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An Experimental Study on Geopolymer Concrete with Flyash and Metakaolin as Source Materials

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Abstract: The major problem the world is facing today is the environmental pollution. In the construction industry mainly the production of Portland cement will causes the emission of pollutants results in environmental pollution. We can reduce the pollution effect on environment, by increasing the usage of industrial by-products in our construction industry. Geo-polymer concrete is such a one and in the present study, to produce the geo-polymer concrete the Portland cement is fully replaced with GGBS (Ground granulated blast furnace slag) and Metakaolin and alkaline liquids are used for the binding of materials. The alkaline liquids used in this study for the polymerization are the solutions of Sodium hydroxide (NaOH) and sodium silicate (Na2Sio3). 10Molar Sodium hydroxide is taken for the preparation of different mixes by varying the percentages of GGBS (Ground granulated blast furnace slag) and Metakaolin. The cube specimens are taken of size 150mm x 150mm x 150mm for compression test. The curing was done directly by placing the specimens to direct sunlight. The geo-polymer concrete specimens are tested for their compressive strength at the age of 3, 7 and 28days and compared with conventional concrete. For this study M30 concrete mix was used for experimental work. The result shows that there is an increase in the strength of Geopolymer concrete up to 40%GGBS content and then it is decreasing. Therefore it is preferable to use 40%GGBS with metakaolin to get high strength. Metakaolin and GGBS can be used as a replacement material for cement gives an excellent result in strength aspect and quality aspect since it is better than the control concrete.
Keywords: Geopolymer concrete, GGBS, Metakaolin, Alkaline solutions, curing, compressive strength.

I. METAKAOLIN-FLYASH BASED GEOPOYMER

In this work, Metakaolin-Fly ash based geopolymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The Metakaolin-Fly ash based Geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods.

As in the case of OPC concrete, the aggregates occupy about 75-80 % by mass, in Geopolymer concrete. The silicon and the aluminum in the Metakaolin-Fly Ash react with an alkaline liquid that is a combination of sodium silicate(A53) and sodium hydroxide solutions of different molarities like 8M to 16M can be used but in our project we have used 8M, 10M and 12M only to form the Geopolymer paste that binds the aggregates and other un-reacted materials.

II. OVERVIEW ON POZZOLANIC PROPERTY

The term pozzalona is employed to designate a siliceous and aluminous material which itself possesses no cementatious value but in presence of water, chemically react with calcium hydroxide to form compounds possessing cementatious properties .The material which having the Pozzolanic property known as Pozzolanic material. In general Pozzolanic materials are Industrial byproducts or Agricultural byproducts(waste).Pozzolanic materials are those, which produce cementatious compounds on addition of lime. Non-Pozzolanic materials are those which do not produce sufficient cementatious compounds even on addition of lime. Here lime would obtain during hydration process of cement take place.

III. MATERIALS USED IN GEOPOLYMER CONCRETE:

A. Metakaolin

Metakaolin has a great potential in concrete as cement replacement at lower cost as compared to traditionally used super pozzalona. Concrete produced with metakaolin shows similar behavior to that with one produced with silica fume. It is expected that use of Concrete admixtures, like metakaolin will grow very fast in cement, mortars and High Performance Concrete(Sabir et al., 2001; Rojas and Cabrea, 2002).

1) *Ground Granulated Blast Furnace Slag (GGBFS):* Ground Granulated Blast Furnace Slag (GGBFS) is a byproduct of the steel industry. Blast furnace slag is defined as "the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace." In the production of iron, blast furnaces

are loaded with iron ore, fluxing agents, and coke. When the iron ore, which is made up of iron oxides, silica, and alumina, comes together with the fluxing agents, molten slag and iron are produced. The molten slag then goes through a particular process depending on what type of slag it will become. Air-cooled slag has a rough finish and larger surface area when compared to aggregates of that volume which allows it to bind well with Portland cements as well as asphalt mixtures. GGBFS is produced when molten slag is quenched rapidly using water jets, which produces a granular glassy aggregate (Partha Sarathi Deba, 2003).

