8 respectively. Naturally available sand used as fine aggregate of zone-II, its zone conformed with IS 383 (1970) [9]. Crushed stone used as Coarse aggregate and there physical properties were tested according to IS 2383-1963 [10]. Super Plasticizer used was Master Glenium ACE 30 conformed to IS 9103:1999 [11].

In the present study Steel Fibres were used for the optimized SCGPC mix i.e., SCGPC2. The physical properties of steel fibers were tested as per the code ISO 13270:2013. For the development of the SCGPFRC single hooked end steel fibres of aspect ratio, 60 were used.

Generally aspect ratio of steel fibers ranges from 30 to 150. The physical properties of steel fibers having Specific gravity: 7.85, Diameter:0.5mm, Length:30mm, and Aspect ratio (l/d):60. And the mechanical properties having tensile strength and elastic modulus are 1100 MPa, and 205GPa respectively.

3.1. Alkaline activator solution

Alkaline solution prepared with the combination of NaOH (sodium hydroxide) and NaSiO3 (sodium silicate) solutions. The alkaline solution prepared based on the previous literatures knowledge. The role of alkaline activators and their impact on the binding nature of the fly ash and GGBS is very important. In the present work 16M Sodium Hydroxide with 98% purity are used. The solution of sodium hydroxide are prepared by dissolving flakes of NaOH into the distilled water. The alkaline activator solution were prepared by combining sodium hydroxide solution with sodium silicate solution and allowed for 24hours at ambient temperature to cool down prior to use in mix [12].

4. Development of mix proportions

Several trial mixes for Self-Compacting Concrete with varying contents of cement and Ground Granulated Blast Furnace Slag were prepared and several mixes with varying fly ash and GGBS along with alkaline activators used to activate alumina-silicate polymerization. Further steel fibers used to the optimum Geopolymer mix. one conventional concrete mix (100% cement) were prepared. The fresh properties along with hardened properties were determined. The nomenclature for these concretes were given as SCC1 to SCC3, SCGPC1 to SCGPC3 and SCGPFRC1 to SCGPFRC3, and CC1. All these mixes were designed based on the Nan-Su method of mix design was used to calculate the quantities of the constituent materials. Nan-Su et al, (2001) proposed the new method of mix design for self compacting concrete. In this method first calculate the amount of aggregate needed is determined, then powder content (cement, fly ash, ggbs) and water content calculated, thereafter trail batches, tests are performed and made some adjustments if required [13]. The advantage of this mix design is the ratio of sand content to total aggregate is more (53-60%) therefore the amount of binder can be less, which reduces the cost. are present in the concrete volume will be more than coarse aggregate. Sand content ran and the details of quantities of the constituent materials were listed in the below Tables 1-3 respectively.

Table 1
Quantities of Constituent materials for SCC mixes.

Mix designation	Cement (Kg/m^3)	GGBS (Kg/m^3)	W/C ratio	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Super Plasticizer (% of powder content)
CC1	500		0.35	950	830	2
SCC1	400	100	0.35	950	830	2
SCC2	300	200	0.35	950	830	2
SCC3	200	300	0.35	950	830	2

Table 2
Quantities of Constituent materials for SCGPC mixes.

Mix designation	Powder (Kg/m^3)		Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Sodium Hydroxide (Kg/m^3)	Sodium silicate (Kg/m^3)	Super Plasticizer (percentage of powder content)	Extra Water (percentage of powder content)
	Fly Ash	GGBS						
SCGPC1	400	100	950	830	40	115	2	24
SCGPC2	300	200	950	830	40	115	2	24
SCGPC3	200	300	950	830	40	115	2	24

Table 3
Quantities of Constituent materials for SCGPFRC mixes

Mix designation	Powder (Kg/m^3)		Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Sodium Hydroxide (Kg/m^3)	Sodium silicate (Kg/m^3)	Super Plasticizer (percentage of powder content)	Steel Fibres (percentage of powder content)	Extra Water (percentage of powder content)
	Fly Ash	GGBS							
SCGPFRC1	300	200	950	830	40	115	2	1	24
SCGPFRC2	300	200	950	830	40	115	2	1.5	24
SCGPFRC3	300	200	950	830	40	115	2	2	24

5. Fresh Properties

All the mixes listed in the above tables were tested for fresh properties according to the guidelines laid by EFNARC [march 2006] and the details were listed in the below table 4.

