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A STUDY ON GEOPOLYMER CONCRETE PAVER BLOCK WITH RECYCLED AGGREGATES

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ABSTRACT - *Production of a high quality, eco-favorable, interlocking geopolymer concrete paver block is possible. After the introduction of Geopolymer concrete (GPC), many inventions took place to bring out wide scope for its utilization, as it takes part as an appreciable substitute to cement. In order to attain maximum beneficial property from materials, it is inevitable to follow few norms. Studies confirmed that with little proper execution in steps with awareness of behavior of utilized materials, desired target can be achieved. A short survey on previous research is carried out to outline few past exploration on history of GPC, advancement in its application, materials used for manufacture, regarding mix design for preparation, methods of curing the specimens etc., relevant to the same subject concerned, few experts advise are summarized in this paper.*

Key words: Interlocking Concrete Block Pavement (ICBP), Geopolymer concrete (GPC), Reclaimed Asphalt Pavement (RAP), Alkaline solution, Geo-polymerization.

1. INTRODUCTION

In this development field, civil industries have prioritized in making concrete, for usage from ages. The decision of utilization of such material has slowly expanded an antagonistic effect on natural condition. Despite the fact that, need and circumstance requests, the ecological limitations are should be thought of.

Advancement, settle numerous worldwide issues by discovering source of difficulties. Every year, for the construction developments, million tons of cement are manufactured in industries that causes emission of enormous amount of poisonous carbon dioxide gas. To replace cement utilization in few construction practice and to cut down harms caused, use of eco-friendly products are unavoidable. It urges to reexamine and utilize accessible materials in a viable manner.

The absolute substitution of concrete has been made convincible since the presentation of Geopolymer by Prof. Joseph Davidovits, in 1979 [2]. He suggested that an alkaline fluid could be utilized to respond with the silicon (Si) and the aluminum (Al) in a source material (binder), for example, low calcium fly ash confirming standard specifications to create good binding material. Since, chemical reacts resulting process of polymerization, he instituted the term 'Geopolymer' to present these special binders. Geopolymer concrete (GPC) is often regarded as green concrete that bring non-toxic environment which enables to consider as a preferable alternative over conventional cement concrete.

In past seventy decades, as a replacement for paver blocks of bricks, in Holland, first ever blocks of paver made of cement concrete were introduced [9]. As days passed, improvement occurred in moderate way where the blocks are changed to desired shapes in more conventional way. Once which were non-interlocking in nature, now completely changed into multiple interlocking blocks known as interlocking concrete block pavement (ICBP), making its utilization in wide ranges.

Developing country like India, endeavors movement in advancements in different fields, with an inclination to satisfy the requests which present day time demands. Specifically in development field like pavement constructions, buildings etc., it is difficult to meet such demands without hindrance like accessibility of sufficient resources with this pace of growing population. Thus, mass amounts of concrete block pavement (CBP), that has interlinking sides are manufactured in industries as ICBP, which comes in different shapes with varied dimensions for the utilization.

Results from exploration and practices through decades, ICBP proved to possess enough strength properties and higher impact resistances with satisfactory durability. ICBP demonstrated implicitly better decision of substitution over asphalt and concrete pavement in unpredictable condition.

As choice of materials matter, replacing natural, non-renewable source from utilizing few available industrial and construction wastes, creates a cycle of reusing materials that optimizes the use of natural resources. As an example, inclusion of aggregates and asphalt binders from a previous pavement structure known as Reclaimed Asphalt Pavement (RAP) can be adopted as a substitute for choice of aggregates.

2. MATERIALS

2.1 Fly ash

As one of the main constituent of GPC, is the binder material. Binder material should possess silicon and aluminum content like fly ash, silica fumes, ground granulated blast furnace slag (GGBS), metakaolin etc. Usually Fly ash is adopted as a binder. It is of two kinds ASTM class 'C' and ASTM class 'F'. Low calcium (ASTM class 'F') fly ash is utilized as a binder than high calcium (ASTM class 'C') fly ash, as enriched calcium in mix, might be hindrance to the polymerization. Other than its constituent mineral percentage, characteristics like particle size, amorphous content, origin of fly ash and loss of ignition as well as morphology, influences the stability of fly ash [4].

