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Performance of 12 Molarity Based Geopolymer Mortar with Fly Ash and GGBS

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Abstract

Ordinary Portland cement is an important material used in production of concrete. However manufacturing of OPC has many disadvantages such as depletion of raw materials like lime stone and the clay. Each ton of cement releases equal amount of CO2. One such alternative is Geopolymer which is an ecofriendly material and reasonable strength gain in short time. Geopolymer technology is presented with the aim of introducing the technology and the vast categories of materials that may be synthesized by alkali-activation of aluminosilicates. The fundamental chemical and structural characteristics of geopolymer derived from fly ash and slag are explored in terms of the effects of raw material selection on the properties of geopolymer composites.

All the materials used were characterised for physical, chemical, morphological and mineralogical characteristics. The setting characteristics of the geopolymer paste were determined. Geopolymer mortar cubes are cast using fly ash, ground granulated blast furnace slag (GGBS) as binders with alkaline solution The available codal provisions were followed to cast and test the specimens. The flow characteristics of the mortar was determined in fresh state. The specimens were tested for compressive strength at different ages along with the study of microstructure. The development of compressive strength of the blocks was analyzed to get the optimum mix. Based on the findings, the feasibility of using geopolymer mortar block as a structural unit was ascertained.

The materials used for the investigation were found suitable for making geopolymer mortar. The results of the investigation reveal that the maximum strength developed in the mortar for the combination of 80% GGBS and 20% Fly ash. It was found 33.59 N/mm2 at the age of 7 days for the fluid-to-binder ratio of 0.45. The geopolymer mortar develops strength at ambient conditions without any conventional curing. The compressive strength of the geopolymer mortar tends to increase with the GGBS content for different fluid to binder ratios. The microstructure of the geopolymer was denser with the age and amount of GGBS. Overall it was found that the geopolymer has large potential to use as sustainable building material.

INTRODUCTION

Portland cement (PC) concrete is the most popular and widely used building materials, due to its availability of the raw materials over the world, its ease for preparing and fabricating in all sorts of conceivable shapes. The applications of concrete in the realms of infrastructure, habitation, and transportation have greatly prompted the development of civilization, economic progress, and stability and of the quality of life. Nowadays, with the occurrence of high performance concrete (HPC), the durability and strength of concrete have been improved largely. However, due to the restriction of the manufacturing process and the raw materials, some inherent disadvantages of Portland cement are still difficult to overcome. There are two major drawbacks with respect to sustainability. About 1.5 tonnes of raw materials is needed in the production of every ton of

PC, at the same time; about one ton of carbon dioxide (CO_2) is released into the environment during the production. Therefore, the production of PC is extremely resource and energy intensive process.

The contribution of ordinary Portland cement (OPC) production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually or approximately 7% of the total greenhouse gas emissions to the earth's atmosphere. Also, it has been reported that many concrete structures, especially those built in corrosive environments, start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life. To produce environmentally friendly concrete, Mehta [1] suggested the use of fewer natural resources, less energy, and to minimize carbon dioxide emissions. He categorized these short-term efforts as industrial ecology. The long-term goal of reducing the impact of unwanted by-products of industry can be attained by lowering the rate of material consumption.

The use of pozzolanic materials in the manufacture of concrete has a long, successful history. In fact, their use pre-dates the invention of modern day Portland cement by almost 200 years. Today, most concrete producers worldwide recognize the value of pozzolanic enhancements to their products and, where they are available; they are becoming a basic concrete ingredient. Mineral admixtures such as ground granulated blast furnace slag (GGBS), fly ash and silica fume are commonly used in concrete because they improve durability reduce porosity and improve the interface with the aggregate. Economics (lower cement requirement), energy, and environmental considerations have had a role in the mineral admixture usage as well as better engineering and performance properties. The lower cement requirement also leads to a reduction for CO_2 generated by the production of cement. The engineering benefits from the use of mineral admixtures in concrete result partly from their particle size distribution characteristics, and partly from the pozzolanic and cementitious reactivity.

Hence, environmental preservation has become a driving force behind the search for new sustainable and environmentally friendly composites to replace conventional concrete produced from OPC. Although the use of Portland cement is still unavoidable until the foreseeable future, many efforts are being made in order to reduce the use of Portland cement in concrete. These efforts include the utilisation of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and finding alternative binders to Portland cement.