Fig. 1. Flow table test.

Fig. 2. L-Box test.

For the determination of the fresh properties of Self Compacting Concrete EFNARC [2006] guidelines were used and corresponding tests such as Flow table test and L-Box test are performed. These tests are done for finding the ability of concrete to filling, by measuring the average diameter of flow of concrete formed, when the concrete slump is allowed to flow.

The values of slump diameter for SCC as per EFNARC guidelines should range from 650 mm to 800 mm. The flow property is also measured with stopwatch it is denoted as T_{50cm}. T_{50cm} should range from 2 to 5 seconds. As per the EFNARC guidelines for L-Box test the blocking ratio $(\frac{H2}{H1})$ values ranges from 0.8 to 1. Figure 3 shows the graphical

Representation of the variation of Diameter of spread with respect to GGBS and cement content in SCC mix, with respect to the proportion of Fly ash and GGBS in SCGPC mix, with respect to the fibre content in SCGPFRC mix.

Figure 4 shows the graphical representation of the variation of T_{50cm} value with respect to GGBS and cement content in SCC mix, the proportion of Fly ash and GGBS in SCGPC mix, and fibre content in SCGPFRC mix.

Figure 5 shows the graphical representation of the variation of L-Box test ratio with respect to GGBS and cement content in SCC mix, the proportion of Fly ash and GGBS in SCGPC mix, and fibre content in SCGPFRC mix.

Table 4
Fresh properties values for all mixes.

Mix Designation	**Flow table test**		**L-Box test ratio**
	Diameter of flow (mm)	**T_{50} (seconds)**	
SCC1	610	9	0.71
SCC2	707	7	0.89
SCC3	660	7	0.79
SCGPC1	797	5	0.89
SCGPC2	720	5	0.87
SCGPC3	687	7	0.78
SCGPFRC1	680	7	0.85
SCGPFRC2	660	7	0.83
SCGPFRC3	630	9	0.72

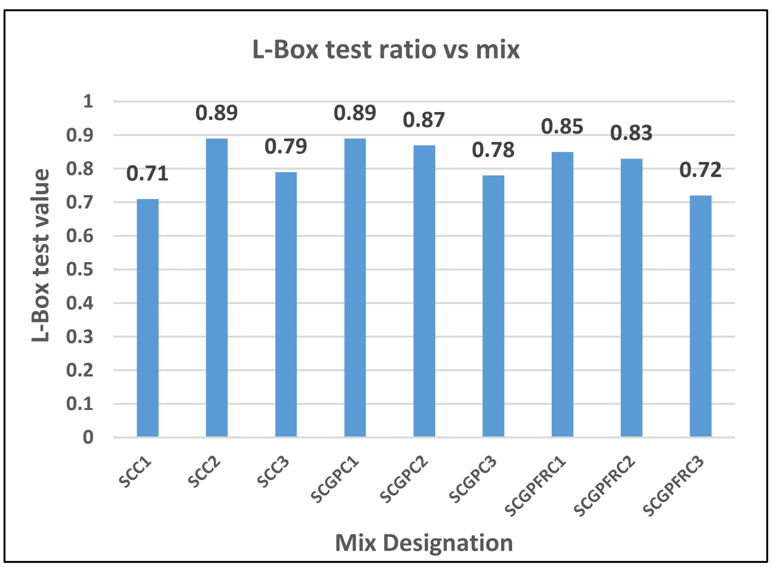

Fig. 3. Graph showing the variation of diameter of flow for all the mixes.

