Studies of Ferro-Geopolymer for High Column Water Retention

Shivam Kumari Bhadouriya[1] Prof. Nancy Soni[2]
[1]M. Tech. Student [2]Assistant Professor
[1]Department of Civil Engineering
[1]RKDF College of Engineering, Bhopal, M.P., India.

Abstract— The aim of the dissertation is to develop a Ferro Geo-polymer that can be utilized in water tight structures for retaining water. Especially in dams, where the main problem is faced due to unwanted seepage of water through the base of the structure and fails the purpose of dam construction. The designed ferro- Geo-polymer is strong enough to bear loads and has very low permeability of water under pressure. Geo-polymer is an eco-friendly construction material that is prepared by mixing any pozzolonic material, other than cement into the sand and simultaneously activated by an alkali solution. In this dissertation we used flyash as the pozzolonic material, which is a threat to the disposal authorities. Fly-ash is a by-product retained from the industries that uses coal as their raw material and an important contributor to the global warming. Since fly-ash particles are extremely small and hard to be trapped in the scrubbers installed in the industries, they create nuisance. Developing any material that utilizes fly-ash into it is an economical and environmental friendly technique. Ferro Geo-polymer utilizes chicken wire mesh to prepare a durable, strong and cheap material that can withstand sufficient loads and also does not allow water to pass through it. Several cubes of Ferro Geo-polymer were moulded in the laboratory and after proper curing is subjected to the tests that were performed to observe the properties of the developed material. Compression test & water penetration test was the main focus of the dissertation, and the Ferro Geo-polymer material designed proved its competence on the decided criteria.

Key words: Geo-Polymer, Ferro Geo-Polymer, Fly-ash, Pozzolonic Material, Water Retaining Structures, Global Warming, Compression Test, Water Penetration Test

I. INTRODUCTION

Ferro-cement is a form of reinforcement mortar that differs from conventional reinforced or pre-stressed mortar primarily by the manner in which the reinforcing elements are dispersed and arranged. It consists of closely spaced, multiple layers of mesh or fine rods completely embedded in cement mortar.

In recent decades, the industrialization and urbanization are the two phenomena that are going unabated all over the world. Apart from the need for these phenomena, one has to look into their negative impacts on the global environment and social life.

Most important ill effect of these global processes has been the generation of large quantities of industrial wastes. Therefore, the problems related with their safe management and disposal has become a major challenge to environmentalists and scientists. Second related problem is the pressure on land, materials and resources to support the developmental activities, including infrastructure.

Energy requirements for the developing countries in particular are met from coal- based thermal power plants. The disposal of the increasing amounts of solid waste from coal-fired thermal power plants is becoming a serious concern to the environmentalists. Coal ash, 80% of which is very fine in nature and is thus known as fly ash is collected by electrostatic precipitators in stacks. Fly ash generated at present is largely responsible for environmental pollution.

One of the main problems associated with the Ferro cement is that the mesh which is sandwiched inside the mortar got corroded with time.

A. Fly-Ash – A Waste as a By-product:

Fly ash, being treated as waste and a source of air and water pollution till recent past, is in fact a resource material and has also proven its worth over a period of time. Fly ash is one such example, which has been treated as waste materials, in India, till a decade back, and has now emerged not only as a resource material but also as an environment savior.

During the last 30 years, extensive research has been carried out to utilize the fly ash in various sectors, as this is not considered as hazardous waste. Broadly, fly ash utilization programmers can be viewed from two angles, i.e. mitigating environmental effects and addressing disposal problems (low value–high volume utilization).

In order to keep the pace with the rapid industrialization there is a necessity to select such process, which would cause minimum pollution in to the environment. In order to keep pace with the rapid industrialization there is a necessity to select such process, which would cause minimum pollution in environment

The demand for the mortar as a material of construction will increase as the demand for infrastructure development increases, especially in countries such as China and India. In order to meet this demand, the production of Portland cement must increase. However, the contribution of greenhouse gas emission from Portland cement production is about 1.35 billion tons annually or about 6% of the total Green House Gas (GHG) emissions to the earth's atmosphere. Furthermore, Portland cement is among the most energy-intensive construction materials, after aluminium and steel.

