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GEOPOLYMER CONCRETE: A CONCRETE OF NEXT DECADE

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Abstract-- *This paper presents the progress of the research on making Geopolymer Concrete using fly ash. This aims at studying the different properties of Geopolymer Concrete using fly ash and the other ingredients locally available. Potassium Hydroxide and sodium Hydroxide solution can be used as alkali activators in different mix proportions. The actual compressive strength of the concrete depends on various parameters such as the ratio of the activator solution to fly ash, morality of the alkaline solution, ratio of the activator chemicals, curing temperature etc. In recent years, Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The amount of the carbon dioxide released during the manufacture of OPC due to the calcinations of limestone and combustion of fossil fuel is in the order of one tonne for every tonne of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminum. Attempts to reduce the use of Portland cement in concrete are receiving much attention due to environment-related. Fly ash-based Geopolymer Concrete is a 'new' material that does not need the presence of Portland cement as a binder.*

Keywords—*Geopolymer Concrete, behaviour of GPC, severe environmental conditions, experimental program*

I. INTRODUCTION

Concrete is till now the most popular material for construction on earth. To act as binder, ordinary Portland cement (OPC) is most widely used with other materials like water and aggregates. The global use of concrete is second only to water. As the demand for concrete as construction material increases, so also does the demand for Portland cement. But still extensive research works are being conducted around the globe to search for an alternative binding agent for concrete keeping in mind the effect of cement on environment as well as the economy involved. The amount of carbon dioxide released during the manufacturing process of OPC is of the order of every ton for 1 ton of OPC produced. Globally the OPC production contributed to around 7% of carbon dioxide. Moreover cement is a costly binder material.

Geopolymer is such an alternative construction material which can act as a binder replacing cement. It mainly makes use of waste or by-product substances like fly ash which is cheap and will reduce environmental pollution to a large extent. Fly ash based geo-polymer concrete is a new product in which no cement is used and geo-polymer paste acts as only binder. Fly ash is available in plenty. Recent research works have focused on the properties of fly ash based geo-polymer concrete. The results of these studies have shown potential use of geo-polymer concrete as a construction material. It possesses good qualities such as high strength, very little drying shrinkage, low creep, durable nature etc to be used as an alternative of OPC.

II. EXPERIMENTAL PROGRAM

An experimental program was carried out in Applied Mechanics laboratory of S.V. National Institute of Technology, Surat. In this work, low-calcium fly ash-based geo-polymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The fly ash-based geo-polymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geo-polymer concrete, with the presence of admixtures. The manufacture of geo-polymer concrete is carried out using the usual concrete technology methods as in the case of OPC concrete .The silicon and the aluminium in the low calcium fly ash, react with an alkaline liquid that is a combination of sodium Hydroxide and Potassium Hydroxide solutions to form the geo-polymer paste.

2.1 MATERIALS USED

Most of the fly ash available globally is low-calcium fly ash formed as a by-product of burning anthracite or bituminous coal. Commercial grade Potassium Hydroxide in pallets form (97% -100% purity) and sodium Hydroxide solution (NaOH=18.2%, SiO2=36.7%, Water = 45.1%) were used as the alkali activators. The potassium Hydroxide pallets were dissolved in the required amount of water according to the desired molarities. Locally available aggregate and fine river sands were used as aggregates for the concrete. Note that the mass of water is the major component in both the alkaline solutions. For improving the workability of the concrete super-plasticizers was used.

2.2 MIXING AND CURING

1].Mixing of all the materials was done manually in the laboratory at room temperature. The fly-ash and aggregates were first mixed homogeneously and then the alkaline solutions which were made one day before and super-plasticizer were added to the mixture of fly ash and aggregates.

2].The Potassium Hydroxide and the sodium Hydroxide solutions were first mixed with each other and stirred to obtain a homogeneous mixture of the solutions before adding them to the solids. Alkaline solution is added into the dry mixtures. The mixing of total mass was continued until the binding paste covered all the aggregates and mixture become homogeneous and uniform in color.

3].A Pan Type concrete mixer that offers mechanical sharing action can be used for obtaining uniform mixture with less effort. A typical dry mixture of solids was used to make the cube (150x150x150mm) specimens. The fresh geo-polymer concrete was used to cast cubes of size 150x150x150mm to determine its compressive strength.

4].Each cube specimen was cast in three layers by compacting manually as well as by using vibrating. Each layer received 25 strokes of compaction by standard compaction rod for concrete, followed by further compaction on the vibrating table.

