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RESEARCH ARTICLE

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A STUDY ON THE STRENGTH PROPERTIES OF INORGANIC POLYMERIC NEW MATERIALS WITH GGBS AND METAKAOLIN

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ABSTRACT

The main objective of this thesis work is to study the workability and mechanical properties of Polypropylene Fibre based Geo-Polymer concrete with GGBS and Metakaolin with different proportions of Metakaolin and GGBS with Fibre and Without Fibre. The alkaline Solutions used in this thesis are Sodium Silicate and Sodium hydroxide which are commonly used and cheaply available material. The proposed investigation is carried out to study the workability and mechanical properties like Compressive strength and Split tensile strength of Metakaolin and GGBS with fibre reinforced Geo-polymer concrete. The curing is done at ambient temperature for 7 days and 28days for determining the mechanical properties.

Keywords: Geo-polymer, GGBS, Metakaolin, Polypropylene, Workability, Compressive Strength, Split Tensile Strength.

INTRODUCTION

Cement is largely used in construction industries, so it very usually linked with Global economy. [16]According to Portland cement Association nearly cement produced is around 4.0% annually in the year 2014 and it is expected that it will remain same growth of cement during 2015-2016. Portland cement concrete has developed universally in the construction industry for many years. The demand for concrete in the construction industry has increased day by day due to increase in the infrastructure development. Cement manufacturing is very high in energy and also discharges emission because of high heat produced. Hence, Portland cement concrete develops problems like discharge of carbon-di-oxide gases which in turn lead to harmful gases in the atmosphere. This will severally effect the eco-system and adds impurity to the environment. In our present construction cement is main binding material used for production of concrete. Hence by producing cement it leads to lots of CO2 in the atmosphere.CO2 is produced in two different sources. Main largest is combustion of other fossil fuels which is used to operate the rotary kiln and chemical process in which calcination of the limestone is produced in lime in the cement kiln during production CO_2.]In India the CO_2 produced in the year of 2010 is nearly 2,069,738 thousands of metric tons. 5% of total global CO_2 emission is mainly contributed due to cement industry. On the other hand, cement manufactures use raw materials to manufacture cement such as lime stone, clay and other minerals, by quarrying these raw materials lots of pollutions developed which leads to health hazards.

[08]On the other hand ground granulated blast furnace slug (GGBS) is a by-product from blast furnaces which is used in making iron which is usually operated at a temperature of 1500°C. Then the ore is melted in form of iron and the remaining material form a slag. This slag is quenched in large quantity of water. Due to this process it produces the cementitious property which is same as fine aggregates. This cementitious binder is then dried and powered finely for making GGBS. GGBS is used as replacement of cement because it enhances very less heat in hydration, give good durability and is very good in resisting the sulphate and chloride attacks.

During the present days of concrete, usage is increasing day by day for different usages of preparing and fabricating in all different shapes and sizes. Hence to avoid this problem, the environmental friendly concrete is used to reduce CO_2 in the atmosphere.

MATERIAL PROPERTIES

1 Ground Granulated Blast Furnace Slag

FIG 1 - Ground granulated blast furnace slag

GGBS is obtained from JSW industry. JSW cement gives value added GGBS, and eco-friendly product for JSW steel plants.

TABLE 1- Typical chemical properties

Parameters	Experimental value (%)	Requirement as per IS 12089 – 1987
Silica	37.73	(CaO + MgO + Al2O3) / SiO2 1.94>1
Calcium oxide	37.34	
Magnesium oxide	8.71	
Aluminium oxide	14.42	
Iron oxide	1.11	
Loss of ignition	1.41	
Insoluble residue	1.59	
Glass content	92	

TABLE 2-Typical physical properties

Sl.no	Properties	Values
1	Colour	White
2	Specific gravity	2.73
3	Fineness by using 90µ sieve	6%

3.2 METAKAOLIN

FIG 2 - METAKAOLIN

Metakaolin is obtained from Zigma international, Mumbai, whose distributors are jeetmulljaichandlall (M) Pvt Ltd., Chennai.