Table 2.1 - General properties of fly ash.

Chemical component	Bituminous coal	Sub bituminous coal
	Value	
SiO_2 (%)	20-60	40-60
Al_2O_3 (%)	5-35	20-30
Fe_2O_3 (%)	10-40	4-10
CaO (%)	1-12	5-30
LOI (%)	0-15	0-3
Properties	**Value**	
Specific Gravity	1.90 - 2.96	
Particle size (µm)	10 - 100	
Colour	Light brownish/light grey/dark grey	
Fineness (m^2/kg)	250 - 350	

2.2 Alkaline solution

The most widely recognized basic alkaline fluid for geo-polymerization is a mix solution of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) and potassium silicate. With concern of cost effective material, commercially available sodium based soluble alkali of more than 95% purity is usually recommended[3]. In most of the studies, the sodium hydroxide solution was used of 8M (molar), 10M, 12M, 14M and 16M. The alkaline solution to binder ratio ranges from 0.3 - 0.45 by mass, the Na_2SiO_3 solution with Na_2O = 14.7%, SiO_2 = 29.4%, and water 55.9% by mass, i.e., SiO_2 - to - Na_2O ratio approximately to 2 by mass [5]. The ratio of Na_2SiO_3 solution to NaOH solution ratio ranges from 0.4 – 2.5. The solution must be prepared a day before mixing, GPC mixture.

2.3 Aggregates

Combined aggregates of about 75% - 80% of the total mass of the GPC mixture is recommended. For any kind of replacement to aggregates, as per standards recommendation nominal size of aggregates should not be more than 12 mm and water absorption should be well within the range of 2% of their own mass of water [10].

2.3 Super plasticizer

Based on the materials nature and mix design, fresh geo polymer mortar might end up with dry and stiff, in such cases to attain enough workability, naphthalene based super-plasticizer is recommended [5]. In most of the studies, super plasticizer is recommended about not more than 3% of cementitious material.

3. EXPERIMENTAL METHODOLOGY

3.1 Mix design

Studies revealed that there is no standard procedure for mix proportioning of materials, instead experts performed several preliminary tests for materials to get familiarized its kind and observed the behaviour of fresh state of mixture, by trial and error methods. Few recommendations are listed below:

- Mix design for GPC can be designed same as that of ordinary Portland cement mix.
- Low calcium fly ash is preferred over high calcium fly ash as a binder.
- Combined aggregates of about 75% - 80% of the total mass of the GPC mixture.
- The alkaline solution to binder ratio ranges from 0.3 - 0.45 by mass.
- With concern of cost effective material and remarkable results from test as well, the ratio of Na_2SiO_3 solution to NaOH solution is usually fixed to 2.5.
- In terms of molar, sodium hydroxide solution can be of choice ranging 8M to 16M.
- Addition of super plasticizer should not be more than 3% of fly ash, by mass.

3.2 Mixing

For a pre-cast paver block, GPC mix of dry or low slump is sufficient. If needed as per requirement, extra water can be added. It is better to mix all dry solid constituents before adding the alkaline solution. Since water plays a vital role in GPC mix, care should be taken such that its addition make mix neither to bleed nor segregate. A good 3 minutes of mixing dry ingredients in mixer is

recommended. Later for about 4 more minutes of mixing after the addition of alkaline solution is sufficient.

3.3 Casting

Clean, dry casting moulds must be greased enough, such that demoulding can be done with ease. GPC mix poured in layers with proper compaction for each layer suffice, to attain target strength.