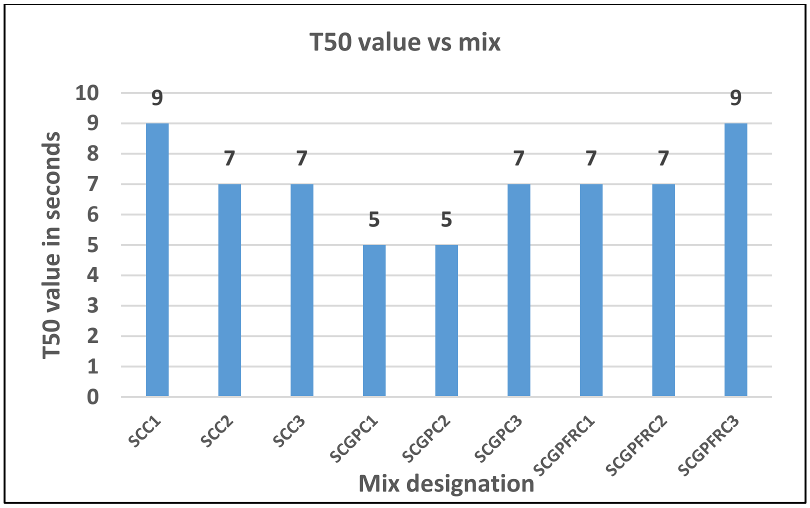

Fig. 5. Graph showing the variation of L-Box test values for all mixes.

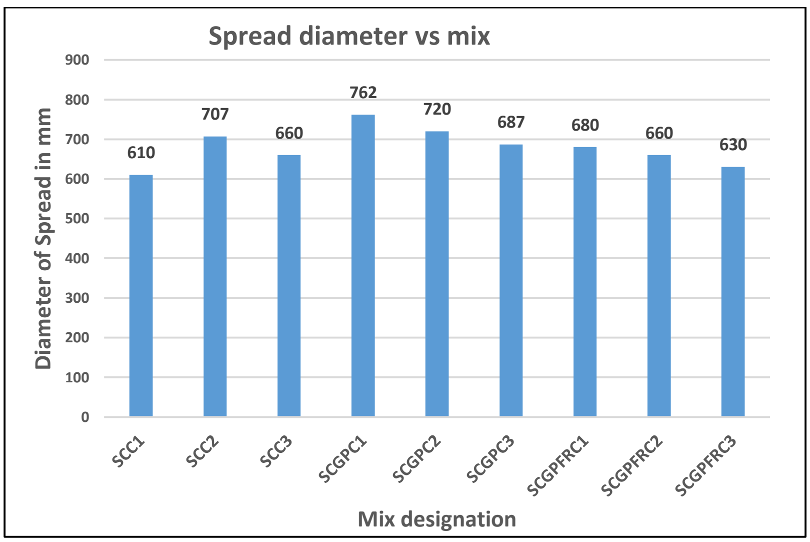

Fig. 4. Graph showing the variation of T_{50cm} value for all mixes.

The proportion of Cement to GGBS in SCC was taken in an incremental variation with 20% in GGBS content as shown in the mix design section. The mix proportion for SCGPC mix was also taken in the same way and the fresh properties for each mix were tabulated in table 4, graphical representation of the variation of different flow parameters for each mix was shown in figures 3-5.

From SCGPC mixes, the assessed fresh properties of mix SCGPC1 and SCGPC2 were found to be very much satisfying the guidelines laid by EFNARC [march 2006] and the strength attained after 7days for mix SCGPC2 was found to be higher than the SCGPC1. Hence the mix proportion for SCGPFRC mixes was finalised as the same mix of SCGPC2 with the addition of single hooked steel fibres of aspect ratio 60 in an incremental order of 0.5% of powder content in the concrete.

Fig. 6. Casted specimens.

Assessment of Fresh properties has enabled us to understand the optimum amount of GGBS that can be incorporated in SCC to meet the flow requirements and filling requirements.