TABLE 3- Typical physical properties

Appearance	cremish ivory powder
Density(gm/cc)	0.366-0.45
Specific gravity	2.56
Moisture on board	Max. 0.5
Loss on ignition	<2.0%
Sieve residue on 45 micron	<0.5%

TABLE 4- Particle size analysis

d50: average particle size	2-3micron
d50: average particle size	<20 micron

TABLE 5-Typical chemical properties

SiO2+Al2O3+Fe2O3	<92%
TiO2	<1.00%
Na2O+ K2O	<1.2%
CaO+MgO	<1.0%
Loss on ignition	1.8-2.0%

TABLE 6-ASTM CODE

ASTM CODE	ASTM C-618

3.3 ALKALINE ACTIVATOR

The alkaline activators are the important solution in geo-polymer mix which is in the form of liquid. The most common used materials for preparing the alkaline activator is sodium silicate and sodium hydroxide. This solution is prepared in different molarities such as 3M, 6M, 9M, 12M etc. In general in this present topic the molarity ratio used is 9M molarity. It is recommended that alkaline activator solution should be prepared at least 24hrs before it is mixed with geo-polymer concrete.

3.4 SODIUM SILICATE

Sodium silicate can also be called as water glass or liquid glass which is in the form of gel based (liquid).

Since polypropylene fibre are used in making geo-polymer concrete, sodium silicate is recommended to be used is of lowest cost i.e., up to 92% purity.

FIG 3 - Sodium silicate

3.5 SODIUM HYDROXIDE

Usually sodium hydroxide is in form of solid which is usually in form of pellets or flakes, normally the cost of sodium hydroxide varies with the purity of the material.

FIG 4 - Sodium hydroxide

3.6 AGGREGATES

FIG 5 - Aggregates

TABLE 7- Sieve analysis for coarse aggregates (12.5 mm) as per Indian standards.

Sieve size (mm)	Weight retained in IS sieves (kg)	Percentage weight retained on each IS sieve	Cumulative percentage retained in IS sieves	Cumulative percentage passing in IS sieves
16	0.00	0.00	0.00	100.00
12.5	0.434	4.34	4.34	95.66
10	5.346	53.46	57.8	42.20
4.75	4.132	41.32	99.12	0.88
2.36	0.022	2.20	99.34	0.66
Pan	0.040	-	-	-

TABLE 8 - Gradation table.

Sieve size	Graded	Single sized
20 mm	100	100
12.5 mm	90 – 100	85 – 100
10 mm	40 – 85	0 -45

TABLE 9 - Properties of coarse aggregates (12.5 mm)

Sl. No	Properties of coarse aggregates (12.5 mm)	Results
1.	Fineness modulus	6.56
2.	Specific gravity	2.64

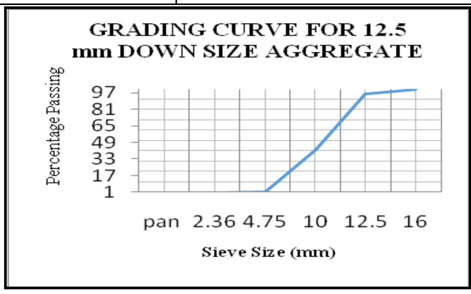

FIG 3.6- Grading curve for 12.5mm size coarse aggregate

3.7 GRANULATED BLAST FURNANCE SLAG

Fig 3.7- Granulated blast furnace slag

TABLE 3.10- Sieve analysis for fine aggregates done as per IS 383 – 1970.

Sieve size	Weight retained in IS sieve (gm)	Cumulative % retained in IS sieve	Cumulative % passing in IS sieve	Zones Different specifications as per IS 383 – 1970 for percentage passing in IS sieve			
				Zone 1	Zone 2	Zone 3	Zone 4
4.75 mm	0.00	0.00	100.00	90 – 100	90 – 100	90 – 100	95 - 100
2.36 mm	2.80	2.80	97.20	60 – 95	75 - 100	85 – 100	95 - 100

1.18 mm	13.50	16.30	83.70	30 - 70	55 - 90	75 - 100	90 - 100
600 µ	35.60	51.70	48.30	15 34	35 - 59	60 - 79	80 - 100
300 µ	18.20	83.70	16.30	5 – 20	8 - 30	12 - 40	15 - 50
150 µ	14.20	98.50	1.50	0 – 10	0 - 10	0 - 10	0 - 10
Pan	1.1	99.60	0.4	-	-	-	-

TABLE 3.11- Properties of fine aggregates

Sl. No	Properties of fine aggregates	Results
1.	Fineness modulus	2.53
2.	Specific gravity	2.65
3.	Bulk density in kg/m3	1430