3.4 Curing

Studies confirmed that GPC specimens can be cured in more than one way. To aid geo-polymerization, specimens can be subjected to ambient curing, oven curing, steam curing, membrane curing, hot gunny curing or water curing [6]. However, the most effective method of curing is oven curing. In order to prevent excessive evaporation at elevated temperatures, demoulded GPC specimens should be wrapped [6]. For near perfect geo-polymerization the curing temperatures were observed between 40°C to 85°C and exposure timing ranged from 4 hr to 96 hr, but there was no significant strength increase beyond 24 hr. Among these above said methods, specimens with oven cured at 60°C for 24 hr, showed remarkable strength results.

4. STRENGTH PROPERTIES OF GPC PAVER

4.1 Test on fresh GPC

Usually the fresh geopolymer concrete mix are very cohesive in nature. For a paver, dry or low workability is preferred. To assess workability of GPC, conventional slump test is recommended. Researchers observed that addition of water increases workability, but there was noticeable decrease in compressive strength [2]. Other than water, combined aggregates content, super plasticizer, concentration of NaOH plays as a factors affecting workability [3].

4.2 Test on hardened GPC (compressive strength)

To ascertain strength property on hardened GPC, compression test is favourable. As per IS 15658:2006, compression test on demoulded GPC paver blocks should be performed at 1 day, 3 days, 7 days and 28 days. Studies confirmed that as geopolymer concrete ages, compression strength value increases, this holds good only when specimens are not heat cured. Along with that, factors like molarity of NaOH solution, ratio of alkaline solution to binder, water content, aggregate content affects final strength of GPC paver. From the studies, it was observed that with an increase in molarity of NaOH solution, compression strength increase as well. Higher the ratio of sodium silicate solution to sodium hydroxide solution, higher will be the compressive strength. It was noticed that GPC yields high early strength as compared to ordinary Portland concrete [2]. Also fly ash based GPC shows higher compressive strength when compared to metakaolin based geopolymer [5].

4.3 Test on abrasion resistance

GPC paver blocks were found to have superior abrasion resistance than OPC pavers [3]. As per Indian Standards 15658:2006, paver blocks should be subjected to abrasion resistance test at 28 days. From the studies it was observed that the abrasion resistance of GPC paver block is higher than OPC. Other than this as per requirement, optional strength tests like tensile splitting strength, density check, water absorption test, permeability check, flexural strength, sulphuric acid resistance and freeze-thaw durability test on hardened paver blocks can be determined.

5. APPLICATIONS

Geopolymer paver blocks are mainly focused for pre-cast applications that are utilized in multiway with varied situations according to desired purpose and condition. Construction and maintenance of GPC pavers are of ease, simple and cost effective. To ensure the acceptable quality of final paver products, specific Indian standards are adopted to deliver, solid blocks. In concern with utilization of eco-friendly pavers in wide range as a complimentary alongside arriving at customer demands, an attempt is made in consideration with certain natural constraints. Since it includes sensitive chemicals like alkaline solution and controlled heat curing regime, it brings out a challenge in handling with care. This GPC can be recommended for utilization where small structural elements which does not demands cast-in-situ.

6. LIMITATIONS

- GPC cannot be recommended for cast-in-situ conditions.
- Cost of alkaline solution.
- Cost of good quality fly ash.
- Heat curing regime involves practical difficulties [3].

7. CONCLUSIONS

- The average density of a fly ash based GPC mix showed comparatively similar to OPC mix.
- With addition of water in GPC mix, there is increase in slump value.
- Relation between the ratio of water-to-binder by mass and compressive strength, is inversely proportion.

- Ratio of Na_2SiO_3 solution to NaOH solution and compression strength of GPC paver is directly proportional to each other.
- Fly ash based GPC mortar does not show any exothermic action like OPC mortar does.
- For an oven cured GPC paver, compressive strength does not depend on age of mix.
- Longer the curing time of fly ash based GPC paver, higher is the compressive strength.
- GPC paver blocks have superior resistance to chemical attack making them suitable for aggressive soils.
- If there are appreciable conditions, Portland cement can be completely replaced by GPC.
- Utilization of GPC has wide scope in precast industries.
- A GPC paver promises a cement free eco-favorable product, with inclusion of industrial wastes as a vital component with excellent beneficial property for utilization in both economic and engineering way.

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