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A Study on Performance Behavior of Fibre (Steel) Reinforced Geopolymer Concrete Composites

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ABSTRACT: Due to growing environmental concerns of the cement industry, alternative cement technologies have become an area of increasing interest. It is now believed that new binders are indispensable for enhanced environmental and durability performance. On the other hand, already huge volumes of fly ash are generated around the world, most of the fly ash is not effectively used, and a large part of it is disposed in landfills. As the need for power increases, the volume of fly ash would increase. Both the above issues are to be addressed. An effort in this regard is the development of geopolymer concrete, synthesized from the materials of geological origin or by product materials such as fly ash, which are rich in silicon and aluminum. So far, the main thrust of research involving geopolymer concrete has been aimed at characterizing the mechanical properties of geopolymer concrete. Majority of these studies are limited to geopolymer concrete cured at elevated temperature. Practical applications of geopolymer concrete are affected by this curing method. This method would prevent the geopolymer concrete to be applied in a cast in situ concrete work. Therefore this research is focused on the utilization of ambient temperature to cure the geopolymer concrete.

INTRODUCTION: studies to investigate the effect of addition of fibres on the strength characteristics of geopolymer concrete are limited. Hence, there exists a technical knowledge gap in this area. Hence, an attempt has been made through the present investigation to conduct an experimental programme to study the effect of addition of fibres such as steel, polypropylene and glass on the strength and other engineering properties of geopolymer concrete composites. Despite the engineering characteristics of the geopolymer concrete, the performance of fibre reinforced geopolymer concrete composites under impact loading is not still well known.

Hence aneffort has been made in this investigation to study the performance effectiveness of plain and fibre reinforced geopolymer concrete under impact load. In addition to that, the information on the flexural behavior of fibre added geopolymer reinforced concrete beams is also not available in the past literatures. And flexural behaviour study is vital for the use of fibre reinforced geopolymer concrete for structural applications. Therefore, extensive experimental and analytical investigations were carried out, to study the flexural behavior of plain and fibre added geopolymer composite RC beams.

on the fresh and hardened properties such as workability, density, compressive strength, split tensile strength, flexural strength, impact strength, modulus of elasticity, water absorption and sorptivity of geopolymer concrete composites.

Based on the investigations conducted for the above parts, the following conclusions are drawn:

Geopolymer concrete did not harden immediately at room temperature as in conventional concrete. Geopolymer concrete specimens took a minimum period of 3 days for complete setting without leaving a nail impression on the hardened surface. These two observations are considered as drawbacks of this concrete to be used for practical applications. Limitations of GPC mix was eliminated by replacing 10% of fly ash by OPC which resulted in Geopolymer concrete composite. Unlike GPC, geopolymer concrete composite hardens immediately and starts gaining its strength within a day without any necessity of heat curing.

- Addition of steel fibres in GPCC resulted in improvement of compressive strength, split tensile strength, flexural strength,

- impact strength, modulus of elasticity, ductility and energy absorption capacity. Geopolymer concrete composite specimens reinforced with steel fibres leads to lower water absorption and sorptivity values compared to control GPCC specimens. The average density of GPCC increases with the increase in the volume fraction of steel fibres.
- Even though the addition of polypropylene fibres in GPCC did not show any significant improvement in the compressive strength, but the split tensile and flexural strengths were improved due to the addition of fibres. Inclusion of polypropylene fibres considerably improved the ability of concrete to absorb kinetic energy and hence the impact resistance of PFRGPCC is significantly very high.
- In case of GFRGPCC, the addition of 0.01% and 0.02% of glass fibres did not improve the compressive strength, split tensile strength, flexural strength and modulus of elasticity while the GFRGPCC specimens with 0.03% of glass fibres improves theabove mentioned properties. The impact resistance of GFRGPCC specimen is comparatively lower than SFRGPCC and PFRGPCC specimens.
- In case of SFRGPCC beams, the first crack load and the ultimate load increased as the volume fraction of steel fibres increases. The gain in ultimate load carrying capacity is more significant in the case of SFRGPCC beams due to the addition of steel fibres. For steel fibre reinforced geopolymer concrete composite beams, as the fibre content increases, the ductility also increases. The maximum value of the ductility factor is obtained for the beam with a fibre volume fraction of 0.5%. Due to the addition of polypropylene fibres, the increase in ultimate load is very marginal as compared to control GPCC beam. Beams reinforced with polypropylene fibres did not show any improvement in ductility when compared with control GPCC beam. In case of GFRGPCC beams, the increase in ultimate load carrying capacity was not that much significant when compared to control GPCC beam. In the case of glass fibre reinforced geopolymer concrete beams, ductility factor increases for all the volume fractions, however the maximum ductility was observed for the beam with a volume fraction of 0.01%.
- The failure mechanism of GPCC beam and fibre reinforced GPCC beams were modeled quite well using finite element software ANSYS and the failure loads predicted were found to be very close to the failure load recorded during experimental testing. The analytical models developed using ANSYS have shown to provide accurate prediction of the load-deflection behaviour of GPCC and fibre reinforced GPCC beams.

