

# Strength Assessment on Geopolymer Concrete using Ceramic Waste Powder and M-Sand

S.Kavipriya, D.Dhavashankaran, M.Vijay

**Abstract:** The use of abundantly available wastes such as Fly ash and ceramic powder in construction industry in the form of geopolymer concrete turns out to be the search of a very promising building material for a sustainable future[15]. This study has been undertaken to investigate the strength and durability properties of geopolymer concrete by adding ceramic powder in different percentage as source material in addition with flyash[16]. All investigations are mainly focused towards geopolymer concrete mainly with flyash as source material. In this study, ceramic waste powder is added since it is also one of the major waste material as flyash. Nowadays, almost all the construction are carried out with ceramic products which results with more ceramic waste powder. Thus this work focused to utilize this waste powder into geopolymer concrete. Characteristic strength and primary durability properties are carried out by adding ceramic powder with 50%,40% and 30% with fly ash. Thus this paper focuses on varying the proportions of fly ash and ceramic waste powder (50:50, 60:40, 70:30) in geopolymer concrete incorporating with polypropylene fibres in percentage of 0.5%,0.75% and 1% in volume of concrete to evaluate its strength and durability characteristics. The alkaline activator solution used is a mixture of 10 molar Sodium hydroxide and Sodium silicate in the ratio 1:3. Ambient curing condition is applied for the specimens. M-Sand is used instead of fine aggregate, since many literature reveals addition of M-Sand gains more strength in geopolymer Concrete.

**Keywords :** CC-Conventional Concrete, CWP-Ceramic Waste Powder, GPC-Geopolymer Concrete, FA-Flyash, M-Sand-Manufacture Sand.

## I. INTRODUCTION

Geopolymer is synthesized by mixing aluminosilicate-reactive material with strong alkaline solutions, such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate or potassium silicate. [17]The mixture can be cured at room temperature. When fly ash comes in contact with highly alkaline solutions like sodium hydroxide or sodium silicate, it forms an inorganic alumina-silicate polymer product yielding polymeric Si-O-Al-O bonds known as Geo-polymer. The most commonly used alkaline activators are NaOH, since sodium based solutions were cheaper than Potassium based solutions[5]. Research says that, the mechanical strength of the mortar increases when sodium silicate is added to sodium

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hydroxide compared to using only sodium hydroxide[4]. Also, the compressive strength of fly ash based geopolymer concrete can be improved by either increasing the molar concentration or by increasing the mass ratio of sodium silicate to sodium hydroxide. Comprehensively, geopolymer concrete provides excellent engineering properties that make them suitable for structural applications and has proven to be the best replacement for cement concrete.

## II. MATERIAL PROPERTIES

**Flyash:** As per ACI Committee 116 fly ashes are the small particles collected by deducting of coal burning power plants.[11] For the present investigation fly ash using was conformation to ASTM class F and the properties of flyash and ceramic waste powder are mentioned in table.I

**Table-I: Properties of Flyash and Ceramic Waste Powder**

	Properties	Values
Flyash	Specific gravity	2.87
	Bulk density g/cc	1.20
	Finesses m <sup>2</sup> /kg	290
	Colour	Grey
Ceramic Waste Powder	Specific gravity	2.76
	Bulk density g/cc	1.45
	Finesses m <sup>2</sup> /kg	310
	Colour	Grey

**Ceramic waste powder:** It consists of angular particles similar to cement and it is mainly consists of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>. Ceramic waste powder is generated by crushing and grinding the ceramic waste generated during the production of ceramic tiles.[2] The chemical composition of ceramic waste powder is shown in table II and it is shown in "Fig.1"



**Fig.1.Ceramic Waste Powder**

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**Table-II: Chemical Properties of Ceramic Waste Powder**

Constituents	Percentage by mass
Silica dioxide (SiO <sub>2</sub> )	66.57%
Aluminum Oxide (Al <sub>2</sub> O <sub>3</sub> )	21.60%
Iron Oxide (Fe <sub>2</sub> O <sub>3</sub> )	1.41%
Calcium Oxide (CaO)	2.41%
Sodium Oxide (Na <sub>2</sub> O)	1.41%
Potassium Oxide (K <sub>2</sub> O)	2.79%
Zirconium Oxide (ZrO <sub>2</sub> )	1.49%

**Sodium Silicate Solution:** Generally sodium silicate is known as water glass or liquid glass available in liquid form. It is used as raw material in detergents, pulp and paper ceramic industry and manufacture of titanium di oxide[11]. The weight ratio of SiO<sub>2</sub> to NaOH is 3.0 and the chemical properties of sodium silicate is presented in table.III.