5].The specimens were wrapped by plastic sheet to prevent loss of moisture and placed in an oven. Since the process of geo-polymerization needs curing at high temperature, the specimens were cured at two different temperature 250c and 600c for 24 hours in the oven.They were cured for 24 hours then left to open air (room temperature 250c in the laboratory until testing.

2.3 OBSERVATION AND TEST RESULTS

In the present work, the effects of various salient parameters on the compressive strength of low-calcium fly ash-based Geopolymer concrete are discussed by considering ratio of alkaline solution to fly ash (by mass) 0.35 constant. All the cube moulds were tested for compressive strength using the compression testing machine in the Applied Mechanics laboratory of S.V. National Institute of Technology, Surat. Compressive strength of concrete cubes was tested at the age of 1, 3, 7, and 28 days. Fig. 1 shows the testing of cubes cured at 600c at compressive testing machine to determine its compressive strength. After testing, there was equal cracking of all four exposed faces with little or no damage to the faces (top and bottom) in contact with the platens. Cracking was in vertical zigzag pattern. The failure pattern is shown in Fig.2.

Fig.1-Measuring Compressive Strength of Geopolymer Concrete

Fig.2-Failure Pattern of Cube After Testing

III. LIMITATIONS OF GPC

The main limitations of fly ash based Geopolymer concrete are:-

1]. Slow setting of concrete at ambient temperature.

2]. Necessity of heat curing.

And these limitations are eliminated by addition of Ground Granulated Blast Furnace Slag (GGBS) powder which shows considerable gain in strength. The geopolymer concrete gained strength within 24 hours at ambient temperature without water curing. The necessity of heat curing of concrete can be eliminated by incorporating GGBS and fly ash in a concrete mix. The strength of Geopolymer concrete can be increased with increase in percentage of GGBS in a mix.

IV. BEHAVIOUR OF GEOPOLYMER CONCRETE UNDER SEVERE ENVIRONMENTAL CONDITIONS

Ever since the introduction of geopolymer binders by Davidovits in 1978, it has generated a lot of interest among engineers as well as in the field of chemistry. In the past few decades, it has emerged as one of the possible alternative to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness. Though geopolymers can be manufactured from various source materials rich in silica and alumina such as fly ash, silica fume, ground granulated blast furnace slag and metakaolin etc, fly ash based geopolymers have attracted more attention. Geopolymer binders might be a promising alternative in the development of acid resistant concrete since it relies on alumina-silicate rather than calcium silicate hydrate bonds for structural integrity. Davidovits found that geopolymer concrete has very low mass loss of 5%-8% when samples were immersed in 5% sulphuric acid and hydrochloric acid solutions. In contrast, Portland cements could be completely destroyed in the same environment.

4.1 DISCUSSIONS

i] *Workability*:-The workability of the geopolymer concrete decreases with increase in the grade of the concrete, this is because of the decrease in the ratio of water to geopolymer solids. As the molarity of the NaOH solution increases the workability of the geopolymer concrete decreases, because of the decrease in the water content. Thus we can say that as the grade of the concrete increases, the mix becomes stiffer decreasing the workability.

ii] *Sulphuric Acid and Magnesium Sulphate Attack on Geopolymer Concrete (GPC) and Ordinary Portland Concrete (OPC) Specimens*

(a).*Visual appearance* :-

From figure 3, it can be seen that the specimens exposed to sulphuric acid undergoes erosion of the surface. In the case of ordinary Portland cement, sulphuric acid attack manifests itself by deposition of a white layer of gypsum crystals on the acid-exposed surface of the specimen. Whereas, geopolymer cement tested, unlike Portland cement, no gypsum deposition can be detected visually. Figure 4 clearly indicates that there is no change in shape and remained structurally intact without visible cracks. Specimen surfaces received white deposits throughout the duration of exposure. These deposits were soft and powdery during, early stage of exposure, it became harder with time. The visual examination of normal concrete subjected to sulphate test has received less deposit of white and less deterioration on the surface of concrete.