Following are the Disadvantages of conventional cement

- Cement has high rate of hydration.
- It is very difficult to provide idoneous curing conditions
- Not ideal for situation when settlement is expected
- Results in high heat resulting cracks
- Absorbs moisture from atmosphere and gets harden

In this respect, the geopolymer technology proposed by Davidovits [2] shows considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of reducing the global warming, the geopolymer technology could reduce the CO_2 emission to the atmosphere caused by cement and aggregates industries by about 80%. Fly ash is an industrial waste normally used to replace Portland cement for making concrete. However, it can only partially replace Portland cement since SiO_2 and Al_2O_3 in fly ash still need $Ca(OH)_2$ from Portland cement hydration for its pozzolanic reaction to produce calcium silicate hydrate and calcium aluminate hydrate. Recently, another form of cementitious materials called geopolymer has been developed. This geopolymer is usually made of fly ash activated technology with alkaline solution at low temperature and it is sometimes called alkali-activated fly ash.

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The term geopolymer was coined by Davidovits in 1988 [3] to represent a broad range of materials characterized by chains or networks of inorganic mol¬ecules (Geopolymer Institute 2010). There are nine different classes of geo¬polymers, but the classes of greatest potential application for transportation infrastructure are comprised of aluminosilicate materials that may be used to completely replace Portland cement in concrete construction (Davidovits 2005), [4]. These geopolymers rely on thermally activated natural materials (e.g., kaolinite clay) or industrial by-products (e.g., fly ash or slag) to provide a source of silicon (Si) and aluminium (Al), which is dissolved in an alka¬line activating solution and subsequently polymerizes into molecular chains and networks to create the hardened binder. Such systems are often referred to as alkali-activated ce¬ments or inorganic polymer cements.

Geopolymer materials represent an innovative that is generat¬ing considerable interest in the construction industry, particularly in light of the ongoing emphasis on sustainability. In contrast to Portland cement, most Geopolymer systems rely on minimally processed natural materials or industrial by-products to provide the binding agents. Since Portland cement is responsible for upward of 85 percent of the energy and 90 percent of the carbon dioxide attributed to a typical ready-mixed concrete, the potential energy and carbon dioxide savings through the use of Geopolymers can be considerable. Consequently, there is growing interest in Geopolymer applications in transportation infrastructure. Unlike ordinary Portland/pozzolanic cements, geopolymers do not form calcium- silicate-hydrates (CSHs) for matrix formation and strength, but utilize the poly condensation of silica and alumina precursors to attain structural strength. Two main constituents of geopolymers are: source materials and alkaline liquids. The source materials on alumino-silicate should be rich in silicon (Si) and aluminium (Al).They could be by-product materials such as fly ash, silica fume, slag, rice-husk ash, red soil, etc.

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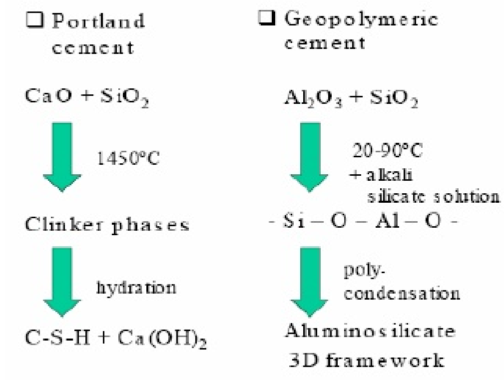

Fig 1: Comparison of Portland cement And Geopolymer Cement

Applications of Geopolymer Cement:

- Used in industrial floor repairs.
- Airfield repairs (in war zones).
- Fireproof composite panels.
- External repair and structural retrofit for aging infrastructure.
- For storage of toxic and radioactive wastes.
- Potential utilizations in Art and Decoration.
- LTGS Brick, railway sleepers, electric power poles, Marine structures, Waste containments etc..

Advantages of Geopolymer Cement

Geopolymer concrete is more resistant to corrosion and fire, has high compressive and tensile strengths, gains its full strength quickly (cures fully faster), low creep, no shrinkage, good acid resistance, low

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permeability, resistance to sulphate attack and Durable Finishes.

CHARACTERIZATION OF MATERIALS

Material that contains mostly Silicon (Si) and Aluminium (Al) in amorphous form are all possible source materials for the manufacture of geopolymer. Manufacture of GEOPOLYMER by Several minerals and industrial by-product materials have been investigated in the past by many researchers.

Procurement

The above mentioned materials are procured. GGBS is obtained from Bellary district in Karnataka. The type of fine aggregate used in this study is locally available sand. Sodium hydroxide and sodium silicate powder was obtained from Dutta Scientific works Bangalore.

GGBS

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder

Characteristics of GGBS

The chemical composition and physical characteristics of GGBS were determined and the results are tabulated in Tables 3.1.and 3.2.