It is also known that the production of each ton of Portland cement releases almost one ton of carbon dioxide (CO_2) into the atmosphere. The production of Portland cement is also very energy intensive (Meyer, 2009).

B. Portland Cement:

In 1824 Aspdin patented Portland cement and is so called due to its resemblance in color and character to the naturally occurring stone of Portland Bill, of the south coast of England .It is commonly manufactured from limestone or chalk as a source and clay, shale or sand as a source of silica, certain waste products, such as flyash, can also be used as a silicon source. The blended materials, known as raw meal, are fired in a rotary kiln at a high temperature about 1450 ^{0}C, and inevitably involve the consumption of significant quantities of fuel generally coal.

Cement production is a highly energy - intensive process. There are four basics types of cement process currently in use namely wet process; semi wet process, semi dry process and dry process.

1) Wet process: This is particularly useful when the raw material contain a significant amount of moisture as quarried. This process has the advantage of uniform feed blending, but requires more energy than other types of kiln, since the water must be evaporated during the process. The raw materials are prepared and mixed with the aid of water (30-40%) and fed into the kiln as slurry.
2) Semi-wet process: In the semi-wet cement manufacturing process the raw materials prepared by wet processing are first mechanically dewatered and then fed in the form of nodules to a drying unit.
3) Semi-dry process: In the semi-dry process, nodules or pellets (approximately 12% water) formed from raw meal with the aid of water are used.
4) Dry process: In this process the raw material is fed to the kiln as dry powder.

Desired physical and chemical properties of cement can be obtained by changing the percentages of the basic chemical components, lime alumina, silica and iron oxide (CaO, SiO2, Al2 O3 , Fe2O3 , MgO, SO3 . etc.). Approximate oxide limits of ordinary Portland cement (OPC) is shown in the table 1.1.

Oxides	Percent Content
CaO	60 - 67
SiO2	17 - 25
Al2O3	3 - 8
Fe2O3	0.5 – 6
MgO	0.1 – 4
Alkalies (K2O , Na2O)	0.4 – 1.3
SO3	1.3 – 3

Table 1: Oxide Content of Ordinary Portland Cement

C. Geopolymer:

In 1978, Joseph Davidovits developed inorganic polymeric material and coined the term “Geopolymer” for it in 1990. Geopolymer is a novel binding material produced from the reaction of fly ash with an alkaline solution. In geopolymer Portland cement is not utilized at all. It has the potential to replace OPC in mortar manufacturing and produce fly ash based geopolymer mortar, low calcium with excellent physical and mechanical properties. In order to produce geopolymer low calcium flyash needs to be activated by an alkaline solution to produce polymeric Si-O-Al bonds. Geopolymer mortar has the potential to reduce greenhouse gas emission from the mortar industry by 80% (Hardjito et al. 2008).

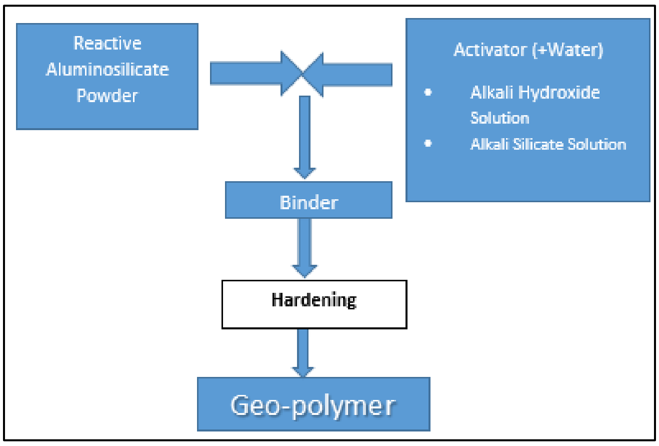

Fig. 1: Flowchart of Making of Geopolymer

Ferro cement is a versatile structural construction material possessing unique properties of strength and serviceability. It is made with closely-knit wire mesh and mild steel reinforcing bars filled with rich cement mortar. Welded mesh may also be used in place of reinforcing bars. The materials required for making it, namely, cement, sand, wire mesh, and mild steel reinforcing bars, are easily available in most places. It is possible to fabricate in fibrocement a variety of structural elements which are thin, light, and durable and possessing a high degree of impermeability. Ferro cement combines the lightness of steel and mouldability of mortar and can be cast to any shape.

