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STRENGTH BEHAVIOUR OF GEOPOLYMER CONCRETE USING SILICA FUME FOR M_{60} GRADE

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***ABSTRACT:** The use of Portland cement in concrete construction is under critical review due to high amount of carbon dioxide gas released to the atmosphere during the production of cement. In recent years, attempts to increase the utilization of Silica Fume to partially replace the use of Portland cement in concrete are gathering momentum. Most of this by-product material is currently dumped in landfills, creating a threat to the environment. Geopolymer concrete is a 'new' material that does not need the presence of Portland cement as a binder. Instead, the source of materials such as Silica Fume, that are rich in Silicon (Si) is activated by alkaline liquids to produce the binder. Hence concrete with no Portland cement. This thesis reports the details of development of the process of making silica fume-based geopolymer concrete. Due to the lack of knowledge regarding making of geopolymer concrete based on silica fume since there is no codification for it, so took the data which is in the published literature, this study adopted a rigorous trial and error process to develop the technology of making, and to identify the salient parameters affecting the properties of fresh and hardened concrete.*

As far as possible, the technology that is currently in use to manufacture and testing of ordinary Portland cement concrete were used. Silica fume was chosen as the basic material to be activated by the geopolimerization process to be the concrete binder, to totally replace the use of Portland cement.

The M60 grade is used in this paper with different water/binder ratios for case 1, 0.3 for GPC(Geopolymer concrete) and 0.3 for OPC(Orginary portland concrete) case 2 , 0.34 for GPC(Geopolymer concrete) and 0.32 for OPC(Ordinary portland concrete), The binder is the only difference to the ordinary Portland cement concrete. To activate the Rich Silicon content in silica fume, a combination of sodium hydroxide solution and sodium silicate solution was used. Manufacturing process comprising material preparation, mixing, placing, and compaction and curing is reported in the thesis. Naphthalene based super plasticiser was found to be useful to improve the workability of fresh silica fume based geopolymer concrete, as well as the addition of extra water. The main parameters affecting the compressive strength of hardened silica fume-based geopolymer concrete are the curing temperature and curing time, the molar H_2O-to-Na_2O ratio, and mixing time. Fresh silica fume-based geopolymer concrete has been able to remain workable up to at least 120 minutes without any sign of setting and without any degradation in the compressive strength.

I. INTRODUCTION

Concrete, artificial engineering material made from a mixture of Portland cement, water, fine and coarse aggregates and a small amount of air. It is the most widely used construction material in the world. Concrete is the only major building material that can be delivered to the job site in a plastic state. This unique quality makes concrete desirable as a building material because it can be molded to virtually to any form or a shape. Concrete provides wide latitude in surface textures and colors and can be used to construct a wide variety of structures such as

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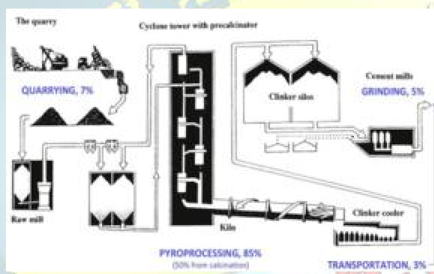
highways and streets, bridges, dams, large buildings, airport runways, irrigation structure, break waters, piers and docks, sidewalks, soils and farm building homes and even barges and ship. Other desirable qualities of concrete as a building material are its strength, economy and durability. Depending on the mixture of materials used, concrete will support, in compression, 700 or more kg/sq cm, (10,000 or more 1b/sq cm). The tensile strength of concrete is much lower when compared to compressive strength of concrete, but by using properly designed steel reinforcing, the structural members can be made that are as strong as in compression. The durability of concrete is evidenced by the fact that concrete columns built by the Egyptians more than 3600 years ago are still standing.

Concrete is the premier construction material around the world and is most widely used in all types of construction works, including infrastructure, low and high-rise buildings, and domestic developments. It is a man-made product, essentially consisting of a mixture of cement, aggregates, water and admixture(s). Inert granular materials such as sand, crushed stone or gravel form the major part of the aggregate. These materials are blended in required proportions according to the strength parameter and Grade of concrete.



