International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 04 | Apr 2021 www.irjet.net p-ISSN: 2395-0072

Study on Properties of Geopolymer Concrete with Metakaolin and Fly-Ash

Mohammed Asim uddin[1], Mohd Abdul Rahman[2], Faraz Ali Farhan [3], Mr. Mir Firasat Ali[4]

[1, 2, 3]B.E Students, Dept. of Civil Engineering, ISL Engineering College, Hyderabad
[4]Assistant Professor, Dept. of Civil Engineering, ISL Engineering College, Hyderabad

---

Abstract – *Concrete usage around the world is second only to water. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. But the amount of carbon dioxide released during the manufacture of OPC due to the calcinations of lime stone and combustion of fossil fuel is in the order of 600 kg for every ton of OPC produced. In addition, the extent of energy requires to produce OPC is only next to steel and aluminum. On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize (by – product of burning coal, regarded as a waste material) as substitute for OPC to manufacture concrete. Binders could be produced by polymeric reaction of alkali liquids with the silicon and the aluminum in the source materials such as fly ash and rice husk ash and these binders are termed as Geopolymer. In Geopolymer Concrete, fly ash and aggregates are mixed with alkaline liquids such as a combination of Sodium Silicate and Sodium Hydroxide.*

Large volume of fly ash is being produced by thermal power stations and part of the fly ash produced is used in concrete industry, low laying area fill, roads and embankment, brick manufacturing etc. The balance amount of fly ash is being stored in fly ash ponds. Hence it is imperative on the part of Scientists and Engineers to devise suitable methodologies for the disposal of fly ash. Disposal of fly ash has the objective of saving vast amount of land meant for ash pond to store fly ash. Further, use of fly ash as a value added material as in the case of geopolymer concrete, reduces the consumption of cement. Reduction of cement usage will reduce the production of cement which in turn cut the CO2 emissions.

***Key Words*: Geopolymer, reduce the CO2 emissions, Global warming, Fly-ash, Metakaolin.**

1. INTRODUCTION

Geopolymer is an alkali aluminosilicate binder formed by the alkali silicate activation of aluminosilicate materials. During 1950s Glukhovsky developed alkali activated cements. He worked predominantly with alkali activated slags containing large amounts of calcium, where as Davidovits pioneered the use of calcium- free system based calcined clay. Alkali activation of aluminosilicates can produce X-ray amorphous aluminosilicate gels, or geopolymers, with excellent mechanical as well as chemical properties. The structural backbone of these aluminosilicate (geopolymeric) gels has historically been depicted as consisting of a three dimensional frame work of SiO4 and AlO4 tetrahedra interlinked by shared O atoms. The negatively charged and tetrahedrally coordinated Al (III) atoms inside the network are charge-balanced by alkali metal cations such as Na, K and Ca. These gels can be used to bind aggregates, such as sand and natural rocks, to produce mortars and concretes. In other words, geopolymers are inorganic binders that function as the better-known Portland cement. Over the last decade, much research has been conducted on the chemical, mechanical and micro structural aspects of geopolymers. But inadequate research focus is given to the study of the interactions between aggregates and geopolymeric binders.

Geopolymers as an alternative binder systems are becoming one of the main interest in research and development nowadays. Geopolymers can display outstanding technical properties, such as high strength, low water absorption, high acid resistance and also high temperature resistance. It has been reported that geopolymer also can give a good performance by utilized the secondary raw materials (industrial wastes like fly ash). This explains the strong interest in this development from countries with growing industrialisation. The use of waste for geopolymer production could not only solve a waste problem, but also reduce the consumption of primary raw materials. Geopolymers are inorganic aluminosilicate polymers that form solid ceramic-like materials at near ambient temperature. The geopolymer cement is produced as an alternative way to replace the Ordinary Portland Cement (OPC). This is because the production of one ton of Portland cement emits approximately one ton of carbon dioxide (CO2) an it will lead to global warming. Hence, the use of geopolymer technology not only will reduce the CO2 emissions by the cement industries, but also enhancing the properties of the geopolymer paste. One of the possible sources for making geopolymer binders is fly ash because it is available abundantly worldwide, and yet it is rarely used . Therefore, consumption of fly ash in the manufacture of geopolymers is an important strategy in making concrete more environmentally friendly. Other than that, metakaolin is also one of the geopolymer binder. Metakaolin is obtain from the calcination of kaolin at a certain time and high temperature to remove its moisture. There have been some interests in the use of metakaolin as it probably the most effective pozzolanic material for use in concrete. For this reason, fly ash and metakaolin have been chosen as a base material for this project in order to utilize this industrial waste and to improve the paste properties.