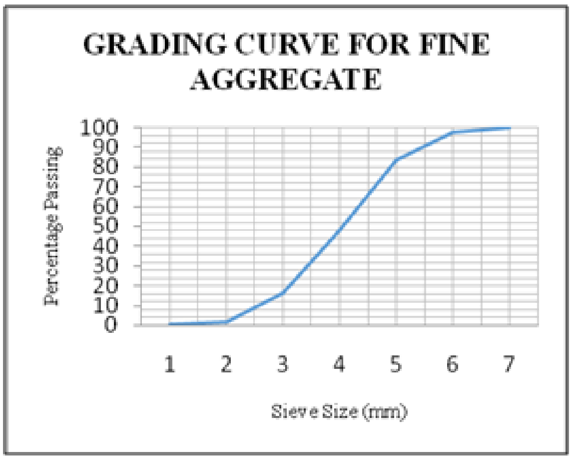

FIG 3.8-Grading curve for fine aggregate

3.8 POLYPROPYLENE FIBRE

FIG 3.9- Polypropylene fibre

In this present research work the Polypropylene fibre is used for conducting the experiment. This fibre is used because it gives good strength and resists thermal effects than other type of fibres and also increases the compressive strength.

TABLE 12-Specifications

Type	With non-woven fabric
Cell size (mm)	9
Color	White
Density (kg/m^3)	70-80
Compressive strength (Mpa)	1.5-2.2
Shear strength (Mpa)	0.5
Effective temperature range °c	From -15 to +80
Water absorption max	0.1
Thickness (mm)	10mmµ

WORKABILITY RESULTS

The freshly prepared Geo-Polymer concrete was tested for workability. By using the slump cone apparatus the slump values were measured. Firstly, the prepared Geo-Polymer was mixed thoroughly and was filled in the slump cone in four layers. Each layer is tamped using tamping rod. Then the top layer which is over filled is levelled using tamping rod, and the slump cone is vertically lifted immediately to record the slump values.

It was observed during the slump test that the concrete was cohesive enough and glossy in appearance which is due to the presence of sodium silicate solution present in it. It was also observed that by introducing polypropylene fibre in the Geo-Polymer concrete the slump value reduces. Further increase in fibre dosage will increase the workability.

Table13-WORKABILITY

	Mix no	AA/CB	AAR	Slump (mm)	Degree of workability as per IS456:2000
GPC_1	G_1	0.45	2.5	190	Very high
	G_2	0.45	2.5	230	Very high
	G_3	0.45	2.5	250	Very high
	G_4	0.45	2.5	260	Very high
	G_5	0.45	2.5	270	Very high
	G_6	0.45	2.5	170	Very high

GPC_2	G_7	0.45	2.5	230	Very high
	G_8	0.45	2.5	240	Very high
	G_9	0.45	2.5	260	Very high
	G_{10}	0.45	2.5	260	Very high
GPC_3	G_{11}	0.45	2.5	170	Very high
	G_{12}	0.45	2.5	230	Very high
	G_{13}	0.45	2.5	230	Very high
	G_{14}	0.45	2.5	240	Very high
	G_{15}	0.45	2.5	250	Very high
GPC_4	G_{16}	0.45	2.5	150	High
	G_{17}	0.45	2.5	200	Very high
	G_{18}	0.45	2.5	210	Very high
	G_{19}	0.45	2.5	220	Very high
	G_{20}	0.45	2.5	220	Very high
GPC_5	G_{21}	0.45	2.5	130	High
	G_{22}	0.45	2.5	180	Very high
	G_{23}	0.45	2.5	190	Very high
	G_{24}	0.45	2.5	200	Very high
	G_{25}	0.45	2.5	220	Very high

MIX DESIGN CALCULATION OF ECONOMIZED GEO-POLYMER CONCRETE

In mix design of Economized geo-polymer concrete absolute volume method is followed. The optimum mix design is obtained when alkaline activator to cementitious binder ratio is 0.45 and alkaline activator ratio is 2.5, this optimum mix exhibits good slump and compressive strength.

For G_{12} mix (75% GGBS, 25% Metakaolin, 0.4% polypropylene) with slump value of 230mm.

