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An Experimental Study of Low-Calcium Fly Ash and Slag Based Geopolymer Concrete:

[1]Akhand Pratap Singh, [2]Dr. Anil Kumar Saxena,[3]Dr. Abhay Kumar Jha

[1]Post graduate student, [2] Professor, [3]Professor
[1]Department of Civil Engineering,
[1]L.N.C. T Bhopal, India.

ABSTRACT

Following an extensive review of the literature, six elements—three beams and three geopolymer columns—were cast in regular Portland cement concrete as part of the experimental investigations. Don't take longer than thirty minutes. There is a noticeable increase in moisture content. To meet workability standards, 100 to 150 ml of water must be added every 15 to 20 minutes.

This current investigation work has been conducted with these crucial factors in mind in order to manufacture the environmentally friendly concrete for M30 Grade of concrete using industrial pozzolanic wastes (fly ash and GGBS) at ambient curing conditions. The ideal content of the aggregates used in this study is known to be roughly 40% based on numerous trial mixes.The mix proportion for geopolymer concrete is said to be fly ash (85% of cement) + coarse aggregates (15% of cement) + fine aggregates + 40% of coarse aggregates. The mix proportion for conventional concrete is said to be cement + fine aggregates + coarse aggregates. The geopolymer concrete exhibits an average split tensile strength that is 10.26% greater than that of the control mix. Flexural strength values for the geopolymer concrete mixture are 4.7% greater than those for the OPC control mix. Geopolymer concrete has a modulus of elasticity that is 12.8% higher than that of the control mix. Concrete based on OPC and geopolymer have similar bond strength values. Geopolymer concrete has a significantly lower water absorption capacity than OPC-based concrete, indicating its greater durability. Concrete with geopolymer can decrease sorptivity by nearly 72.9%, increasing concrete's durability. Compared to the control OPC concrete mix, geopolymer concrete has a density of less than 3.8%.Because alkaline activators and byproducts are more expensive to transport than the control mix, geopolymer concrete production is more expensive than it is for the former.

Keywords: Fly-ash, Flexural strength, Modulus of elasticity, Bond Strength, Sorptivity

1. Introduction

Numerous Studies also investigated that, in general, these studies are carried out using a rich supply of Silica and Alumina solely for understanding the kinetics of geopolymerisation, behind the geopolymer binders. e.g. Metakaolin. As flyash is the main ingredient it is necessary to study its chemistry, mechanical properties.Fly ash is the most widely used substantial for the production of source materialbased gpconcrete, It is derived from coal fire/thermal power plants and its synthesis with GGBS gives high strength GPC at ambient cured condition. GGBS and OPC has the same chemical structure as of cement and is attained from steel/iron industry. Alkali ggbs can produce concrete of high strength. India produces about 42.3 mega tons of steel per year. For every ton of steel made, approximately 0.47-0.52 ton of blowing furnace slag will be created. As it is to be disposed of as waste detrimental to the environment. Because of the early resistance achievement and the disposal issue, use of GGBS in geopolymer concrete can reduce building expense.As the source of flyash varies from site to site it is difficult to predetermine the properties of flyash, as it shows significantly different particle geomorphology and the chemical properties, while most of the investigations concentrated on experimental investigation that encourages the usage of geopolymer by importance, the eco-friendlyaids of reprocessing of flyash interested in geopolymer concrete. Limited information has been presented regarding mix design/proportions, activator solution concentration, curing conditions etc.,

The main vision of this experimental examination is to conduct and study the flexural behavior of reinforced concrete structural elements made with low calcium flyash and ggbs geopolymer concrete and comparing the same with conventional concrete elements at 28 days.

1.1. SCOPE OF THE PRESENT STUDY

The scopes of this present investigation are,

Characterization of material

Design of concrete mix

Preparation of concrete mixtures of geo polymer concrete with fly ash and conventional concrete

Casting of specimens

Testing for strength properties of hardened control concrete.

