International Journal of Engineering Research
Volume No.5, Issue Special 1 pp : 203-206
ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

Properties of Fly Ash Based Geopolymer Mortar with Ambient Curing

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Abstract ***: Geopolymer concrete is one of the green concrete. It becomes a solution on social environmental problems, such as disposal of fly ash produced by thermal power plants and the air pollution due to production of cement. Geopolymer concrete is very advantageous due to its durability, economy and environmental credit point of view. The Geopolymer requires the temperature curing for obtaining the sufficient strength. Practically it is impossible to produce the temperature curing to structure at site. Due to that this concrete is only useful for construction of precast members in industry. If geopolymer concrete attains the required strength at room temperature this will be the boon to society for saving the environment. Some effort is made in this direction for achieving the sufficient strength of Geopolymer cure at room temperature. The various percentages of Lime and OPC were added in fly ash for obtaining the strength at room temperature. The effect of lime and OPC on initial setting time and compressive strength were studied. From this experimental work it is observed that increase in the percentage of lime and OPC the initial setting time reduces as the compressive strength increases. In case of strength the Geopolymer mix incorporated with OPC gives the better results of strength as compared to the mix with lime.***

Keywords: Geopolymer, Lime, Ordinary Portland cement, activator solution, Ambient Curing.

Introduction

Day by day India is becoming a super power by using the innovative technology in all sectors. The electricity plays the major role in development of country. Consumption of electricity is increasing day by day. While producing the electricity by thermal power plants the fly ash is produced in huge quantity. For protecting environment it is very essential to dispose or utilize this fly ash. Construction industries have been using the fly ash as supplementary binding material or mineral admixtures in various types of concrete. But only 17-20 % fly ash was used in concrete. World without concrete cannot be imagined. Use of concrete is only the second after the water. The production of cement increases as per increase in the demand of concrete. The world wide consumption of concrete is estimated to be about 11.5 billion tons per year (Palomo) and year 2050 expects demand of 18 billion tons of concrete per year. The manufacturing of Portland cement releases carbon dioxide (CO_2) which is a significant contribution to green house effect. It is well known that there are environmental benefits of reducing the use of Portland cement in concrete and using a cementitious material such as fly ash or ground granulated blast furnace slag or rice husk ash or metkaolin instead. Devidovits proposed the 100 % replacement of cement by cementitious materials which are rich in silica and alumina by activating alkaline solution. Another effort to make environmentally friendly concrete is the development of inorganic alumina-silicate polymer, called geopolymer, synthesized from materials of geological origin or by-product materials such as fly ash that are rich in silicon and aluminium (Davidovits). Fly ash, one of the source materials for geopolymer binders, is available abundantly world wide, but to date its utilization is limited. In 2011 India's coal ash production was 589 million tons annually, but its utilization was less than 15%. In the future, fly ash production will increase, especially in countries such as India and China. In India the production of the fly ash will be about 1373 million tons annually (ICC 2012). Accordingly, efforts to utilize this by-product material in concrete manufacture are important to make concrete more environmentally friendly. For instance, every million tons of fly ash that replaces Portland cement helps to conserve one million tons of lime stone, 0.25 million tons of coal and over 80 million units of power, not withstanding the abatement of 1.5 million tons of CO_2 to atmosphere. There are solutions by using flyash as a substitute for portland cement. Due to more perccentage of silicon and aluminium, Fly ash has great potential as a cement replacement material in concrete.Yet near about 40 % fly ash were used as cement replacement in high volume fly ash concrete. But to replace the portland cement totally, fly ash need to be activated by using alkaline sodium or potasium based solution. Then polymerisation chemical reaction were formed.

The strength of geopolymer depends on the nature of source material, chemical composition, types of activator solution, solution to fly ash ratio, rest period, types of curing and curing temperature. But in practice it is not possible to produce the temperature curing to structure. Without temperature cuting the geopolymer concrete can not set early and gain straingth. But it is possible by using lime and opdinary portland cement in some percentage with fly ash. This paper presents information on fly ash based geopolymer morter with ambient curing. In this experimental works the paper covers the materials and chemical proportions, curing temperature and type and the effect of addition of lime and OPC in geopolymer concrete. In experimental work unprocessed fly ash were used as a source material which was collected form Sofiya thermal power plant, Amravati. In addition to that the hydrated lime and opc were used as a curing agent.