The optimum mix design steps is as follows,

1. Consider the unit weight of Economized geo-polymer concrete same as conventional concrete i.e.; 2400 kg/m^3.
2. Total percentage of aggregates is taken as 75%, increase in total aggregates percentage decreases cementitious binder and vice-versa. As per trails done to improve the cohesiveness of mix it is taken as 75%.
3. The product of total percentage of aggregates and unit weight gives total aggregates required.0.75 × 2400 = 1800 kg/m^3.
4. The difference of unit weight and total aggregates gives cementitious binder; this cementitious binder is combination of alkaline activator and binder material.
   2400 – 1800 = 600 kg/m^3.
5. The total percentage of coarse aggregates and fine aggregates are decided as mainly depending on least void content. The product of percentage of coarse aggregates and total percentage of aggregates gives total weight of 12.5 mm coarse aggregates. The difference of total percentage of aggregates and total weight of coarse aggregates gives total weight of fine aggregates.
   Total weight of coarse aggregates = 1080 × (60 / 100) = 1080kg/m^3.
   Total weight of fine aggregates = 1800 – 1080 = 720 kg/m^3.
6. Ratio of alkaline activator to cementitious binder can be varied, as per t rails conducted it was varied from 0.4, 0.45, 0.5, 0.55, 0.6 where 0.45 was optimum value achieved (it had good workability and compressive strength). As this ratio decreases the binder content gradually increases and workability improves by decreasing this ratio.
   $\frac{\text{Alkaline activator liquid (AA)}}{\text{cementatious binder (CB)}}$=0.45
   Let us consider cementitious binder (binder material) as 'x'.

AA = 0.45 x.

But CB is combination of alkaline activator and binder material (from step 4).

AA + binder material = 600 kg/m^3.

AA + x = 600 kg/m^3.

0.45x + x = 600 kg/m^3.

x = binder material = 420 kg/m^3.

Quantity of GGBS = 0.749*420=306.6kg/m^3.

Quantity of Metakaolin = 0.249*420=96.6kg/m^3.

Quantity of Polypropylene = 0.2/100*420=0.84 kg/m^3.

7. Alkaline activator ratio is the ratio of sodium silicate to sodium hydroxide. This ratio can also be varied, as per the trails conducted it was varied from 2, 2.5, 3, and 3.5 where 2.5 was optimum value achieved. By decreasing this ratio compressive strength gradually increases and by increasing this ratio workability gradually increases.

   We know that, AA = 0.45x (from step 6).

   $\frac{sodiumsilicate}{sodiumhydroxide}$=AA=0.45 × 420 = 189 kg/m3.

   Sodium hydroxide =189 / (1 + 2.5) = 54 kg/m^3.

   Sodium silicate is achieved by subtracting AA and sodium hydroxide.

   189 – 54 = 135 kg/m^3.

   Molarity= 9M

   Quantity of sodium hydroxide per molar solution= 40

   Quantity of NaoH for 9M molarity= 360 moles

   Total Quantity of distilled water and NaoH= 1360 lts

   Quality of water for 100%= 270 lts/m^3

   Usually it is not as pure. Soo its ratio is calculated to 92%= 248.4 gm/lt

   Therefore total solids= 25%

   Therefore total liquids=75%

8. To achieve total solids in sodium hydroxide, as per the above results the total solids in sodium hydroxide was found to be 25% and liquid content was 75%.

   To find solid content in 54 kg/m3 sodium hydroxide, it is multiplied with percentage of total solids in sodium hydroxide.

   Solid content = 54*25/100 = 13.5 kg / m^3.

   Liquid content in 54 kg/m^3 is obtained by subtracting it with solid content in 54 kg/m^3 of sodium hydroxide.

   Liquid content = 54 – 13.5 = 40.5 kg/m^3.

9. It is found that sodium silicate available commercially for industrial purpose has 55.9% total liquid and 44.1% total solids.

   Liquid content in 135 kg/m^3 of sodium silicate is obtained by multiplying it with percentage of total liquid.

   Liquid content = $135 \times (\frac{55.9}{100})$ = 75.465 kg/m^3.

   Solid content in 135 kg/m^3 is obtained by subtracting it with liquid content in 135 kg/m3 of sodium silicate.

   Solid content = 135 – 75.465 = 59.535 kg/m^3.

10. Water to geo-polymer solid ratio is the ratio of liquid content in sodium hydroxide and sodium silicate to binder material (cementitious binder) and solid content in sodium hydroxide and sodium silicate.

   $\frac{water}{Geo-Polymer\ \ solids}$= $\frac{75.46+40.5}{420+59.535+13.5}$=

   0.24<0.45

   This ratio is freezed to 0.45 because for mixes having 0.45 as alkaline activator liquid to cementitious binder ratio, it was seen that water to geo-polymer solid ratio was lesser than 0.45 and for mixes with alkaline activator liquid to cementitious binder ratio = 0.45 . Hence, for mixes having water to geo-polymer solid ratio up to 0.45, there is no need of adding extra water.