1.2 OBJECTIVES OF THE PRESENT INVESTIGATION

Study the effect of geo polymer concrete with fly ash and conventional concrete on strength properties of hardened concrete.

Study the effect of geo polymer concrete with fly ash and conventional concrete on mechanical properties of hardened concrete.

2. LITERATURE SURVEY

Chavteer et al. (1987) said that ground agricultural waste from a power plant that produced electricity was used to partially replace cement. We looked into the expansion and loss of compressive strength that occur when mortars are attacked by sulphates. At weight percentages of 0%, 10%, 30%, and 50% of the binder, SCBA was utilized in place of Portland cement for the parametric study. Both 0.55 and 0.65 were the water-to-binder ratios. Utilizing 5% solutions of magnesium sulfate ($MgSO_4$) and sodium sulfate (Na_2SO_4), the durability of mortar exposed to sulfate attack was examined.

Amen (1993) indicated how waste from the sugar industry, bagasse ash, can be recycled to make concrete instead of cement. This effectively addresses environmental issues related to waste management. Researchers have looked into how the partial replacement of cement with bagasse ash affects the mechanical and physical characteristics of hardened concrete, such as resistance to chloride ion penetration, splitting tensile strength, and compressive strength. With an ideal replacement ratio of 20% cement, bagasse ash is an effective mineral admixture and pozzolan that reduced chloride diffusion by more than 50% without negatively affecting other properties of the hardened concrete, according to the results.

Chindaprasirt et al. (2011) evaluated the viability of using both traditional pulverized coal combustion fly ash and fluidized bed combustion fly ash as aluminosilicate base materials for geopolymer mortar production. There have been attempts to compare the mass ratios of fluidized bed combustion fly ash and conventional pulverized coal combustion fly ash, and they were 20:80, 40:60, 60:40, 80:20, and 100:0. The ratios of sand to ash, sodium hydroxide to sodium silicate, and sodium hydroxide concentration of 10 M were set at 1.5 and 2, respectively. Every geopolymer specimen was cured for 48 hours at 65°C and then at room temperature, which was 25°C. For the production of geopolymer mortars with a compressive strength of seven days, a blend of 60% fluidized bed combustion fly ash and 40% conventional pulverized coal combustion fly ash was found to be beneficial. The compressive strength of geopolymer mortars decreased with a higher ratio of fluidized bed combustion fly ash to conventional pulverized coal combustion fly ash as the reactivity decreased..

Naidu et al. (2012) investigated the best qualities of five-ratio-prepared geopolymer concrete that had minimal fly ash and slag content. According to reports, the formulation with a higher concentration of GGBS has a high compressive strength. It was observed that 90% of the compressive strength was reached in just 14 days.

Panda and Sahoo (2021) Around the world, using regular Portland cement as a binding material is widely accepted in the construction industry. The enormous demand for cement in the building sector results in increased CO_2 emissions and the use of absolute energy from the cement industry. As a result, the global cement industry is having more and more trouble conserving energy and materials and lowering its CO_2 emissions. Similar to this, a variety of industrial wastes are produced today as a result of growing industrialization, increasing urbanization, and rising standards of living brought about by technological innovation. These wastes include fly ash, ground granulated blast furnace slag, waste recycled product, cement kiln dust, silica fume, quarry dust, glass waste, rubber waste, and red mud, which is contributing to the waste disposal issue and dangerous environmental risks. Thus, by partially substituting fly ash (FA) and ground granulated blast furnace slag (GGBS) for cement, efforts have been made in this paper to reduce waste management and production costs as well as environmental pollution. Waste by-products of the iron industry and thermal power plants, respectively, are industrial wastes like GGBS and FA. In the current study, different percentages of these by-products were used to partially replace cement in the concrete. The tests involved partial replacement of GGBS at different percentages of 0, 10, 15, 20, and 25% and FA at different percentages of 0, 5, 7.5, 10, 12.5, and 15% by the dry weight of cement. Tests on the workability and compressive strength of concrete mixtures with varying GGBS and FA proportions were conducted. The results of the experiment show that incorporating additional GGBS and FA into partially replaced cement-concrete greatly increases its strength, paving the way for practical uses in the building industry. The experimental results indicate that the percentage of fly ash and GGBS in concrete increases with its compressive strength. This evaluation enables the design of GGBS and FA mixed concrete for medium strength concrete.