Projecting the growth of ghg's: co_2 emissions from cement industry

Since the beginning of the industrial revolution in 1760 there has been an increase in the use of fossil fuel energy resulting in amplified emissions of GHG's (Greenhouse Gases) (Slanina, 2004). This increased global dependency on oil, coal and natural gas has resulted in the release in excess of 1100 Gt (Giga tonne) of CO_2e emissions to the atmosphere (IPCC, 2001). The release of GHGs contributes to anthropogenic induced global warming with the most significant of these gases being CO_2 (Carbon dioxide) (IPCC, 2001). This is due to the sheer quantities that are being emitted, even though it does not have the highest radioactive forcing potential. The cement industry is energy intensive and accounts for a significant portion of these anthropogenic GHG emissions.

Globally the cement industry contributes between five and eight percent of all CO_2e (Carbon dioxide equivalent) emissions (CIF, 2003; Flower and Sanjayan, 2007; Ulm, 2007). World production totalled 42 billion tonnes in 2013 with the three major global contributors being China accounting for 11 billion tonnes (46 percent), USA accounting for 6 billion tonnes (16 percent) and India accounting for 2.6 billion tonnes (six percent) (USDoI, 2013).

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A major producer of CO_2 is the cement industry. It is estimated that the cement activity contributes five to eight percent of global anthropogenic CO_2 emissions. Cement is only a constituent of concrete and accounts for 15 to 30 percent of the world's GHG's.

Concrete is the most commonly used construction material in the world because of its outstanding strength, durability, and availability. In fact, concrete is the world's most consumed man-made material and its use is expected to increase substantially.

From the above discussions it is been clear that the concrete industry producing vast amount of CO_2 around the world and production of concrete is not environmentally friendly, so there is emergency to reduce the usage of cement and this can be achieved by different alternatives

The manufacture of Portland cement clinker involves the calcinations of calcium carbonate according to the reactions:

$$3CaCO_3 + SiO_2 \rightarrow Ca_3SiO_5 + 3CO$$

$$2CaCO_3 + SiO_2 \rightarrow Ca_2SiO_4 + 2CO_2$$

In order to reduce further the CO_2 emissions associated with concrete further viable alternatives to replace OPC are being examined with geopolymer materials considered to be one such alternative.

GEOPOLYMER CONCRETE

In the context of increased awareness regarding the ill-effects of the over exploitation of natural resources, eco-friendly technologies are to be developed for effective management of these resources. Construction industry is one of the major users of the natural resources like cement, sand, rocks, clays and other soils. The ever increasing unit cost of the usual ingredients of concrete have forced the construction engineer to think of ways and means of reducing the unit const of its production. At the same time, increased industrial activity in the core sectors like energy, steel and transportation has been responsible for the production of large amounts like fly ash, blast furnace slag, silica fume and quarry dust with consequent disposal problem.

The geopolymer technology was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymer technology could reduce the CO_2 emission caused due to cement industries. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. Any material that contains mostly silicon (Si) and aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer. Metakaolin or calcined Kaolin, low calcium ASTM Class F fly ash, natural Al-Si minerals, combination of calcined minerals and non-calcined minerals, combination of fly ash and metakaolin, combination of granulated blast furnace slag and metakaolin have been studied as source materials. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate.

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Materials Required For Geopolymer Concrete

- **Cementitious binder**

Various industrial by-products and naturally available materials can be used to produce geopolymer concrete. Commonly used cementitious binders are fly ash, GGBS, silica fume, metakaolin, rice husk ash, etc.

- **Alkaline activators:**

Alkaline activators are the important ingredient of geopolymer mix, it undergoes geopolymerization and gives binding property by igniting the Al and Si present in the cementitious binder. It mainly uses high pH activators like combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate. Christo Ananth et al.[3] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

- **Aggregates:**

Aggregates used to produce geopolymer concrete should be chosen and tested as per IS standards.

- **Super plasticizer:**

This is used in concrete to accelerate or decelerate the setting time and also to attain good workability conditions in a concrete

The geopolymer concrete mix was prepared as follows

NaOH (in water) + Na2SiO3 ⟹ Alkaline Liquid

Alkaline Liquid +Super plasticizer + Extra water + Aggregate + silica fume ⟹ GeopolymerConcrete.