TYPICAL CHEMICAL COMPOSITION	
Calcium oxide	40%
Silica	35%
Alumina	13%
Magnesia	8%

TYPICAL PHYSICAL PROPERTIES	
Colour	Off-white
Specific gravity	2.9
Bulk density	1200 kg/m3
Fineness	>350m2/kg

Chemical Composition	Percentage (%)
SiO_2	62.62
Al_2O_3	28.63
Fe_2O_3	1.07
MgO	0.15
CaO	0.16
$Na_2O + k_2O$	4.03
TiO_2	0.36
Loi	2.0

Chemical composition of Metakaolin

B. FLY ASH

Fly ash is a fine, glass-like powder recovered from gases created by coal-fired electric power generation. U.S. power plants produce millions of tons of fly ash annually, which is usually dumped in landfills. Fly ash is an inexpensive replacement for Portland cement used in concrete, while it actually improves strength, segregation, and ease of pumping of the concrete. Fly ash is also used as an ingredient in brick, block, paving, and structural fills.

C. Chemical And Physical Properties Of Pozzolanic Materials

The following table gives the chemical properties of the above Materials. However, the values given here are only to appreciate the range and percentage of each of the elements contained in them.

Chemical Composition	Fly Ash (%)	GGBFS (%)	Silica Fume (%)
SiO_2	35.8 - 42.83	32.6	90.11
Al_2O_3	18.0 - 26.9	12.8	1.63
Fe_2O_3	6.5 - 8.2	1.3	1.98
MgO	3.5 - 4.1	7.2	0.78
SO_3	2.2 - 3.5	0.03	--
$Na_2O + k_2O$	--	--	1.97
P_2O_5	--	0.05	1.18
CaO	18.8 - 19.8	41.0	--
Moisture(H_2O)	0.2 - 1.9	--	--

Table 1: Chemical and physical properties of Pozzolanic Materials

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Physical property	Silica Fume	Fly Ash	Cement
SiO2 Content	85-97	35-48	20-25
Surface Area m2/kg	17,000-30,000	400-700	300-500
Pozzolanic activity (with cement%)	120-210	85-110	n/a
Pozzolanic activity (with lime%)	1,200-1,660	800-1,000	---
(MPa)	(8.3-11.4)	(5.5-6.9)	n/a

Table 2: Comparison of Chemical and Physical Characteristics - Silica Fume, Fly Ash and Cement.

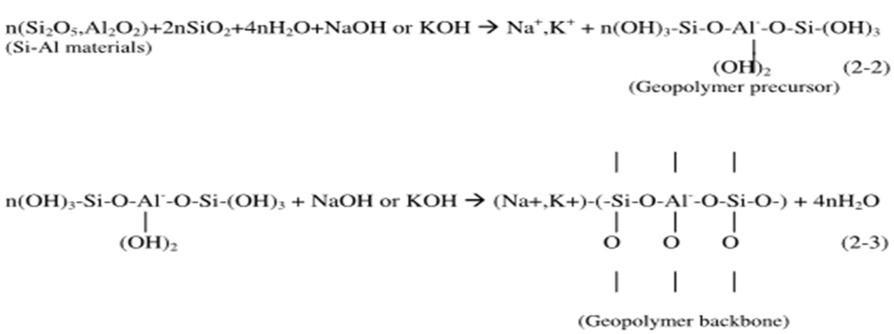
D. Geopolymers

In 1978, Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in byproduct materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, Davidovits (1994, 1999)) coined the term 'Geopolymer' to represent these binders.

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 instead of crystalline (Palomo et al. 1999; Xu and van Deventer 2000). The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, that results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows (Davidovits 1999):

$$M_n [-(SiO_2)_z–AlO_2]_n . wH_2O$$

Where: M = the alkaline element or cation such as potassium, sodium or calcium; the symbol – indicates the presence of a bond, n is the degree of polycondensation or polymerization; z is1,2,3, or higher, up to 32. The schematic formation of Geopolymer material can be shown as described by Equations (2-2) and (2-3) (van Jaarsveld et al. 1997; Davidovits 1999):



The chemical reaction may comprise the following steps (Davidovits 1999; Xu and van Deventer 2000)

1) Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
2) Transportation or orientation or condensation of precursor ions into monomers.
3) Setting or polycondensation/polymerization of monomers into polymeric structures.

