International Journal of Engineering &Technology, 7 (3.12) (2018) 337-340

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Strength and Durability Characteristics of Steel Fibre Reinforced Geopolymer Concrete

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Abstract

Owing to the upturn inrepair and rehabilitation of structures that undergoes deterioration even before its intended life span; it has become necessary to study the durability properties of the structures. This paper deals with an experimental approach on the strength and durability characteristics of Geopolymer Concrete and Steel Fibre Reinforced Geopolymer Concrete with varying proportions of Fly ash, Waste Glass powder and GGBS (Ground Granulated Blast furnace Slag) as base material cured at room temperature. Sodium hydroxide (14M) and Sodium silicate are used as alkali activators. Steel fibres of length 60mm, 0.75mm diameter are used in two different proportions (0.25% and 0.50%). The results are compared with that of the Portland cement based plain and fibre reinforced control concrete. The durability characteristic involved in this study is Sorptivity test. The results reveal that Steel fibre reinforced Geopolymer concrete procures surpassing characteristics than that of Geopolymer concrete which in turn possess superior characteristics than that of conventional concrete.

Keywords: *Compressive strength, Sorptivity, Fly ash, Waste glass powder, GGBS, Steel fibres*.

1. Introduction

The method of manufacturing the Portland cement which is the binding material in conventional concrete releases about 1 tonne of CO_2 to the atmosphere for a unit production [1]. Moreover, the conventional concrete structures under particular environmental surroundings are not as much durable [2]. As an alternative, Davidovits [3] set forth the Geopolymer technology. This involves the alkali activation of materials rich in silica and alumina resulting in the formation of inorganic alumina silicate polymers [4]. This approach is environmental friendly and has economical benefits as it involves the usage of industrial by-products [5]. In case of conventional concrete, strengthening is achieved by the hydration of conventional cement and in the case of Geopolymer concrete; the polymerisation process strengthens the structure [6].
The concept of Fibre reinforced concrete has been advanced in the recent years. The incorporation of fibres in the concrete revamps its tensile, flexural and post cracking ductility. Of all, steel fibres are found to increase the tensile and flexural strength, toughness and ductility of concrete significantly. Ganesan et al [7], studied the durability characteristics of plain and fibre reinforced geopolymer concrete and stated that the GPC and SFRGPC specimens attained superior qualities than that of CC specimens. Faiz Uddin Ahmed Shaikh and Anwar Hosan [8], carried out an investigation experimentally on mechanical properties of fibre reinforced geopolymer concrete with steel fibers at elevated temperatures using Na and K based alkaline activators and concluded that both GPC and SFRGPC retained their original mechanical properties upto 400^{o}C.

The most important phenomenon during the life span of a concrete structure is its durability.
The concrete structures should be capable of withstanding the physical, chemical and mechanical conditions which they are ought to come across during their life period. There are numerous studies being carried out to determine the durability properties of the concrete structures. The durability tests on GPC(Geopolymer Concrete) and SFRGPC (Steel Fibre Reinforced Geopolymer Concrete) such as chloride ion penetrability test, absorption characteristics, resistance to acid attack, resistance to marine attack under alternate wetting and drying conditions have been carried out so far and it has been outlined that they surpass their characteristics when compared to that of CC (Conventional Concrete) [4], [5], [9], and [10].
Since room cured geopolymer concrete with fly ash shows slow strength development, it has become mandatory to make use of alternatives to make it more suitable for practical applications. Such alternatives include the use of GGBS as a partial replacement of fly ash. Partha Sarathi Deb et al [11] studied the shrinkage and mechanical properties of GPC blended with GGBS and stated that the properties improved with the increase in the percentage of GGBS cured at room temperature. Mostafa Vafaei and Ali Allahverdi [12] carried out an experimental investigation on the feasibility of waste glass powder based GPC along with CAC (Calcium Aluminate Cement) and outlined that it resulted in the significant improvement of material and microstructural properties.
This paper involves the study of strength and durability characteristics of GPC and SFRGPC cured at room temperature. A combination of Fly ash, Waste Glass powder and GGBS at varying proportions is used as base material. The results are then compared with that of plain and fibre reinforced CC.