II. LITERATURE REVIEW

This chapter presents a review of recent research on geopolymers and geopolymer concrete, with an emphasis on low calcium fly ash-based geopolymer paste and concrete. New building materials that enhance both greenness and durability could reduce long-term costs by eliminating the need for the replacement of non-obsolescent structures and thereby reduce the environmental impact. In this connection, geopolymers promise to have a great potential for greenness and durability.

LITERATURE REVIEW ON MIX DESIGN

Davidovits J and Sawyer J L [1], used ground blast furnace slag to produce geopolymer binders. This type of binders patented in the USA under the title Early High-Strength Mineral Polymer was used as a

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supplementary cementing material in the production of precast concrete products. In addition, a ready-made mortar package that required only the addition of mixing water to produce a durable and very rapid strength gaining material was produced and utilized in restoration of concrete airport runways, aprons and taxiways, highway and bridge decks, and for several new constructions when high early strength was needed. Geopolymer has also been used to replace organic polymer as an adhesive in strengthening structural members. Geopolymers were found to be fire resistant and durable under UV light.

Joseph Davidovits [2], proposed a new type of concrete without Portland cement which is called as geopolymer concrete. Geopolymer, an inorganic alumina-silicate polymer, is synthesized from predominantly silicon (Si) and aluminium (Al) material of geological origin or by-product material. The chemical composition of geopolymer materials is similar to zeolite, but they reveal an amorphous microstructure. During the synthesized process, silicon and aluminium atoms are combined to form the building blocks that are chemically and structurally comparable to those binding the natural rocks. Geopolymer cements are acid resistant cementitious materials with zeolitic properties developed for the long term containment of hazardous and toxic wastes. Geopolymer cements even with alkali contents as high as 9.2% and higher, which do not generate any dangerous alkali aggregate reaction. Addition of GGBS accelerates the setting time of concrete and the improves compressive and flexural strength of geopolymer concrete.

Van Jaarsveld J GS, Van Deventer J S J and Schwartzman A, carried out experiments on geopolymers using two types of fly ash. They found that the compressive strength after 14 days was in the range of 5 – 51 MPa. The factors affecting the compressive strength were the mixing process and the chemical composition of the fly ash. A higher CaO content decreased the microstructure porosity and, in turn, increased the compressive strength. Besides, the water-to-fly ash ratio also influenced the strength. It was found that as the water-to-fly ash ratio decreased the compressive strength of the binder increased.

Palomo A, Grutzeck M W and BlancoM T [4], studied the influence of curing temperature, curing time and alkaline solution-to-fly ash ratio on the compressive strength. It was reported that both the curing temperature and the curing time influenced the compressive strength. They reported that the utilization of sodium hydroxide (NaOH) combined with sodium silicate (Na_2SiO_3) solution produced the highest strength. Compressive strength up to 60 MPa was obtained when cured at 85°C for 5 hours.

MIX DESIGN OF CONCRETE FOR TWO CASES

CASE 1

FINAL PROPORTION OF OPC CONCRETE & FINAL PROPORTIONS OF GPC CONCRETE

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	Cement	F.A	C.A	Water	Super plasticizer
Ratio	1	1.16	2.45	0.3	0.03

	Silica Fume	F.A	C.A	Water	NaOH	Na_2Sio_3	Super plasticizer
Ratio	1	1.3	3.05	0.09	0.06	0.23	0.015

AMOUNT OF METERIALS USED IN OPC & GPC COMPOSITION OF SILICA FUME

	OPC (Kg/m³)	GPC (Kg/m³)
Cement	493	_
Silica fume	_	424.62
Fine Aggregate	575	555
Coarse aggregate	1210	1295
NaOH	_	28.31
Na_2SiO_3	_	99.08
Water	133	42.46
Super plasticizer	15	12.73

CASE 2

FINAL PROPORTION OF OPC CONCRETE & FINAL PROPORTIONS OF GPC CONCRETE

	Cement	F.A	C.A	Water	Super plasticizer
Ratio	1	1.3	2.6	0.32	0.03

	Silica Fume	F.A	C.A	Water	NaOH	Na_2Sio_3	Super plasticizer
Ratio	1	1.36	3.16	0.04	0.1	0.25	0.03