Agnihotri et al. (2022) This study examines the behavior of concrete in the form of an adhesive composed of aluminum and activated silicon in a highly alkaline solution. There is a lot of research done on concrete made with low calcium fly ash. Additionally, the high-calcium fly ash can be used as a base material to make geopolymers. In this study, the precise amount of GGBS replacement that is ideal is: It was found that the fly ash to PPC concrete mix ratio was 60:40. Different outcomes were obtained for varying chemical ratios of sodium hydroxide and sodium silicate in the concrete mix. The performance of different strength concretes and GGBS as partial cement substitutes are better understood as a result of this research. Acid attack and mechanical strength and durability characteristics were found in the GGBS and Fly Ash concrete mix. It has been found that sodium hydroxide and sodium silicate influence different combinations as well as strength and durability.

Thakur and Bawa(2023) Common feature throughout the world, Portland cement is a building material that is frequently used. The use of Portland cement (PC) in concrete construction is called into question due to its substantial contribution to carbon dioxide emissions, in addition to deforestation and the burning of fossil fuels. Finding a substitute for the current one therefore becomes essential. One relatively new and inventive type of concrete that can be prepared without the need for PC is called geo polymer concrete (GPC). The focus of this study is on evaluating the strength and durability of GPC that has dolomite, fly ash (FA), and ground-granulated blast furnace slag (GGBS) as binders. FA serves as the only binder in the control mix, while five other mixes are prepared by substituting 20% FA with dolomite or GGBS, or both, in different amounts. The concrete's workability is evaluated using the slump test. Important mechanical characteristics like split tensile strength and compressive strength are also measured, in addition to non-destructive examinations like electrical resistivity and ultrasonic pulse velocity. Initial surface absorption and capillary suction absorption tests are performed at different curing ages to evaluate GPC durability.

The results indicate that strength and durability of FA-based GPC are significantly increased by adding GGBS and dolomite. Nevertheless, in comparison to the control mix, this improvement lessens the workability. When GGBS and dolomite are added, compressive strength increases significantly—up to 67%—and initial surface absorption decreases significantly—up to 65%—when compared to the control mix over a 56-day period. When 20% of GGBS is substituted for FA, the best outcomes are obtained in terms of strength and durability. Furthermore, the mix with 10% GGBS and 10% dolomite produces results that are similar to the mix with 20% GGBS, making it a more affordable option.

3.METHODOLOGY

3.1MATERIALS

- Ordinary Portland Cement (OPC)-53 Grade
- Fly ash (Class F)
- Ground Granulated Blast Furnace Slag (GGBS)
- Fine aggregates
- Coarse aggregates
- Na_2siO_3 solution
- NaoH pills
- Water
- Super Plasticizer – ssulphonate NaphthaleneeFormaldehyde

3.2 ORDINARY PORTLAND CEMENT

Usual cement of Portland(OPC) is one of the world's utmost common construction materials. Cement can be well-defined as a binding material with interconnected and adhesive properties, which makes it possible to attach and to create a compact assembly with different building materials. In this analysis, cement was used as (OPC) grade 53 which verified IS 12269 (1987) (with specific gravity of 3.1). Ordinary Portland cement, where there is no sulphate exposure in ground or soil water, is the most common cement used in general concrete building.