II. LITERATURE REVIEW

Mudgal et al. (2007) presented the detailed description of advances which are going on in treatment technologies used for industrial hazardous waste management. In this paper, it is discussed that the management of hazardous wastes is a major issue of concern in India and industrial processes/ operations are the largest contributor of hazardous waste. It is also explained that there are four main characteristics of hazardous waste viz. Ignitability, corrosivity, and reactivity and extraction potential toxicity.

– Ignitability: Ignitable wastes are liquids with a flashpoint below 600 0C, or solids capable of causing fire under standard temperature and pressure.
– Corrosivity: Corrosive wastes are aqueous wastes with a pH below 2 or above 12.5, or which corrode steel at a rate in excess of 0.25 inches per year.
– Reactivity: Reactive wastes are normally unstable react violently with air or water, or potentially explosive mixtures with water. This category also includes wastes that emit toxic fumes when mixed with water and materials capable of detonation.
– Toxicity: The fourth characteristic is Extraction Potential (EP) toxicity. The characteristic of toxicity is more difficult to define. The objective of this parameter is to determine whether toxic constituents in a solid waste sample will leach into ground water if the waste is placed in a municipal solid waste landfill. If this is the case, then the waste will be declared hazardous.

It is important to mention here that as per Indian regulations, Fly ash is classified as non-hazardous and considered that it satisfies the criteria for landfill disposals. Even then the utilization of Fly ash in a manner safer than disposal is a best & encouraging initiative.

Davidovits (1988; 1994) 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 by product material such as fly ash and rise husk ash to produce binders. Because that takes place in this case is a polymerization process, he coined the term "Geo polymer" to represent these binders.

Nicholson et al. 2005 discussed that the geo polymer material are inorganic polymer synthesized by reaction of a strongly alkaline solution and an alumina-silicate source at near ambient temperature. The low energy process results in fast setting material that exhibits exceptional hardness and strength and, in this respect, geo polymer are similar to cement

ACI Committee 226 (1987), defined fly ash " the finely divided residue resulting from the combustion of ground or powdered coal which is transported from the firebox through the boiler by flue gases, known in UK as PFA"

Alam and akhtar (2011) discussed in the study that according to ASTM C-618 Fly ash is broadly into two major categories: Class F and Class C fly ash. The chief difference between these two classes is the amount of calcium, silica, alumina, and iron content. The chemical properties of fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite).

Hardjito et al. (2004) studied that to reduce GHG emission efforts are needed to develop environmentally friendly construction material. In geo polymer binder, a by-product material rich in silicon and aluminium, such as low-calcium (ASTM C 618 Class F) fly ash, is chemically activated by a high alkaline solution to form a paste that binds the fine aggregate and other unreacted material in the mixture. The test result show the effects of various parameters on the properties of geo polymer binder like as the curing temperature in the range of 30 to 900 C increase, the compressive strength of geo polymer binder also increase, longer curing time in the range of 6 to 96 hours (4 days), produces large compressive strength of geo polymer binder, the fresh geo polymer binder is easily handled up to 120 min without any sign of setting and without any degradation in the compressive strength, the geo polymer binder undergoes very little drying shrinkage and low creep etc. So, applications of geo polymer binder and future research needs are also identified.

Swanepoel and Strydom (2002) studied that finding means of utilizing waste product is a very important field of research at the moment. In this study, fly ash, a waste product of the electricity and petrochemical industries, was investigated as a basic ingredient of a new geo polymeric material. The similarity of fly ash to natural pozzolans has encourage the use of this waste product in the synthesis of geo polymer, which in turn, can best be viewed as consisting of a polymeric Si-O-Al framework. Manufacturing the geo polymers was conducted by mixing fly ash, kaolinite, sodium silicate solution, sodium hydroxide and water. The sample was cured at 40, 50, 60 and 70 degree C for different time intervals (6, 24, 48 and72 hours). X-ray diffraction measurements show quartz as the main constituent with the largest part of the geo polymer structure being amorphous and glass-like.