**Table-III: Chemical Properties of Sodium Silicate Solution**

Chemical Formula	Na <sub>2</sub> SiO <sub>3</sub>
Na <sub>2</sub> O	14.70%
SiO <sub>2</sub>	29.40%
Water	55.90%
Appearance	Liquid (Gel)
color	Light Yellow
Specific Gravity	1.57

**Sodium hydroxide:** It is available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance[1]. The geopolymer concrete is homogeneous and its man process is to activate sodium silicate, so it is recommended to use sodium hydroxide with marginally lower cost. Assay is purity of the solution as given by the manufacturer and "Fig.2" represents pellets of sodium hydroxide and Table.IV shows the chemical properties of sodium hydroxide.



**Fig.2. Sodium Hydroxide**

**Table-IV: Chemical Properties of Sodium Hydroxide**

Chemical Formula	NaOH
Appearance	Pellets
Color	White color
Specific Gravity	1.16
Assay	97% Min

**Polypropylene fibers:** According to ASTM C-1116 fibres

are used in the construction industry as a secondary reinforcement to arrest cracks, to increase impact resistance and abrasion and also to improve the quality of construction and the life span of the concrete fibres are added into the concrete[3]. These are inorganic fibres with monofilament in shape of 12mm standard length and 18micron diameter with specific gravity 0.91.

**Manufacture Sand:** (M-Sand) is a substitute of river sand for concrete construction. Manufactured sand is produced from hard granite stone by crushing[10]. The crushed sand is of cubical shape with grounded edges, washed and graded to as a construction material. As per IS 383-1970 the size of manufactured sand (M-Sand) is less than 4.75mm and Table.V represents the properties of coarse aggregate and manufacture sand.

**Table-V: Properties of Coarse aggregate and M-Sand**

Properties	Coarse aggregate	M-Sand
Specific gravity	2.7	2.6
Bulk density(Kg/m <sup>3</sup> )	1780	1670
Fineness modulus	5.85	2.7
Water absorption	1.20%	0.50%
Source	Crushed granite stone	Granite quarry

## III. MIX PROPORTION

M35

Fly Ash: 550 kg/m<sup>3</sup>

Ceramic Waste Powder: 480.29 kg/m<sup>3</sup>

M-Sand: 491.56 kg/m<sup>3</sup>

Coarse aggregate: 827.85 kg/m<sup>3</sup>

Na<sub>2</sub> SiO<sub>3</sub> = 206.25 kg/m<sup>3</sup>

NaOH = 27.5 kg/m<sup>3</sup>

Water = 53.69 kg/m<sup>3</sup>

Molarity of Sodium hydroxide : 10M

Ratio of fly ash to sodium silicate solution: 0.75

Ratio of sodium hydroxide to sodium silicate solution : 3

**Designations:**

P1: 50% of flyash + 50% of ceramic waste powder.

P2: 60% of flyash + 40% of ceramic waste powder.

P3: 70% of flyash + 30% of ceramic waste powder.

P1(0.5): 0.5% addition of Polypropylene Fibres in P1

P2(0.5): 0.5% addition of Polypropylene Fibres in P2

P3(0.5): 0.5% addition of Polypropylene Fibres in P3

P1(0.75): 0.75% addition of Polypropylene Fibres in P1

P2(0.75): 0.75% addition of Polypropylene Fibres in P2

P3(0.75): 0.75% addition of Polypropylene Fibres in P3

P1(1.0): 1.0% addition of Polypropylene Fibres in P1

P2(1.0): 1.0% addition of Polypropylene Fibres in P2

P3(1.0): 1.0% addition of Polypropylene Fibres in P3

IV. METHODOLOGY

**Sieve Analysis :** A sieve analysis is a practice used to access the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular material including sand, crushed rocks, clays, granite, feldspars, coal, soil and Table.VI shows the particle size distribution of M-Sand.