Table 1: Composition of cement

S. no.	Constituent	Standards of Percentage (%)	Percentage acquired
1	CaO	60-67	63.5
2	SiO_2	17-25	21
3	Al_2O_3	3-8	5.5
4	Fe_2O_3	0.5-6.0	3.25
5	MgO	0.5-4.0	2.25
6	K_2O	0.3-1.2	0.55

7	SO_3	2.0-3.5	2.5

Table2: Cement (physical and chemical features)

S NO.	Physical and chemical properties	Test method	Test results	Indian standards
1	Standard consistency	Vi-cat Apparatus (IS:4031 Part - 4)	33%	-
2	Fineness	On sieve no.9(IS:4031 Part –1)	1.3%	10%
3	Initial Setting time	Vi-cat Apparatus (IS:4031Part - 4)	45mins	Not ≤30 mins
4	Final setting time	Vi-cat Apparatus (IS:4031Part - 4)	190mins	Not ≤ 10 hours
5	Soundnesss	Le-Chatlier Method (IS: 4031 Part – 3)	4mm	Not ≥ 10mm
6	Compressive strength	IS 4031 (Part 6): 1988	56.3 N/mm^2	-
7	Specific gravity	Specific gravity bottle (IS: 4031 Part - 4)	3.17	-

3.3Fly ash

Fly ash is the material left of an explosive oven. Fly ash's components are amorphous (60%), quartz (20%), molite (17%), magnetitis (1,7%), and hematitis Components (.9 percent).[IS: 3812(part-1)].Ash fly is the fine break residue formed by the ignition of powdered carbon and transported by exhaust gasses from the ignition compartment.Fly ash is generated by power plants fueled by coal and steam. In the boiler ignition chamber, charcoal is usually pulverized and air blasted, where it ignites, creates temperature and a meltedinert residue instantly. Reservoir tubes heat from the tank, refresh flue gas and harden and form ash, which is the origin of the molten mineral residue. The bottom part of the combustion chamber is coarsely ash, or slag, while the lighter fine ash part called ash fly is also suspension.I the flue gas. Preceding to exhausting the flue gas, fly ash is seperated by particulate matter discharge controller unit, such as staticelectro Cottrell precipitator.Fly-ash is normally more subtle than cement and lime in Portland. Fly ash is made up of silt particles that typically range from 10 to 100 microns, and are generally spherical. The fluidity and workability of fresh concrete increase with these tiny glass spheres. Fineness isthe major physical-characteristics of the pozzolanic fly-ash reactivity. The ashes of class F usually are made from anthracite and bitumen and are predominantly composed of aluminum-silicate glass, also found in quartz, mullite and magnetite. Class F is less than 10% CaO, or low calcium fly ash is less.

Table2: Composition of fly ash as determined by XRF (mass%)

SiO_2	Al_2O_3	CaO	Cr	Fe_2O_3	k_2O	MgO	Na_2O	P_2O_5	SO_3	TiO_2	MnO	LOI
49.27	24.16	2.48	0.0	14.06	0.63	1.05	0.34	1.77	0.53	1.17	0.09	1.1

LOI*=loss of Ignition

A high strain, low cracking, strong acidity tolerance, and low shrinking concrete was created from geopolymer concrete. Geopolymer paste with fly-ash, which also has pozzolanic possessions such as opc, rich in aluminum and silicon, is the substitute for the bonding position in concrete.

3.4. GGBS

Granulated Blast Furnace Slag (GGBS) is produced by rapid cooling (extinguishing) the melted ash from the heater with the help of water.The slag is split and turned into amorphous granules, in accordance with IS 12089:1987 requirement (manufacturing specification for granulated slag used in Portland Slag Cement). The granulated slack is rendered such that GGBS is generated with the necessary fineness.

GGBS subsidizes to the manufacture of superior cement through its chemical composition. Its load bearing features can continue to expand over time, as it captivates excess calcium released during hydration to form further hydrates of calcium silicates. These hydrates improve cement strength.

Table3.4: Composition of Chemicals present in GGBS (mass %)

CaO	SiO_2	Al_2O_3	MgO	MnO	TiO_2	K_2O	N_2O
30-50%	28-38%	8-24%	1-18%	0.68%	0.58%	0.37%	0.27%

Table 3 Properties of Fly Ash and GGBS.

