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

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ABSTRACT

Based on a comprehensive study of the literature, experimental investigations were carried out by casting a total of 6 elements, 3 beams and 3 geopolymer columns, cast in normal Portland cement concrete. Do not exceed 30 minutes. A further increase in moisture content is observed. Every 15 to 20 minutes, 100 to 150 ml of water must be added to meet workability standards.

By taking these critical parameters in consideration, this present investigation work has been carried out in order to manufacture the eco-friendly concrete at ambient curing conditions by using industrial pozzolanic wastes (fly ash and GGBS),for M30 Grade of concrete. Based on many trial mixes, the optimum content of aggregates used in this present study are known to be about 40%.For conventional concrete the mix proportion is said to be as Cement + fine aggregates + coarse aggregates, For geopolymer concrete the mix proportions is said to be as Fly ash (85% of cement) + coarse aggregates (15% of cement) + fine aggregates + 40% of coarse aggregates. The average split tensile strength of geopolymer concrete is higher than the control mix by 10.26%..The flexural strength values for geopolymer concrete mixture is higher than OPC control mix by 4.7%.The modulus of elasticity of geopolymer concrete is more than the control mix by 12.8%.The bond strength values of geopolymer concrete are comparable with OPC based concrete. The water absorption capacity of geopolymer concrete is much lesser than OPC based concrete which shows that geopolymer concrete is more durable. Geopolymer concrete can reduce the sorptivity by almost 72.9%, thereby improving the durability of concrete. The density of geopolymer concrete is less than 3.8% than the control OPC concrete mix. The cost for production of geopolymer concrete is higher than the control mix due to high transportation cost of the by-products and cost of alkaline activators.

Keywords: Fly-ash, Split tensile strength, Compressive strength test, slump

1. Introduction

Construction is now one of the fastest growing sectors in the world. As concrete is the world's most adaptable, strong and stable construction material, people's development has increased their interest in concrete, resulting in improved consumption of concrete as a development material. “Ordinary Portland cement has traditionally been used as a binder in concrete. We are looking for eco-friendly alternative binders to help reduce the "increasing trend of global warming and climate change". Given the severe impact of CO2 on the climate and the continued evolution of industrial development and growth, "the building industry needs to be freed from its heavy reliance on Portland cement through the use of alternative binder systems." . A potential alternative binder that has attracted attention is fly ash, with “currently India producing about 200 million tonnes of fly ash,” plus slag as a spare alternative, which is a manufacturing by-product, and then geothermal as an alternative. Polymer cover, the birth zone of innovation. French scientist Joseph Davidovitz initially used soluble liquids to form basic materials of geographic origin (or) silicon (Si) and aluminum (Al) oxides of resulting materials such as fly ash and rice. I supported being able to react. The production of cement requires strength and consumes approximately 120 kWh of energy. Approximately 200 kg of coal is consumed for the production of 1 ton of cement. Ash is produced all over the world. A large portion of fly ash is not used properly and a significant portion of it is disposed of as waste, affecting the surface area of groundwater and freshwater bodies. The most expensive existing concrete-cement.

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

This experimental investigation emphases on using fly ash to produce a cement-free geopolymer concrete and to study the flexural and compression of GPC of grade G30 to conventional concrete made with natural coarse aggregates with grade of M30. In this present study following properties are determined.

Study the effect of geo polymer concrete with partial replacement of fly ash and GGBS with conventional concrete on the properties of fresh concrete.

2. LITERATURE SURVEY

Bilodeau and Malhotra (2000) presented the findings of research done to determine the various durability aspects of high-volume fly ash concrete using eight fly ashes and two Portland cements from US sources. In high-volume fly ash concrete, fly ash makes up between 55 and 60 percent of the total cementitious materials content. At about 115 and 155 kg/m3 of concrete, respectively, the water and cement contents are kept low.

Wan et al. (2004) Analysis of geometric characteristics of GGBS particles and their influences on cement properties.

Cui et al. (2020) Experimented and statistically studied the mechanical attributes of geopolymer concretes.