The use of prefabrication for other materials can be made like lintels, sun shades, cupboard shelves, kitchen working slab and shelves, precast Ferro cement tanks, precast staircase steps, precast Ferro cement drains (P.K.Adlakha and H.C.Puri, 2002)

Thin precast RCC lintel normally lintels are designed on the assumption that the load from a triangular portion of the masonry above, acts on the lintel. Bending moment will be WL/8 where W is the load on the lintel and L is the span assumed for the design purpose. By this method, a thickness of 15 cm is required. Thin precast RCC lintels are designed taking into account the composite action of the lintel with the brick work. Design chart prepared for thin precast RCC lintels in the brick walls of normal residential building is applicable only when the load on the lintel is uniformly distributed. The brick work over the lintel is done in a mortar not leaner than 1:6. The thickness of the lintel is kept equal to the thickness of brick itself having a bearing of 230 mm on either supports. Use of precast lintels speeds up the construction of walls besides eliminating shuttering and centring. Adoption of thin lintels results in up to 50% saving in materials and overall cost of lintels. (P.K.Adlakha and H.C.Puri, 2002).

Mass housing targets can be achieved by replacing the conventional methods of planning and executing building operation based on special and individual needs and accepting common denominator based on surveys, population needs and rational use of materials and resources. Adoption of any alternative technology on large scale needs a guaranteed market to function and this cannot be established unless the product is effective and economical. Partial prefabrication is an approach towards the above operation under controlled conditions. The essence lies in the systematic approach in building methodology and not necessarily particular construction type or design. The methodology for low cost housing has to be of intermediate type- less sophisticated involving less capital investment. (P.K.Adlakha and H.C.Puri, 2002).

III. OBJECTIVE OF STUDY

The prime aim of the present investigation is to assess the usefulness of geopolymer based Ferro binder in water retaining structures by observing its permeability under water of static pressure. In order to achieve the objectives a series of experiments are carried out on geo-polymer Ferro mortar sample. Compressive strength test is carried out to ensure strength of sample under nominal loads.

IV. MATERIAL

- Fly Ash: The fly ash from Satpura Thermal Power Plant, Sarni, District. – Betul is selected for the experimental procedure. It is the largest coal fired Power station generating about 1400 megawatt in Madhya Pradesh, contributing to approximately 70% of total electricity supply of the state. The typical fly ash was chosen for mortar component because of its local availability and excellent reactivity. The collection of Fly ash was done by means of electrostatic precipitators at the thermal power station.
- Fine Aggregate : IS 383-1963 defines fine aggregate as the aggregate most of which will pass 4.75 mm sieve.

Locally available river sand which was obtained from river Narmada & called Narmada sand, having a lower size of about 0.07 mm or little less was used as fine aggregates.

– Activated Alkaline Solution: This solution was prepared from dissolution of alkali chemicals in water & used for activation of Fly ash. Special care & protection was required during its preparation & use in laboratory.
– Water : Tap water supplied in laboratory was used for preparation of activated solution which was later used for preparation of geo polymer mortar.
– Welded mesh: A Welded mesh is used in the manufacturing of the green Ferro geo-polymer mortar. The mesh is sandwiched in cement free geo-polymer mortar in panel mould was compacted manually.

V. Experimental Programme

For making cement free-geo-polymer composite panels fly-ash, fine aggregate, Chicken mesh and alkali activators solution of optimized composition were mixed thoroughly.

The experimental procedure involves the evaluation of the compressive strength and the water penetration of the Ferro geo-polymer specimen. Many set of specimen were casted for the experimental purpose. Curing regime condition involved in the experiment, which includes the curing at 600 C for 48 hrs (oven method).

30 moulded sample of size 150mm x 1500mm x 150mm is casted in the experiment, so that 3 cubes of 1:2 and 3 cubes of 1:3 Ferro Geo-polymer mix that can be tested for compressive strength, each on 3rd, 7th, 14th and 28th day after casting and 3 for water penetration test of both 1:2 and 1:3 Ferro Geo-polymer mix cubes on 28th day of curing.

All the specimens samples were cured were cured in the oven for 48 hours with the curing temperature was kept constant at 60°C. At the end of the curing period(48 hrs), the specimens were taken out from the oven and were left undisturbed in laboratory at ambient conditions until these were tested for compressive strength for 3 ,7, 14 and 28 days. This was resulted into finding out the increase or decrease in the compressive strength. Water penetration test is conducted as per German standard DIN 1048 (Part 5).

