Comparison of Geopolymer Paver Block Using Natural Aggregate and Recycled Aggregate as Fine Aggregate and Slag as Coarse Aggregate

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Abstract. An approximate 400-500 million metric tons of fly ash is generated annually from thermal power plant. The maximum use of fly ash is necessary for the sustainable development. In this research, it attempted to develop a method for manufacture of paver block using fly ash based geopolymer technology. The influence of ratio of alkaline solution and fly ash on geopolymer paver block studied. The fly ash, fine aggregate, coarse aggregate mixed with alkaline solution of 14 molar concentration of NaOH and cured at 90°C temperature. The paver blocks casted for different Na2SiO3/NaOH ratio using natural aggregate and recycled aggregate as fine aggregate and slag as coarse aggregate. Paver blocks tested for compressive strength, flexural strength, water absorption, abrasion resistance. The study results compared against geopolymer paver block using natural aggregate and recycled aggregate as fine aggregate and slag as coarse aggregate. The geopolymer paver block with recycled aggregates having mix proportion as GPC4 showed all the test results within limit as per IS15658, hence it can be used in residential driveways, light vehicles/public pedestrian and light vehicle paths.

1. Introduction
Segmented concrete paving is a system of individual blocks arranged to form a continuous surface overlay. Over the past two decades, paving blocks became a feature of our towns and cities. It is to be found in commercial industrial and residential areas, in the paving malls, plazas, parking areas and bus stops. Extensive research has been carried out on the engineering characteristics and structural performance of paving block [1]. This paper presented a study on the processing of geopolymer concrete paver block using fly ash and alkaline activator with geopolymerization process. This process of manufacturing of paver block utilizes 100 % fly ash replacement to cement.
Approximately 500-600 million metric tons of fly ash is generated annually from the thermal power plant in the world. Out of which 50% of fly ash is being used in cement and brick industry, while rest of fly ash is dumped into ash bund thus, ultimately wasting land use. About 1 ton of cement manufacturing leads to CO2 emissions of 0.95 tons. It is important to reduce CO2 emissions through maximum use of substitute to ordinary Portland cement (OPC) like fly ash. Fortunately in this scenario Geo-polymer concrete emerged that can help in mitigating the problem. Geopolymer binders utilize waste materials that contain a high volume of aluminium and silicon species, typically fly ash from coal-burning power plants which activate in a highly alkali solution, such as sodium hydroxide (NaOH) [2]. Geopolymer concrete being very resistant to aggressive acids and sulphates overcomes durability issues that can plague conventional concrete. Geopolymer concrete can prepare by using 100% of fly ash instead of cement. In geo-polymer concrete fly ash activates using alkaline solution to form binders. Davidovits proposed that binders can be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminum in source materials of geological origin or by-product materials such as fly ash and rice husk ash [3]. Fly ash is the non-combustible mineral portion of coal generated on coal combustion power plant. Fly ash exhibits the pozzolanic activity, due to its highly pozzolanic and cementitious properties. Abundantly available and cheaper use of Fly ash in concrete has to be maximized not only for the benefits imparted to concrete, but also for reducing the global environmental problem caused by cement manufacturing. Currently, number of materials apart from fly ash can be used as pozzolanic material to react with the alkaline activator, including clay, silica fume sand bottom ash. The strength properties of geopolymer materials depend on a number of factors, such as effect of chemical activators, their proportioning, curing temperature, curing time. Thus, the research on geopolymer offers a wide scope for using a number of combinations of the relevant variables involved and finding one that gives the optimum results.

This paper dealt with the use of 100% fly ash with alkaline solution and aggregate for manufacturing of geopolymer paver blocks. It aimed to reduce carbon footprint by replacing the use of cement and to reduce the energy requirement substantially. The geopolymer is an alkaline solution, formed by mixing sodium hydroxide and sodium silicate in water. Many researchers studied technical viability of geopolymer in concrete for strength parameters. Also, effect of the concentration of alkaline activator in the geopolymer mix was extensively studied. NaOH concentration has a positive effect on the compressive strength of the geopolymer, i.e. higher concentration results in higher compressive strength. A majority of the research carried out on geopolymers has employed NaOH concentration of 14M or higher [4]. Often the range of molarity varies from 10M to 20M. A large amount of research carried out on geopolymer concrete, but while implementation on practical purpose, it has limitations. The limitations of geopolymer concrete include curing the concrete on site and it’s high costing in comparison with cement replacement in concrete. A need was felt for new research on geopolymer paver block considering the shortage of literature on the same.

The paper presented the results of geopolymer paver blocks manufactured by using various ratios of sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solution mixed with water used as an alkaline activator. Also, in this research efforts made to check feasibility of replacement of recycled aggregate with natural aggregate in geopolymer concrete for paver block. The strength parameters checked for geopolymer paver block for its application. The compressive strength of geopolymer paver block tested after 7 days of casting, because the strength was approximately constant after 7 days [5]. Also, comparison carried out for results of test such as water absorption, flexural strength and abrasion resistance.