Gambo et al. (2020) investigated the metaklin-based GPC in steps of 200 degrees Celsius over a high temperature range of 200 to 800. It's interesting that they came to the conclusion that MKGC loses compressive strengths by 59.69% and 71.71%, respectively, at 600 and 8000C. The results obtained also showed decreased abrasion resistance and increased water absorption. From the above, the present authors were unable to locate a significant body of literature that elaborates on the mechanical properties of geopolymer concrete with different cement compositions that combine ground granulated blast furnace slag and flyash. However, in terms of environmentally friendly building construction engagements, this research aspect is crucial. The study has a connection to the building industry's economic growth as well. Therefore, additional research and analysis are needed to create improved geopolymers with better mechanical qualities. In response to this request, considerable effort has been put into an experimental endeavor for this article in order to fill this significant research gap.

Jayarajan and Arivalagan (2021) The biggest problem facing the world today is environmental pollution. The primary source of air pollution in the construction industry is the production of Portland cement. We will lessen the environmental effects of emissions in our construction business by utilizing industrial by-products. In the most recent research, ground granulated blast-furnace slag (GGBS) and flea ash are used in place of geopolymer cement, which makes it so unique. The fine aggregate is changed to quare sand and M.Sand. 10 mm coarse aggregates are used in place of 20 mm coarse aggregates. Alkaline solutions are used to bind materials. The polymerization in this analysis is done using sodium hydroxide (NaOH) and sodium silicate (Na2Sio3) resolution. The project work employed the ratios M40 and M60. Comparing grade control concrete M40 to hardened concrete with flyash and GGBS weight replacement in place of cement yields superior results in terms of tensile strength and compressive resistance. The compressive strength of geopolymer concrete rises as the curing period is extended from three to twenty-eight days. The greatest increase in strength was observed at 5% and 1.0% of the steel fiber incorporation.

In conclusion, the use of fly ash and GGBS in the production of cement helps to reduce air emissions by removing carbon dioxide and carbon monoxide. The study's findings indicate that adding more GGBS to reinforced geopolymer concrete—both in plain and hardened fiber—improves the system characteristics of all the mixes examined. The tensile strength compressive, bent, and broken showed a significant increase with the addition of hard fibers.

Oner and Akyuz (2022) An experimental study on optimum usage of GGBS for the compressive strength of concrete.

Chen et al. (2023) This study thoroughly examined the synergistic effects of ground-granulated blast slag (GGBS) and fly ash (FA) on the durability and compressive behavior of recycled aggregate concrete (RAC). In order to replace some of the cement in the RAC, FA and GGBS were added either separately or concurrently to the RAC that contained 0%, 35%, and 50% recycled coarse aggregate (RCA). Furthermore, the rapid freeze-thaw cycle test and the rapid chloride permeability test were used to experimentally determine the frost resistance and chloride penetration resistance of RAC, respectively (RCPT). The findings indicated that by substituting some of the cement with FA and GGBS, an ideal replacement ratio might be found to enhance the characteristics of RAC. The best proportions for concurrently incorporating GGBS and FA to replace some cement in order to increase RAC's resistance to chloride penetration and 90-day compressive strength were 10% and 20%, respectively; however, 15% and 15% was the best ratio for increasing RAC's resistance to frost. Furthermore, combining FA and GGBS at the same time had a greater synergistic effect on improving RAC performance than did incorporating FA or GGBS separately. The 90-day compressive strength, resistance to chloride penetration, and frost resistance of RAC incorporating 50% RCA were all better than those of regular concrete when 15% FA and 15% GGBS were simultaneously incorporated.