In SCGPC it was found that SCGPC1(80% Fly Ash and 20% GGBS) and SCGPC2(60% Fly Ash and 40% GGBS) has shown better performance in meeting the self-compatibility requirements laid by EFNARC [march 2006].

6. Hardened properties

Hardened properties for CC1 SCC, SCGPC and SCGPFRC mixes were found out by testing the specimens for Compression, Flexure and splitting tensile strength after curing for 7 and 28 days. The code followed for the testing the specimens was IS 516 (1959) [14]. The mix SCC shows higher strength than Geopolymer concrete with and without adding steel fibres. Geopolymer concrete showed good resistance against the abrasion compared to conventional SCC. The abrasion resistance of concrete is determined by using under water methods according to the code (ASTM C 1138, 2019) [15].

6.1. Compressive strength

To assess the compressive strength of the concrete mix, cubes of dimensions 150mm*150mm*150mm were casted and demoulded after 24 hours and then allowed for curing at ambient conditions. The hardened tests were performed on specimens at an age of 7 days and 28 days.

Fig. 7. Flexural strength test.

Table 5 gives the values of compressive strength obtained for different mixes at an age of 7 days as well as 28 days.

Table 5
Compressive strength values for all mixes.

Mix Designation	Compressive Strength (MPa)	
	7 days	28 days
CC1	48.32	69.64
SCC2	46.65	70.11
SCGPC1	35.08	48.19
SCGPC2	36.14	49.53
SCGPC3	36.29	50.86
SCGPFRC1	36.63	51.43
SCGPFRC2	37.46	54.52
SCGPFRC3	34.43	52.76

6.2. Flexural strength

Fig. 8. specimen failed in flexural test.

For this test, prism specimens of size 100mm ×100mm × 500mm were tested to determine flexural strength of the concrete. There are two ways of loading the beam for testing the specimen according to IS: 516(1959), i.e. center point loading and four-point loading. For flexural strength of specimen, we have used four point loading for flexural testing and the load at which the specimen fails is recorded. The four point loading which distributes the load over a long length.

Table 6
Flexural strength values for all mixes.

Mix Designation	Flexural strength (MPa)	
	7 days	28 days
CC1	3.89	4.70
SCC2	4.11	4.89
SCGPC1	2.13	3.58
SCGPC2	2.39	3.94
SCGPC3	2.47	4.06
SCGPFRC1	3.24	4.12
SCGPFRC2	3.76	4.56
SCGPFRC3	3.50	4.24

6.3. Split tensile strength

It is a measure of tensile strength of the concrete. For this test, cylindrical specimens of dimensions 300mm in height and 150mm in *diameter* were used. The specimen was placed in Compression Testing Machine in such a way that 300mm was horizontal as shown in figure. The test is performed according to IS 5816 (1999).

Fig. 9. spilt tensile strength testing machine.

Table 7
Split tensile strength values for all mixes.

Mix Designation	Split Tensile Strength (MPa)	
	7 days	28 days
SCC1	3.04	4.01
SCC2	3.21	4.31
SCGPC1	2.01	2.83
SCGPC2	2.32	3.02
SCGPC3	1.96	2.21
SCGPFRC1	2.47	3.12
SCGPFRC2	3.72	4.25
SCGPFRC3	3.70	4.20

6.4. Abrasion test

This test was carried in Abrasion testing machine which consists a rotating device, which rotates at a rate of 1100 rpm to 1300 rpm. The abrasion resistance of concrete is determined by using under water methods according to the code (ASTM C 1138, 1997). The specimen size used in the test was 150mm diameter and 100mm height. Inside the rotating drum it has 70 grade 1000 chrome steel balls called as charge, of nominal sizes, which comes under the Rockwell hardness that used to produce abrasion effect on the specimen.

The specimen of size 300mm in diameter and 100mm in height casted and cured for 28 days. The specimen is weighed and the value is noted which gives the initial weight of the specimen before subjecting to the abrasion effect. Now the specimen is kept in the abrasion testing machine and the machine is made to run, with this test the resistance of specimen to abrasion effect was found by taking the values for every 12 hours up to 72 hours.