AMOUNT OF METERIALS USED IN OPC & GPC COMPOSITION OF SILICA FUME

	OPC (Kg/m³)	GPC (Kg/m³)
Cement	463	_
Silica fume	_	409
Fine Aggregate	600	555
Coarse aggregate	1210	1295
NaOH	_	41
Na_2Sio_3	_	103
Water	148	16
Super plasticizer	14	13

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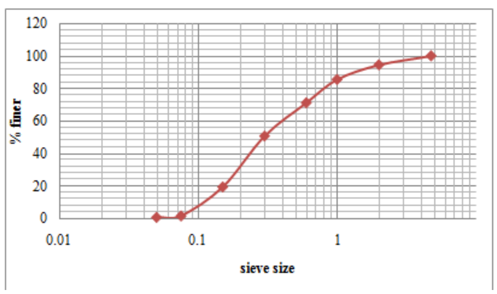
III. RESULTS AND ANALYSIS

1. TEST ON THE CEMENT :

S.No	Property	Test method	Test Result	Requirements of IS 12269-1987
1	Standard consistency	Vicat Apparatus (IS: 4031 Part - 4)	32%	–
2	Specific gravity	Sp. Gravity bottle (IS:4031 Part - 4)	3.15	–
3	Initial setting time (min)	Vicat Apparatus (IS: 4031 Part - 4)	33	Minimum 30
4	Final setting time (Hours)	Vicat Apparatus (IS: 4031 Part - 4)	8 hrs	Maximum 600
5	Specific Surface Area (m^2/Kg)	Blaine's Air permeability (IS:5516-1996)	385	Minimum 225
6	Soundness (mm)	Le-Chatlier's method (IS: 4031 Part – 3)	2	Not more than 10mm
7	Compressive strength (N/mm^2)	Compression mould (IS: 4031 Part – 6)	55	53
8	Fineness	Sieve test on sieve no.9 (IS: 4031 Part – 1)	7%	10%

2. TEST RESULTS AGGREGATES

GRADING OF FINE AGGREGATES



TESTS ON AGGREGATES

S. No	Property	Method	Fine Aggregate	Coarse Aggregate
1	Specific Gravity	Pycnometer IS:2386 Part 3 - 1986	2.6	2.66
2	Bulk Density (Kg/m^3)	IS:2386 Part 3 - 1986	1650	1780
3	Fineness Modulus	Sieve Analysis (IS:2386 Part 2 - 1963)	2.76	6.04
4	Absorption (%)	IS:2386 Part 3 - 1986	0.1	0.52
5	Moisture content (%)	IS:2386 Part 3 - 1986	0	0

SILICA FUME AND ITS PROPERTIES

S.No	Property	Test method	Test Result	Requirements of IS 15388: 2003
1	Specific gravity	Sp. Gr bottle (IS:4031 Part - 4)	1.62	-
2	Specific Surface Area (m^2/Kg)	Blaine's Air permeablity (IS:5516-1996)	18000	Minimum 15000
3	Bulk Density (Kg/m^3)	IS:2386 Part 3 - 1986	650	-
4	Physical Appearance	-	Powder form	-

TEST RESULTS ON FRESH AND HARDENED CONCRETE

1. SLUMP CONE TEST

Slump test is the most commonly used method of measuring workability of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete.

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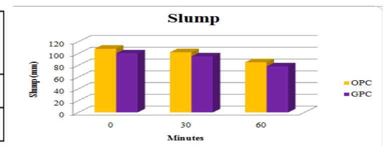
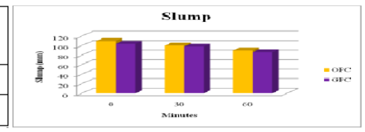
- **CASE 1**


	Slump @ 0 min	Slump @ 30 min	Slump @ 60 min
OPC	108	102	85
GPC	100	95	78



- **CASE 2**

Property	Slump @ 0 min	Slump @ 30 min	Slump @ 60 min
OPC	110	100	90
GPC	104	98	86

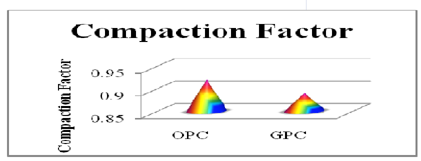


2. COMPACTION FACTOR TEST

The compaction factor test is designed primarily for use in the laboratory. It is more precise and sensitive than the slump test and is mostly useful for very low workability concrete mixes.