2. Experimental Program

2.1 Materials

Low calcium Class F Fly ash of particle size less than 90μ, Waste Glass Powder of particle size less than 70μ and GGBS of particle size less than 70μ were used as the base material of GPC and SFRGPC whereas Ordinary Portland Cement (OPC) 43 grade conforming to IS 8112 (ASTM Type 1) was used as the base material for CC and SFRC. The properties of the base materials are presented in Table 1. The alkaline activator used is a combination of sodium hydroxide and sodium silicate in the ratio of 1:2. Sodium hydroxide with 98-99% purity in the form of flakes was diluted in water to form a solution of 14M concentration. Sodium silicate solution with the modulus ratio of SiO_2 to Na_2O was 2.61 (SiO_2 = 30% and Na_2O =11.5% and water = 58.5%). Steel fibres of 60mm length and 0.75mm diameter were used in the proportions of 0.25% and 0.50%. Coarse aggregates of 20mm with the specific gravity of 2.73 and locally available river sand of fineness modulus 3.78 and specific gravity 2.71 were used in this investigation. A naphthalene based super plasticizer was added to the mix which improved its workability.

2.2 Mix design

M30mix of GPC and CC were designed as per the guidelines given by Rangan [1] and IS 10262-2009 [13] resp. SFRGPC were designed with varying proportions of steel fibres such as 0.25% (19.32 kg/m^3) and 0.50% (38.64 kg/m^3). The percentage of GP (Glass Powder) was kept constant at 10% and the percentage of GGBS varied by 5%, 10%, 15% and 20% for four different mixes. The percentage of fly ash thus varied accordingly. The mix proportions of CC and GPC, SFRC and SFRGPC are listed in Table 2 and Table 3 respectively.

Table 1: Properties of base materials

Formula	Concentration (%)			
	Cement	Fly Ash	GP	GGBS
CaO	69.00	1.45	8.83	45.02
SiO_2	24.91	58.62	75.31	28.86
Al_2O_3	5.85	29.39	1.11	12.23
Fe_2O_3	0.20	5.28	-	0.54
MgO	0.04	0.65	2.80	-
Na_2O	-	0.13	10.77	0.32
K_2O	-	1.55	0.41	0.40
SO_3	-	0.21	-	3.60
P_2O_5	-	0.58	-	0.06
TiO_2	-	1.80	-	0.45
Specific gravity	3.17	2.6	2.5	2.81
Loss on Ignition	-	0.70	0.32	2.37

Table 2: Mix proportions in kg/m^3

Mix	Cement	Fly ash	GP	GGBS	NaOH	Na_2SiO_3	Coarse Aggregate	Fine Aggregate	SP	Water
CC	380	-	-	-	-	-	1160	670	15	171
GPC1	-	323	38	19	57	114	1160	670	15	-
GPC2	-	304	38	38	57	114	1160	670	15	-
GPC3	-	285	38	57	57	114	1160	670	15	-
GPC4	-	266	38	76	57	114	1160	670	15	-

2.3 Preparation of Specimens

Three cubes of 100mmx100mmx100mm and cylinder of 100mmx50mm were prepared for each mix. The alkaline solutions were prepared 24hours prior casting. Fine aggregates and the base materials were first mixed uniformly at surface dry conditions. Later coarse aggregates were added and mixed thoroughly. The alkaline solutions were then added to the mix. For SFRC and SFRGPC mixes, steel fibres were randomly distributed to the mix. After casting, the GPC specimens were kept at room temperature and the CC specimens were immersed in water for curing.

Table 3: Mix proportions in kg/m^3

Mix	Steel fibres (%)	Cement	Fly ash	GP	GGBS	NaOH	Na_2SiO_3	CA	FA	SP	Water
SFRC 1-1	0.25	380	-	-	-	-	-	1160	670	15	171
SFRC 1-2	0.50	380	-	-	-	-	-	1160	670	15	171
SFRGPC 1-1	0.25	-	323	38	19	57	114	1160	670	15	-
SFRGPC 1-2	0.50	-	323	38	19	57	114	1160	670	15	-
SFRGPC 2-1	0.25	-	304	38	38	57	114	1160	670	15	-
SFRGPC 2-2	0.50	-	304	38	38	57	114	1160	670	15	-
SFRGPC 3-1	0.25	-	285	38	57	57	114	1160	670	15	-
SFRGPC 3-2	0.50	-	285	38	57	57	114	1160	670	15	-
SFRGPC 4-1	0.25	-	266	38	76	57	114	1160	670	15	-
SFRGPC 4-2	0.50	-	266	38	76	57	114	1160	670	15	-

3. Results and Discussion

3.1 Compressive Strength Test

It is the most common test carried out to determine the structural properties of concrete. For this test, cubes of size 100mmx100mmx100mm were cast and cured at room temperature before being tested. The test was done in a CTM of 3000 kN capacity after 28 and 56 days of curing as per IS 516: 1959 under normal room temperature. The results are shown in Table 4.
The compressive strength of the mixes GPC 1 and GPC 2 was found to be lesser than that of CC.