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Addition of steel fibres in GPCC resulted in improvement of compressive strength, split tensile strength, flexural strength, impact strength, modulus of elasticity, ductility and energy absorption capacity.

Geopolymer concrete composite specimens reinforced with steel fibres leads to lower water absorption and sorptivity values compared to control GPCC specimens. The average density of GPCC increases with the increase in the volume fraction of steel fibres.

Even though the addition of polypropylene fibres in GPCC did not show any significant improvement in the compressive strength, but the split tensile and flexural strengths were improved due to the addition of fibres. Inclusion of polypropylene fibres considerably improved the ability of concrete to absorb kinetic energy and hence the impact resistance of PFRGPCC is significantly very high.

In case of GFRGPCC, the addition of 0.01% and 0.02% of glass fibres did not improve the compressive strength, split tensile strength, flexural strength and modulus of elasticity while the GFRGPCC specimens with 0.03% of glass fibres improves theabove mentioned properties. The impact resistance of GFRGPCC specimen is comparatively lower than SFRGPCC and PFRGPCC specimens.

In case of SFRGPCC beams, the first crack load and the ultimate load increased as the volume fraction of steel fibres increases. The gain in ultimate load carrying capacity is more significant in the case of SFRGPCC beams due to the addition of steel fibres. For steel fibre reinforced geopolymer concrete composite beams, as the fibre content increases, the ductility also increases. The maximum value of the ductility factor is obtained for the beam with a fibre volume fraction of 0.5%. Due to the addition of polypropylene fibres, the increase in ultimate load is very marginal as compared to control GPCC beam. Beams reinforced with polypropylene fibres did not show any improvement in ductility when compared with control GPCC beam. In case of GFRGPCC beams, the increase in ultimate load carrying capacity was not that much significant when compared to control GPCC beam. In the case of glass fibre reinforced geopolymer concrete beams, ductility factor increases for all the volume fractions, however the maximum ductility was observed for the beam with a volume fraction of 0.01%.

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Concrete is the most commonly used construction material. Customarily, concrete is produced by using the Ordinary Portland Cement as the binder. However, the manufacturing of the Portland Cement is an energy intensive process and releases a very large amount of green house gas to atmosphere. Production of one ton of Portland cement requires about 2.8 tons of raw materials, including fuel and other materials and hence it is well known that cement production depletes significant amount of natural resources. As a result of de-carbonation of lime, manufacturing of one ton of cement generates about one ton of carbon dioxide. Nowadays, there is a big concern about the development of alternative materials to Portland cement. Therefore, there are efforts to develop the other form of cementitious materials for producing concrete.

In order to address the above said issues, several materials were proposed to replace the function of cement in concrete. Waste materials that contain silica and alumina were applied to replace some portion of cement in concrete. Fly ash, Rice husk ash, silica fume and ground granulated blast furnace slag are some of the examples of cement replacement materials that are commonly used. The binder product resulted from pozzolanic reaction

that occurred between cement replacement materials and hydration paste has significantly improved conventional concrete properties. However, these materials can only replace up to certain percentages of portion of cement in concrete.

In the year 2002, high volume fly ash concrete has been developed by Malhotra that utilized fly ash to replace cement up to 60% without reducing concrete performance. Percentage replacement of cement above 60% would not provide any improvement to the concrete performance, therefore new binder material that could fully replace cement portion in concrete is necessary to create superior and more environmentally friendly concrete.