Table-VI: Particle Size Distribution of M-Sand

S. No	Aperture size of sieve (mm)	Wt of soil retained (gm)	% of Weight retained	Cumulative percentage retained	% of finer	Zone 2
1	4.75 mm	64	12.85	12.85	87.15	90-100
2	2.36 mm	14	2.81	15.66	84.34	75-100
3	1.18 mm	230	46.18	61.84	38.16	55-90
4	1 mm	20	4.01	65.85	34.15	45-70
5	0.600mm	116	23.29	89.14	10.86	35-59
6	0.300mm	54	10.84	99.98	0.02	8-30
7	0.150mm	0	0	99.98	0.02	0-20
8	0.075mm	0	0	99.98	0.02	0-15

**Workability:** A slump test is a method used to determine the consistency of concrete. The consistency, or stiffness, indicates how much water has been used in the mix. The stillness of the concrete mix should be matched to the requirements for the finished products quality[14]. The concrete slump test is used for the measurement of a property of a fresh concrete. The test is an empirical test that measures the workability of fresh concrete. More specifically, it measures consistency between batches.

**Water absorption:** Water absorption capacity of geopolymer concrete is an important property of concrete and determines the porosity of the concrete. This test also measures the capillary rise of geopolymer concrete.

Concrete cube samples of size 100 x 100 x 100mm are casted and cured for 28days for testing. Wash the samples in deionized water before beginning this test dry the samples in oven for 24 hours at 60° C then weigh them and dry them. Repeat until mass of all samples are constant.

Submerge the samples in deionized water and at constant time intervals take them out and weigh them. Repeat the process until all samples weight remains unchanged and the test results of water absorption percentage of different mixes at every 15 mins.

**Compressive Strength Test:** One of the important properties of concrete is its strength in compression. The strength in compression has definite relationship with all other properties of concrete[13]. The aim of these experimental tests is to determine the maximum load carrying capacity of test specimen.

Mix proportions were casted with the mix of 50 : 50, 60 : 40, 70 : 30. Polypropylene fibres are incorporated in all mixes at 0.5%,0.75% and 1% with all trial mixes of above

percentage with respect to volume of concrete respectively. Cubes of size 150 x 150 x 150 mm were casted and cured at ambient temperature and tested for 7 and 28 days strength.

**Procedure**

- ❖ The specimen was taken after 7 days and 28 days of ambient curing.
- ❖ The specimen was placed in compression testing machine in such a Lo that the load was applied in casted surface.
- ❖ The load was applied in uniform rate until the sample gets failed then the load at failure has been noted.

Compressive strength = Failure load / Cross sectional area of the cube.

**Flexural Strength Test:** Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending[6]. The results of flexural test on concrete expressed as a modulus of rupture which denotes as(MR) in MPa.

Mix proportions were casted with 50:50, 60:40, 70:30. Using prisms of size 100 x 100 x 500 mm and fibres are added in different percentage with 0.5%,0.75%,1% with respect to volume of concrete respectively and tested for its 7 and 28 days strength with curing under ambient temperature.

**Procedure**

- ❖ The specimen was taken after 7 days and 28 days of ambient curing.
- ❖ The specimen was placed in flexural testing machine in three point load configuration.
- ❖ The load was applied in uniform rate until the sample gets failed then the load at failure has been noted.

$$MR=3PL/2bd^2$$

MR: Modulus of rupture

P: Ultimate applied load indicated by testing machine

L: Span length

b: Average width of the specimen at the fracture

d: Average depth of the specimen at the fracture



Fig.8.Flexural Strength test

V. RESULTS AND DISCUSSION

**Workability:** The test is Popular due to simplicity of apparatus used and simple procedure and all the mass and slump values are shown in table.VII."Fig.3" and "Fig.4" shows the mass and slump values of all different mixes of GPC specimens[9].