Table 3.1 Chemical Composition of GGBS

Sl No	Chemical constituents (as oxides) %	GGBS
1	SiO_2	40.0
2	Al_2O_3	13.5
3	CaO	39.2
4	MgO	3.6
5	Fe_2O_3	1.8
6	SO_3	0.2
7	L.O.I	0.0

Table 3.2 Physical properties of GGBS

Physical properties	GGBS
Colour	Off white
Specific gravity	2.94
Density units	2.9
Fineness	$450m^2/kg$

Fly Ash

Flyash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of coal tired power plants and is one of the two types of ash that jointly are known as coal ash the other bottom ash is removed from the bottom of coal furnaces. Depending upon the source and make up of the coal being burned, the components of fly ash vary considerably but all fly ash includes various chemical composition which was shown in Table 3.3 having substantial amounts of silicondioxide (SiO2) and calcium oxide (Cao). Toxic constituents include cobalt, lead, manganese, mercury, arsenic, beryllium, boron, cadmium, chromium, Malybdenum, selenium, etc.

Table 3.3 chemical composition of Fly Ash

Chemical	Percentage	Description
SiO_2	20-60	Silicon dioxide
Fe_2O_3	10-40	Iron oxide
Al_2O_3	5-35	Aluminium oxide
CaO	1-12	Lime
LOI	0-15	Loss of ignition

Alkaline Solution

The Alkaline solution used for experimental investigation is a combination of Sodium silicate solution and Sodium Hydroxide solution. It is seen that the Geopolymers with Sodium Hydroxide solution exhibit better Zeolitic properties than Potassium Hydroxide activated Geopolymers. Also it has been confirmed that addition of Sodium Silicate Solution to Sodium Hydroxide enhanced the reaction rate between Source material and the alkaline solution. A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid.

Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions.

Sodium Hydroxide

The Sodium Hydroxide is in flakes and pellet form with about 98% purity. These pellets were mixed with distilled water to obtain the sodium hydroxide solution of required molarity. In the present study, The Molarity of the solution is kept constant at 12M for all the experimental investigations. NaOH is also commonly used as an alkaline activator in geopolymer production. While it does not maintain the level of activation as a K+ ion, sodium cations are smaller than potassium cations and can migrate throughout the paste network with much less effort promoting better zeolitization. Furthermore, it bears a high charge density which promotes additional zeolitic formation energy.The concentration and molarity of this activating solution determines the resulting paste properties. While high NaOH additions accelerate chemical dissolution, it depresses ettringite and CH (carbon-hydrogen) formation during binder formation.

Furthermore, higher concentrations of NaOH promote higher strengths at early stages of reaction, but the strength of aged materials were compromised due to excessive OH- in solution causing undesirable morphology and non-uniformity of the final products.

It is found that geopolymers activated with sodium hydroxide develop greater crystallinity thus improving stability in aggressive environments of sulfates and acids. Additionally, the use of sodium hydroxide as an activator buffers the pH of pore fluids, regulates hydration activity and directly affects the formation of the main C-S-H product in geopolymer pastes.

Table 3.5 – Specifications of Sodium Hydroxide Flakes

Minimum Assay(Acidimetric) Maximum Limits Of Impurities	96%
Carbonate	2%
Chloride	0.1%
Phosphate	0.001%
Silicate	0.02%
Sulphate	0.01%
Arsenic	0.0001%
Iron	0.005%
Lead	0.001%
Zinc	0.02%

Preparation of Geopolymer mortar Samples

1. A Geopolymer motor cube was prepared by using Fly ash and Ground granulated blast furnace slag (GGBFS) and locally available fine aggregate which is passing through 4.75 mm IS Sieve.
2. The alkaline solution which includes Sodium Hydroxide and Sodium silicate which was mixed in water as per 12 Molarity basis by the ratio 1:2 for the different Fluid to Binder.
3. The alkaline solution was prepared one day prior to do the Geopolymer mortar cubes.
4. The experimental program was conducted on next day by weighing the materials like Fly ash, GGBFS and fine aggregate and mixed uniformly for 3 min at the ratio of 1:2.
5. The samples of Geopolymer mortar was obtained by mixing the binder and fine aggregate with alkaline solution for another 3 to 5 min.
6. The mortar was placed in 70.6mm x 70.6mm x 70.6mm mould in three equal layers and compacted well and then the samples were placed in vibrator for further compaction.
7. Three cubes were prepared to obtain the compressive strength for the different ages i.e. 1 day, 3 days and 7 days respectively and the samples were subjected to ambient curing.

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8. At the next day, the Geopolymer mortar cubes were demoulded which was shown in Fig 4.1 and average compressive strength for one day was obtained by placing the samples in universal testing machine as shown in Fig 4.2 Repeating the same procedure for obtaining the average compressive strength for 3 days and 7 days respectively.