In 1978, a new material was introduced by Davidovits, which can be used as an alternative binder to cement. This material was named as geopolymer for its reaction between alkaline liquid and geological based source material. Followed by this, in the year 2002, Hardjito and Rangan carried out research on fly ash based geopolymer concrete and studied the engineering properties by applying steam curing in order to accelerate the polymerization process in this geopolymer concrete,

The term geopolymer was coined by Davidovits in 1978 to represent a broad range of materials characterized by chains or networks of inorganic molecules. These geopolymers rely on thermally activated natural materials (e.g., kaolinite clay) or industrial byproducts (e.g., fly ash or slag) to provide a source of silicon (Si) and alumina (Al), which is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and networks to create the hardened binder. Such systems are often referred to as alkali-activated cements or inorganic polymer cements.

Geopolymer is an inorganic polymer similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline. The polymerization process involves substantially a fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. The geopolymerisation reaction is exothermic and takes place under atmospheric pressure at temperatures below 100°C.

The exact mechanism by which geopolymer setting and hardening occurs is not yet fully understood. However, the most proposed mechanisms for the geopolymerization includes the following four stages that proceed in parallel and thus, it is impossible to be distinguished: (i) Dissolution of Si and Al from the solid aluminosilicate materials in the strongly alkaline aqueous solution, (ii) Formation of oligomers species (geopolymers precursors) consisting of polymeric bonds of Si-O-Si and/or Si-O-Al type, (iii) Poly-condensation of the oligomers to form a three-dimensional aluminosilicate framework and (iv) Bonding of the unreacted solid particles and filler materials into the geopolymeric framework and hardening of the whole system into a final solid polymeric structure.

REVIEW OF LITERATURE

Monita Olivia and Hamid R. Nikraz (2011) investigated the strength development, water absorption and water permeability of low calcium fly ash geopolymer concrete with variations of water/binder ratio, aggregate/binder ratio, aggregate grading, and alkaline/fly ash ratio. The results indicated that the strength of fly ash geopolymer concrete was increased by reducing the water/binder and aggregate/binder ratios and the water absorption of low calcium fly ash geopolymer was improved by decreasing the water/binder ratio, increasing the fly ash content, and using a well-graded aggregate. It was also observed that there was no significant change in water permeability coefficient for the geopolymer with different parameters. The test data indicates that a good quality of low calcium fly ash geopolymer concrete can be produced with appropriate parameterisation and mix design.

The effects of various factors such as the age of concrete, curing time, curing temperature, quantity of superplasticizer, the rest period prior to curing, and the water content of the mix on the properties of fly ash based geopolymer concrete, especially the compressive strength have been studied by Djwantoro Hardjito et al (2004). The test results show that the compressive strength of geopolymer concrete does not vary with age, and curing the concrete specimens at higher temperature and longer curing period will result in higher compressive strength. Furthermore, the commercially available Naphthalene-based superplasticizer improves the workability of fresh geopolymer concrete. The start of curing of geopolymer concrete at elevated temperatures can be delayed at least up to 60 minutes without significant effect on the compressive strength. The test data also show that the water content in the concrete mix plays an important role.

Fareed Ahmed (2011) documented the assessment of the compressive strength and workability characteristics of low-calcium fly ash based self compacting geopolymer concrete. The essential workability properties of the freshly prepared self-compacting geopolymer concrete such as filling ability, passing ability and segregation resistance were evaluated by using Slump flow, V-funnel, L-box and J-ring test methods. The fundamental requirements of high flow ability and segregation resistance as specified by EFNARC guidelines on self compacting concrete were satisfied. In addition, compressive strength was determined and the test results were included. The effect of extra water, curing time and curing temperature on the compressive strength of self-compacting geopolymer concrete was also reported. The test results show that extra water in the concrete mix plays a significant role. Longer curing time improves the geopolymerisation process resulting in13 higher compressive strength. The compressive strength was highest when the specimens were cured for a period of 96 hours; however, the increase in strength after 48 hours was not significant. Concrete specimens cured at 70°C produced the highest compressive strength as compared tospecimens cured at 60°C, 80°C and 90°C.

The mechanical properties of fly ash based geopolymer concrete were studied by Ivan Diaz- Loya et al (2011).Experimentally measured values of the static elastic modulus, Poisson's ratio, compressive strength and flexural strength of geopolymer concrete specimens made from 25 fly ash stockpiles from different sources were recorded and analyzed. The results were studied using regression analysis to identify tendencies and correlations within the mechanical properties of geopolymer concrete. It was found that the mechanical behavior of geopolymer concrete is similar to that of ordinary Portland cement concrete.