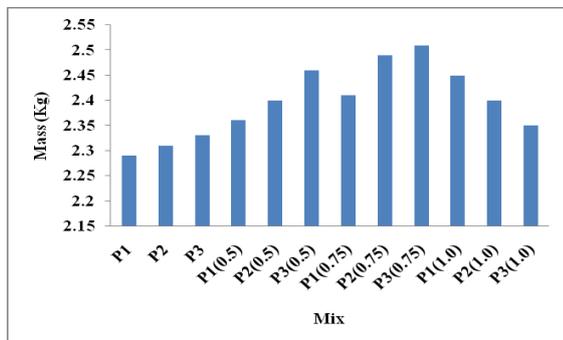


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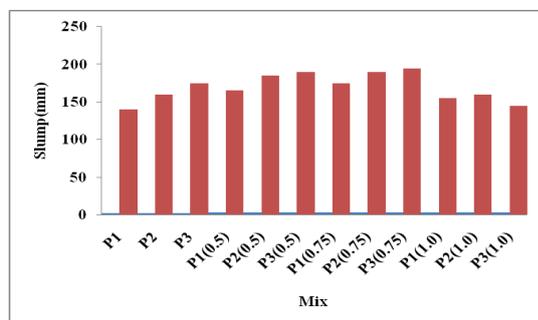
The mass density of specimens gets increased when the percentage of ceramic waste reduced. The mass density values reduced due to more fineness of ceramic waste powder compared to flyash. And when fibres are added into the mix the density of specimens gets increased upto 0.75% addition of fibres. When further 1% of polypropylene fibres are added the mass value of specimens again gets reduced. Also the slump values of specimens increased in reduction of percentage of ceramic waste powder. Further addition of fibres increases the slump of specimens upto 0.75% and at 1% the slump value gets reduced due to incorporation of more percentage of fire content into the concrete. The maximum slump value attained by adding 0.75% of fibres in 70:30 combination of flyash and ceramic waste powder.

**Table-VII: Mass and Slump Values of different Mixes.**

Mix	Mass (kg)	Slump (mm)
P1	2.29	140
P2	2.31	160
P3	2.33	175
P1(0.5)	2.36	165
P2(0.5)	2.40	185
P3(0.5)	2.46	190
P1(0.75)	2.41	175
P2(0.75)	2.49	190
P3(0.75)	2.51	195
P1(1.0)	2.45	155
P2(1.0)	2.40	160
P3(1.0)	2.35	145



**Fig.3. Mass of all mixes**



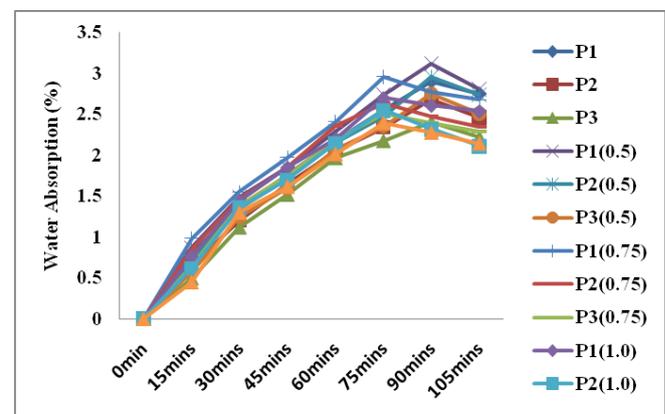
**Fig.4. Slump Values of all mixes**

**Water absorption:** The results are shown in table. VIII. "Fig.5" shows the water absorption percentage plot of all mixes. Water absorption capacity of all specimens are calculated at every 15 minutes intervals. It was observed that the water absorption percentage of specimens gets reduced when the percentage of ceramic waste powder gets decreased. Thus it clearly shows that ceramic waste powder

absorbs less water compared to flyash. And when fibres are added in to the above mix of specimens water absorption percentage gets increased in 0.5% and 0.75% whereas percentage of water absorption gets reduced when percentage of fibres are added with 1%. And at every 15 minutes interval the water absorption percentage increased upto 90 minutes for specimens cast without fibres and specimens with 0.5% whereas specimens cast with 0.75% and 1% reached its saturated stage at 75 minutes itself. The maximum water absorption capacity was achieved with 0.75% of fibres incorporated specimens with 50% of flyash and 50% of ceramic waste powder. Less water was absorbed by specimens cast with 70% of fly ash and 30% of ceramic waste powder compared to 60:40 combination.

**Table-VIII: Water absorption % of all mix specimens**

Mix	WA (%) 15 min	WA (%) 30 min	WA (%) 45 min	WA (%) 60 min	WA (%) 75 min	WA (%) 90 min	WA (%) 105 min
P1	0.80	1.35	1.76	2.18	2.56	2.90	2.75
P2	0.65	1.20	1.64	2.05	2.34	2.68	2.46
P3	0.50	1.12	1.52	1.97	2.18	2.41	2.22
P1(0.5)	0.87	1.49	1.85	2.29	2.74	3.12	2.81
P2(0.5)	0.72	1.35	1.72	2.15	2.48	2.96	2.74
P3(0.5)	0.58	1.24	1.60	2.07	2.35	2.75	2.51
P1(0.75)	0.98	1.55	1.97	2.41	2.96	2.77	2.68
P2(0.75)	0.85	1.46	1.86	2.36	2.64	2.48	2.35
P3(0.75)	0.65	1.38	1.75	2.19	2.51	2.40	2.29
P1(1.0)	0.76	1.44	1.85	2.20	2.70	2.61	2.54
P2(1.0)	0.62	1.36	1.70	2.15	2.55	2.32	2.11
P3(1.0)	0.45	1.30	1.62	2.02	2.40	2.28	2.15