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	56.3N/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	0.01	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

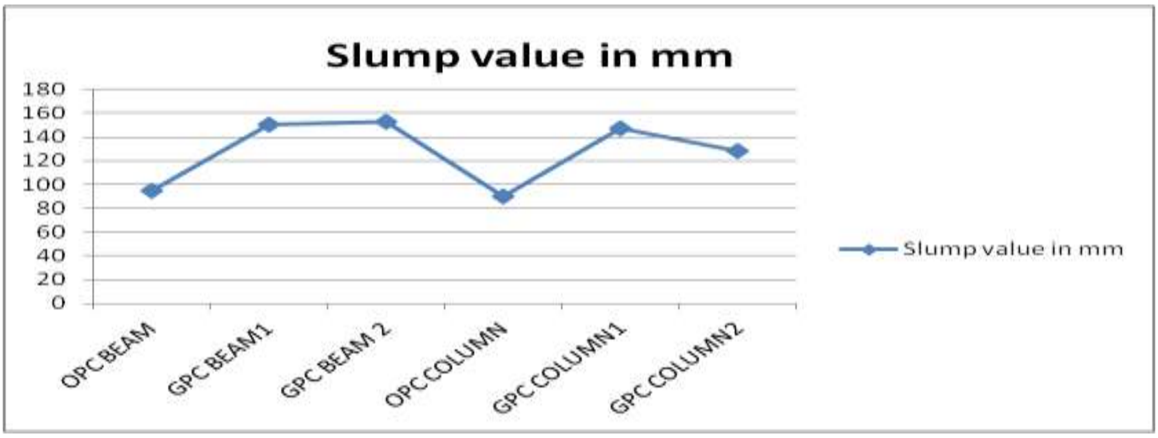
Table 8 materials required

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	sauper Plasticizer	9	9

4.RESULTS AND DISCUSSION

4.1Workability

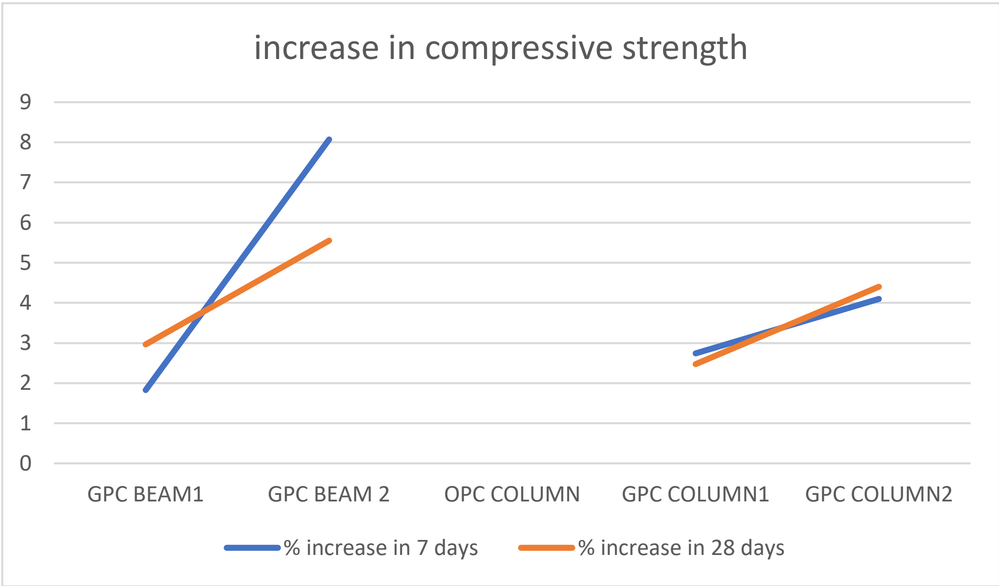
Recession testing is the most well-known and widely used test method to characterize the practicality of fresh solids. Inexpensive testing, which measures stability, is increasingly used at job sites to determine whether concrete should be accepted or rejected. The test method is widely standardized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