The durability of the fly ash based geopolymer concrete prepared with sodium silicate and sodium hydroxide as activators was studied by Sathia et al (2008). The concretes were prepared with varying fly ash content of 350, 450 & 550 kg/m^3 and activator solution to fly ash ratio of 0.4 and 0.5. Compressive strength in the range of 10-60 MPa was obtained. The performance of these concretes in aggressive environments was also studied, using tests on absorption, acid resistance and potential. Results indicated that the water absorption decreased with an increase in the strength of the concrete and the fly ash content. All geopolymer concretes showed excellent resistance to acid attack (3% H_2SO_4) compared to the normal concrete.

Ravindra N. Thakur and Somnath Ghosh (2009) reported results of an experimental study on development of compressive strength and microstructure of geopolymer paste and mortar specimens prepared by thermal activation of Indian fly ash with sodium hydroxide and sodium silicate solution. The effect of main synthesis parameters such as alkali content, silica content , water to geopolymer solid ratio and sand to fly ash ratio of geopolymer mixture and processing parameters such as curing time and curing temperature on development of compressive strength and microstructure of fly ash based geopolymer paste and mortar were studied. The compressive strength of 48.20 MPa was obtained for geopolymer mixture cured at 85°C for 48 hours with alkali content (Na_2O/Al_2O_3) of 0.62 and silica content (SiO_2/Al_2O_3) of 4.0. The mineralogical and microstructure studies on hardened geopolymer performed by means Scanning electron microscope and X-ray diffraction, showed formation of a new amorphous alumino-silicate phase such as hydroxysodalite and herschelite, which influenced development of compressive strength.

The effects of various parameters on the properties of geopolymer concrete have been presented by Djwantoro Hardjito et al (2004). Based on the experimental investigations, they found that higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength of geopolymer concrete and higher the ratio of sodium silicate to sodium hydroxide liquid ratio by mass, higher is the compressive strength of geopolymer concrete. It was also reported that, as the curing temperature (in the range of 30 to 90°C) increases, the compressive strength of geopolymer concrete also increases. Longer curing time, in the range of 6 to 96 hours (4 days), produces larger compressive strength of geopolymer concrete. However, the increase in strength beyond 48 hours was not significant. The addition of high range water reducing admixture, upto approximately 2% of fly ash by mass, improved the workability of fresh geopolymer concrete with very little effect on the compressive strength of hardened concrete. The rest period between casting of specimens and the commencement of curing up to 60 minutes has no effect on the compressive strength of geopolymer concrete. It is also reported that the fresh geopolymer.

Concrete is easily handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength. As the ratio of water to geopolymer solids by mass increases, the compressive strength of the concrete decreases. The compressive strength of geopolymer concrete cured for 24 hours at 60°C does not depend on the age. The geopolymer concrete undergoes very little drying shrinkage and low creep. The resistance of geopolymer concrete against sodium sulfate is excellent. The applications of geopolymer concrete and future research needs are also identified.

Olivia et al (2008) presented a detailed experimental investigation on water penetrability properties, namely water absorption, volume of permeable voids, permeability and sorptivity of low calcium fly ash geopolymer concrete. In this research, geopolymer concrete is made from fly ash with a combination of sodium hydroxide and sodium silicate as alkaline activator. Seven mixes were cast in 100 x 200 mm cylinders and cured for 24 hours at 60°C in the steam curing chamber. After 28 days, the cylinders were cut into slices for permeability, sorptivity and volume of permeable voids tests. In addition, a microstructure characteristic of geopolymer concrete was studied using Scanning Electron Microscopy. Results indicate that geopolymer concrete has low water absorption, volume of permeable voids and sorptivity. It is found that the geopolymer concrete could be classified as a concrete with an average quality according to water permeability value. Moreover, a low water/binder ratio and a well graded aggregate are some important factors to achieve low water penetrability of geopolymer concrete.

