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Strength characteristics of Flyash and metakaolin based geopolymer concrete

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Abstract

The major problem in 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. Geopolymer concrete is such a one and in the present study, to produce the geo-polymer concrete the Portland cement is fully replaced with fly ash & metakaolin are used for the binding of materials. This paper presents the strength characteristics of Flyash and metakaolin based geopolymer concrete with different proportion of binder and molarities. The alkaline liquids used in this study for the polymerization are the solutions of Sodium hydroxide (NaOH) and sodium silicate (Na_2Sio_3). Different molarities of sodium hydroxide solution i.e. 10M, 12M and 14M are taken to prepare different mixes and the compressive strength is calculated for each of the mix. There are 60 cube specimens are taken of size 150mm x 150mm x 150mm. The Geopolymer concrete specimens are tested for their compressive strength at the age of 7days and 28 days. They are curing by oven at 60^0C for 24 hours then after ambient temperature. The test results presented in this paper show the strength of Geopolymer concrete based on fly ash and metakaolin with increase the molarities of sodium hydroxide (NaOH) and also comparable with that of Ordinary portland cement concrete.

Keywords:- ***Geopolymer concrete, PCC, Alkaline solution, NaOH, Na_2Sio_3, flyash, metakaolin, cement(OPC 43 grade), compressive strength.***

1. INTRODUCTION

Portland cement is used as binder in production of cement concrete due to its availability of the raw materials over the world, due to its ease for preparing and fabricating in all sorts of conceivable shapes. The usage of Portland cement is found to be satisfactory in most of the civil engineering structures. Each year, the concrete industry produces approximately 12 billion tons of concrete and uses about 1.6 billion tons of Portland cement worldwide. However, Portland cements are highly internal-energy intensive and cause emission of greenhouse gas, CO_2 during their production. These Portland cement based conventional concretes are found to be less durable in some of the very severe environmental conditions. The contribution of ordinary Portland cement production worldwide to greenhouse gas emission is approximately 7% of the total greenhouse gas emission to the atmosphere. It is reported that the world wide cement industry contributes about 1.65 billion tonnes of greenhouse gas emissions Annually. Due to the production of Portland cement it is estimated that by the year 2020, the CO_2 emissions will rise by about 50% from the current levels. The production of 1 ton of Portland cement consumes 1GJ energy and produces about 1 ton of carbon dioxide to the atmosphere. About half of the CO_2 emissions from Portland cement production are due to calcination of limestone and other half are due to combustion of fossil fuel.

Geopolymer concrete—an innovative material that is characterized by long chains or networks of inorganic molecules—is a potential alternative to conventional Portland cement concrete for use in transportation infrastructure construction. It relies on minimally processed natural materials or industrial by products to significantly reduce its carbon footprint, while also being very resistant to many of the durability issues that can plague conventional concrete. However, the development of this material is still in its infancy, and a number of advancements are still needed. This Tech Brief briefly describes geopolymer concrete materials and explores some of their strengths, weaknesses, and potential applications.

2. EXPERIMENTAL INVESTIGATIONS

1.1 Materials:-

The following materials have been used in the experimental study:-

2.1.1 Metakaolin:- Metakaolin is one of the most abundant natural minerals which produced by heat-treating kaolin. It is highly reactive metastable clay that is an anhydrous aluminosilicate obtained from calcining kaolin to around 650–7000C.There are physical properties are:-

Physical properties	Values
Specific gravity	2.5
Mean grain Size(μm)	2.54
Specific area cm2/gm	120000-180000
Colour	White
Physical form	powder

2.1.2 Fly Ash (Class F) collected form Sanjay Gandhi Thermal power plant Brishinghpur pali (M.P.), having specific gravity 2.21.

Table chemical composition of flyash

S. No.	Elemental oxides	Percentaage
1	SiO_2	53.14
2	Al_2O_3	25.88
3	Fe_2O_3	3.14
4	TiO_2	1.51
5	CaO	0.34
6	MgO	1.13
7	NaO_2	1.19
8	K_2O	1.22
9	SO_3	0.53
10	P_2O_5	1.65

2.1.3 Cement(OPC43 GRADE) Cement must develop the appropriate strength. It must represent the appropriate rheological behavior.

Physical Properties	Test Result
Normal consistency	29%
Initial setting time (mint.)	45mint
Final setting time (mint.)	350mint
Specific gravity	3.148
Colour	gray

2.1.4 Fine aggregate: Sand confirming to Zone of IS: 383-1970 and some other physical properties are:-

Physical Properties	Test Result
Zone of Fine aggregate	Zone-II
Specific gravity	2.66
% of moisture	0.8%
Fineness modulus	2.95
Source	Narmada River

2.1.5 Coarse aggregate: Crushed granite metal confirming to IS:383-1970 having

Physical Properties	Test Result
Specific gravity(10&20mm)	2.86
% of moisture	0.3%
Fineness modulus(10&20mm)	6.12&7.05
Source	Jabalpur