S. No	Characteristics	Percentage by Mass	
		Fly Ash	GGBS
1	Loss on ignition	1.90	2.10
2	Silica, Sio_2	52.16	42.32
3	Alumina,Al_2O_3	36.93	15.66
4	Calcium, CaO	4.67	34.53
5	Iron, Fe_2O_3	4.23	3.68

3.5 Fine aggregates

The fine aggregate utilized in the present experimental investigation was brought from local suppliers. The tests like specific gravity, Fineness Modulus and bulk density were conducted on fine aggregates to full fill the specifications of IS: 383 – 1970.

Table3.6: fine aggregates [physical properties confined to IS: 2386 – 1963]

S.no.	Property	Method	Fine aggregates
1	Specific gravity	Pycnometer IS:2386 - 1986 Part 3	2.65
2	Bulk density (compact)	IS:2386 - 1986 Part 3	1711 kg/cum
3	Bulk density (loose)	IS:2386 - 1986 Part 3	1631 kg/cum
4	Fineness modulus	Sieve analysis IS:2386 - 1963 Part 2	2.64
5	Bulking	IS:2386 - 1986 Part 3	4% w/c

Fine aggregates is from zone II.

3.6 Coarse aggregates

Gross add-ons are an irregular broken stone or rounded gravel which is used for concrete production. Materials of 4.7 mm large scale are known as coarse aggregates with a max magnitude of upto 6.3cm. Coarse aggregates are generally obtained by blasting in stone quarries or by crushers. Machine-crushed stones consist of various sizes whereas Hand-smashed aggregates consist of only single size stones. To produce classified aggregates for high-quality concrete, they are mixedagain in definiteratios.

Coarse aggregates used in this project are locally available crushed granite of uniform size 20mm. The physical properties of natural coarse aggregate area tested in accordance with IS:2386 - 1963 and are shown in the below table.

Figure3.5: Natural aggregates

Table4 : Physical properties of coarse aggregates of size 20mm

S.no.	Property	Method	20mm aggregates
1	Specific gravity	Pycnometer IS:2386 – 1986 Part 3	2.62
2	Water absorption	IS:2386 – 1963 Part 3	1.109
3	Daftness Index	IS:2386 – 1986 Part 2	4.13
4	Extension Index	IS:2386 – 1986 Part 2	5.96
5	Bulk density (compact)	IS:2386 – 1986 Part 3	1579 kg/cum
6	Bulk density (loose)	IS:2386 – 1986 Part 3	1431 kg/cum
7	Fineness modulus	Sieve analysis IS:2386 – 1963 Part 2	7.02

Table5 : Properties of Na_2Sio_3 solution

Properties of Na_2SiO_3 solution

Specific Gravity	**1.57**
Molar mass	**122.06 $grams/mol$**
Na_2O (by mass)	**13.35%**
SiO_2(by mass)	**30.0%**
Water (by mass)	**45.00%**
Weight (SiO_2 to Na_2O)	**2.5**
Ratio of Molarity	**0.98**

3.7 NaOH/Sodium Hydroxidepellets

In geopolymer manufacturing, NaOH is still used extensively as an alkaline activator. NaOH is usually sold in the form of pellets or flakes of 96% to 98% pure, where the prices for the product depends on the pureness of the material. It was dissolved into water of different molarity that produced the NaOH solution.

This solution specifies the concentration and molarity of the resultantadhesive. Although greater NaOH add-ons quicken chemical suspension, ettringites and CH (carbon-hydrogen) are depressed during the forming of binder. In addition, higher NaOH concentrations at the early reaction stages facilitate greater intensity, but the strength of the ageing materials was .