Materials Details

For geopolymer mortar, the unprocessed fly ash, 90 % particle smaller than 45µ was used as a source material, produced from coal based Sofiya Thermal Power plant, Amravati, India. The localy available hydrated lime which is generally used as a construction material were used for early setting. Also OPC was used for early setting and gaining strength at room temperature. The chemical properties of fly ash are given in Table-1. Sodium based hydroxide and silicates were used as an alkaline activator. The sodium hydroxide (NaOH with 98% purity) flake form, and sodium silicate (Na_2SiO_3 with Na_2O = 14.3%, SiO_2 = 32.9%, H_2O = 52.8% and specific gravity 1.58) liquid form were used as an alkaline activator collected from local supplier. Sodium Hydroxide of 14 molar was used for making alkaline activator solution with sodium silicates liquid. Both the chemicals were well mixed together and then added in to the dry mix of fly ash and fine aggregate. For all trials both the chemicals were stirred equally (20 times) by using two jars for applying a same effect of stirring in all mixes. For compressive strength the cubes of size 70.6mm were used. After casting the cubes moulds were kept for ambient curing at room temperature. Then cubes were left in ambient temperature up to testing at 7 days. The surrounding temperature was 25 to 33 ^oC

In geopolymer the strength is depends on various factors, such as types of source material, fineness and chemical composition of source materials, types of activator solution, ratio of solution to source material, Na_2SiO_3 to NaOH, rest period, cruring temperature, types of curing and concentration of NaOH solution. In this experiment testing of cement for fly ash was carried out. First of all the consistency of fly ash was found out by using Vicats apparatus, and it was found to be 29% water required for making a standard paste of fly ash. The following parameters were optimized step by step.

1) Time between preparations of activator solution (Na_2SiO_3 + NaOH) to mixing with fly ash.
2) Rest period
3) Curing temperature
4) Solution to Fly ash ratio
5) Sodium silicate to Sodium hydroxide ratio

For optimizing the any one parameter the other parameters were kept constant. Before starting this work some trials were done for finalizing the all parameters (solution to fly ash ratio, sodium silicates to sodium hydroxide ratio, rest period, curing temperature etc.). After several trials following all the parameters were finalized from results and are given as under:

1) Solution to fly ash ratio = 0.5
2) Ratio of Na_2SiO_3 to NaOH = 1.5
3) Rest period = 1 day
4) Curing Temperature = 80 ^oC
5) Curing Duration = 24 hrs.

For this study the total 12 mixes of mortar were studied. The Mix 1 is design for Plain geopolymer mortar and serve as a control mix. The strength of this mix was used for comparison with strength of all other mixes. The cubes of mix 1 were cured at an elevated temperature of 80 ^oC for 24 hrs, with 1 day rest period. Lime was added 2%, 4%, 6%, 8% and 10% of total binder in the mixture 2, 3, 4, 5, 6, 7 to 8 respectively. In another mixtures ordinary Portland cement were added 2%, 4%, 6%, 8% and 10% of total binder in the mixture 9, 10, 11, 12,13 and 14 respectively. All mixtures were activated by a constant amount of alkaline activator as 50% of the total binder. All of the mixtures in this study were designed at constant amount of water 90 gm and without super plasticiser.

The quantity of water calculated for geopolymer mortar in the same way as cement mortar. That is [(P/4)+3] % of mass of total materials (ie. fly ash + Sand + total solids in activator solution). P is a standard consistency of Fly ash.

Table 1: Composition of Fly Ash (Mass %)

Contents	Percentage	Contents	Percentage
SiO_2	61.85	TiO_2	1.84
Al_2O_3	27.36	MgO	1.0
Fe_2O_3	5.18	P_2O_5	0.54
CaO	1.47	SO_3	0.05
Na_2O	0.08	LOI*	1.0
K_2O	0.63		

*Loss of Ignition

Table 2: Mix Proportion Details

Mix	Fly Ash (gm)	Lime (gm)	OPC (gm)	SH (gm)	SS (gm)	Water (gm)
TC	600	0	0	120	180	90
AC-1	600	0	0	120	180	90
AC-2	594	06	0	60	90	90
AC-3	588	12	0	120	180	90
AC-4	582	18	0	120	180	90
AC-5	576	24	0	120	180	90
AC-6	570	30	0	120	180	90
AC-7	564	36	0	120	180	90
AC-8	594	0	06	120	180	90
AC-9	588	0	12	120	180	90
AC-10	582	0	18	120	180	90
AC-11	576	0	24	120	180	90
AC-12	570	0	30	120	180	90
AC-13	564	0	36	120	180	90
AC-14	540	0	60	120	180	90

TC : Mixture for temperature curing.
AC : Mixture for Ambient curing.

Mixing and Curing of Geopolymer Mortar

The mixing of geopolymer mixtures can be done in two major steps: preparation of the alkaline activator solution and final mixing of all ingredients. The alkaline activator solution was prepared at the time of final mixing with the other ingredients. The sodium hydroxide solution and sodium silicate solution of desired quantity were mixed together and stirred well All the mixes of geopolymer mortars were mixed manually in a laboratory pan to obtain a uniform mixture. Saturated surface dry (SSD) sand and the binders (fly ash, lime and OPC) were mixed thoroughly before adding the activator solution. Premixed alkaline activator solution was then added gradually and mixing was continued for another 3–4 min until a consistent mixture was obtained. The similar procedure of mortar mixing was followed for the mixing of

ISSN:2319-6890(online),2347-5013(print)
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concrete. Fine aggregates and the binders (fly ash, lime and OPC) were dry-mixed thoroughly in the mixing pan for two minutes before adding the activator solution. Fresh mortar mixture was cast in cube moulds. (70 mm x70 mm x 70 mm) The moulds were filled in two layers and each layer was compacted on a vibrating table. They were then stored at a room temperature of 23–32°C (Ambient curing). Samples were removed from the mould after 24 h of casting and left again at room temperature.