The specimens were subjected to abrasion test and readings were taken for every 12 hours up till 72 hours and the obtained results were tabulated

Fig. 10. Abrasion testing machine.

The average depth of abrasion (mm) for SCC, SCGPC, SCGPFRC at 72^{nd} hour are 1.321, 0.892, 1.358 respectively. We can observed that the specimen casted with steel fibers shows more depth of abrasion when compared to the specimen casted without steel fibers i.e SCC and SCGPC. The loss of volume of material seen more in specimen casted with steel fibers and specimen casted without steel comparatively shows less loss of material.

Table 8 gives the values of the average depth of abrasion obtained for SCC2 and SCGPC2 mixes for each 12 hours up to a duration of 72 hours.

Table 6
Abrasion test readings.

	SCC2	SCGPC2
Time in hours	**Average Depth of Abrasion (mm)**	**Average Depth of Abrasion (mm)**
12	0.312	0.310
24	0.398	0.401
36	0.490	0.469
48	1.031	0.774
60	1.321	0.892
72	1.395	0.963

7. Discussion of test results

The results that are obtained in this experimental investigation on conventional concrete (CC1) self compacting concrete (SCC2), SCGPC and SCGPFRC are discussed in the following sections and assessing its fresh as well as hardened properties.

Optimization of mix proportions for SCC and SCGPC mixes

7.1 Mechanism

Different methods to minimize the use of cement in concrete, either partially or completely have been attempted by many researchers.

Geopolymer concrete completely replaces cement in concrete. Geopolymer binder can be manufactured using alkali-activated industrial waste materials, like flyash and ground granulated blast furnance slag, which are rich in silica and alumina etc.

Alumina-silicate materials that are activated using alkaline solutions. These alkaline activators are KOH, K2SiO3 (OR) NaOH, Na2SiO3. The specimens are cured at ambient temperature or at high temperature. Curing at high temperatures fasten the polymerization reactions leads to an early gain of strength. From previous literature elevated temperature curing generally followed up to 90^{o}C.

Alkali activated solution used to increase the reactivity of mineral admixture (fly ash, slag etc) and introducing hydraulic properties (CSH gel formation). Alkali helps in dissolution of aluminates and silicates components from the inorganic material. High temperature promotes the linkage between the alumina-silicate ions form the network. Poly silicate forms a network leading to Harding process.

7.2 Fresh properties

SCC

As explained in the previous sections several trial mixes for SCC with varying contents of cement and Ground Granulated Blast Furnace Slag are prepared and the fresh properties along with hardened properties are determined. The 28 days maximum strength was obtained for mix SCC2 and its compressive, flexural and split tensile strength values are tabulated as shown in table 9.

Table 7
Hardened properties for SCC2 mixes.

SCC2	Age	
	7 days	28 days
Compressive Strength (MPa)	46.65	70.11
Flexural Strength (MPa)	4.11	4.89
Split Tensile Strength (MPa)	3.21	4.31

The fresh properties of SCC mixes are found to be varied based on the quantities of Ground Granulated Blast Furnace Slag and cement. As the content of GGBS increased up to the certain amount the fresh properties were found to be increased and after that, a slight decrease was observed, based on the fresh properties of the trial mixes an optimized mix i.e SCC2, is finalized and specimens are casted for the determination of hardened properties of this concrete.

SCGPC

The mix design for SCGPC mixes was initiated with 80% of fly ash and 20% of GGBS. The mix design of this concrete is similar to the previous concrete mix with extra alkali activator as Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3). The detailed mix proportion was shown in table 2. The analysis of fresh properties for SCGPC mixes shows that when the proportion of fly ash to GGBS is 80% and 20%(SCGPC1), 60% and 40% (SCGPC2), 33.33% and 66.66% (SCGPC3). As observed that decrease of fly ash content (SCGPC1 to SCGPC3) decreases the fresh properties of concrete. But fresh properties were satisfying the limits given by EFNARC [2006].