   0.24 < 0.45, therefore extra addition of water is required.

11. Whereas for mixes having water to geo-polymer solid ratio below 0.45 extra water should be added, extra water required is obtained by,

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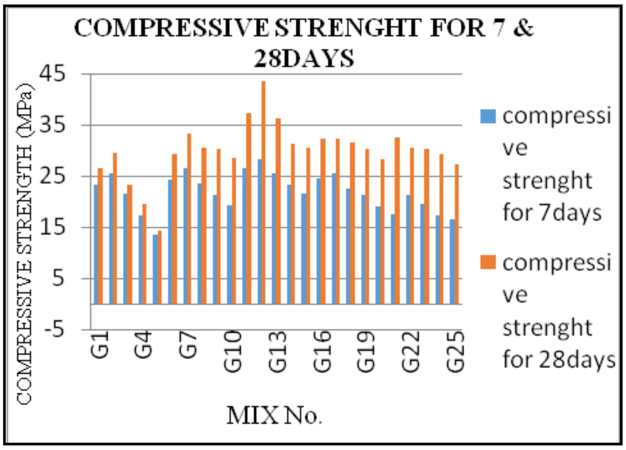
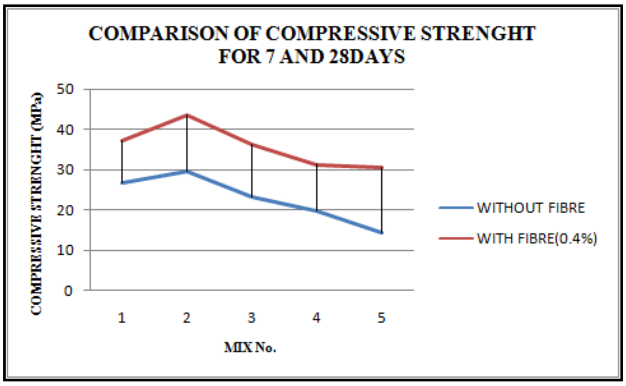
Extra Water = [(Water/Geo-polymer solids) × geo-polymer solids (binder material and solids present in sodium hydroxide and sodium silicate)] – [geo-polymer liquids (liquids present in sodium hydroxide and sodium silicate)].= 2.37 kg/m^3

RESULTS AND DISCUSSIONS

Compressive Strength Test Results

	Mix no	AA/CB	AAR	Compressive strength (MPa)	
				7 days	28 days
GPC_1	G_1	0.45	2.5	23.33	26.67
	G_2	0.45	2.5	25.67	29.67
	G_3	0.45	2.5	21.67	23.33
	G_4	0.45	2.5	17.33	19.67
	G_5	0.45	2.5	13.67	14.33
GPC_2	G_6	0.45	2.5	24.33	29.33
	G_7	0.45	2.5	26.67	33.33
	G_8	0.45	2.5	23.67	30.67
	G_9	0.45	2.5	21.33	30.34
	G_{10}	0.45	2.5	19.33	28.66
GPC_3	G_{11}	0.45	2.5	26.67	37.33
	G_{12}	0.45	2.5	28.33	43.67
	G_{13}	0.45	2.5	25.66	36.33
	G_{14}	0.45	2.5	23.33	31.33
	G_{15}	0.45	2.5	21.66	30.67
GPC_4	G_{16}	0.45	2.5	24.67	32.33
	G_{17}	0.45	2.5	25.67	32.33
	G_{18}	0.45	2.5	22.6	31.67
	G_{19}	0.45	2.5	21.29	30.33
	G_{20}	0.45	2.5	19	28.33
GPC_5	G_{21}	0.45	2.5	17.66	32.67
	G_{22}	0.45	2.5	21.33	30.67
	G_{23}	0.45	2.5	19.67	30.33
	G_{24}	0.45	2.5	17.33	29.33
	G_{25}	0.45	2.5	16.67	27.33