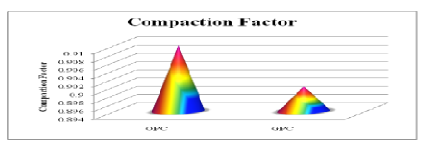
- **CASE 1**

	OPC	GPC
Compaction Factor	0.92	0.89



- **CASE2**

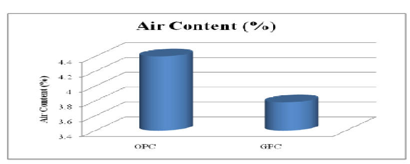
Property	OPC	GPC
Compaction Factor	0.91	0.9



3.AIR CONTENT

- **CASE 1**

	OPC	GPC
Air Content (%)	4.4	3.78



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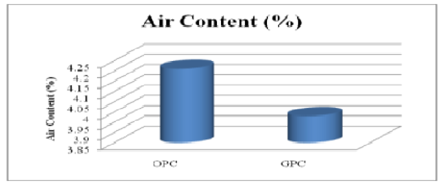
- **CASE 2**

Property	OPC	GPC
Air Content (%)	4.21	3.98



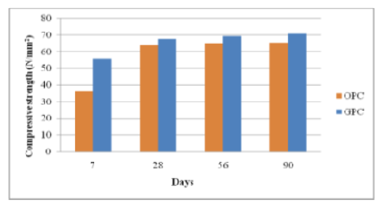
3. COMPRESSION TEST RESULTS

Compression test is the most common test conducted on hardened concrete because most of the desirable characteristic properties are qualitatively related to its compressive strength.

- **CASE 1**

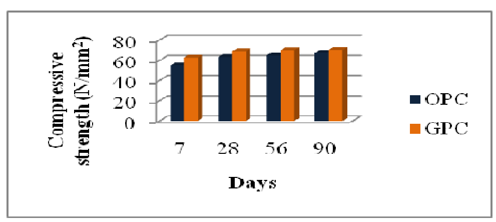
Results When Normally Cured

Days	OPC		GPC	
	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa
7	2379	36.2	2400	55.73
28	2400	63.71	2417	67.9
56	2410	64.8	2420	69.4
90	2420	65.1	2428	70.6



Results When Cured At Acclerated Temperature

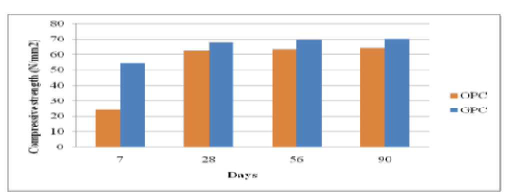
Days	OPC		GPC	
	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa
7	2380	54.9	2385	62.67
28	2409	63.21	2400	68.9
56	2415	64.66	2422	69.9
90	2423	67.38	2430	70.2



- **CASE 2**

Results When Normally Cured

Days	OPC		GPC	
	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa
7	2418	24.27	2421	54.43
28	2400	62.76	2427	67.9
56	2402	63.75	2379	69.82
90	2428	64.5	2428	70.3



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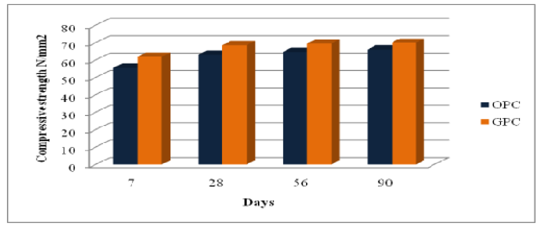
Results When Cured At Acclerated Temperature

Days	OPC		GPC	
	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa	Density (Kg/m³)	Compressive Strength N/mm² (or) Mpa
7	2388	55.77	2416	62.2
28	2414	63.27	2411	68.58
56	2429	64.85	2419	69.5
90	2410	66.2	2431	70.14

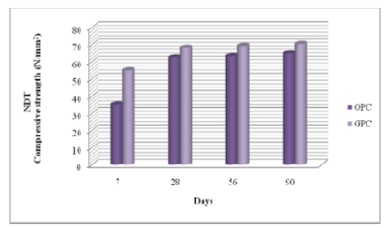


4. NON DESTRUCTIVE TEST RESULTS

The rebound hammer is a surface hardness tester for which an empirical correlation has been established between strength and rebound number.