2. LITERATURE REVIEW

Prakash R. Voraa, Urmil V. Dave has evaluated that use of pozzolona materials in the place of cement has enhanced the performance of concrete. Around 20 GPC mix proportions have been casted and were tested to evaluate the mechanical properties and efficiency of Geo Polymer Concrete. Parameters such as solid to alkaline liquid ratio, Alkaline liquid ratio, period of curing, type of curing and percentage of super plasticizer has been considered for variation to study the properties of concrete. Also has been concluded that naphthalene based super plasticiser improves the workability of fresh geopolymer concrete. It was further observed that the water content in the geopolymer concrete mix plays significant role in achieving the desired compressive strength.

Mr.G.Hemanaag, Mr.B.S.R.K.Prasad An inorganic polymer material that uses the by-product materials such as Metakaolin, fly ash etc is known as geo polymer. Instead of cement the above said by products are activated by alkaline liquids such as sodium silicate and sodium hydroxide from 2 Molar to 8 Molar were used in variable of 2M to produce the binder. Type of materials, Mix Ratio and Binding Process were covered in this project. Trial and Error method was used in this study to produce a binder and compressive strength values for various molarities were determined. From the observations it was clear that when the molarity increased, the compressive strength was increased. Compared to fly ash based concrete the compressive strengths of metakaolin based concrete are high, but the cost of metakaolin based concrete is more.

M.Narmatha and Dr.T.Felixkala (2017):conducted the test on concrete specimens with 5, 10, 15, 20, 25% replacement of cement by metakoline and fly ash for all mix 10%.The addition of fly ash in concrete improves certain properties such as workability, later age strength development and few durability characteristics. Concrete is the high volume of fly ash and metakaolin as a partial replacement of ordinary Portland cement .The conventional concrete M60 was made using OPC 53 with metakaolin and fly ash. To evaluate optimize ratio and mechanical properties of metakaolinbased on concrete and compare with conventional mix .From the optimization 20% cement replacement by metakaolin superior than all the mixes.

Smt. Bhavna K. Shah and Hemant Chauhan (2011):carried an experimental program toachieve this higher strength, OPC as a cementitious material is not sufficient, so in this paper industrial waste like activated fly ash (class F), Iron Oxide and Metakaolin are used as supplementary cementitious materials in various proportions. By using this mineral admixtures with OPC cement, different five types of cement were prepared and same were used to find compressive strength of concrete cubes at 3,7,14,28 and 56 days.

A.R.R. Kalaiyarrasi(2017): The objective of this research is to synthesizeMK based GP concrete, by replacing FA in GP by MK in 25, 50, 75% and test for strength and durability. Three MK samples with Si/Al mass ratio of 0.87(M1), 1.11(M2), 1.21(M3) have been used in this research. Study of Micro structural property of MK based GP using Fourier Transform Infra-Red Spectroscopy (FTIR), Electron Dispersive Spectroscopy (EDS) and Scanning Electron Microscopy (SEM) techniques has been carried out. Evaluation of axial compressive strength of MK geopolymer brick masonry (MKBP) with aspect ratio between 2 and 5 has been done and compared with the compressive strength and Elastic modulus of Clay Brick Prism (CBP).

Prakash R. Voraa, Urmil V. Dave has evaluated that use of pozzolona materials in the place of cement has enhanced the performance of concrete. Around 20 GPC mix proportions have been casted and were tested to evaluate the mechanical properties and efficiency of Geo Polymer Concrete. Parameters such as solid to alkaline liquid ratio,Alkaline liquid ratio,period of curing,type of curing and percentage of super plasticizer has been considered for variation to study the properties of concrete. Also has been concluded that naphthalene based super plasticiser improves the workability of fresh geopolymer concrete. It was further observed that the water content in the geopolymer concrete mix plays significant role in achieving the desired compressive strength.