However, these three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately

E. Alkaline Liquids

The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate (Davidovits 1999; Palomo et al. 1999; Barbosa et al. 2000; Xu and van Deventer 2000; Swanepoel and Strydom 2002; Xu and van Deventer 2002). The use of a single alkaline activator has been reported (Palomo et al. 1999; TeixeiraPinto et al. 2002), Palomo et al (1999) concluded that the type of alkaline liquid plays an important role in the polymerisation process. Reactions occur at a high rate when the alkaline liquid contains soluble silicate, either sodium or potassium silicate, compared to the use of only alkaline hydroxides. Xu and van Deventer (2000) confirmed that the addition of sodium silicate solution to the sodium hydroxide solution as the alkaline liquid enhanced the reaction between the source material and the solution. Furthermore, after a study of the geopolymerisation of sixteen natural Al-Si minerals, they found that generally the NaOH solution caused a higher extent of dissolution of minerals than the KOH solution.

F. Tests On Cement

Checking of materials is an essential part of civil engineering as the life of structure is dependent on the quality of material used. Following are the tests to be conducted to judge the quality of cement.

1) Fineness
2) Consistency
3) Initial And Final Setting Time
4) Soundness
5) Specific gravity

G. Preparation Of Alkaline Solution

For 10M NaoH:

10M NaoH = 10 x40 = 400 gm/lit.

Total NaoH to be mixed = 400/(sp.gravity of NaoH)
= 400/2.541
= 160 gm/lit

Assume $\frac{\text{sodium silicate}}{\text{sodium hydroxide}} = 2.5$

Na_2Sio_3 = 2.5 x NaoH
= 2.5 x 400
= 1000 gm/lit

Total Na_2Sio_3 = 1000/(sp.gravity of Na_2Sio_3)
= 1000/2.7
= 370.37gm/lit

Finally for one litre of water mix:

NaoH = 160gm/lit
Na_2Sio_3 = 370.3gm/lit

H. Mixing and Casting

It was found that the fresh Geopolymer masonry mix was grey in colour and was cohesive. The amount of water in the mix played an important role on the behavior of fresh mix.

Davidovits (2002) suggested that it is preferable to mix the sodium silicate solution and the sodium hydroxide solution together at least one day before adding the liquid to the solid constituents. The author suggested that the sodium silicate solution obtained from the market usually is in the form of a dimmer or a trimmer, instead of a monomer, and mixing it together with the sodium hydroxide solution assists the polymerization process.

Compaction of fresh concrete in the cube moulds was achieved by compacting on a vibration table for ten seconds. After casting, the specimens were left undisturbed for 24 hours. Five different mixes were developed in this study, for each mix 12 cubes of 150mm were cast to study compressive, strength of each mix.

I. Curing Method

Ambient CURING / oven curing: Water Curing is not required for these Geopolymer blocks. The heat gets liberated during the preparation of sodium hydroxide which should be kept undisturbed for one day.

For the curing geo-polymer concrete cubes, two methods are used, one by placing the cubes in hot air oven and by placing the cubes in direct sun-light.

For oven curing, the cubes are placed in an oven at 60 degrees centigrade for 24 hours. For the sun light curing, the cubes are demoulded after 1 day of casting and they are placed in the direct sun light for 3 and 7 days geopolymer concrete will gain it strength from 24 hours to 4 days only so 28 days testing will not play a vital role in knowing the strength of geopolymer concrete

The different percentages of fly ash and buff Metakaolin based Geopolymer concrete with 12 molarity alkaline solution are as follows:

MIX ID	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
METAKAOLIN (%)	100	90	80	70	60	50	40	30	20	10	0
GGBS (%)	0	10	20	30	40	50	60	70	80	90	100

For the above percentages cubes of 150mmx150mmx150mm and beams of 500mm X 100mm X100mm are casted and compressive strength and flexural strength results are compared with the conventional mix.

IV. RESULTS AND DISCUSSION

The following tabular column shows the physical Tests results of Bharathi opccement

S.no	Physical Tests	Obtained results	Requirements as per IS CODES
1	Fineness	0.026	Not>10% as per IS 4031 part 1
2	Standard Consistency	0.275	IS 4031 part 4
2	Initial Setting time	47min11sec	Not less than 30 minds as per IS 4031 part 5
3	Final setting time	498 min	Not more than 600 minutes as per IS 4031 part 5
4	Soundness	5mm	Not>10mm as per IS 4031 part 3
5	Specific gravity	3.01	IS 2720 part 3(3.15isgeneral value)

Physical Tests results of Bharathi opc cement

A. Tests On Aggregate

The following tabular column shows the physical Tests of Aggregates which were used in Geopolymer concrete.