The approach induces detrimental morphology and non-uniformity of finished goods because of an unnecessary OH agreement. Geopolymer with sodium hydroxide activated is observed to produce improved crystallinity, which increases stability in violent sulphate and acid conditions. [IS: 9103].Sodium hydroxide was procured from the locally available vendors. Sodium hydroxide's physical and chemical characteristics given by the vendor are tabulated below

Table6.: physical properties of NaOH

Appearance	White solid pellets
Molar mass	40 $grams/mol$
Density	2 $grams/cc$
Melting pt	319°C
Boiling pt	1380°C
Heat dissolved in water is released	276 $cal/gram$

Table7.: Chemical properties of NaOH pellets

Purity	97% (assay)
Na_2Co_3	2%
CI	0.01%
SO_4	-0.0.1%
SiO_2	0.02%
Zinc	-0.02%
PO_4	0.00%
Aluminum (AL)	0.00%

3.8Water

Water is a crucial ingredient in conventional concrete and geopolymer concrete. It actively plays major role in the chemical reaction which takes place with the cement. As per IS 456:2000 the water used for mixing of concrete and curing is must be free away from all impurities.

3.9Super plasticizer

An SNF (sulphonate Naphthalene formaldehyde) based super plasticizer known as Master Rheobuild 920 SH was utilized For the M30 and G30 classes, fly ash & GGBS are combined by 2 to 2,5% by weight to boost fresh geopolymer activityand controlled concrete. This Superplasticizer is very much useful and worked properly in obtaining the workability and strengths of geo-polymer and controlled concretes.

Fig4: super plasticizer

Table 8 materials required

sr.no	Material	Geopolymer(kg/m^3)	conventional (kg/m^3)
1	flyash,GGBS and cement	370	400
2	Alkaline solution	14	-
3	water	50-60	160
4	Fine Aggregate	682	670
5	coarse aggregate	1184	1090
6	Super Plasticizer	9	9

3.10. MIX DESIGN

Mixing ratios of different mixing ratios were considered and considered from the literature review. The mix design procedure for geopolymer concrete was prepared using the binder material, the NaOH:Na2SiO3 ratio as sol/binder amount ratio, and the experimental NaOH sol concentration. The gpc mixing amount of M30 fault technology was obtained to find the strength characteristics of structural elements, and the optimal mixing ratio content was adopted in this investigation.

3.10.1. Conventional Concrete blend estimates (M30)

Adopt procedures according to IS:10262-2019 and IS:456-2000 to calculate M30 and G30 concrete mix designs.

Table9: Mix proportions of M30

Water	Cement	Fine aggregate	Coarse aggregates	Plasticizer	Workability (mm)
163 liters	362 kgs	694.6 kgs	1182.5 kgs	9.05	100