The effect of curing conditions on the compressive strength of self compacting geopolymer concrete prepared by using fly ash as base material and combination of sodium hydroxide and sodium silicate as alkaline activator has been studied by Fareed Ahmed Memon et al (2011). The experiments were conducted by varying the curing time and curing Temperature in the range of 24-96 hours and 60-90°C respectively. The essential workability properties of freshly prepared Self compacting geopolymer concrete such as filling ability, passing ability and segregation resistance were evaluated by using Slump flow, V-funnel, L-box and J-ring test methods. The fundamental requirements of high flow ability and resistance to segregation as specified by guidelines on Self compacting Concrete by EFNARC were satisfied. Test results indicate that longer curing time and curing the concrete specimens at higher temperatures result in higher compressive strength. There was increase in compressive strength with the increase in curing time. However increase in compressive strength after 48 hours was not significant. Concrete specimens cured at 70°C produced the highest compressive strength as compared to specimens cured at 60°C, 80°C and 90°C.

The results of an experimental investigation on the durability of fly ash based Geopolymer concretes exposed to 10% sulphuric acid solutions for up to 8 weeks have been presented by Song et al (2005). A class F fly ash based Geopolymer concrete was initially cured for 24 hours at either 23°C or 70°C. The compressive strength of 50 mm cubes at an age of 28 days ranged from 53 MPa to 62 MPa. After immersion in a 10% sulphuric acid having a fixed ratio of acid volume to specimen surface area of 8 ml/cm^2, samples were tested at 7, 28, and 56 days. The mass loss, reduction of compressive strength and the residual alkalinity were determined on the basis of modified ASTM C267 tests. The results confirmed that geopolymer concrete is highly resistant to sulphuric acid in terms of a very low mass loss, less than 3%. It was also observed that, geopolymer cubes were structurally intact and still had substantial load capacity even though the entire section had been neutralized by sulphuric acid.

From the detailed experimental investigations on fly ash based Geopolymer concrete (GPC) given in chapter 3 the following two limitations have been observed namely delay in setting time and necessity of heat curing to gain strength at early ages. These limitations are considered as the drawbacks of this concrete to be used for practical applications. In order to overcome these two limitations of GPC mix, 10% of fly ash in the geopolymer concrete was replaced by Ordinary Portland Cement (OPC) and the mix design was altered accordingly which results in Geopolymer Concrete Composites (GPCC). This chapter describes the mix proportion and preparation of Geopolymer concrete composites. The fresh and hardened properties such as workability, density, compressive strength, split tensile strength and flexural strength of Geopolymer Concrete Composites (GPCC) are presented in this chapter. A comparison on the strength and behaviour between GPC and GPCC is also discussed.

Preparation of Alkaline Activator Solution.

A combination of Sodium hydroxide solution of 12 molarity and sodium silicate solution was used as alkaline activator solution for geopolymerisation. To prepare sodium hydroxide solution of 12 molarity (12 M), 480 g (12 x 40 i.e, molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup to one liter. The mass of NaOH solids is equal to 354.45 g per kg of NaOH solution.

STEEL FIBRE REINFORCED GEOPOLYMER CONCRETECOMPOSITES.

The effect of addition of steel fibres on the strength characteristics of geopolymer concrete composites. The fresh and hardened properties such as workability, density, compressive strength, split tensile strength, flexural strength, impact strength, modulus of elasticity, water absorption and sorptivity of Steel Fibre Reinforced Geopolymer Concrete Composites (SFRGPCC) is presented .A comparison of the strength and durability aspects between GPCC and SFRGPCC is also discussed.

The following parameters were considered in this experimental investigation:

(a) Volume fraction of steel fibers: 0% , 0.25% , 0.5% and 0.75%

(b) Age of concrete at time of testing: 1day, 3days, 7 days and 28 days

Materials Used

Fly ash, Cement, Fine Aggregate, Coarse Aggregate, Sodium Hydroxide ,Sodium Silicate ,Super plasticizer,Water,Steel fiber.

Mix Proportion of SFRGGPCC.

Details of mix proportions of SFRGPCC

Mix ID	Fly Ash	OPC	FA	CA	NaOH Solution	Na_2SiO_3 Solution	Extra Water	SP	Steel fibres
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
GPCC	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	--
S0.25	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	19.63
S0.5	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	39.25
S0.75	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	58.88

Curing of SFRGPCC Specimens

SFRGPCC specimens were removed from the moulds immediately after 24 hours since they set in a similar fashion as that of conventional concrete. All the specimens were left at room temperature in ambient curing till the date of testing.

DENSITY

Density was calculated by measuring the weight of cube specimens before subjecting them to compression test.

COMPRESSIVE STRENGTH

Totally thirty six cubes of size 150 mm x 150 mm x 150 mm were cast to study the compressive strength of SFRGPCC. Standard cast iron moulds were used for casting the test specimens.