SCGPFRC

In addition of steel fibres into the concrete mix will definitely increase the flexural strength. Steel fibres of varying content of aspect ratio 60 are introduced into the SCGPC mixes at the time of dry mixing and the mixes are casted.

From the previous literature it can be concluded that longer the length of steel fibers in concrete higher is the ultimate and compressive strength [16]. In the present work 3mm length and 0.5mm diameter steel fibers are used to the optimum mix SCGPC2. It is observed that decrease in fresh properties was for all the mixes. The fresh properties of this concrete mixes with varying content of steel fibres as 1%, 1.5% and 2% of powder content, were examined, the optimum fibre content that can satisfy the self-compatibility conditions laid by EFNARC [march 2006] was found to be SCGPFRC1 (1%) and SCGPFRC2 (1.5%) (in fresh properties point of view).

7.3. Compressive strength

Table 5 shows the compressive strength values for each mix at 7 days as well as 28 days. It can be noted that the compressive strength of SCC was found to be slightly higher than CC. Compared to other concrete initial strength (7 days) attainment was very high.

Figure 11 shows the variation of compressive strength with respect to mixes (varying quantities of fly ash and GGBS) graphically. It can be inferred from the graph that the mix SCGPC2 has shown similar compressive strengths in 7 days as well as 28 days to that of the SCGPC3 and the fresh properties of SCGPC2 were better compared to SCGPC3, hence SCGPC2 mix is considered as the optimized mix.

The mix (SCGPFRC2) having 1.5% of fibre content showed a better compressive strength than the remaining mixes, the introduction of steel fibres showed a slight increase in compressive strength by 10% when compared to the SCGPC2 mix.

It can be inferred that the early age strength (7 days) attainment was low for SCGPC and SCGPFRC mixes. When compared to CC1 and SCC mixes. The compressive strength of SCGPFRC is not increased, but rather it had fulfilled the requirements for what grade it was designed for and also environmental and economical point of view provides good results.

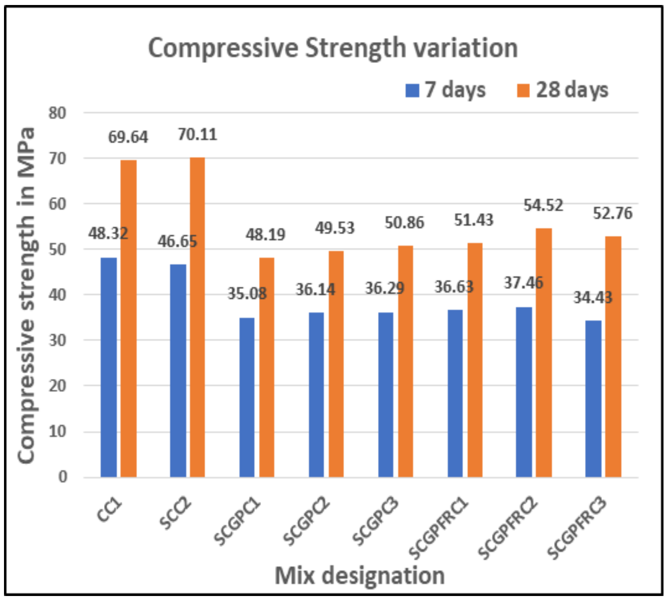

Fig. 11. Graph showing the variation of Compressive strengths for all mixes.

7.4. Flexural strength

Table 6 shows the flexural strength values and figure 12 shows the variation of flexural strength for each mix for 7days as well as 28days.

Although mix SCGPC3 has flexural strength more than SCGPC2, the increase was very low (1.2%) and negligible and moreover the fresh properties of SCGPC2 are greatly satisfying than SCGPC3, Hence SCGPC2 is considered as the optimized mix in Self-Compacting Geopolymer Concrete.