(b).*Compressive Strength and Split Tensile Strength in Sulphuric Acid* :-

As the grade of concrete and molarity of the solution increases, the compressive strength of geopolymer concrete also increases. The reduction in compressive strength observed for GPC and OPC specimens were 7%, 15%, 23% and 10%, 15%, 40% respectively for 15, 30 and 45 days of exposure. The reduction in split tensile strength observed for GPC and PPCC specimens were 8%, 18%, 25% and 15%, 18%, 45% respectively for 15, 30 and 45 days of exposure. The strength of GPC and OPC gradually decreases as the day of exposure increases

(c).*Compressive strength and split tensile strength in Magnesium sulphate* :-

The reduction in compressive strength observed for GPC and OPC specimens were 3%, 7%,12% and 5%, 12%, 25% respectively for 15, 30 and 45 days of exposure. The reduction in split tensile strength observed for GPC and OPC specimens were 4%, 9%, 15% and 7%, 14%, 30% respectively for 15, 30 and 45 days of exposure.

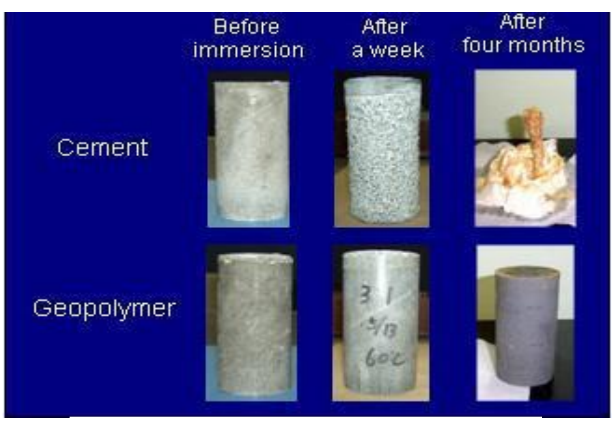

Fig.3-GPC and OPC specimens exposed to Sulphuric acid solution.

Fig.4-GPC and OPC specimens exposed to magnesium sulphate solution

V. APPLICATIONS OF GPC

5.1 SALMON STREET BRIDGE OVER THE WEST GATE FREEWAY-PRECAST GEOPOLYMER CONCRETE PANELS

A total of 180 precast footway units based on a required equivalence to a concrete were manufactured and installed at the Salmon Street Bridge in 2009. The full scale production and installation of the 180 units was completed within the same timeframe as achieved by conventional type concrete. The in-service performance of the precast footway geopolymer panels has been visually monitored for over 5 years since installation. In general the precast geopolymer concrete panels are performing satisfactorily with the surface finish looking good. However, Out of the total 180 unit, some 8 of them were characterized by minor cracking of less than 0.15 mm. It is considered that this cracking would have been there since manufacture and installation rather than in-service. Structurally the precast footway geopolymer panels are considered to be performing very satisfactory without evidence of distress.

5.2 GEOPOLYMER FLY-ASH CONCRETE WALLS

With only the sun powering its new technologies, UNC Charlotte's UrbanEden will be an innovative, sustainable, efficient and eco-friendly house that is at the same time attractive and comfortable. The house will be completely solar powered using several new technologies and renewable technologies, so it's innovative and novel. One of the most innovative aspects of the home will be the use of geopolymer fly-ash concrete for its walls and floors. This is very likely going to be the first geopolymer application of this type. Using fly ash in the concrete is better than using the traditional Portland cement because it cuts down on carbon dioxide emissions.

5.3 GEOPOLYMER CONCRETE FOR AIRPORT

In Australia, on September 28, 2014, the newly complete Brisbane West Wellcamp airport (BWWA) held a community open day. More than 27,000 Queenslanders attended and took advantage of the opportunity to explore the airport before it officially begins operation on 17 November. Wellcamp airport becomes the greenest airport in the world. More than 30,000 cubic metres of the world's lowest carbon, cement-free geopolymer concrete was used to save more than 6,600 tonnes of carbon emissions in the construction of the airport.

Fig.5-Salmon Street Bridge Precast Footway Panels

Fig.6-Geopolymer Fly Ash Concrete Walls being assembled

Fig.7-Wellcamp Airport made by Geopolymer Concrete

VI. ADVANTAGES OF GEOPOLYMER CONCRETE

Geopolymer concrete is a newer product that is making traditional concrete look not so spectacular. Here are some of the top advantages of geopolymer concrete.