Compressive strength of SFRGPCC specimens

Spec.	Avg. Ultimate load in kN	Avg. CompressiveStrength MPa
S_0 A_1	175.2	7.79
$S_{0.25}$ A_1	115.7	5.14
$S_{0.50}$ A_1	116.0	5.16
$S_{0.75}$ A_1	162.5	7.22
S_0 A_3	279.6	12.43
$S_{0.25}$ A_3	228.3	10.15
$S_{0.5}$ A_3	345.7	15.37
$S_{0.75}$ A_3	271.7	12.07
S_0 A_7	446.1	19.83
$S_{0.25}$ A_7	466.3	20.72
$S_{0.50}$ A_7	514.1	22.85
$S_{0.75}$ A_7	563.2	25.03
S_0 A_{28}	861.4	38.28
$S_{0.25}$ A_{28}	955.0	42.44
$S_{0.50}$ A_{28}	969.6	43.09
$S_{0.75}$ A_{28}	1074.7	47.76

Based on the test results, using least square regression analysis, an equation for predicting the 28 days compressive strength of SFRGPCC in terms of the compressive strength of plain GPCC and percentage volume fraction of fibres (V_f) is obtained and given in Equation.

f_{cs}= 28 days compressive strength of SFRGPCC

f_c= 28 days compressive strength of GPCC without fibres V_f = Percentage volume fraction of steel fibres.

The compressive strength of SFRGPCC predicted from the proposed analytical equation was compared with the experimental results as shown in Table. It was found that a good correlation is obtained between the experimental results and those got from the proposed equation. It can be seen that the proposed equation

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predicts the compressive strength of SFRGPCC well with good accuracy.

Comparison of experimental and analytical results

Volume fraction of fibres %	Compressive strength MPa		Analytical/ Experimental
	Experimental	Analytical	
0	38.28	38.28	1.00
	45.24	41.30	0.91
0.25	40.62	41.30	1.02
	41.47	41.30	1.00
	40.54	44.31	1.09
0.5	46.84	44.31	0.95
	41.89	44.31	1.06
	47.42	47.33	1.00
0.75	48.89	47.33	0.97
	46.98	47.33	1.01

SPLIT TENSILE STRENGTH

Cylinders measuring a diameter of 150 mm and 300 mm length were cast to evaluate the split tensile strength of SFRGPCC. The effect of various factors such as addition of steel fibres in different volume fractions and age of concrete at the time of testing on the split tensile strength of geopolymer concrete composite has been investigated and presented.

Split tensile strength of SFRGPCC specimens

Spec.	Avg. Ultimate load in kN	Avg. Split tensile Strength MPa
^{S}0 ^{A}7	86.4	1.22
^{S}0.25 ^{A}7	101.0	1.43
^{S}0.50 ^{A}7	116.3	1.65
^{S}0.75 ^{A}7	148.7	2.10
^{S}0 ^{A}28	188.3	2.67
^{S}0.25^{A}28	191.0	2.70
^{S}0.50^{A}28	221.5	3.14
^{S}0.75^{A}28	234.7	3.32

The split tensile strength of SFRGPCC predicted from the proposed analytical equation was compared with the experimental results as shown . It was found that a good correlation was obtained between the experimental results and those got from the equation. It can be seen that the proposed equation predicts the split tensile strength of SFRGPCC well with good accuracy.

Comparison of experimental and analytical results.

Volume fraction of fibres %	Split tensile strength MPa		Analytical / Experimental
	Experimental	Analytical	
0	2.67	2.67	1.00
	2.85	2.88	1.01
0.25	2.68	2.88	1.07
	2.58	2.88	1.11
	2.91	3.09	1.06
0.5	3.21	3.09	0.96
	3.28	3.09	0.94
	3.28	3.30	1.00
0.75	3.55	3.30	0.93
	3.14	3.30	1.05

FLEXURAL STRENGTH

Totally eighteen prisms of size 500 mm x 100 mm x100 mm were cast to evaluate the flexural strength of SFRGPCC. Standard cast iron moulds were used for casting the test specimens.The effect of addition of steel fibres with different volume fractions and age of concrete at the time of testing on the flexural strength of geopolymer concrete composite has been investigated and presented. Test results of flexural strength are presented.

Flexural strength of SFRGPCC specimens.