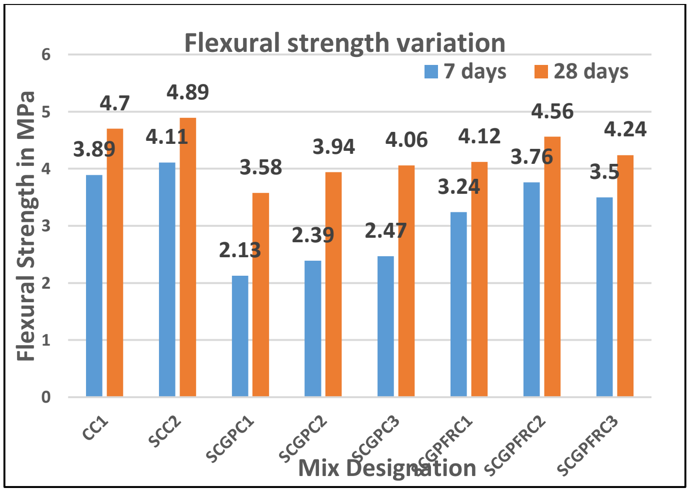

Fig. 12. Graph showing the variation of flexural strength for all mixes.

With the introduction of fibres into the concrete the flexural strength was significantly increased when compared to SCGPC mixes. It can be inferred that at a fibre content of 1.5% (SCGPFRC2) the value of flexural strength was found to be increased by 15.73% when compared to SCGPC2 mix.

7.5. Split tensile strength

Table 7 shows the split tensile strength values for each mix and figure 13 shows the variation of split tensile strength for each mix for 7 days as well as 28 days.

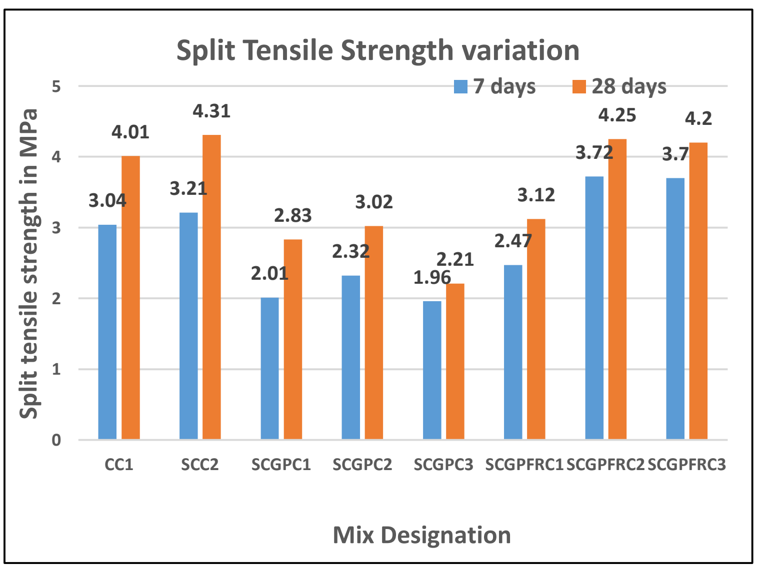

Fig. 13. Graph showing the variation of Split tensile strength for all mixes.

Mix SCGPC2 has a way similar strength to that of the SCGPC3 and moreover the fresh properties of SCGPC2 are greatly satisfying than SCGPC3, Hence SCGPC2 is considered as the optimized mix in Self-Compacting Geopolymer Concrete.

With the introduction of fibres into the concrete, the splitting strength is significantly increased when compared to SCGPC mixes. It can be inferred that at a fibre content of 1.5% (SCGPFRC2) the value of split tensile strength was found to be increased by 40.72% when compared to SCGPC2 mix.

7.6. Resistance against abrasion

There are many test methods are available to measure the abrasion of concrete for specific condition. It is well known that no single test method which measures the abrasion resistance of concrete in all conditions. In the present study abrasion resistance of concrete is determined by using under water methods according to the code (ASTM C 1138, 1997).
Table 8 shows the abrasion test values for SCC optimum mix i.e., SCC2 and SCGPC optimum SCGPC2 and Figure 14 shows the abrasion readings graphically, the results are represented as variation of depth of abrasion vs time. It can be inferred that SCGPC concrete has showed better resistance against abrasion than SCC.