1. *High Strength:* Geopolymer concrete has a higher compressive strength as compared to ordinary concrete. It also has rapid strength gain and cures very quickly, making it an excellent option for quick builds. Also it has high tensile strength and is brittle than Portland cement. It is not completely earthquake proof, but does withstand the earth moving better than traditional concrete.
2. *Very Low Creep and Shrinkage:* Shrinkage can cause severe cracks in the concrete from the drying and heating of concrete or even the evaporation of water from the concrete. Geopolymer concrete does not hydrate. It is not as permeable and will not experience significant shrinkage. Creep is the tendency of the concrete to become permanently deformed due to the constant forces being applied against it. And the creep of geopolymer concrete is very low.
3. *Resistance to Heat and Cold*: It has the ability to stay stable even at temperatures of more than 2200 degrees Fahrenheit. Excessive heat can reduce the stability of concrete causing it to spall or have layers break off. Geopolymer concrete does not experience spalling unless it reaches over 2000 degrees Fahrenheit. As for cold temperatures, it is resistant to freezing. The pores are very small but water can still enter cured concrete. Geopolymer Concrete will not freeze.
4. *Chemical Resistance:* Geopolymer concrete has a very strong chemical resistance. Acids, toxic waste and salt water will not have an effect on geopolymer concrete. Corrosion is not likely to occur with this concrete as it is with traditional Portland Concrete.
5. *Some other Benefits of Geopolymer Concrete:* Geopolymer concrete uses industrial waste products like fly ash and blast furnace slag, it gives good abrasion resistance. GPC offers reduction in cost of concrete from 10% to 20% and 80% reduction in CO2 emissions. It is Environment Friendly. There are wide span of applications of geopolymer concrete.

VII. DISADVANTAGES OF GEOPOLYMER CONCRETE

While geopolymer concrete appears to be the super concrete to take the place of traditional Portland concrete, there are some disadvantages of it.

1. *Difficult to Create:* Geopolymer concrete requires special handling needs and is extremely difficult to create. It requires the use of chemicals such as sodium hydroxide that can be harmful to humans.
2. *Pre-Mix Only:* Geopolymer concrete is sold as only pre-cast or pre-mix material due to the dangers associated with creating it.
3. *Geopolymerization Process is Sensitive:* This field of study has been proven inconclusive and extremely volatile. Uniformity is lacking.

VIII. CONCLUSION

The aim of this study is to provide an exposure to the Geopolymer concrete concepts as a favourable alternative to Portland cement concrete. The main conclusions which can be drawn from the results of this study are the following:

1. The reduced CO2 emissions of geopolymer concrete build them a good alternative to ordinary Portland cement concrete.
2. The strength of geopolymer concrete can be increased with increase in percentage of GGBS in a mix. It gains strength within 24 hours at ambient temperature without water curing.
3. The necessity of heat curing of concrete can be eliminated by incorporating GGBS and fly ash in a concrete mix. High temperature curing is not required in all cases of GPC, as sunlight curing can be used at least in tropical countries for Geopolymer concrete mixes.
4. To make the geopolymer concrete, sodium hydroxide and sodium silicate must be optimized and ambient temperature curing of Geopolymer concrete must be well researched.
5. Geopolymer concrete can be prepared at comparable cost with Ordinary Portland cement based concrete.
6. Compressive strength of GPC increases over controlled concrete by 1.5 times (M-25 achieves M-45). Split Tensile Strength of GPC increases over controlled concrete by 1.45 times. Flexural Strength of GPC increases over controlled concrete by 1.6 times.
7. The fly ash-based Geopolymer concrete shows good fire resistance and shows less reduction in compressive strength than the general OPC concrete, without causing spalling.
8. With its high strength and resistance to corrosion and extreme temperatures, geopolymer technology offers a potentially favourable alternative to Portland cement concrete in certain specialized applications.

IX. SCOPE FOR FUTURE WORKS

From the available literatures on Geopolymer concrete and based on the findings in this study, following works are suggested for further research.

1. Development of high strength geopolymer concrete, manufactured with silicates and hydroxides of potassium and the effects of higher strength in the flexural behavior of geopolymer concrete beams.
2. Study on the addition of various fibres in geopolymer concrete and their effect on enhancement of strengths.
3. Achieving ultra high strength geopolymer concrete by the addition of silica fume, quartz sand and quartz powder.

User-friendly Geopolymer concrete, that can be used under conditions similar to those suitable for OPC, are the current focus of extensive world-wide research efforts. This concrete must be capable of being mixed with a relatively low-alkali activating solution and must cure in a reasonable time under ambient conditions. Until such cements are developed, geopolymer applications in transportation infrastructure will be limited. The production of versatile, cost-effective geopolymer concrete that can be mixed and hardened essentially like Portland cement would represents “game changing” advance-ment, revolutionizing the construction of transportation infrastructure.

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