Spec.	Avg. Ultimate load kN	Avg. Flexural Strength MPa
^{S}0 ^{A}7	9.8	3.93
^{S}0.25 ^{A}7	10.0	4.00
^{S}0.50 ^{A}7	10.7	4.27
^{S}0.75 ^{A}7	14.2	5.67
^{S}0 ^{A}28	14.7	5.87

$^{S}0.25^{A}28$	15.2	6.07
$^{S}0.75^{A}28$	21.0	8.40

IMPACT RESISTANCE

The impact resistance of the specimens was determined in accordance with ACI committee 544 recommendations. The test specimen consists of concrete discs 150 mm diameter by 64 mm thick. Specimens were cast using cast iron moulds.

The effect of addition of steel fibres in different volume fractions in improving the impact strength has been evaluated and presented. Test results of impact strength are presented.

Test Results of impact strength

	First Crack strength (blows)				Failure strength (blows)			
Spec.	Spec1	Spec 2	Spec 3	Avg.	Spec 1	Spec 2	Spec 3	Avg.
GPCC	10	12	9	10	11	13	11	12
$^{S}0.25$	57	48	62	56	96	88	104	96
$^{S}0.50$	71	79	83	78	131	135	149	138
$^{S}0.75$	108	98	114	107	297	265	304	289

MODULUS OF ELASTICITY.

The modulus of elasticity was determined in accordance with Indian Standards IS.516. The test specimen consists of concrete cylinders measuring 150 mm diameter In this investigation, totally twelve geopolymer concrete composite cylinders were cast with and without fibres and 300 mm height.

WATER ABSORPTION.

The water absorption test has been carried out according to ASTM C 642-82, to study the relative porosity or permeability characteristics of SFRGPCC at 28 days. The specimens used for this test were cubes of size 100 mm x 100 mm x 100 mm as shown. Specimens were dried in the hot air oven at a temperature of 105$_{0}$C to constant mass.

SORPTIVITY.

Sorptivity measures the rate of penetration of water into the pores of concrete by capillary suction. When the cumulative volume of water penetrated per unit surface area of exposure is plotted against the square root of time of exposure, the resulting graph could be approximated by a straight line.

t min$^{1/2}$	GPCC	^{S}0.25	^{S}0.5	^{S}0.75
2	0.8000	0.8667	1.1000	1.1000
3	0.9667	1.0000	1.2667	1.3000
4	1.2000	1.1667	1.4667	1.5000
5	1.3667	1.3333	1.6667	1.6667
6	1.5333	1.5000	1.9000	1.8667
7	1.7667	1.7000	2.0667	2.0333
8	1.9333	1.8667	2.2333	2.3000
9	2.1333	1.9667	2.3000	2.4333
10	2.2667	2.0667	2.5000	2.4667
11	2.4667	2.2333	2.6333	2.6333

Cumulative water absorption

FLEXURAL BEHAVIOUR OF FIBRE REINFORCED GEOPOLYMER COMPOSITE R.C. BEAMS.

An experimental investigation on the behavior of geopolymer composite concrete beams reinforced with conventional steel bars and various types of fibres namely steel, polypropylene and glass in different volume fractions under flexural loading is presented. The cross sectional dimensions and the span of the beams were same for all the beams. The first crack load, ultimate load and the load-deflection response at various stages of loading were evaluated experimentally.

This chapter also presents the details of the finite element analysis using "ANSYS 10.0" program to predict the load-deflection behavior of geopolymer composite reinforced concrete beams on significant stages of loading. Nonlinear finite element analysis has been performed and a comparison between the results obtained from finite element analysis (FEA) and experiments were made. Analytical results obtained using ANSYS were also compared with the calculations based on theory and presented. reinforced concrete beams were cast with and without fibres. Three beams were cast with steel fibres in volume fractions of 0.25%, 0.5% and 0.75%. Another three beams were cast with polypropylene fibres with volume fractions of 0.1%, 0.2% and 0.3%. Three more beams containing glass fibres with volume fractions of 0.01%, 0.02% and 0.03% were cast. The cross sectional dimensions and the span of the beams were fixed same for all the ten beams. The dimensions of the beams were 100 mm x 150 mm x 1000 mm. All the beams were reinforced using two numbers of 8 mm diameter tor steel bars at the bottom face that serves as the main reinforcement. The yield strength of the main reinforcement was found to be 547 MPa. Two numbers of 8mm diameter tor steel bars were used as hanger bars at the top and 6mm diameter mild steel stirrups @ 100 mm c/c spacing were provided as shear reinforcement as sown.