For initial 36 hours the abrasion of SSC and SCGPC are almost similar, After that more loss of material seen for SCC concrete compared SCGPC concrete. At 72nd hour the depth of abrasion for SCC was 44.85% more than the mix SCGPC.

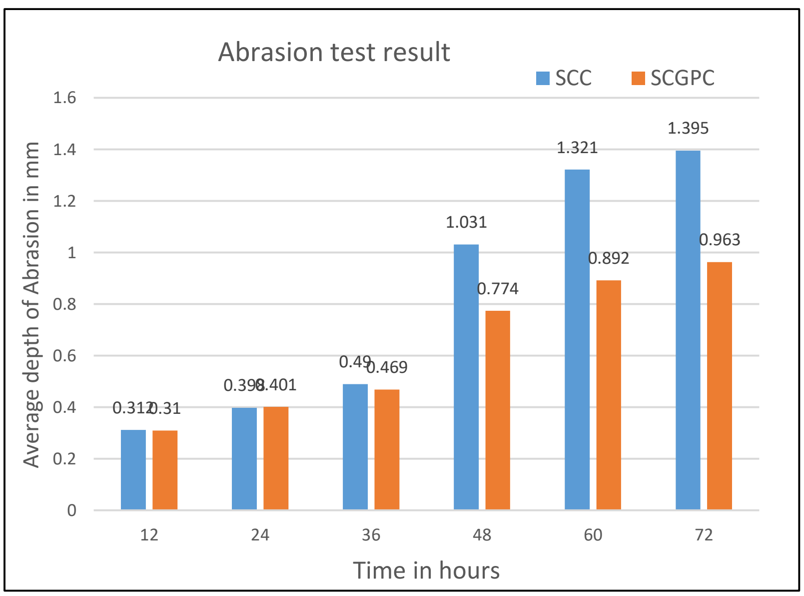

Fig. 14. Graph showing the variation of Depth of abrasion vs time.

8. Conclusions

From the above discussion following conclusion are made.

1. 40% replacement of cement with GGBS i.e., SCC2 mix has showed better fresh properties compared to SCC1 and SCC3. Therefore SCC2 mix taken as the optimum and tested for hardened properties.

2. From fresh property point of view, SCGPC mixes showed better performance and from strength point of view SCC2 mixes showed higher strength.
3. Although there is slight decrease in strength for SCGPC, when compared to conventional concrete(CC1) and SCC2 mix, but it fulfil the strength requirements by achieving the target strength M40 grade.
4. With the addition of fibres in an incremental order of 0.5% of powder content to the optimum mix of SCGPC2, the fresh properties are reduced and at 1.5% maximum strength in flexure and splitting has been achieved.
5. The mix (SCGPFRC2) having 1.5% of fibre content showed better compressive strength than the remaining SCGPFRC mixes, but less compressive strength than that of SCC2.
6. With the introduction of fibres into the concrete the flexural strength SCGPFRC is significantly increased when compared to SCGPC mixes. And SCGPFRC shows approximately same flexural strength that of SCC2 and CC1 mix. It can be inferred that at a fibre content of 1.5% (SCGPFRC2) the value of flexural strength was found to be increased by 15.73% when compared to SCGPC2 mix.
7. With the introduction of fibres into the concrete the splitting strength is significantly increased when compared to SCGPC2 mix. And approximately equal to SCC and CC mixes. It can be inferred that at a fibre content of 1.5% (SCGPFRC2) the value of split tensile strength is found to be increased by 25.88% when compared to SCGPC2 mix and 6% when compared to CC mix.
8. As we observed that SCGPFRC shows good flexural and tensile strength though the strength slightly less than the CC1 and SSC2 but in terms of environmental and economical point of view it can concluded as a good material.
9. With the addition of Alkaline activators, the setting time was reduced for SCGPC and SCGPFRC mixes.

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