2. Materials
Geopolymer fly ash based paver block manufactured with the class F fly ash, aggregate and alkaline solution (sodium silicate + sodium hydroxide + additives). Sodium hydroxide was having 90% purity. The study carried out with two cases; firstly locally available natural aggregates used having maximum size 12.5mm and free from coagulated lumps. Secondly, natural fine aggregate fully replaced by recycled
aggregates and natural coarse aggregates fully replaced by steel slag of size less than 12.5mm. The aggregate tested for the physical properties as per IS: 2386-1968. Table 1 provides physical properties of aggregates. The roles and the influence of aggregates considered to be the same as in case of portland cement concrete. The mass of combined aggregates was 65% to 70% of the mass of geopolymer concrete [6]. Water used normal tap water satisfying as per IS456 quality for mixing of alkaline solution for concrete [7]. Super plasticizer used in the mixtures, to improve the workability of the fresh geopolymer concrete [8]. For this study, naphthalene sulphonate used as super plasticizer. Table 2 provides the information of chemical composition and physical properties of fly ash used for mix.

**Table 1. Physical Properties of Aggregate**

| Physical Properties | Natural aggregate | Recycled aggregate |
|---------------------|-------------------|--------------------|
| Specific Gravity    | 2.7               | 2.65               |
| Fineness Modulus    | 3.25              | 3.06               |

The alkaline solution formed by mixing NaOH and Na2SiO3 in water. Molecular weight of NaOH was 40. To prepare 1 molar solution 40 gram of NaOH added in 1 liter of water [9]. For instant 14 molar solution has 14 x 40 = 560 gm of NaOH in 1 liter of water. A lot of heat generated when NaOH flakes reacted with water, therefore, NaOH solution prepared a day prior to casting. Water was the medium for dissolution and polymerization of silica and aluminium precursors to take place appropriately. It was also necessary to achieve the desired degree of workability of geopolymer concrete (GPC) mix. In accordance with available literature, the ratio of Na2SiO3/NaOH solution was kept in the range of 0.4 to 2.5 initially. A 14 molar solution of NaOH with varying ratio of Na2SiO3/NaOH of 2 and 2.5 were first prepared. The solution mixed well and allowed to mature for a period of one day prior to use [10].

**Table 2. Chemical composition and physical properties of fly ash**

| Constituent                  | Fly Ash |
|------------------------------|---------|
| Silica content (SiO2)        | 52.32   |
| Ferric oxide + Aluminium Oxide | 32.29   |
| Calcium Oxide (CaO)          | 5.83    |
| Sulphate (SO3)               | 0.15    |
| Magnesia (MgO)               | 1.57    |
| Na2O + K2O                   | 0.04    |
| Loss on ignition             | 4.48    |
| Fineness                     | 329     |
| Soundness                    | 0.08    |
| Specific gravity             | 2.23    |
| Lime reactivity              | 5.9     |
Most of the reported works on geopolymer material related to the properties of geopolymer concrete paste, measured by using small size specimens. Fernández-Jiménez and Palomo studied the geopolymerization of low-calcium fly ash using 8 different mixes varying with Na2SiO3/NaOH ratio [11]. Accordingly, for this study, trial mix varied with Na2SiO3/NaOH and also with alkaline solution/fly ash ratio by mass. Table 3 presents the trial mix proportions considered for study. This study carried out on geopolymer concrete (GPC) with Fly Ash as a 100% replacement of cement. The parameters studied include size effect and grading of the aggregate with 10mm aggregate, 20mm aggregate and a combined aggregate of 20mm-60% and 10mm-40% for 150mm cubes.

### Table 3. Trial mix proportion based Na2SiO3/NaOH and Alkaline solution/FA Ratio

| Trial mixes | Fly ash (Kg) | Natural aggregate (Kg) | Recycled + Slag aggregate (Kg) | Na2SiO3 /NaOH | Alkaline solution /Fly Ash |
|-------------|--------------|------------------------|-------------------------------|---------------|---------------------------|
| GPC1N       | 570          | 990                    | 2                             | 0.45          |                           |
| GPC2N       | 570          | 990                    | 2.5                           | 0.45          |                           |
| GPC3N       | 570          | 990                    | 2                             | 0.5           |                           |
| GPC4N       | 570          | 990                    | 2.5                           | 0.5           |                           |
| GPC1RC      | 377          | 1821.9                 | 2                             | 0.45          |                           |
| GPC2RC      | 377          | 1821.9                 | 2.5                           | 0.45          |                           |
| GPC3RC      | 377          | 1821.9                 | 2                             | 0.5           |                           |
| GPC4RC      | 377          | 1821.9                 | 2.5                           | 0.5           |                           |