Load-Deflection Response

The deflections measured at different increments of load. The experimental load-deflection responses for all the tested beams are shown in**.** All the beams followed the same pattern of load-deflection response. In general the load-deflection curve will consist of three regions, the first region is a linear region that indicates the response till the concrete cracks, the second region is also a linear region that shows the response till the steel reinforcement yields and the third region indicates the response after the yielding of reinforcement where there is an enormous rate of increase in deflection for subsequent loads. But it was not able to predict the first crack load exactly from the experimentally obtained load-deflection curve. Hence the first crack load was noticed only through the visual observation made during testing.

CONCLUSIONS

Based on the results obtained in this investigation, the following conclusions are drawn:Addition of steel fibres in GPCC resulted in poor workability. Workability of SFRGPCC decreases as the percentage volume fraction of steel fibres increases.

The density of GPCC and SFRGPCC was found close to that of ordinary Portland cement concrete. At all the ages the average density increases with the increase in the volume fraction of steel fibres. The average compressive strength of geopolymer concrete composites containing steel fibres was higher than those of geopolymer concrete composites without steel fibres. The increase in compressive strength at the age of 28 days was about 11%, 13% and 24% for volume fractions of 0.25%, 0.50% and 0.75% respectively with reference to GPCC mix without steel fibre,Based on the test results, using least square regression analysis, an equation for predicting the 28 days compressive strength of SFRGPCC in terms of the compressive strength of plain GPCC and percentage volume fraction of fibres is obtained. It can be seen that the proposed equation predicts the compressive strength of steel fibre reinforced geopolymer concrete composites well with good accuracy.

Steel fibres in the concrete increases the splitting tensile strength and the increase was more significant at 7 days when compared to 28 days. The highest volume fraction of fibres gives the maximum increase of strength. The split tensile strength improves by 17%, 35% and 72% for 0.25%, 0.5% and 0.75% of steel fibres respectively Based on the test results, using least square regression analysis, an equation for predicting the 28 days split tensile strength of SFRGPCC in terms of the split tensile strength of GPCC without fibres and percentage volume fraction of fibres is obtained. It can be seen that the proposed equation predicts the split tensile strength of SFRGPCC well with good accuracy.

As in the case of split tensile strength, the flexural strength also increases at all ages as the volume fraction of steel fibres increases from 0% to 0.75%. The more the steel fibre amount in geopolymer concrete, the higher the increase in flexural strength. The flexural strength gets increased by 3%, 33% and 43% for 0.25%, 0.5% and 0.75% of steel fibres respectively.

Modulus of elasticity of concrete containing steel fibres is slightly higher than the elastic modulus of concrete without fibres. Addition of steel fibres improvesthevaluesofmodulus,of elasticity by about 4%, 6% and 11% for volume fractions of 0.25%, 0.5% and 0.75% respectively.

Post crack resistance in impact is negligible in case of plain GPCC specimens. From the investigation, it is clear that the addition of steel fibres significantly improves the impact resistance of concrete. The percentage increase in post crack resistance is about 20%, 71%, 77% and 170% for the fibre volume fractions of 0%, 0.25%, 0.5% and 0.75% respectively.

Post crack resistance values that indicate the ability to absorb kinetic energy suggest that adding steel fibres delays failure strength. It is clear from the test results that the addition of steel fibres significantly improves the impact resistance of GPCC and thus it is a suitable material for structures subjected to impact loads

The results of water absorption at 30 minutes indicated that quality of GPCC and SFRGPCC are good as per the recommendations given by the CEB. The water absorption values after 24 hours also indicate that the geopolymer concrete composite specimens reinforced with steel fibres were having lower absorption rate compared to control GPCC specimens.

The addition of steel fibres into the GPCC mix decreases the sorptivity coefficient. This may be due to the decreased porosity in the geopolymer paste in contact zone closer to the steel fibres indicating a denser microstructure. This lower sorptivity value provides higher resistance to concrete towards water absorption. In case of SFRGPCC, sorptivity values increases as the fibre content increases. Specimens with 0.25% of steel fibres showed lower sorptivity values. The higher sorptivity value was obtained for specimens containing 0.75% of fibres.

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