9. After the testing the sample from the Universal Testing Machine (UTM), the cracking pattern of the Geopolymer mortar cubes is obtained as shown in Fig 4.3. The cracking pattern varies with the Fluid to Binder ratio and combinations of the binding material.

10. For lower fluid to Binder ratio like 0.40, the samples are very dry due to lack of reaction of alkaline solution with binders. When these samples are subjected to compressive stress, the crushing pattern of a Geopolymer cubes are obtained like a powder form

Fig 4.1 Samples of Geopolymer Mortar cubes

Fig 4.2 Universal Testing Machine

Fig 4.3 Cracking pattern of Geopolymer samples

RESULTS AND DISCUSSION

Flow characteristics:

The percentage of flow of the mortar for different combinations of Fly Ash and GGBS are determined by using IS 9109 of 1999 flow table tests for different Fluid to Binder ratio. The Fig 5.1 and Table 5.1 indicate percentage of flow at different fluid to binder ratio with varying percentage of GGBS. From the obtained results, the mix proportion of Geopolymer mortar was dry and greater percentage of flow was obtained at lower F/B ratio like 0.40 and 0.45 respectively. The mix proportion of Geopolymer was more workable in nature at F/B ratio of 0.50 and 0.55 respectively which is shown in fig 5.2

Table 5.1-Flow for different percentage of GGBS

Percentage of GGBS	Average flow, %			
	0.40	0.45	0.50	0.55
90	217.95	158.97	174.36	111.11
80	189.74	141.03	66.67	69.23
70	207.69	78.62	97.44	58.68
60	178.21	156.41	125.64	94.02
50	182.56	140.26	78.46	72.91
40	224.62	133.33	73.85	69.06
30	155.13	139.33	105.13	81.49
20	189.74	69.23	112.82	60.68
10	234.87	205.64	86.15	97.26

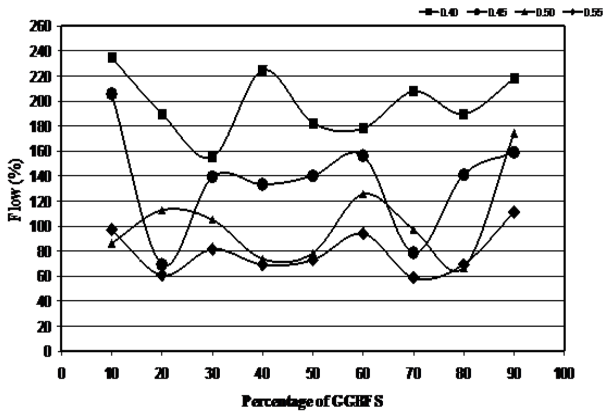

Fig 5.1- Flow of the mortar for different combinations

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Fig 5.2- Flow of the Geopolymer mortar

Microstructure

The SEM images of the geopolymer mortar at 3 and 7 days are shown in the Figures 5.15 and 5.16 respectively. It can be noticed from the images that the microstructure densified with the age. This is due the reaction between the binder and alkaline fluid. As the age progresses the geopolymerisation and hydration together responsible for the densified products. This is also true from the strength studies. Thus dense microstructure is responsible for higher strength of the mortar.