Siti Noorbaini Sarmin has reported on the properties of fly ash/metakaolin-based geopolymer lightweight foamed concrete with inclusion of wood particles. Class F fly ash and metakaolin was mixed with an alkaline activator solution (a mixture of sodium silicate; Na_2SiO_3 and sodium hydroxide; NaOH), and hydrogen peroxide; H_2O_2 was added to the geo polymeric mixture to produce lightweight foamed concrete. The NaOH solution was prepared by dilute NaOH pellets with distilled water. The ratio of fly ash/metakaolin and alkaline activator used was 2.5:1.0 with addition of 0%, 10%, 20% and 30% of wood particles by volume of the total mix. The reactive were mixed to produce a homogenous mixture sized 50mm and cured at two different curing temperatures (80oC for 24 hours and room temperature for seven days). All the experiments were set up in accordance with International standard methods of testing. In reference to the analysis and discussion, the integration of fly ash/metakaolin and wood particles enhanced the properties of the lightweight foamed concrete. The results showed that the samples which were cured at 80oC produced the maximum compressive strength, (5.71 MPa, 10.2 MPa, 7.62 MPa and 6.3 MPa) for 0%, 10%, 20% and 30% of wood particles respectively. The oven-dry density of samples cured at 80oC was greater than room temperature curing. Heat curing which caused the geo polymerization rate to increase, producing a denser matrix.

OBJECTIVES OF THE STUDY:

- The main objective of the present experimental study is to investigate the geopolymer concrete by fully replacement of cement with fly ash, and metakaolin.
- To study the properties of fresh and hardened fly ash metakaolin based Geopolymer concrete.
- To determine the compressive strength & split tensile strength of fly ash/metakaolin based geopolymer concrete at various ages and the result were compared between the obtained mixes.

3. Materials Selection:

Fly Ash: Fly ash also called flue ash, or pulverized fuel ash, is a result of coal combustion that is comprised of fine particles of burned fuel. Ash that falls to the bottom of the boiler is called bottom ash. Fly ash, generally, collected by electrostatic precipitators or any other type of particle filtration machine before these flue gases reach the chimney. The constituents of the ash can vary depending upon the source and composition of the coal which is being burnt, but in general, fly ash entails silicon dioxide (SiO2) (amorphous and crystalline), aluminum oxide and calcium oxide.

Metakaolin: It is a refined kaolin clay which is burnt (Calcinated) under very scrutinized circumstances in order to create an amorphous alumina silicate which can easily react with concrete. The particle size of metakaolin is very fine than the particle size of cement which is the main reason it can replace cement in concrete as it can act as a marvelous pore filling material. Metakaolin is also called supplementary cementitious material

Composition	Fly ash Mass (%)	Metakaolin Mass (%)
CaO	05.01	00.78
SiO_2	59.57	52.68
Al_2O_3	19.87	45.80
Fe_2O_3	06.01	02.14
MgO	07.23	00.16
SO_3	00.05	-
K_2O	00.19	00.62
Na_2O	00.29	00.26

Chemical Composition of Fly Ash and Metakaolin.

Sample Preparation

Samples were prepared and undergo mixing process for solid to liquid (S/L) ratio that was 1.2:1. Na2SiO3 and NaOH solution are most common alkaline activator that had been used in geopolymer paste. Firstly, the NaOH solution was prepared by dissolving the NaOH pellets in 1 L of distilled water and kept it at room temperature for 24 hours. Then, the NaOH solution was mixed with Na2SiO3 solution with ratio of the mixture of Na2SiO3/ NaOH is 2.5:1. This mixture was prepared 24 hours prior to use. The alkaline activator was later mixed with the fly ash and metakaolin as geopolymer based. Fly ash and metakaolin were weighted and mixed according to the different S/S ratio named as Mix 1, Mix 2, Mix 3 etc.. Table 2 shows the mixing proportion ratio for geopolymer paste based fly ash and metakaolin. The solid and liquid were mixed using automatic mixer then placed it in 50mm x 50mm cylinder mould, compacted and kept in the mould until it hardened and taken out after 24 hours. Then, the samples were cured at 60 o C in the oven for 24 hours [9]. The main purpose of this process was to remove the excessive moisture and give more strength to the sample [10]. The sample were then left for 7, 14 and 28 days at ambient temperature before undergo compressive strength and water absorption testing.

MIX-1	CC (100% OPC)
MIX-2	100% FA
MIX-3	100% Mk
MIX-4	80%Mk + 20% FA
MIX-5	60%Mk + 40% FA
MIX-6	40%Mk + 60% FA
MIX-7	20%Mk + 80% FA

Table-1: Mix Designations

Fig.1: Sample Preparation

Fig.2: Demoulding of Specimens

Mix design and casting and curing of specimens

Several geopolymer trial batches were cast and tested, and the mixes which achieved the best cohesive and workable concrete were chosen as can be seen in Table 2 for detailed analyses. Aggregate content, alkaline solution/metakaolin or fly ash, sodium silicate/sodium hydroxide and curing method affect strength and durability of the geopolymer concrete (Olivia and Nikraz 2012). Aggregate content in the GPC occupied the largest amount (70%) in total weight as in the case of usual concrete. Sodium silicate to sodium hydroxide ratio becomes in the range of 1.5 to 2.5 for economic reasons (Olivia and Nikraz 2012) and it was used as 2.5 in the study. Activator liquids/slag or fly ash ratio was selected as 0.45. The mixes are designed with same w/c and max aggregate size. Mixing procedure was as following, dry ingredients; coarse aggregates (SSD condition) and fine aggregates, slag, fly ash, cement (for related mixes) were added into the mixer and mixed for 2.5 minutes. The prepared alkaline solution and superplasticizer added in 1-minute duration and further mixed for 2.5 minute for homogeneity