Sl. No	Physical Tests	Obtained results	Requirements as per IS 383
1	Crushing Test	0.38	Not more than 45% (other than wearing surfaces)
2	Impact Test	0.3295	Not more than 45% (other than wearing surfaces)
3	Los Angeles Abrasion Test	0.285	Not more than 50% (other than wearing surfaces)
4	Flakiness Index	0.2012	Not > 35% as per MORTH
5	Specific gravity		
	a) Coarse Aggregates	2.8	
	b) Fine Aggregates	2.6	
6	Water absorption		Not>2%as per IS:2386-Part 3
	a) Coarse Aggregates	0.002	
	b) Fine Aggregates	0.005	

Tests Results of aggregate

B. Test Results On Conventional Concrete And Geopolymer Concrete

Compressive Strength Of Concrete Form30 Control Mix For 3,7,And 28 Days

S. No	Time(Days)	Compressive Load Kn	Compressive Strength N/Mm2	Average Strength N/Mm2
1	3	345	15.1	15.11
		350	15.2	
		355	15.26	
2	7	470	20.81	20.87
		480	21.11	
		475	21.1	
3	28	870	38.28	38.28
		870	38.28	
		860	38.22	

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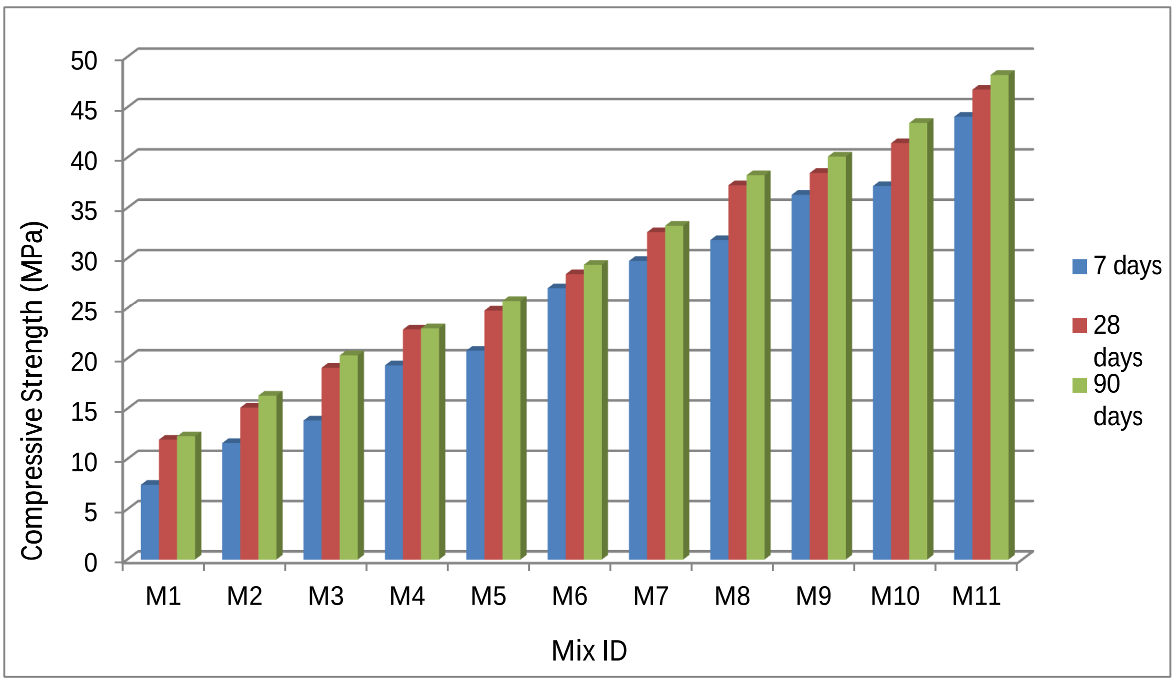
The different percentages of fly ash and buff Metakaolin based Geopolymer concrete with 12 molarity alkaline solution are as follows:

MIX ID	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
METAKAOLIN (%)	100	90	80	70	60	50	40	30	20	10	0
GGBS (%)	0	10	20	30	40	50	60	70	80	90	100

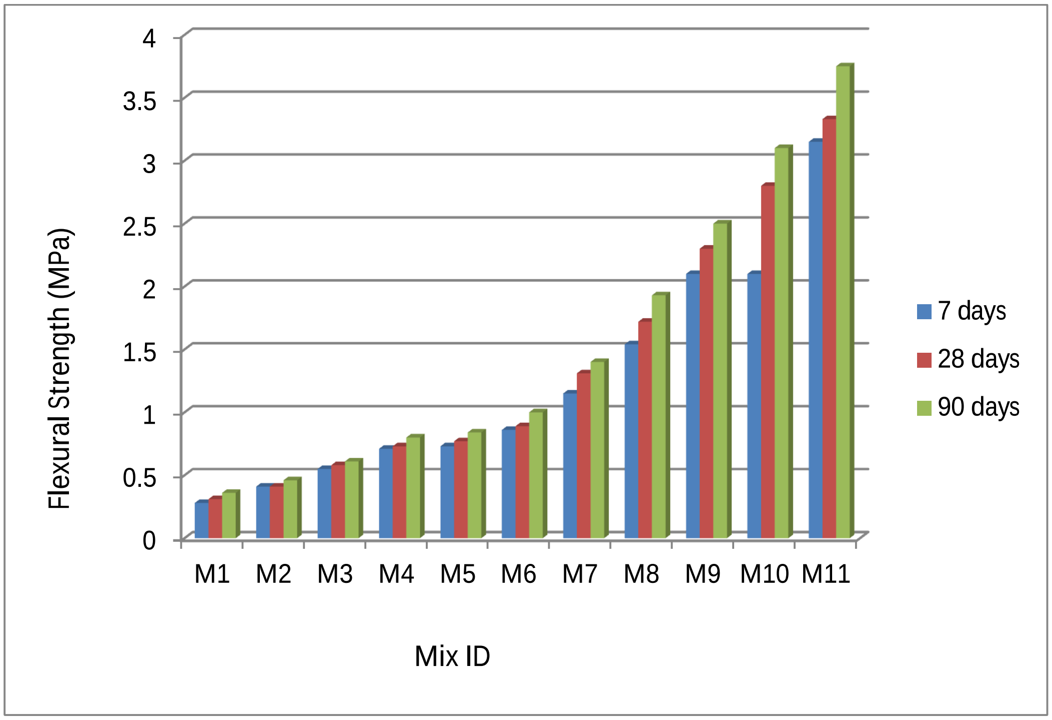
Compressive Strength of Concrete for different percentage of Fly Ash of buff Metakaolin for 3,7,14,28,56,90 days are as follows

MIX ID	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
3	4.76	8.21	10.78	13.52	17.92	18.51	23.71	29.26	30.43	32.40	34.25
7	7.43	11.58	13.83	19.31	20.77	27.02	29.73	31.81	36.30	37.17	44.06
14	9.34	13.85	15.38	21.13	22.77	29.02	31.37	31.18	38.03	39.71	46.60
28	11.92	15.11	19.07	22.88	24.76	28.42	32.59	37.25	38.47	41.43	46.74
56	12.01	16.25	20.10	22.9	25.50	29.10	33.10	38.02	39.79	42.34	47.10
90	12.25	16.30	20.30	22.99	25.75	29.35	33.23	38.24	40.10	43.43	48.20