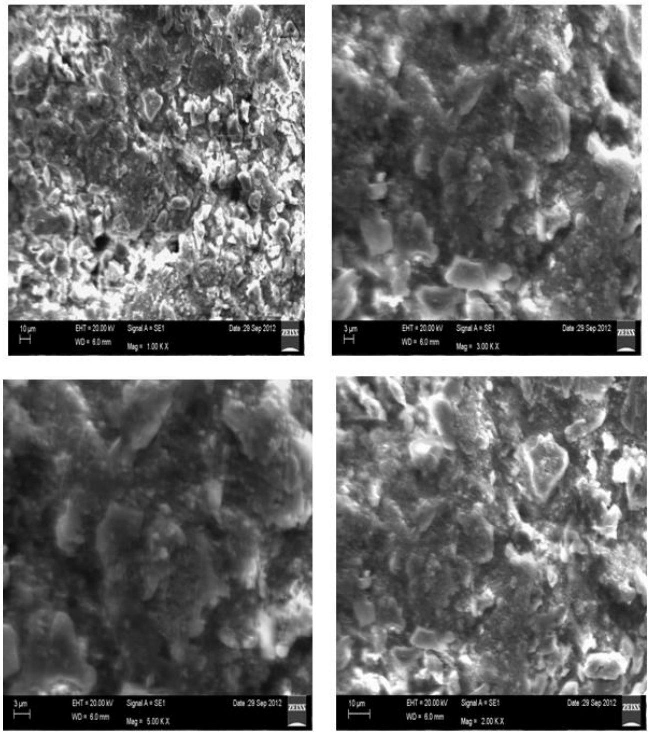

Fig 5.16 SEM image of Geopolymer mortar at 3 days

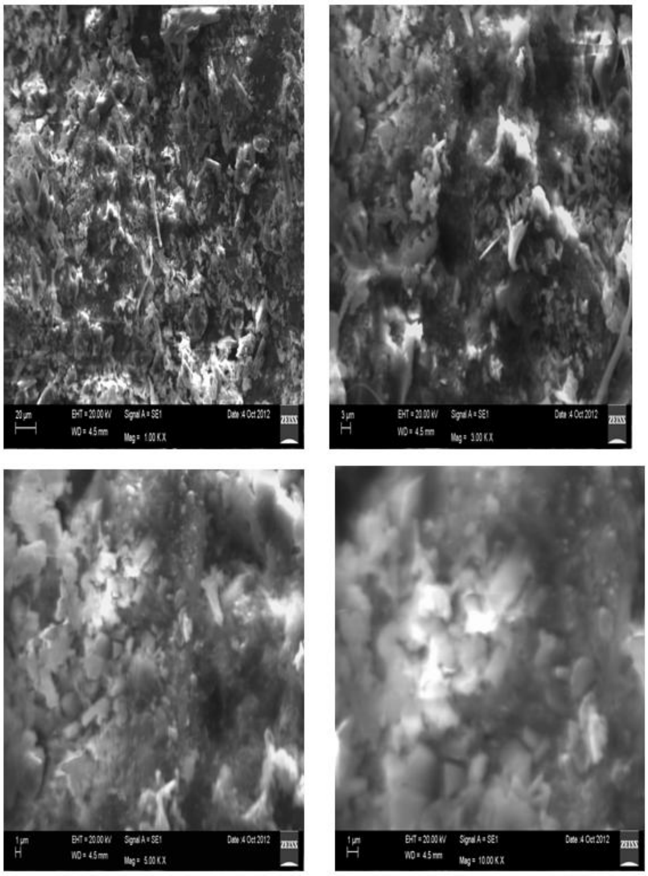

Fig 5.17 SEM image of Geopolymer mortar at 7 days

The test results are discussed in this chapter. The flow, strength and microstructure of the geopolymer mortar were determined for various parameters. The flow decreases with the increase of GGBS and increases with the fluid-to-binder ratio. The compressive strength of the mortar increases with the increase in GGBS content. The microstructure of the paste tends to densify with age and GGBS content. Overall the geopolymer attains comparatively better properties at ambient conditions.

Conclusion

1. The materials like Fly Ash and GGBS as binders with alkaline solution which includes Sodium Hydroxide flakes and Sodium Meta Silicate (commercial grade) are suitable to prepare Geopolymer mortar.

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2. The compressive strength is increased with increase in GGBS content. But the mix was dry for F/B ratio of 0.40 and 0.45 respectively. The compressive strength at the age of 7 days are in the range of 1.163-33.59N/mm2
3. The flow is very dry and greater percentage of flow for F/B ratio of 0.40 and 0.45 respectively.
4. At all the proportions, the compressive strength is increased with increase in age. The maximum strength is attained for F/B ratio of 0.45 at 7 days for the combination of 80% GGBS and 20% Fly Ash.
5. The reaction between the Fly ash and alkaline solution gives low strength for higher F/B ratios like 0.50 and 0.55 respectively. But for the F/B ratio of 0.45, the compressive strength for F/B ratios of 0.40 and 0.45 respectively gives satisfactory results when compared to higher F/B ratios like 0.50 and 0.55 respectively.
6. Locally available sand was used for preparation of Geopolymer mortar with binders and alkaline solution. By conducting fineness modulus of sand, we conclude that it was a medium sand having fineness modulus of 2.83 which is satisfactory for making mortar.
7. The compressive strength obtained for all the combinations with different Fluid to Binder ratio are depends upon the ambient curing of the Geopolymer mortar samples.

Scope for the future work

- A detailed study of the strength development for various other parameters can be studied using fly ash and GGBS from different sources.
- By using the other different alternative materials like red soil, clay and Silica Fume etc., as binder with varying percentage by considering the economical point of view, the properties of the Geopolymer mortar cubes can be studied.
- By conducting more SEM and X-ray Diffraction additional information such as properties of Geopolymer mortar cubes can be determined.
- The mortar can be used to make masonry blocks/bricks. Thus a feasibility study can be made.

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