Table 3: Compressive Strength at 7 days

Mix	Fly Ash (gm)	Lime (%)	OPC (%)	Comp. Strength at 7 Days (N/mm^2)
TC	600	0	0	25.53
AC-1	600	0	0	10.89
AC-2	594	2	0	13.00
AC-3	588	4	0	15.06
AC-4	582	6	0	17.71
AC-5	576	8	0	18.86
AC-6	570	10	0	15.77
AC-7	564	12	0	14.08
AC-8	594	0	2	11.08
AC-9	588	0	4	12.98
AC-10	582	0	6	15.17
AC-11	576	0	8	17.30
AC-12	570	0	10	19.17
AC-13	564	0	12	22.16
AC-14	540	0	20	29.94

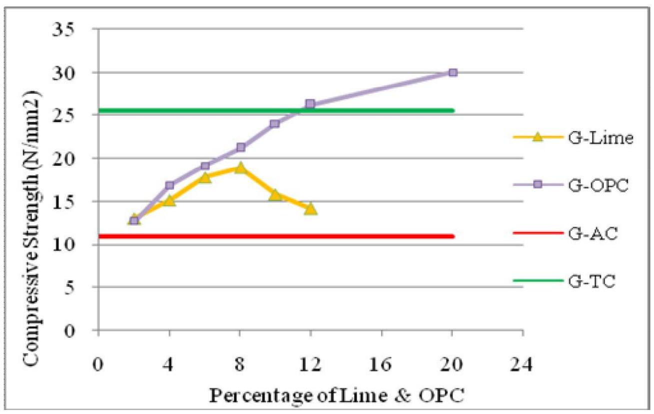

Figure 1: Variation of Compressive Strength vs % of Lime & OPC.

Image 1: Dry mixture and paste of Geopolymer Mortar

Image 2: Casting and Curing of Geopolymer Mortar

Results and Discussion

The total forty five cubes of geopolymer mortar were tested to study the effect of Lime and OPC on setting time and compressive strength of mortar cured in ambient temperature. The mixtures generally appeared stiff and cohesive but when lime and OPC is added in individual mix the concrete mixtures appeared stiffer than mixed with fly ash alone. The mixtures 3, 4, 5, 6, 7 and 8 have increasing amount of Lime and represent the effect of inclusion of Lime in the fly ash based geopolymer. The results were compared with the control geopolymer mixture (Mix 1) which is fly ash alone as the binder. Geopolymer pastes containing fly ash only as the binder took significantly long time (greater than 24 h) before showing any sign of setting due to slow rate of chemical reaction at low ambient temperature. When lime and OPC was incorporated in the mixture, setting time of geopolymer pastes improved significantly. Both initial and final setting time decreased to values comparable to that of fly ash alone paste. It also shows that higher the Lime and OPC content in the paste, the quicker is the rate of setting. In case of Geopolymer with lime, the initial setting time decreases with increas in percentage of lime. After filling the mortar cubes the reaction get started and some bubbles are generated on the surface of paste. This sign of reaction with lime obtained faster mixture to mixture when percentage of lime increases. Geopolymer with 3 % and 6 % lime shows the similar rate of setting as cement paste. But mix with 8 %, 10% and 12 % of lime set very fast. The mix with 8% of lime was set after 50 min. The mix with 10 % and 12% of lime, the mortar paste set after 30 min and 20 min respectively. Geopolymer with 8 % lime shows the highest compressive strength as compared to other mix of lime. In geopolymer with lime, the compressive strength increases when increasing the percentage of lime up to 8%, but after 8% the compressive strength goes on decreasing when increasing the percentage of lime in geopolymer mix for ambient curing. In case of geopolymer with OPC the compressive strength increases when increasing the percentage of OPC. The initial setting time decreases with increasing the percentage of OPC, but the rate of decrease of initial setting time decreases as compared to that of mix with lime. The mix with 12 % OPC achieves the strength more than the mix with fly ash alone with temperature curing (Mix 2).

Conclusion

- As the percentage of lime and OPC increases in the mixtures the workability decreases.

- The initial setting time of Geopolymer mortar with lime decreases when the percentage of lime increases.
- Initial setting time of Geopolymer mortar with lime up to 8% was more than 30 min.
- Geopolymer mortar with 8% lime gives the maximum strength than that of other mixes with lime.
- As the percentage of OPC increases, compressive strength of mortar also increases.
- Mixture with 12% OPC with ambient curing achieves more strength than mixture of fly ash alone with temperature curing.
- Geopolymer mortar with OPC gives better results as compared to geopolymer with lime.

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