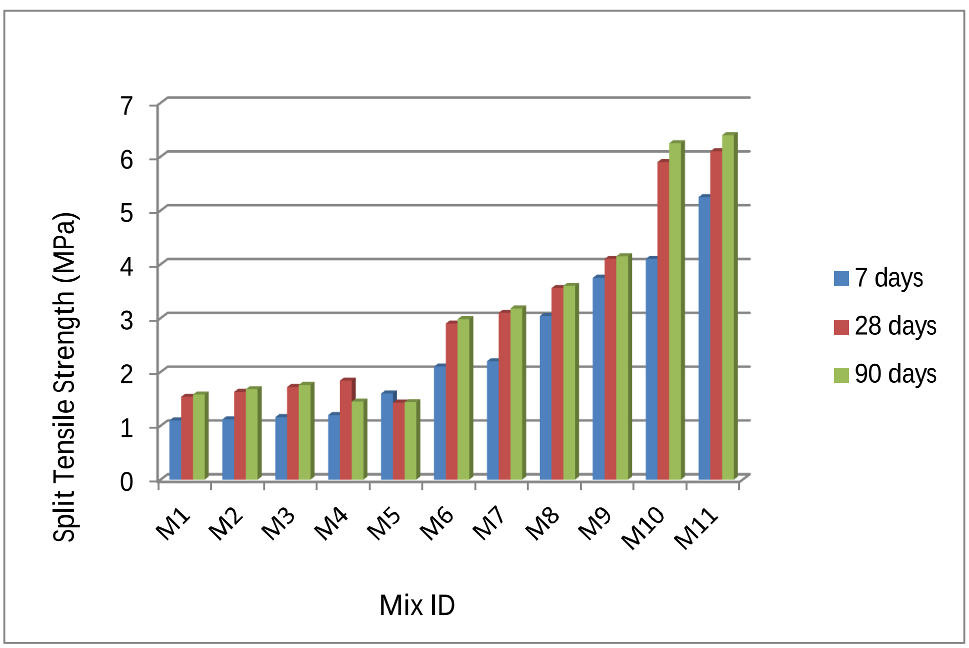
Flexural strength of Concrete for different percentage of Fly Ash of buff Metakaolin for 3,7,14,28,56,90 days are as follows

MIX ID	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
3	0.26	0.38	0.54	0.71	0.72	0.85	1.10	1.45	2.00	2.50	3.10
7	0.28	0.41	0.55	0.71	0.73	0.86	1.15	1.54	2.10	2.10	3.15
14	0.24	0.42	0.56	0.72	0.75	0.88	1.26	1.64	2.20	2.70	3.21
28	0.31	0.41	0.58	0.73	0.77	0.89	1.31	1.72	2.30	2.80	3.33
56	0.34	0.44	0.54	0.79	0.79	0.91	1.35	1.89	2.40	2.90	3.45
90	0.36	0.46	0.61	0.80	0.84	1.00	1.40	1.93	2.50	3.10	3.75



Split Tensile strength of Concrete for different percentage of Fly Ash of buff Metakaolin for 3,7,14,28,56,90 days are as follows

MIX ID	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
3	1.10	1.12	1.16	1.20	1.60	2.10	2.20	3.04	3.75	4.10	5.25
7	1.16	1.22	1.26	1.35	1.75	2.22	2.36	3.11	3.79	4.44	5.65
14	1.23	1.29	1.31	1.38	1.79	2.32	2.46	3.14	3.85	4.72	5.85
28	1.54	1.63	1.72	1.84	1.43	2.90	3.10	3.56	4.10	5.90	6.10
56	1.56	1.66	1.74	1.93	1.94	2.95	3.15	3.56	4.10	5.15	6.35
90	1.58	1.68	1.76	1.45	1.44	2.98	3.18	3.60	4.15	5.25	6.40



V. CONCLUSIONS

1) Buff colored metakaolin was activily participating in the formation of polymerization when it is used as a binding material with alkaline solution and fly ash in the preparation of geopolymer concrete
2) The compressive strength of the geopolymer concrete with metakaolin and fly ash is good when the percentage of fly ash is upto 80% beyond that the strength percentage is decreasing
3) The compressive strength of geopolymer concretewith 100% buff coloured metakaolin is increasing with increasing in the molarity of the solution
4) Combination of different percentages buff metakaolin and flyash are not significant in flexural strength point
5) Buff colored metakaolin with 8M, 10M and 12M are very weak in flexural strength
6) The percentage strength of the Geopolymer concrete is increasing with the increase in fly ash content upto 80% and then reduces, so it is preferable to use flyash upto 80% in the mixesin air dry curing, this is happening because if we use flyash we should go for oven or steam curing
7) The strength of the Geopolymer concrete increases with 2%-4% from 7 to 28 days that means there is no much increase in the strength after 4 days.
8) By using the Metakaolin and flyash as a filler or replacement in cement will reduce environmental pollution.
9) Nearly 90% of total strength of GPC is achieved with in age of 7 days.
10) The increase in total strength of GPC between 7 days and 28 days appeared to be high when compared with 3 days and 7 days.