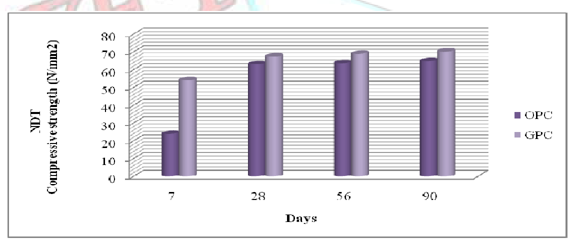
- **CASE 1**

Days	OPC		GPC	
	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa
7	2369	35.23	2361	55
28	2390	62.66	2402	68.22
56	2410	63.4	2420	69.3
90	2413	64.9	2432	70.4



- **CASE 2**

Days	OPC		GPC	
	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa	Density (Kg/m³)	Compressive strength N/mm² (or) Mpa
7	2360	23.96	2361	54.1
28	2400	63.01	2402	67.41
56	2412	63.7	2412	68.94
90	2432	64.8	2437	70.2



5. SPLIT TENSILE TEST RESULTS

In split tensile test the loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load.

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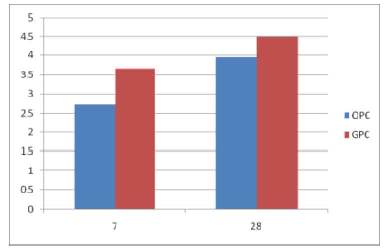
- **CASE 1**

Concrete Cured At Normal Conditions

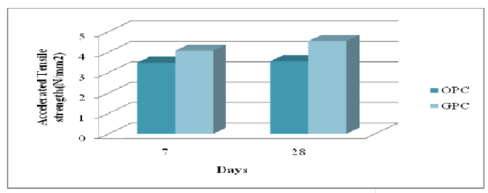

Days	OPC		GPC	
	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa
7	2420	2.71	2425	3.94
28	2456	3.66	2480	4.48



- **CASE 1**

Concrete Cured At Acclerated Temperature

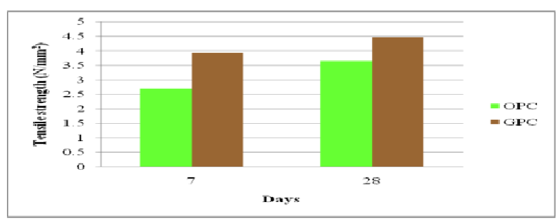
Days	OPC		GPC	
	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa
7	2430	3.49	2444	4.12
28	2455	3.8	2465	4.63



- **CASE 2**

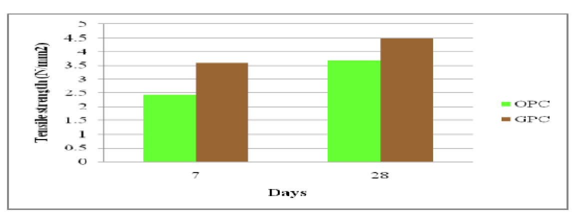
Concrete Cured At Normal Conditions

Days	OPC		GPC	
	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa
7	2440	2.44	2428	3.59
28	2462	3.7	2475	4.5



Concrete Cured At Acclerated Temperature

Days	OPC		GPC	
	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa	Density (Kg/m³)	Tensile strength N/mm² (or) Mpa
7	2473	3.48	2478	4.07
28	2468	3.55	2461	4.54



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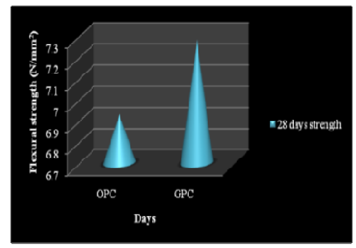
6. FLEXURAL STRENGTH

Flexural strength is the measure of modulus of rupture. The systems of loading used in finding out the flexural strength are central point loading and third point loading.