Fig. 2: Specimen Sample during Experimental procedure

A. *Mix Proportion and Preparation of Specimen:*

Raw materials i.e. fly Ash, sand and welded mesh was weighed manually according to the design mix. The materials were then poured into the mechanical mixer followed the sequences starting with the sand and Fly ash. After the mixture achieved their homogeneity, the alkaline solution was added gradually in the mixer.

Mixing was continued for further 20 minutes or until it develops a uniform mix. The standard cubes of size 15 cm x 15cm x 15cm were casted. Further compaction was done by mechanical vibration using a table vibrator. The procedure of mixing and casting geo-polymer mortar cubes is as per IS 4031.

After casting, the cubes were kept in oven and thermal cured at 60°C for 48 hours. Geo-polymer mortar specimen cubes were tested for compressive strength at the age of 3, 7, 14 and 28 days.

Material	Unit	Quantity
Flyash	Kg	10
Sand	Kg	20
Alkali Activator (Chemical Activator 1 + Chemical Activator 2)	Kg	1.80
Water	Litres	1.5 – 2
Chicken Mesh	m2	4
Slump	mm	150

Table 1: Mix Proportion

For compressive strength testing 03 specimen cubes were tested each on 3rd, 7th, 14th and 28th day after casting and curing, and average value of compressive strength was taken for calculation purpose. Different steps of specimen preparation & testing are shown in Fig.6.

Mix the designed quantity of fly ash fine aggregate in laboratory batch mixer until the mixture is thoroughly blended and is of uniform color then add the designed quantity of chemical solution (prepared by mixing of chemicals in water) and mix it until the mortar appears to be homogeneous and of the desired consistency.

B. *Test Procedures for Water Penetration Test of Geo-polymer mortar Cubes:*

Water penetration test gives the idea of utility of the designed Ferro- geo-polymer in the water retaining structures, like dams, water tanks, etc. In addition to the water penetration test compressive strength is also tested to ensure durability of the designed structure with ferro- geo-polymer in case of its subjection to the loading conditions.

Apparatus : Water penetration testing machine, Pressure regulator, Water reservoir.

Procedure for testing

1) Lift the specimen from laboratory floor or outside after specified age and wipe out any dirt from the surface.
2) Take the dimension of the specimen to the nearest 0.2m
3) Clean the surface of the testing machine
4) Place the specimen in the water penetration cell of the machine shown in figure 3 and fix it with the fixtures provided on the machine to make specimen water tight, as shown in figure 3.
5) Fill the water reservoir up to 75 percent so that the water pressure can be maintained. The water level in the reservoir can be seen with the slit given in the machine and can be regulated with the water regulator shown in fig.4 and 5 respectively.
6) Allow the water to penetrate with an uniform pressure of 5 kg/cm2.for 3 days on each specimen.
7) Open the specimen after 3 days and break it under compression testing machine vertically with the help of

steel rod, so that the penetrated water marks can be observed, as shown in figure 8.

8) Mark the water penetration with the help of a marker and record the maximum depth of penetration, which is the result of water penetration for the designed specimen. Marking of specimen is shown in figure 8.