Geopolymer concretes mix ingredients	
Binder Content	420 kg/m^3
Fine Aggregate:	773 kg/m^3
Coarse Aggregate	773 kg/m^3
Water	152 kg/m^3
Water Cement Ratio	0.36
Admixture	Conplast SP430 at 2% of the weight of cement/Geopolymer
Mix Ratio	1:1.28:3.0:0.4

Table-2: Geopolymer concrete mix designs

4. RESULTS AND DISCUSSIONS

Compressive strength

The specimens used for this test were cubes of standard size 150mm x150mm x150mm for each time period of each mix proportion, 3 specimens were casted i.e.,(A total of 21 specimens were taken for all time periods ie.,7 days,28 days). And from the testing it was observed that specimens with greater percentage of metakaolin yielded good compressive strength compared to that of sole flyash specimens.

Mix Designations	Compressive Strength	
	7days`	28 days
MIX-1	27.75	42.7
MIX-2	Did not set properly	
MIX-3	30.80	47.5
MIX-4	32.30	49.7
MIX-5	26.07	40.12
MIX-6	25.51	39.25
MIX-7	24.32	37.5

Table-3: Compressive strength values

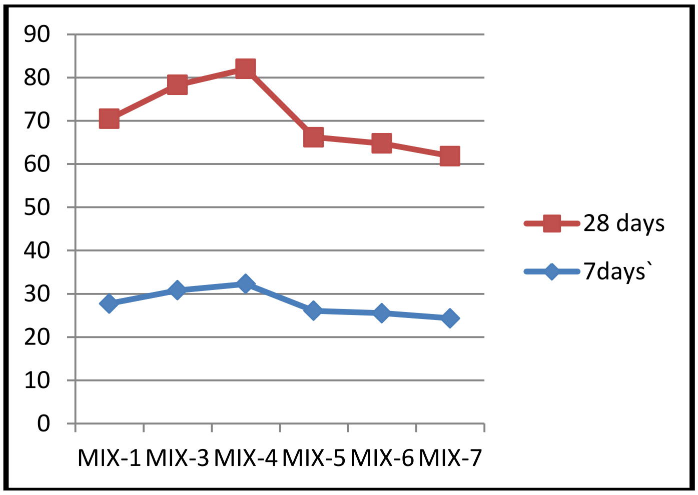

Fig.No-1: Compressive strength graph for 7 and 28 days

Split Tensile Strength:

Mix Designations	Split Tensile Strength	
	7days`	28 days
MIX-1	4.2	4.87
MIX-2	Did not set properly	
MIX-3	2.32	3.78
MIX-4	3.36	5.08
MIX-5	2.89	3.84
MIX-6	2.32	2.45
MIX-7	1.28	1.74

Table-4: Split Tensile strength values

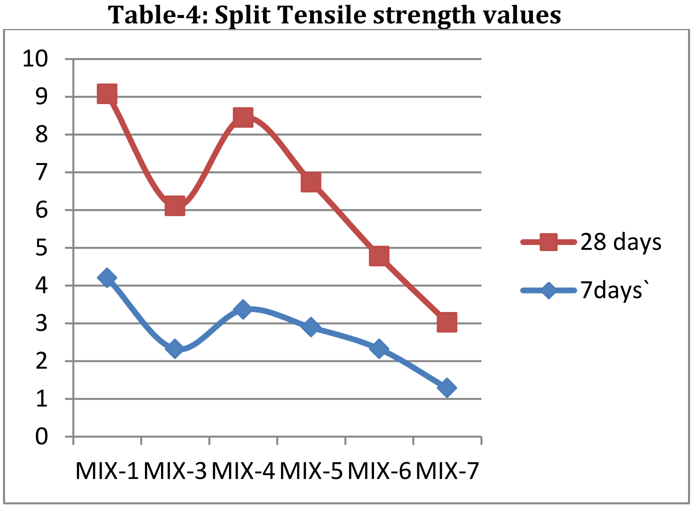

Fig.No-2: Split Tensile graph for 7 and 28 days

5. SUMMARY AND CONCLUSIONS

In the study, the effects of different mix proportions of flyash and metakaolin based geopolymer concrete on both compressive strength and split tensile strength were investigated and the results were compared with OPC.