- **CASE 1**

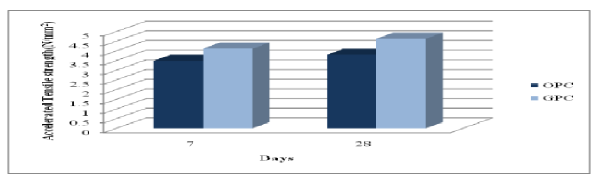
Cured Normally

Days	OPC	GPC
	Flexural strength N/mm^2 (or) Mpa	Flexural strength N/mm^2 (or) Mpa
28	6.93	7.28



Cured At Acclerated Temperature

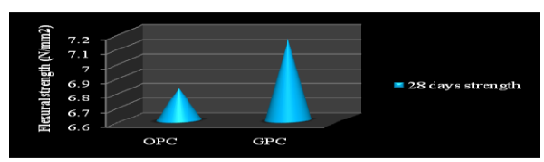
Days	OPC	GPC
	Flexural strength N/mm^2 (or) Mpa	Flexural strength N/mm^2 (or) Mpa
28	6.41	6.98



- **CASE 2**

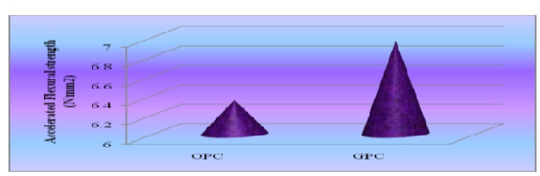
Cured Normally

Days	OPC	GPC
	Flexural strength N/mm^2 (or) Mpa	Flexural strength N/mm^2 (or) Mpa
28	6.82	7.16



- ### *Cured At Acclerated Temperature*

Days	OPC	GPC
	Flexural strength N/mm^2 (or) Mpa	Flexural strength N/mm^2 (or) Mpa
28	6.35	6.96



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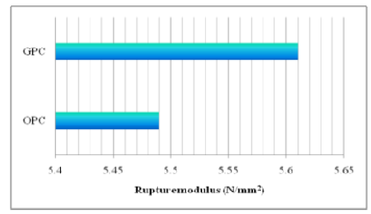
7. RUPTURE MODULUS

Rupture Modulus is a measure of the ultimate strength of the breaking load by unit area of the specimen, as determined from bending and compression test.

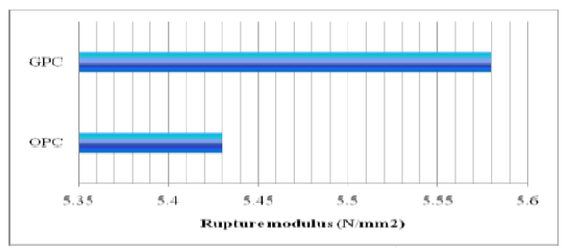
- **CASE 1**

	DENSITY (Kg/m3)	COMPRESSIVE STRENGTH N/mm² (or) Mpa	RUPTURE MODULUS (0.7√fck) N/mm² (or) Mpa
OPC	2478	61.58	5.49
GPC	2392	64.42	5.61



- **CASE 2**

	Density (Kg/m³)	Compressive Strength N/mm² (Or) Mpa	Rupture Modulus (0.7√f_{ck}) N/mm² (Or) Mpa
OPC	2478	60.45	5.43
GPC	2392	63.56	5.58

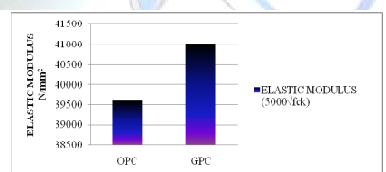


8. ELASTIC MODULUS

Elastic modulus is a mechanical property of linear elastic solid materials. It defines the relationship between stress and strain in the material.

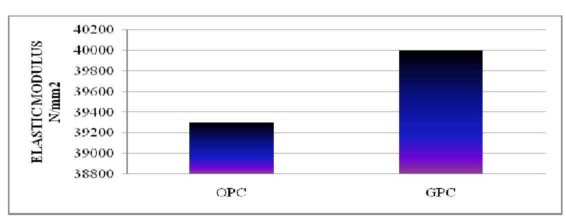
- **CASE 1**

	DENSITY (Kg/m3)	COMPRESSIVE STRENGTH N/mm² (or) Mpa	ELASTIC MODULUS (5000√fck) N/mm² (or) Mpa
OPC	2419	63	0.396 X 10⁵
GPC	2428	68	0.41 X 10⁵