**Fig.5. Water absorption percentage of different mixes.**

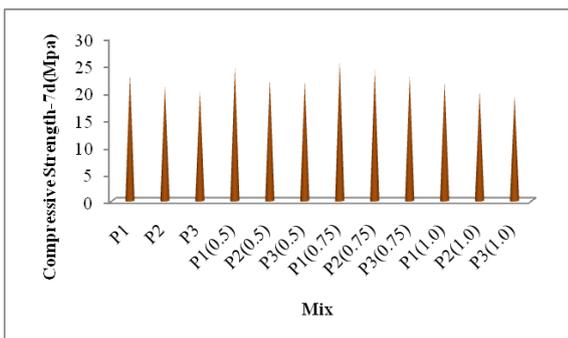
**Compressive Strength Test:** Test results of 7 days and 28 days are tabulated in table. IX.



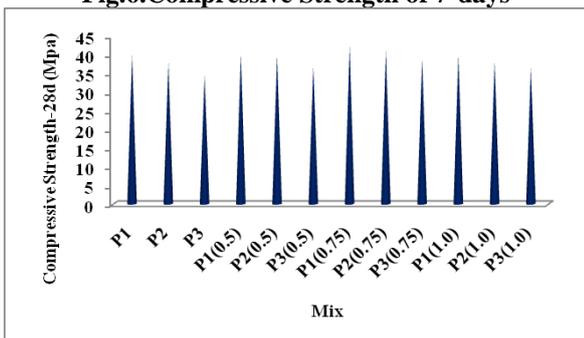
“Fig.6” and “Fig.7” shows the compressive strength of 7 days and 28 days. The strength of specimens cast with 50% of flyash and 50% of ceramic waste powder results in achieving good strength compared to 60:40 and 70:30 combination specimens. Also when fibres are added strength of all specimens increased with 0.5% and 0.75%, whereas when fibres are added more than 0.75% that is when 1% of fibres are added the results get sloped down due to addition of more fibres content. And addition of ceramic waste powder helps in achieving higher early strength in geopolymer concrete. Since ceramic waste consists of 66.57% of silica dioxide (SiO<sub>2</sub>) and 21.60% of aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) addition of ceramic waste enhance the polymerization process of geopolymer concrete. Decrease of ceramic waste percentage obviously shows decrease in percentage of strength. Similar strength results were obtained in 28 days strength also. Thus more strength was obtained with specimens cast with 50% of flyash and 50% of ceramic waste powder in addition of 0.75% of polypropylene fibres.

**Table-IX: Compressive Strength results at 7 and 28 days**

SI. No	Mix Proportion	Compressive Strength -7d (N/mm <sup>2</sup> )	Compressive Strength -28d (N/mm <sup>2</sup> )
1	P1	23.12	39.91
2	P2	21.10	37.76
3	P3	20.07	34.42
4	P1(0.5)	24.49	40.15
5	P2(0.5)	22.25	39.88
6	P3(0.5)	21.95	36.79
7	P1(0.75)	25.57	42.12
8	P2(0.75)	23.98	40.87
9	P3(0.75)	22.98	38.85
10	P1(1.0)	21.84	39.95
11	P2(1.0)	20.07	38.08
12	P3(1.0)	19.28	36.65