This is because of the less percentage of GGBS in the mix. Whereas, the higher compressive strength of GPC 3 and GPC 4 denotes that increase in addition of GGBS (≥ 15%) increased the strength abruptly. With the addition of fibres SFRC1-1 and SFRC 1-2 showed better results than CC.

Like in the previous case, mixes with < 15% GGBS namely SFRGPC 1-1, SFRGPC 1-2, SFRGPC 2-1 and SFRGPC 2-2 showed lesser compressive strength than SFRC 1-1 and SFRC 1-2. However, SFRGPC 3-1, SFRGPC 3-2, SFRGPC 4-1 and SFRGPC 4-2 showed significant increase in compressive strength when compared with the other mixes. This may be due to the fact that the fibres fill the voids in concrete thereby increasing its strength. Maximum average compressive strength of 47.27 MPa was achieved for SFRGPC 4-2 at 56 days.

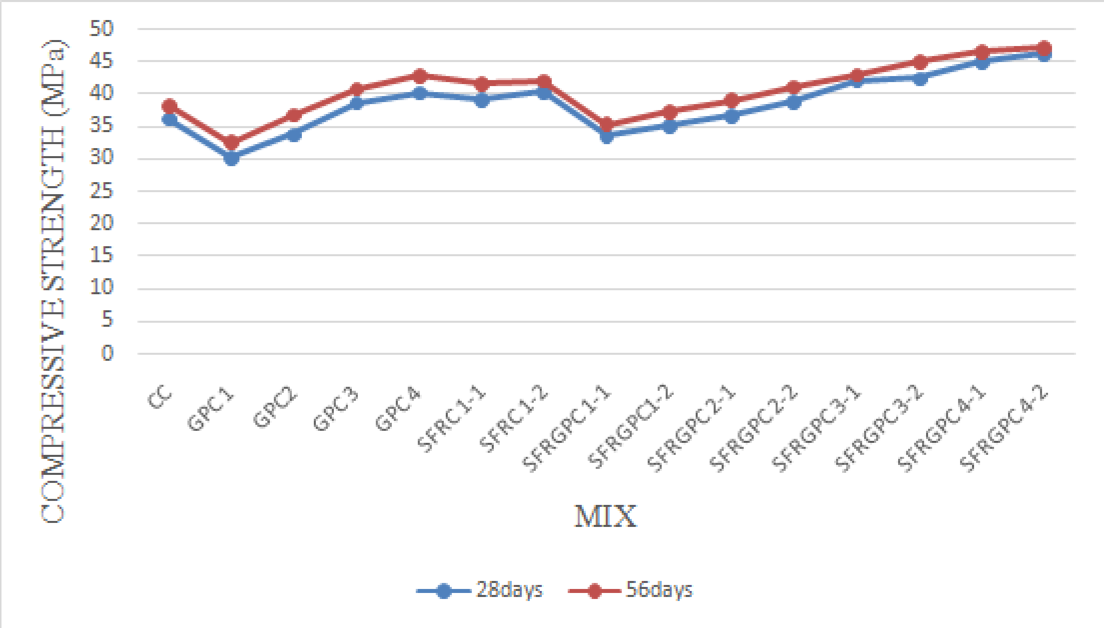

Fig. 1: Compressive strength test results

Table 4: Compressive strength test results

Mix	Compressive strength, MPa	
	28days	56days
CC	36.23	38.12
GPC 1	30.21	32.43
GPC 2	33.8	35.67
GPC 3	38.7	40.72
GPC 4	40.23	42.78
SFRC 1-1	39.2	41.53
SFRC 1-2	40.32	41.95
SFRGPC 1-1	33.62	35.33
SFRGPC 1-2	35.13	37.24
SFRGPC 2-1	36.77	39.02
SFRGPC 2-2	38.8	41.05
SFRGPC 3-1	41.09	42.88
SFRGPC 3-2	42.46	41.96
SFRGPC 4-1	45.08	46.53
SFRGPC 4-2	46.32	47.27