2.2 Alkaline activators:- To activate the fly ash, a combination of sodium hydroxide solution and sodium silicate solution was chosen as the alkaline activator. The sodium hydroxide used was a technical grade sodium hydroxide in pellets form with a specific gravity of 2.1, 98% purity, and obtained from LOBA chemical. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar(M).

properties of Sodium hydroxide(NaOH)

Molar mass	40gm/mol
Appearance	White solid
Density	2.1gm/cc
Mealting point	310^0C
Boiling point	1390^0C
Amount of heat liberates when dissolved in water	266cal/gm

2. Mix Design of Geopolymer Concrete:-

In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 78% of entire mixture by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire mixture by mass. Fine aggregate was taken as 35% of the total aggregates. Taking into consideration the workability, the ratio of sodium silicate to sodium hydroxide solution was kept 2.5. The density of geopolymer concrete is taken similar to that of OPC as 2400 kg/m3. The details of mix design and its proportions for different grades of GPC are given in Table .

MIX	Fly ash	MK	C.A.		F.A.	NaOH + Na_2SiO_3	ALK./ BIN.	SP.
			20MM	10MM				
GC_1	328.5	36.5	852	365	655	163	0.45	2%
GC_2	292	73	852	365	655	163	0.45	2%
GC_3	255.5	109.5	852	365	655	163	0.45	2%
GC_4	328.5	36.5	852	365	655	163	0.45	2%
GC_5	292	73	852	365	655	163	0.45	2%
GC_6	255.5	109.5	852	365	655	163	0.45	2%
GC_7	328.5	36.5	852	365	655	163	0.45	2%
GC_8	292	73	852	365	655	163	0.45	2%
GC_9	255.5	109.5	852	365	655	163	0.45	2%
CC_{10}	365		852	365	655	163	0.45	

3. Preparation, Casting and Curing of Geopolymer Concrete:-

The alkaline activator solution used in GPC mixes was a combination of sodium hydroxide solution, sodium hydroxide pellets and distilled water. The role of alkaline activator solution is to dissolve the reactive portion of source materials Si and Al present in fly ash and provide a high alkaline liquid medium for condensation polymerization reaction. To prepare sodium hydroxide solution of 10, 12, and 14 molarity (M) such as 400g, 480g, and 560g of sodium hydroxide pellets was dissolved in water. The mass of NaOH solids in a solution will vary depending on the concentration of the solution expressed in terms of molar, M. The pellets of NaOH are dissolved in one liter of water for the required concentration. When sodium hydroxide and sodium silicate solutions mixed together polymerization will take place liberating large amount of heat, which indicates that the alkaline liquid must be used after 24 hours as binding agent. Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash & metakaolin and the aggregates were first mixed together dry on pan for about three minutes. The liquid component of the mixture is then added to the dry materials and the mixing continued usually for another four minutes. The addition of sodium silicate is to enhance the process of geopolymerization. For the present study, concentration of NaOH solution are taken as 10M,12M, and 14M with varying ratio of Na_2SiO_3 / NaOH as 2.5 for all the grades of Geopolymer concrete mixes. The workability of the fresh concrete was measured by means of conventional slump test. In order to improve the workability, super plasticizer with a dosage of 2.0 % by mass of the fly ash & Metakaolin was added to the mixture. Extra water (other than the water used for the preparation of alkaline solutions) and dosage of super plasticizer was added to the mix according to the mix design details. The fly ash & Metakaolin and alkaline activator were mixed together in the mixer until homogeneous pate was obtained. This mixing process can be handled with in 10 to 15 minutes for each mixture with different ratios of alkaline solution. The entire specimen transferred to oven set at 60^0C and stored for 24 hours then after ambient temperature. Both curing time and curing temperature influence the compressive strength of Geopolymer concrete. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded procedure is similar to that of routine conventional concrete.

4. RESULTS AND DISCUSSIONS:-

5.1 Workability:-

The workability of concrete mixes was found out by slump test as per procedure. Liquid/binder ratio was kept constant 0.45 for all the concrete mixes. Super-plasticizer was used to maintain the required slump. Dosage of super-plasticizer was maintained 2% by weight of binder on all type of mix. It present the results of the effect of the molarity of alkaline activator on workability of different concrete mixes. The addition of metakolin to concrete mix increase, the workability of concrete mix was found to decrease as compared to control mix of flyash. The addition of metakaolin into concrete mix further decreases the workability. The slump value of all mix varies between 90-110.

5.2 Compressive strength:-

The results of the compressive strength tests conducted on geopolymer concrete specimens of different mixes cured at different a ges are presented,

Mix	Molarity	Discription	7 DAYS	28 DAYS
GC_1	10M	90%FA+10%MK	18.42	27.34
GC_2	10M	80%FA+20%MK	18.78	27.91
GC_3	10M	70%FA+30%MK	19.03	28.36
GC_4	12M	90%FA+10%MK	20.53	29.87
GC_5	12M	80%FA+20%MK	20.86	30.54
GC_6	12M	70%FA+30%MK	21.22	31.09
GC_7	14M	90%FA+10%MK	22.69	32.44
GC_8	14M	80%FA+20%MK	22.88	32.95
GC_9	14M	70%FA+30%MK	23.14	33.27
CC_{10}	-	OPC 43 GRADE	22.53	31.93

Where FA and MK are stands for Flyash and Metakaolin for different molarity also graphical representation of compressive strength of all mix are

I. For a mix of 90% of flyash and 10% of metakaolin, the compressive strength of geopolymer concrete increases when the molarity is increases on 7 and 28 days respectively and compare with OPC 43 grade of cement concrete.