**Fig.6. Compressive Strength of 7-days**

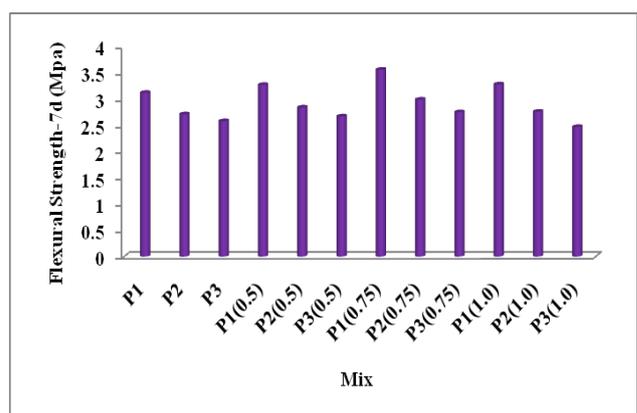


**Fig.7. Compressive Strength of 28-days**

**Flexural Strength Test:** Table.X represents the flexural strength results of 7 and 28 days. “Fig.9” and “Fig.10” shows the flexural strength results of 7 days and 28 days. Similarly compared to compressive strength flexural strength of specimen cast with 50% of flyash and 50% of ceramic waste was found to be excellent compared to other two combinations. Effective flexural strength results were obtained by using equal proportion of ceramic waste with flyash in geopolymer concrete. Since silica and alumina are the two main parameters that enhance the process of polymerization in geopolymer concrete. Good strength results were arrived in specimens with this 50% and 50% of mix proportion of flyash and ceramic waste. When fibres are added this percentage of results are enhanced in an effective way but upto certain percentage. In this experiment upto 0.75% of addition of fibres in concrete enhance the results whereas further addition of fibres in concrete reduces the process of geopolymerization. Addition of polypropylene fibres with ceramic waste produce excellent strength results in geopolymer concrete.

**Table-X: Flexural Strength results at 7 and 28 days**

SI. No	Mix Proportion	Flexural Strength -7d (N/mm <sup>2</sup> )	Flexural Strength -28d (N/mm <sup>2</sup> )
1	P1	3.10	4.57
2	P2	2.72	4.40
3	P3	2.58	4.18
4	P1(0.5)	3.27	4.71
5	P2(0.5)	2.84	4.52
6	P3(0.5)	2.67	4.37
7	P1(0.75)	3.56	4.95
8	P2(0.75)	2.99	4.76
9	P3(0.75)	2.75	4.41
10	P1(1.0)	3.28	4.60
11	P2(1.0)	2.76	4.57
12	P3(1.0)	2.47	4.32



**Fig.9. Flexural Strength at 7 days.**

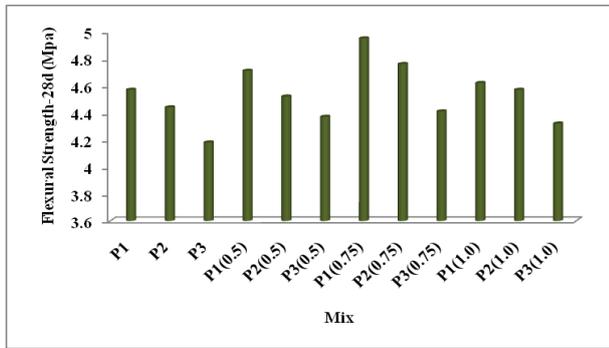


Fig.10. Flexural Strength at 28 days.

## VI. CONCLUSION

- ❖ Addition of ceramic waste powder in equal proportion with flyash (50:50) in geopolymer concrete shows good workability. Decrease of ceramic waste percentage increases the workability of geopolymer concrete.
- ❖ The mass density of specimens increases with decrease of ceramic waste content.
- ❖ Water absorption percentage of geopolymer specimens reduce with decrease in percentage of ceramic waste addition.
- ❖ Addition of 0.5% of fibres tends to reach its saturated stage of water absorption in 75minutes whereas addition of 0.75% and 1% of fibres reaches its saturation stage in 90 minutes.
- ❖ Incorporation of polypropylene fibres increases the workability, water absorption percentage upto 0.75% addition of fibres with respect to volume of concrete.
- ❖ Addition of M-Sand instead of river sand does not affects the fresh and hardened properties of geopolymer concrete.
- ❖ Ambient curing results in achieving good strength thus precast products can be cast under normal temperature itself for attaining good results.
- ❖ Specimens with 50:50 proportion of flyash and ceramic waste shows excellent compressive and flexural strength results compared to 60:40 and 70:30 mix proportions
- ❖ Addition of 0.5% and 0.75% of polypropylene fibres in geopolymer concrete achieves good strength properties compared to 1% addition of fibres.
- ❖ Thus at the end of this work, it is concluded that precast products with equal proportion of flyash + ceramic waste powder and M-Sand with 0.5%, 0.75% addition of polypropylene fibres under ambient curing achieves excellent workability and mechanical properties of geopolymer concrete.

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