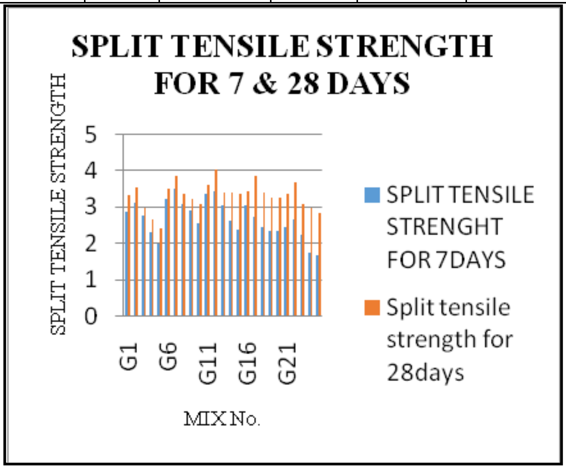


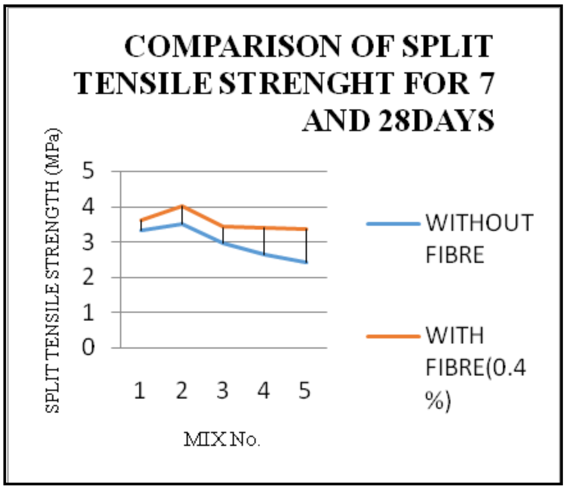


Split TensileStrength Test Results

	Mix no	AA/CB	AAR	Split Tensile strength (MPa)	
				7 days	28 days
GPC_1	G_1	0.45	2.5	2.86	3.33
	G_2	0.45	2.5	3.10	3.52
	G_3	0.45	2.5	2.76	2.96
	G_4	0.45	2.5	2.30	2.64
	G_5	0.45	2.5	2.00	2.43
GPC_2	G_6	0.45	2.5	3.23	3.48
	G_7	0.45	2.5	3.50	3.83
	G_8	0.45	2.5	3.09	3.36
	G_9	0.45	2.5	2.89	3.22
	G_{10}	0.45	2.5	2.55	3.07
GPC_3	G_{11}	0.45	2.5	3.35	3.60
	G_{12}	0.45	2.5	3.41	4.01
	G_{13}	0.45	2.5	3.05	3.40
	G_{14}	0.45	2.5	2.63	3.39
	G_{15}	0.45	2.5	2.37	3.34
GPC_4	G_{16}	0.45	2.5	3.05	3.41
	G_{17}	0.45	2.5	2.73	3.83
	G_{18}	0.45	2.5	2.45	3.39
	G_{19}	0.45	2.5	2.36	3.26

	G_{20}	0.45	2.5	2.33	3.24
GPC_5	G_{21}	0.45	2.5	2.44	3.35
	G_{22}	0.45	2.5	2.64	3.68
	G_{23}	0.45	2.5	2.25	3.07
	G_{24}	0.45	2.5	1.76	2.96
	G_{25}	0.45	2.5	1.68	2.84





CONCLUSIONS

Based on the results and discussions of Ordinary Geo-Polymer concrete and Polypropylene Fibre reinforced Geo-Polymer concrete the following conclusions were drawn

1. By trial and error method it has proved that higher concentration of sodium hydroxide results in lower strength characteristics with mixture of Metakaolin and GGBS.
2. In this present paper the alkaline liquid ratio is fixed for 2.5 and it is proved that the compressive and split tensile strength gives good results than other ratios for normal geo-polymer concrete.
3. As the water cementitious binder ratio increases the workability results effects the normal geo-polymer concrete.
4. The density of normal geo-polymer with Fibre reinforced geo-polymer concrete slightly varies with increase of fibre in concrete.
5. It has been observed that normal geo-polymer for 7days has gained the compressive strength upto 84.4% and split tensile strength upto 86.5%.
6. With the introduction of Polypropylene in the Geo-Polymer concrete has proved that the strength characteristics increases drastically than Normal Geo-Polymer concrete by
7. It has been also observed that 0.4% Polypropylene, 25% Metakaolin, and 75% GGBS has been given better results than other ratios.
8. The results proved that Normal Geo-Polymer concrete ratio to Polypropylene Fibre reinforced Geo-Polymer concrete has increased by 32% more for compressive strength and by 12% extra for Split tensile strength.
9. The increase in Metakaolin ratio has decreased the results has shown in graphs.
10. In this present research ambient curing was preferred and results were more comparative than heat curing or accelerated curing which was observed in literature review.

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