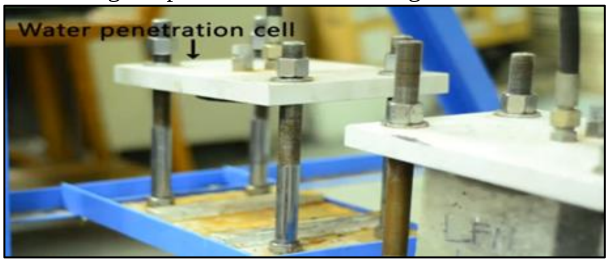

Fig. 3: Water Penetration Cell

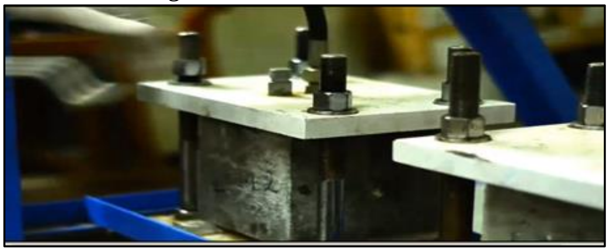

Fig. 4: Tightening of Specimen in Water Penetration Cell

Fig. 5: Water Level Indicator for Water Reservoir

Fig. 6: Water Pressure Regulator

Fig. 7: Breaking of Test Specimen vertically under UTM

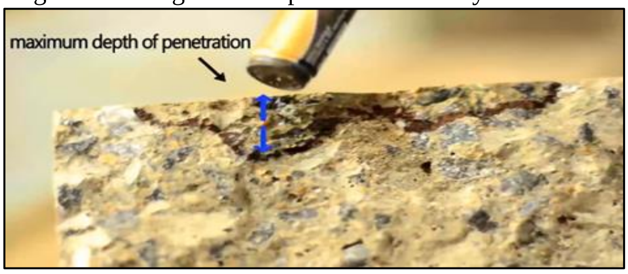

Fig. 8: Marking of Depth of Water Penetration

VI. RESULTS

	3 Days	7 Days	14 Days	28
(1 Flyash : 2 Sand) kg	19	5.51	29.1	30
	20.1	26.68	33.1	31
	17.1	31.98	28.15	32
	21.33	28.05	30.11	31

Table 2: Test Results of Compressive Strength of 1:2 Flyash-sand Ferro Geo-Polymer Cube

	3 Days	7 Days	14 Days	28 Days
(1 Flyash : 3 Sand) kg	21	29	29	29.5
	25	27	23	31
	18	20	20	29
	18.7	25.33	24.00	29.83

Table 3: Test Results of Compressive Strength of 1:3 Flyash-sand Ferro Geo-Polymer Cube

	1:2 (Fly ash - Sand)	1:3 (Fly ash - Sand)
Water Penetration on 28th day of casting and curing	9.2 mm	14.3 mm
	9.0 mm	14.8 mm
	8.4 mm	14.4 mm
	8.86 mm	14.5 mm

Table 4: Test Results of Water Penetration on 1:2 and 1:3 Ferro Geo-Polymer Cube

VII. CONCLUSION

Fly ash obtained from Satpura Thermal Power Plant was characterized and found suitable for geo-polymer mortar preparation . Geo-polymer mortar is more environmental friendly and has the potential to replace ordinary Portland cement mortar in observed test conditions.

Based on the results of the experiments conducted following conclusions can be drawn-

- The compressive strength of 1:3 Fly-ash- sand reference mix thermal cured at 600 C for 48 hrs. was 18.7 MPa at 3 days, 25.33 MPa at 7 days, 24 MPa at 14 days and 29.83 MPa at 28 days.
- The compressive Strength of 1:2 Fly-ash,- sand mix, thermal cured at 600 C for 48 hrs. was 21.33 MPa at 3 days, 28.05 MPa at 7 days , 30.11 MPa at 14 days and 31.00 MPa at 28 days.
- Using welded mesh as reinforcing material in Ferro geo-polymer mortar panels were developed to obtain better engineering properties as geo-Ferro composites.
- The maximum compressive strength, thermal cured at 600 C for 48 hrs. was 29.83 MPa at 28 days.
- Least water penetration is observed the designed specimen. 8.86 mm water penetration is found in 1:2 Geo-polymer mix and 14.5 mm water penetration in 1:3 geo-polymer mix.
- The reaction of fly ash was extremely slow during ambient temperature condition, hence initial thermal curing was observed to be necessary that can improve the geo-polymerization, which led to high strength of geo-polymer mortar.
- The concept of using fly-ash as a cementitious material results in the bulk utilization of industrial waste and solving the environment problems (Air pollution, Ponding, Ground water pollution & Soil pollution etc.).

- The developed Ferro Geo-polymer mortar panels can be utilized for use in partition wall for rural as well as urban toilet and building components.
- Optimized binder can be used for precast building components.
- The Ferro Geo-polymer mortar panels are less susceptible to corrosion.
- The development of Ferro Geo-polymer mortar panels are large scale will lead to bulk utilization of fly-ash, ultimately leads to conservation of environment.

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