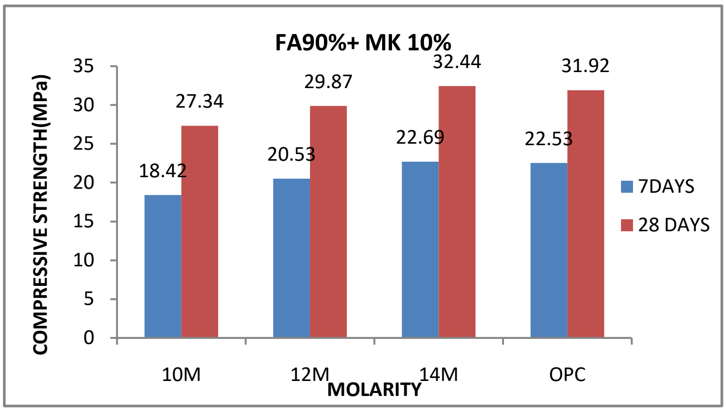

Figure 1 Compressive strength of specimens at the age of 7 and 28 days

II. For a mix of 80% of flyash and 20% of metakaolin, the compressive strength of geopolymer concrete increases when the molarity is increases on 7 and 28 days respectively and compare with OPC 43 grade of cement concrete.

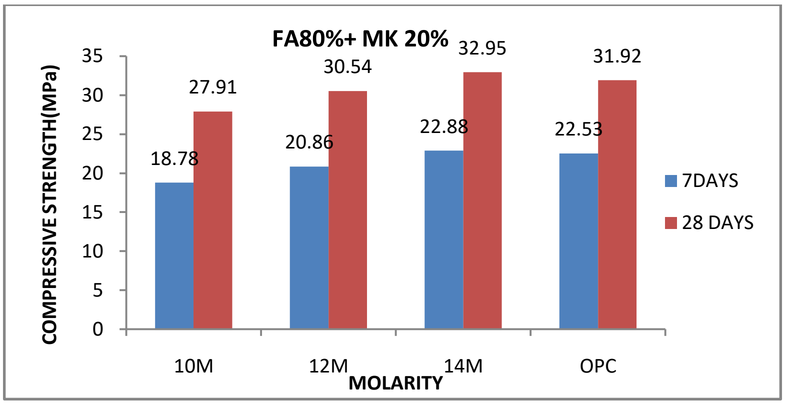

Figure 2 Compressive strength of specimens at the age of 7 and 28 days

II. For a mix of 80% of flyash and 20% of metakaolin, the compressive strength of geopolymer concrete increases respectively and compare with OPC 43 grade of cement concrete.

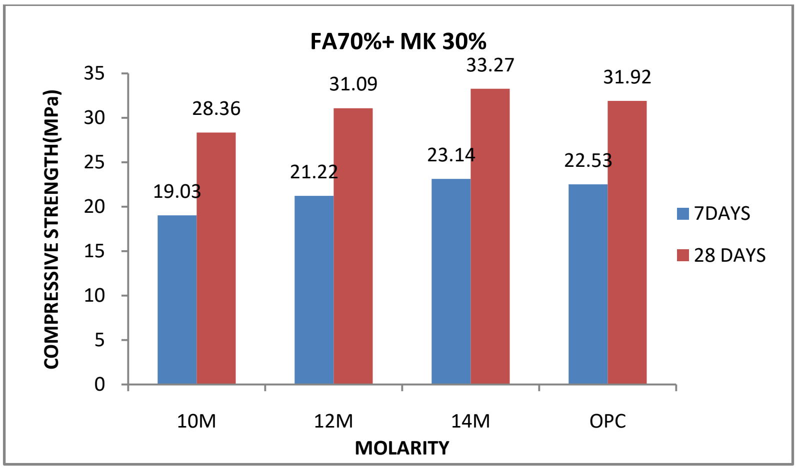

Figure 3 Compressive strength of specimens at the age of 7 and 28 days

5. Conclusion:-

Based on the experimental work reported in this study the following conclusions are drawn:-

1. The addition of metakolin to concrete mix increase the workability of concrete mix was found to decreases as compared to control mix of flyash.
2. Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly ash & metakaolin based geo-polymer concrete.
3. In addition to that fly ash shall be effectively used and hence no land fills are required to dump the fly ash
4. Geopolymer concrete has excellent properties within both acid and salt environments comparing to OPC the production of geopolymer have a relative higher strength and better durability.
5. we Observe that the compressive strength is increased with the increase in the molarity of the sodium hydroxide.
6. Geopolymer concrete made with 30% metakaolin and 70% flyash with 14M of NaOH provide optimum compressive strength as that of OPC specimens.

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