3.2 Sorptivity Test

The test based on Darcy's law of unsaturated flow determines the ability of concrete to absorb water by capillary action. Here, cylinders of size 100mmx50mm were cast and after its curing period, the specimens were kept in oven at 50 ±2^{0} C for 24 hours. The specimens were then removed and cooled at room temperature before being tested. The specimens were immersed in water to a depth of 5to10mm from the bottom with all the three sides sealed using a plastic tape. The initial dry weight of the sample was taken as W. The gain in weight of the specimens at 30mins, 60mins, 90mins and 120mins after being immersed in water were taken.

The results show that the rate of absorption is less in GPC and SFRGPC when compared to CC and SFRC mixes.This may be due to better microstructural properties of GPC and SFRGPC. Adiition of fibres in less proportion decreased the sorptivity of both CC and GPC thus making it more durable. The fibres fill the voids of concrete as the concrete flows through the fibres and making the concrete denser. Thus, less amount of water penetrates through these mixes and provide better microstructural properties.

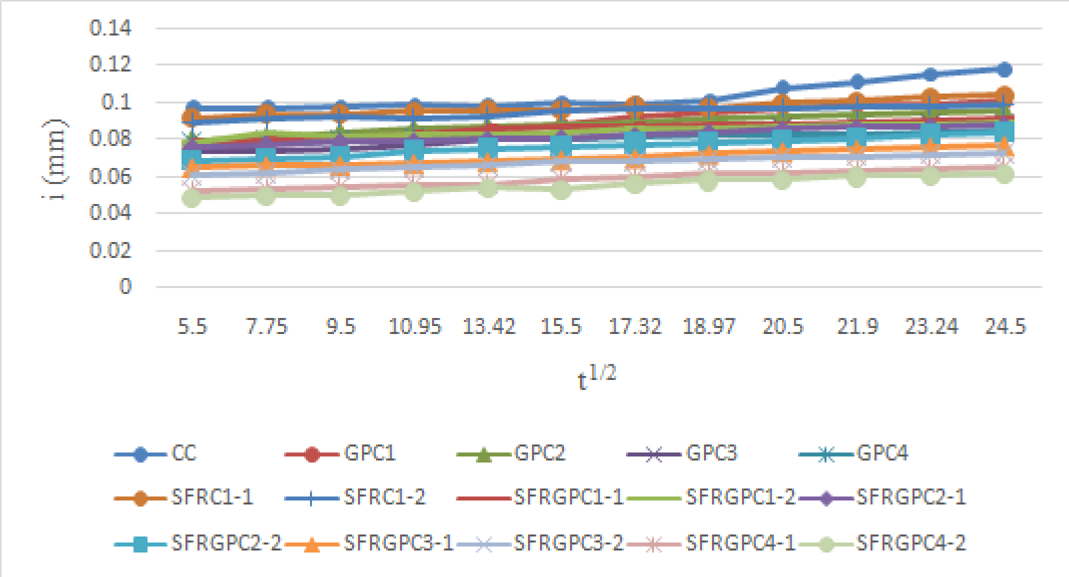

Fig. 2: Sorptivity Test Results

4. Conclusions

In this study, GPC and SFRGPC specimens were prepared using different proportions of Fly ash, GP and GGBS. The alkaline solutions used were NaOH (14M) and $Na_2Si_2O_3$. The specimens were cured at room temperature for 28 and 56 days and tested for compressive strength and sorptivity. From the results obtained, the following conclusions were made:

1. The M30mixes of GPC and SFRGPC were compared with that of CC and SFRC. It was seen that with the addition of GGBS increased the strength and decreased the period of binding at room temperature. The binding period for GPC1 and GPC2 took nearly 3days while for GPC3 and GPC4 the binding period was decreased to 24hours.
2. The compressive strength test results show that SFRGPC and GPC have better strength than SFRC and CC respectively.
3. The sorptivity tests reveal that curve for GPC and SFRGPC were less linear when compared to CC and SFRC.

It can be concluded that GPC and SFRGPC has very low rate of absorption than CC and SFRC. The addition of fibers further lowered the rate of absorption.

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