Mix proportions ratio of cement: FA: CA: water is 1: 0.89: 3.27: 0.45

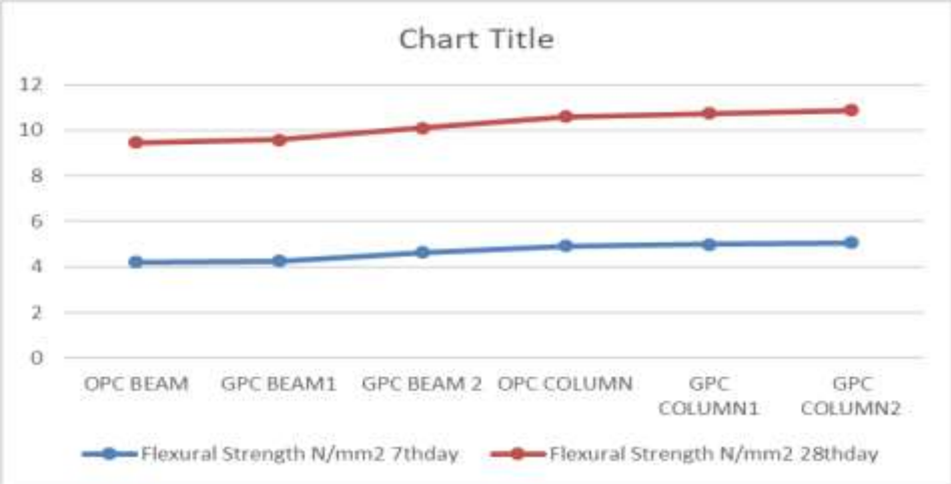
4.RESULTS AND DISCUSSION

4.1Workability

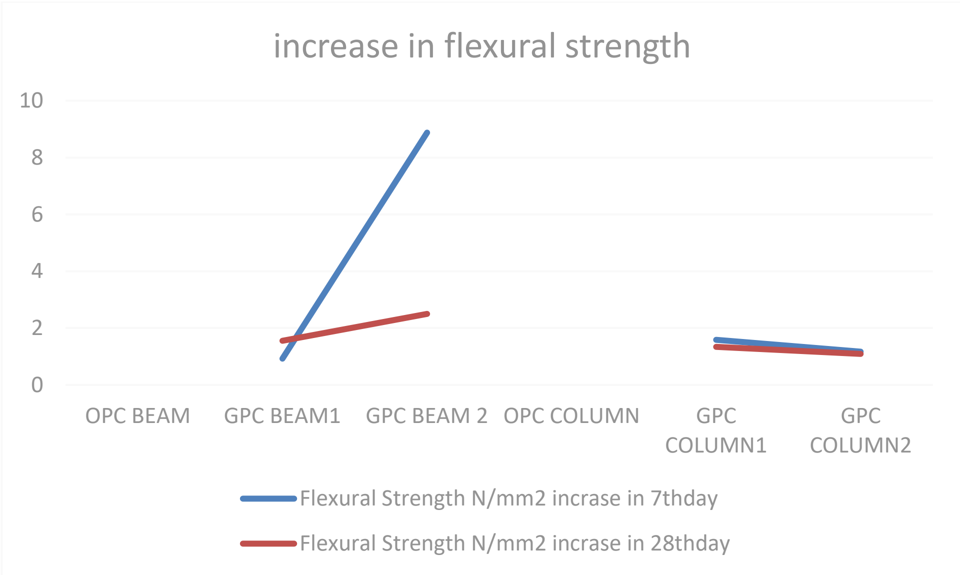
Recession testing is the most well-known and widely used test method to characterize the practicality of fresh solids. Inexpensive testing, which measures stability, is increasingly used at job sites to determine whether concrete should be accepted or rejected. The test method is widely standardized worldwide.

4.2 Flexural strength

The beam specimens of size 100 × 100 × 500 mm were prepared & tested for flexural strength on OPC and geopolymer concrete as per IS 516-1959. Chart-3 shows the results for the average of three specimens. The results shows an increase of 8.87% in the flexural strength of GPC in comparison with M30.