Graph 5.1 Element v/s slump value in mm

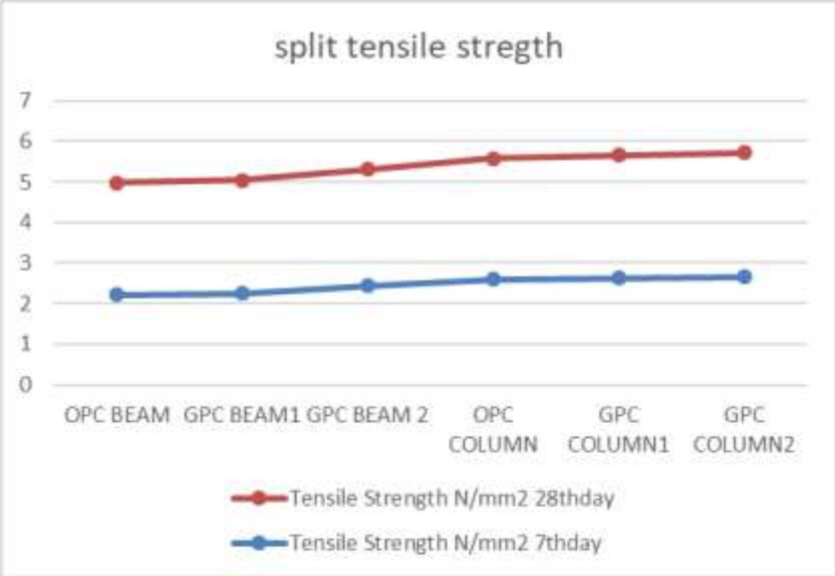
4.2 COMPRESSIVE STRENGTH

The compressive strength of geopolymer concrete cubes at 7th day and 28th day, according to IS 516-1959 are shown in Table 5.2 and graph 5.2. 5% increase in the compressive strength was observed for geopolymer concrete compared to M30 OPC concrete with same mix proportion. Results show that geopolymer concrete attains the target strength at 7th day itself.

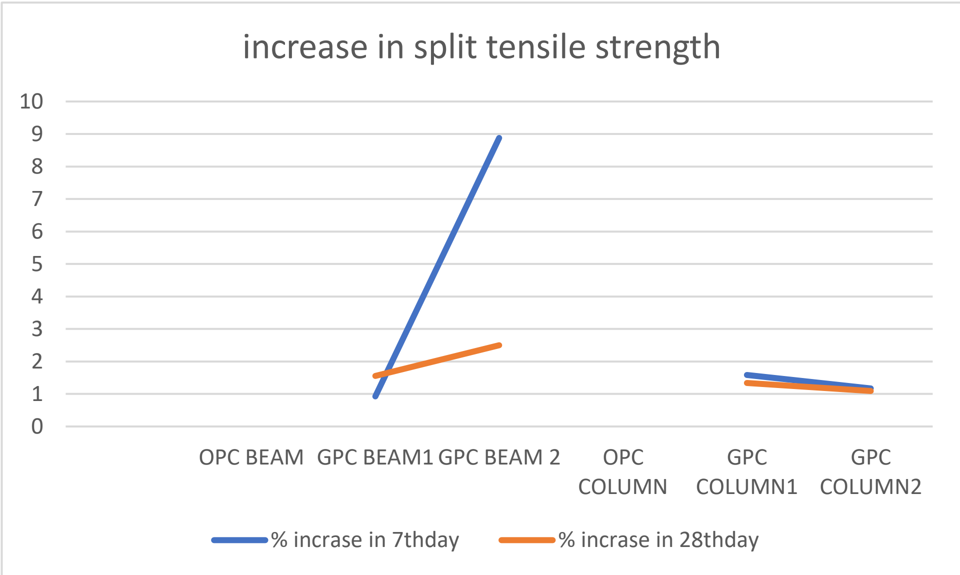


4.3 Splitting tensile strength

A direct measurement of ensuring tensile strength of concrete is difficult. One of the indirect tension test methods is split tension test. The split tensile strength test was carried out on the compression testing machine. The casting and testing of the specimens were done as per IS 5816: 1999. The results show that there is an increase of 8.87% in the tensile strength for GPC in comparison with M30 control mix.



Graph 5.4 Element v/s Split tensile strength



Graph 5.5 Element v/s increase in Split tensile strength

5.Conclusion.

1.The Workability of GPc beam and Column having Maximum Workalbility in Campared to Conventional concrete.

2.Ambient cured fly ash–ground granulated blast furnace slag (GGBS) based geopolymer concrete attains the target compressive strength at 7th day itself and hence can be used for structural application where early strength is required.

3.The average split tensile strength of geopolymer concrete is higher than the control mix by 10.26%.

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