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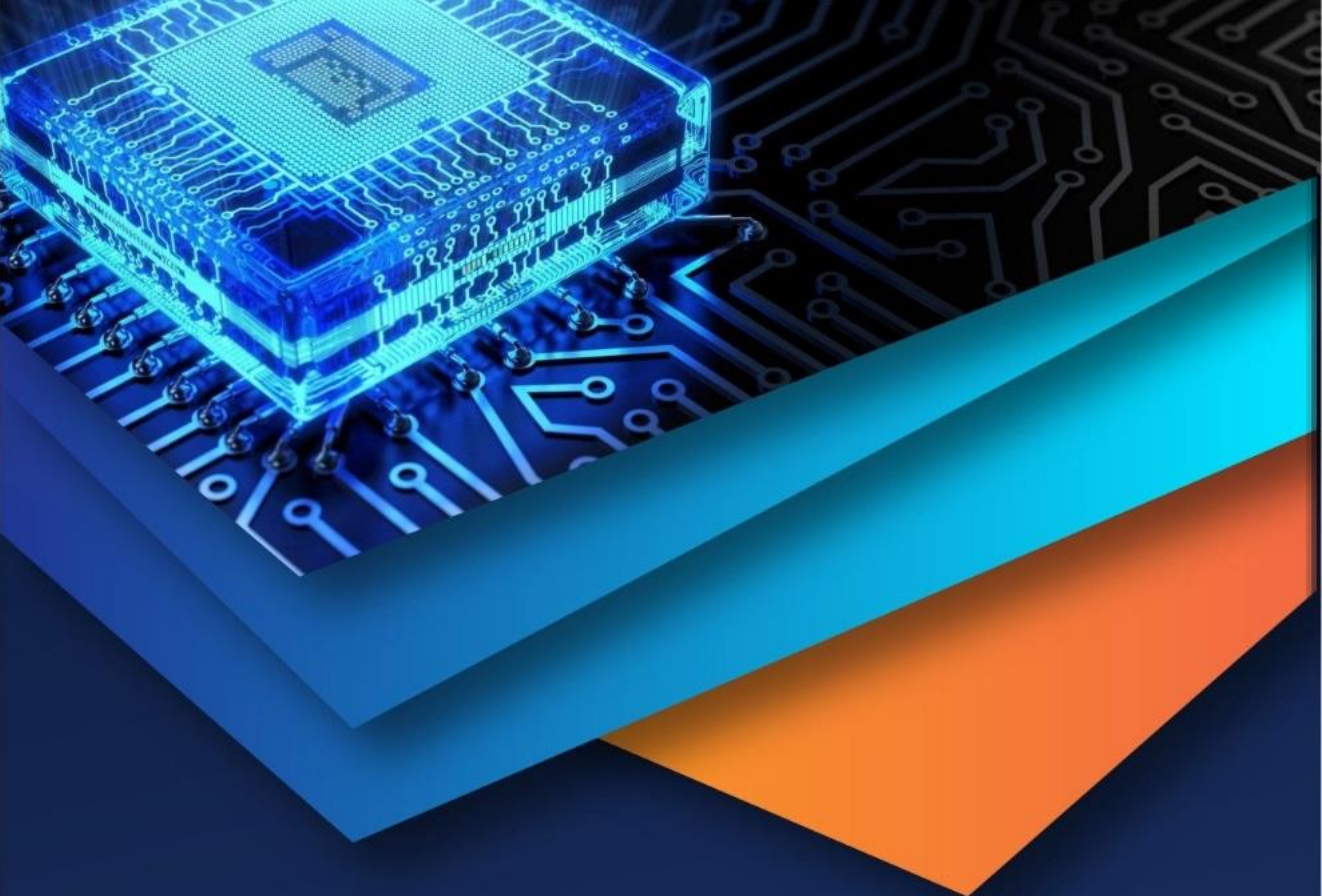

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