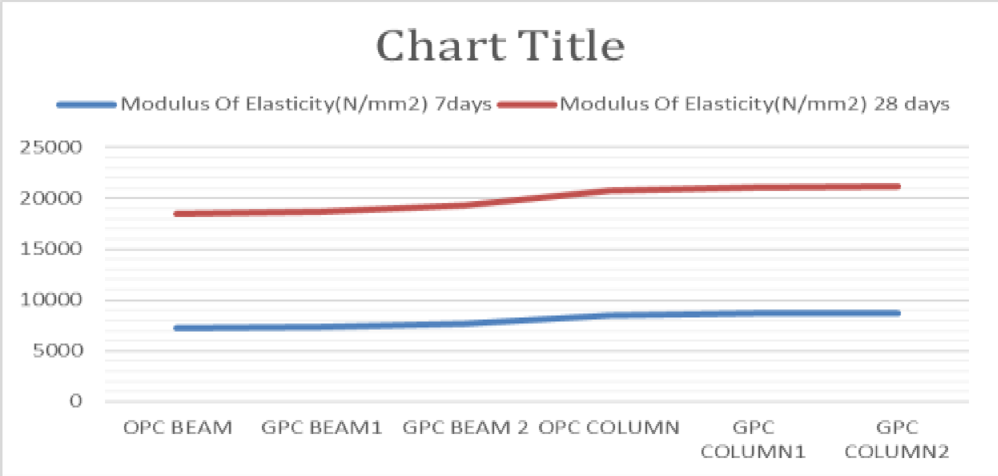
Graph 1 Element v/s Flexural strength



Graph 2 Element v/s Increase Flexural strength

5.3.5 Modulus of elasticity

The modulus of elasticity is essentially the measurement of the stiffness of a material. Modulus of elasticity of concrete is a key factor for estimating the deformation of buildings and members, as well as a fundamental factor for determining modular ratio, m, which is used for the design of section of members subjected to flexure. Knowledge of the modulus of elasticity of high strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability, and for cost-effective designs. Chart-5 shows the average value of modulus of elasticity determined by means of an extensometer as per IS 516 -1959.



Graph 3 Element v/s Modulus of Elasticity

5.3.6 Sorptivity test

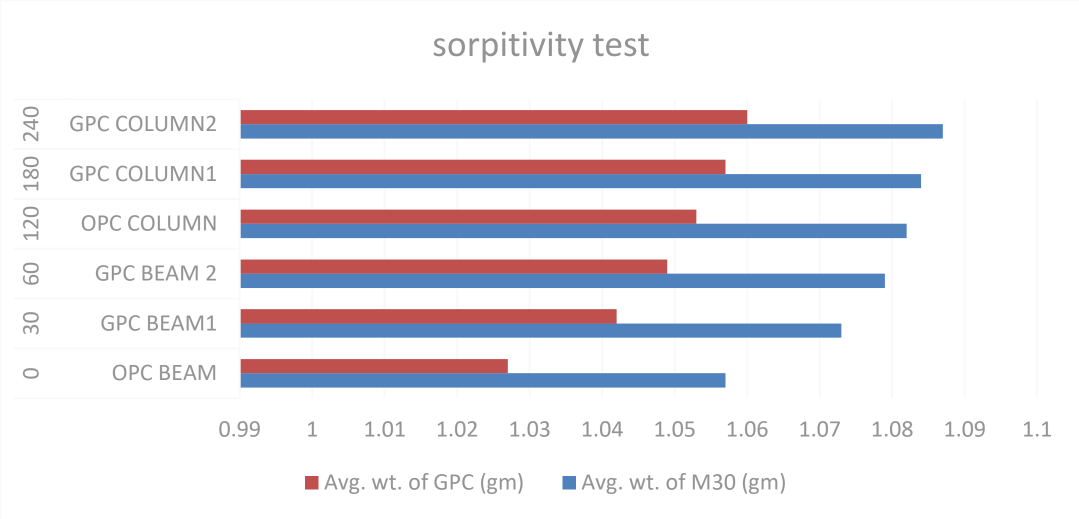
$I = \frac{M_t}{A_\rho}$ and $I = S_i\sqrt{t}$

This test method is used to determine the rate of absorption (sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water is recorded. Fig

-2 shows the test setup. This test method is based on that developed by Hall who called the phenomenon "water sorptivity." The sorptivity test was done for M30 grade OPC mix, geopolymer concrete. The initial sorptivity, defined in accordance with ASTM C1585-04, includes data measured from 1 minute up to 6 hours as shown in the Table 9.

where I is the cumulative absorbed volume after time t per unit area of inflow surface (mm3/mm2), Mt the change in specimens mass at the time t, ? the density of fluid and A the cross-sectional area in contact with fluid.

Fig 5 Sorpitivity test specimen



Graph 4 Element v/s Avg. Weight

5.Conclusion.

1.The flexural strength values for geopolymer concrete mixture is higher than OPC control mix by 4.7%.

5.The modulus of elasticity of geopolymer concrete is more than the control mix by 12.8%.

. Geopolymer concrete can reduce the sorptivity by almost 72.9%, thereby improving the durability of concrete

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