3. Manufacturing Procedure

In the laboratory, the fly ash and the aggregates were first mixed together in dry state about three minutes. The alkaline solution was mixed with the super plasticizer. Davidovits suggested that it is preferable to mix the sodium silicate solution and the sodium hydroxide solution together at least one day before adding the liquid to the solid constituents [12]. The liquid component of the mixture was then added to the dry materials and the mixing continued usually for another 10 to 15 minutes. The fresh concrete poured in standard size steel cube mould and compacted by vibro compactor. Prior casting, steel cube moulds coated with oil on their inner surfaces and placed on a plate. Concrete poured in to the moulds in three layers each layer being compacted using a tamping rod. After 48 hours, concrete cubes with mould kept for curing in oven at 90°C for 24 hours. Heat-curing substantially assists the chemical reaction that occurs in the geo-polymer paste. Both curing time and curing temperature influence the compressive strength of geo-polymer concrete. Longer curing time improves the polymerization process resulting in higher compressive strength. The rate of increase in strength is rapid up to 48 hours of curing time; beyond 48 hours, the gain in strength is only moderate. Therefore, heat-curing time need not be more than 48 hours in practical applications [12]. Higher curing temperature resulted in larger compressive strength. Thus, 3 cubes casted for each trail mix mentioned in Table 3. These cubes tested for different strength parameters.
4. Test results and discussion

Initially, concrete cubes of size 150mm x 150mm x 150mm casted for each trail mix and tested for 7 days compressive strength. All the cubes tested for compressive strength and found that compressive strength increasing with ratio of Na2SiO3 /NaOH. The paver block casted only after satisfactory cube strength results and tested in a laboratory. The test results are discussed below.

4.1 Compressive Strength

From the earlier studies conducted on the compressive strength of geopolymer concrete cubes, it was seen that the various parameters like the Na2SiO3/NaOH ratio, alkaline solution/ fly ash ratio influence on the compressive strength. The targeted compressive strength for GPC paver block was 30MPa. Compressive strength tests performed on geopolymer paver blocks after 7 days on compression testing machine as per Annexure D of IS 15658. Alkaline solution to fly ash ratios for each concentration of Na2SiO3 /NaOH considered for the study of compressive strength. The results of trail mixes are given in Figure 1, which shows the comparison of compressive strength for each mix of GPC with natural aggregates and recycled aggregates as fine aggregate and slag as coarse aggregate. The GPC4 trail mix gave a satisfactory result of compressive strength for both natural and recycled aggregates as fine aggregate and slag as coarse aggregate.

4.2 Water absorption

The water absorption test performed as per Annexure C of IS 15656. Water absorption of paver block should not be more than 6 percent by mass and in individual samples, the water absorption should be restricted to 7%. The water absorption of geopolymer paver block with natural aggregate was less than 6% by mass which satisfying limit as per IS15658. While paver block with recycled aggregates as fine aggregate and slag as coarse aggregate was slightly more i.e. 9%.

![Figure 1. Compressive Strength of trail mix composition](image-url)
4.3 Abrasion Resistance Test

Abrasion resistance test carried out as per Annexure E of IS 15656. The standard size of specimen was 70mm x 70mm x 60mm. The average abrasive resistance that is loss in volume for GPC paver block with natural aggregate was 5555 mm³. For GPC paver block with a natural aggregate, it observed that average loss in weight 4.55% and average loss in depth came out to be 2.5mm for 60mm depth that is 4.16%. Similarly, for GPC paver block with recycled aggregate as fine aggregate and slag as coarse aggregate, it observed that average loss in weight 4.65% and average loss in depth came out to be 2.7mm for 60mm depth that is 4.5%. Thus, for both cases, abrasion resistance was within permissible limit.

4.4 Flexure Test

Test was performed as per Annexure G of IS 15658. As per IS 15658 for residential pathways/public pedestrian paths heavy duty/industrial roads minimum breaking load is 2 KN. From the flexure test calculation for geopolymer paver block dimension of specimen calculated as 0.74 MPa. All geopolymer paver block satisfied the minimum flexure strength as per IS15658.
5. Conclusions
The following conclusions drawn based on the results of the experimental investigation. Research on geopolymer concrete paver blocks is definitely the answer to the need of greener concrete for sustainable development. Fly ash can be used to produce geopolymeric binder phase which can bind the aggregate to form geopolymer concrete. As the alkaline to fly ash ratio increase from 2 to 2.5, the effect of concentration of NaOH solution showed that as the concentration of NaOH increases and the compressive strength also increases [9]. For different mixes of geopolymer concrete increase in alkaline solution increases the compressive strength. The compressive strength of geopolymer paver block increases with Na2SiO3/NaOH ratio. The water absorption of GPC paver block with natural aggregate was within the limit. The abrasive resistance of geopolymer paver block with natural aggregate was less as compared to geopolymer paver block with recycled aggregate as fine aggregate and slag as coarse aggregate. The flexural test result of paver block was satisfied in both cases. The geopolymer paver block with recycled aggregates as fine aggregate and slag as coarse aggregate having mix proportion as GPC4 showed all the test results within limit as per IS15658, hence it can be used in residential driveways, light vehicles/public pedestrian and light vehicle paths.

Acknowledgement
The authors acknowledges, the efforts taken by Mr. S. Durga Vikas, Consulting Transportation Engineer, Hydrabad, for initiating this research.

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