The findings were summarized below.

Optimum mixtures were observed as 80%MK+20%FA. Strength properties for GPC with 80%MK+20%FA gives better results compared to other mix proportions.

The compressive strength generally increases with an increase in metakaolin ratio to flyash ratio until a certain limit depending on the molar ratios of the mix, which can contribute to the impendence of geopolymerisation, beyond which strength starts to reduce.

Similarly, split tensile strength also improves with an increase in metakaolin content; the highest split tensile strength was achieved with Mk content of 80% and reduced significantly when it decreased to 20%.

Compacted and well condensed microstructure has fewer cracks where higher energies are required to initiate and propagate cracks. The degree of the fly ash reactivity and continuous gel formation govern the density of the gel microstructure. In contrast, a higher number of unreacted fly ash particles indirectly cause an increase in the crack width. This results in the creation of discontinuities leading to the forming of a less dense microstructure. This, in turn, produces a lower density and elasticity modulus of geopolymer concrete.

ACKNOWLEDGEMENT

We are thankful to **Dr. Mohammed Masood,** Principal, ISLEC, for his encouragement throughout the project. We would also like to express our heartfelt thanks to **Ms. K. Nanchari,** Head of Civil Engineering Department, ISLEC for her help and unending cooperation with us during completion of this work.

REFERENCES

1. Prakash R. Voraa, Urmil V. Dave.(2013)."Parametric Studies on Compressive Strength of Geopolymer Concrete".Elsevier Procedia Engineering 51 (210-219). 2013.
2. Mr.G.Hemanaag, Mr.B.S.R.K.Prasad (August 2014),Geo-Polymer Concrete using Metakaolin,Fly-Ash and thgeir compostion". International Journal of Engineering Research & Technology (IJERT) ,Vol.3,Issue-8,August 2014.
3. Siti Noorbaini Sarmin(May 2016),"Charecterization of FlyAsh/Metakaolin-based GEopolymer Lightweight Concrete Reinforced Wood Particles".Internation Conference on sustainable Built Environment,May-11-2016.
4. T.R. Naik. (May 2008). "Sustainability of Concrete". Practice Periodical on Structural Design and Construction. (Online article). Volume 13, issue 2 May 2008.

5. Van Jaarsveld, J. G. S., J. S. J. Van Deventer and G.C.Lukey. 2003. The Characterization of Source Materials in Fly Ash-based Geopolymers. Materials Letters. 57(7): 1272-1280.
6. Davidovits J. 1999. Chemistry of Geopolymeric Systems, Terminology. Geopolymer '99 International Conference, France.
7. Davidovits J. and Davidovics M. 1988. Geopolymer room temperature ceramic matrix for Concrete International.July: pp.30-40.
8. Mr. Ahmed Mohamed Ahmed Blash, Dr. T.V.S. Vara Lakshmi, "Properties of Geopolymer Concrete produced by Silica Fume and Ground –Granulated Blast-Furnace Slag", International Journal of Science & Research, (IJSR), Oct 2016, Vol: 5, issue 10, pp. 319-323.
9. P. Chindaprasirt, P. D. Silva, and S. Hanjitsuwan, "Effect of Highspeed mixing on properties of high calcium fly ash geopolymer paste," Arabian Journal for Science and Engineering, vol. 39, issue 8, pp. 6001-6007, 2014
10. P.Pavithra, M.Srinivasula Reddy, Pasla Dinakar, B.Hanumantha ,B.K.Satpathy,A.N.Mohanty(2016),"A mix design procedure for geopolymer concrete with flyash".Elsevier Journal of Cleaner production.133 (2016) Pg.No.117-12.
11. Mr. Ahmed Mohamed Ahmed Blash, Dr. T.V.S. Vara Lakshmi, "Studies on the physical properties of ground granulated blast-furnace slag incorporating in Geopolymer concrete", International Journal of

BIOGRAPHIES

Mir Firasath Ali, Assistant Professor, Department of Civil Engineering, ISLEC, Hyderabad, India

Mohammed Asim Uddin,
Student, Department of Civil Engineering, ISLEC, Hyderabad, India

Mohd Abdul Rahman,
Student, Department of Civil Engineering, ISLEC, Hyderabad, India

Faraz Ali Farhan,
Student, Department of Civil Engineering, ISLEC, Hyderabad, India