- **CASE 2**

	Density (Kg/m³)	Compressive Strength N/mm² (Or) Mpa	Elastic Modulus (5000√f_{ck}) N/mm² (Or) Mpa
OPC	2419	62	0.393 X 10⁵
GPC	2428	67	0.4 X 10⁵



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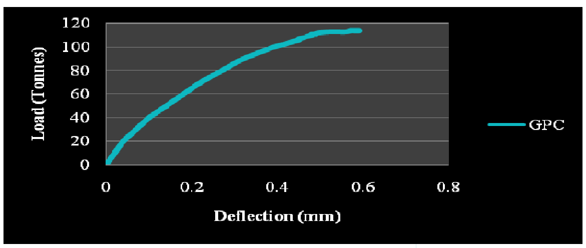
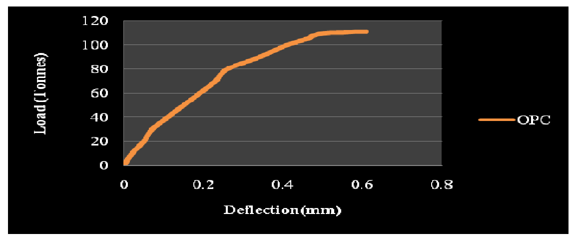
9. STRESS STRAIN PARAMETER RESULTS

Modulus of elasticity of concrete is a very important property to determine the deflection of the structural elements.

- **CASE 1**

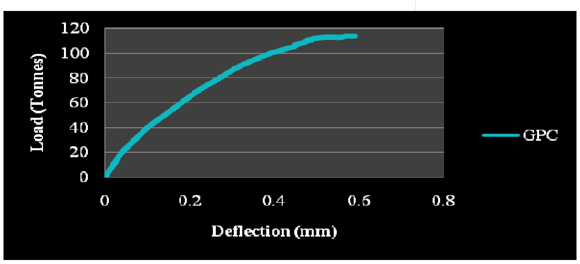

	STRESS--(6) (N/mm²)			STRAIN---(e)			
	Load (Tonnes)	Area (mm²)	Compressive Stress N/Mm² (Or) Mpa	Change In Length (mm)	Original Length (mm)	Strain	Youngs Modulus (N/mm²)
OPC	108	17671.45	60.2	0.49	300	0.00162	0.372 X 10⁵
GPC	114	17671.45	63.16	0.49	300	0.00163	0.386 X 10⁵

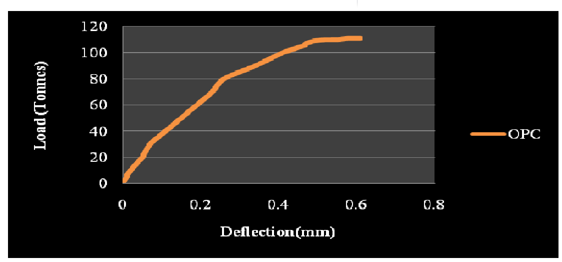




- **CASE 2**

	STRESS--(6) (N/mm²)			STRAIN---(e)			
	Load (Tonnes)	Area (mm²)	Compressive Stress N/Mm² (Or) Mpa	Change In Length (mm)	Original Length (mm)	Strain	Youngs Modulus (N/mm²)
OPC	108	17671.45	60.2	0.49	300	0.00162	0.372 X 10⁵
GPC	114	17671.45	63.16	0.49	300	0.00163	0.386 X 10⁵





IV.CONCLUSIONS

The project achievements are as follows:

- The Slump of GPC is almost satisfying the slump of OPC.
- As the compaction factor is satisfying the workability conditions we can replace the usage of OPC with GPC.
- Air content of GPC is reducing; it is more beneficial to the property of hardened concrete in terms of durability.

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- The high amount of strength in shorter period is obtained by GPC when compared to OPC.
- GPC does not require accelerated curing conditions in order to attain early high strength which is different from OPC condition.
- From the comparison of OPC & GPC in both normal and accelerated curing conditions it is concluded that GPC is attaining higher strength than OPC.
- Both the concretes have been satisfied the proposed elastic modulus values.
- The rupture modulus values obtained for OPC & GPC are satisfactory.
- The value of elastic modulus obtained from the 28 days characteristic strength and the value of young's modulus from load-deflection curve are almost similar for both the concretes.

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