PROPERTIES OF DOUBLE LAYER GEOPOLYMER CONCRETE PAVER BLOCKS WITH POLYESTER FIBRES

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ABSTRACT
Portland cement is the most widely used binder material for concrete and also it generates large amount of carbon-di-oxide (CO₂) which is responsible for global warming. The other major engineering problem is disposal of solid waste from coal fired thermal power plants namely fly ash. Geopolymer concrete is prepared without using conventional cement and it can be self-cured. The industrial by products like fly ash and Ground Granulated Blast furnace Slag (GGBS) can be activated using alkaline solutions to get cementitious binder. This paper aims to develop the double layered geopolymer concrete paver blocks by the activation of fly ash and GGBS by adding polyester fibres in the top half thickness of paver blocks. In this experimental investigation properties like density, compressive strength, split tensile strength, flexural strength, water absorption, and abrasion resistance of paver blocks were determined by adding polyester fibres in proportions of 0%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5% by volume of concrete. The paver blocks developed were tested as per IS 15658:2006. Test results indicated that addition of polyester fibres in paver blocks has significant advantages with respect to flexural strength and abrasion resistance.

Keywords: Paver block, Geopolymer, Polyester fibre, Fly ash, GGBS, Flexural strength, Split tensile strength

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1. INTRODUCTION
Use of Paver blocks is one of the best and low cost solutions for outdoor applications. Concrete block pavement technology was introduced in India in construction a decade ago, for applications in footpaths, parking areas etc. Recently paver blocks are being extensively used in situations where the conventional pavement construction using hot bituminous mix or cement concrete technology is not feasible or desirable. Concrete block paving is versatile, aesthetically attractive, functional and cost effective and requires little or no maintenance if
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properly manufactured and laid. The paver blocks allows for better drainage through their interlocks and prevent soil erosion or increase water level in the surrounding land area. Recently in concrete paver block fibres are introduced to increase strength, durability and cracks reduction. Usage of fibres in concrete paver blocks improves their properties. Basic research findings on application of industrial waste materials like fly ash and GGBS and geopolymer are reviewed briefly here.

In an experimental investigation by G. Navya and J.Venkateswara Rao (1), compressive strength, water absorption and flexural strength of paver blocks were determined by adding polyester fibres in the top 20mm thickness from 0.1 to 0.5%. Test results indicated that addition of polyester fibre by 0.4% paver block attains maximum compressive, flexural strengths and minimum water absorption at 7 and 28 days. The same authors experimentally investigated the compressive strength, water absorption and flexural strength of paver blocks by adding coconut fibres in the top 20mm thickness from 0.1 to 0.5%. Test results indicated that addition of coconut fibres by 0.3% in paver block attains maximum compressive strength (2). Basil Mali and Renjan Abraham (3) concluded that geopolymer concrete is an excellent alternative to Portland cement concrete. Low calcium fly ash based Geopolymer concrete pavers have excellent compressive strength within 3days and are suitable for practical applications. The investigation reveals that the geopolymer concrete gives better performance than Ordinary Portland Cement concrete, in both ambient and elevated temperatures. Banupriya. C. et al (4) investigated the use of quarry dust by replacing with river sand for making geopolymer bricks and paver blocks. The geopolymer concrete specimens were tested for compressive strength, split tensile strength and flexural strength. Geopolymer bricks using 65% fly ash & 35% GGBS produced good compressive strength.

Thakur et al. (5) investigated on the effect of partial replacement of cement by fly ash and using nylon fibre in concrete paver blocks. Initially nylon fibre was used in the range of 0.1-0.4% by weight of cement and later fly ash was also added in the range of 10-40% along with optimum nylon fibre content. It was concluded that 20% of partial replacement of cement with fly ash and 0.3% nylon fibre improved the mechanical properties of paver block. A research has been carried out by Bhavin K.Kashiyani et al.(6), by addition of polypropylene fibres in paver blocks to show the change in the abrasion resistance and flexural strength of paver blocks when compared to standard paver block. Test results indicated that, addition of polypropylene fibres by 0.3% and 0.4% gives good results for abrasion resistance and flexural strength at 28 days respectively. Abhinav S. Pawar, K.R. Dabhekar (8) studied the behaviour of rigid pavement (concrete) when cementing waste material (GGBS) and steel fibres were added and were compared with normal concrete of M40 grade. For this study, concrete cubes and beams were produced of five partial GGBS replacement ratios (10%, 20%, 30%, 40% and 50%) with constant water-cement ratio (0.37). The cubes and beams were tested at the age of 7, 28 and 56 days. After testing it was found that at 30% GGBS replacement we can get M40 strength of concrete. In the present investigation eco-friendly paver blocks using geopolymer concrete were developed without cement using geopolymer technology and polyester fibres were added to improve the properties of paver blocks.

2. EXPERIMENTAL PROGRAM

2.1. Materials used

**Aggregates:** Fine aggregate used is Manufactured sand [M-Sand] which is less than 4.75mm. As per IS 387-1970, fine aggregate are aggregates which passes through IS sieve 4.75 mm. M sand used conforms to zone II with a specific gravity 2.13. The nominal size of coarse aggregate used in production of paver blocks shall be 12mm as per IS 15658:2006 (9). In this
work, grey coloured stone chips are used with the average size of aggregate being 6mm as shown in Figure 1. The physical properties of aggregates are given Table 1.

Table 1 Physical properties of materials

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Property</th>
<th>Fly ash</th>
<th>GGBS</th>
<th>Fine aggregate</th>
<th>Coarse aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Specific gravity</td>
<td>1.80</td>
<td>2.20</td>
<td>2.13</td>
<td>2.87</td>
</tr>
<tr>
<td>2.</td>
<td>Fineness modulus</td>
<td>-</td>
<td>-</td>
<td>2.58</td>
<td>6.84</td>
</tr>
<tr>
<td>3.</td>
<td>Bulk density</td>
<td>-</td>
<td>-</td>
<td>1700 kg/m³</td>
<td>603.7 kg/m³</td>
</tr>
</tbody>
</table>

Figure 1 Coarse aggregate

Fly Ash: Fly ash is an artificial pozzolan from coal fired thermal power plants. Low calcium fly ash with a specific gravity of 1.80 is used. Ground Granulated Blast Furnace Slag: GGBS was obtained by grinding the quenched blast furnace slag to fine powder. The specific gravity of GGBS is found to be 2.2. Chemical composition of Fly ash and GGBS is given in Table 2.

Table 2 Chemical properties of Binders

<table>
<thead>
<tr>
<th>Binders</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>Na₂O</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>54.54</td>
<td>28.41</td>
<td>7.26</td>
<td>2.82</td>
<td>0.81</td>
<td>0.35</td>
<td>5.14</td>
</tr>
<tr>
<td>GGBS</td>
<td>35.46</td>
<td>19.47</td>
<td>0.8</td>
<td>33.25</td>
<td>8.69</td>
<td>-</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Alkaline Solution: A combination of sodium hydroxide and sodium silicate is taken as alkaline solution. The sodium hydroxide (NaOH) solids of commercial grade in form of flakes were dissolved in water to make the solution. The mass of NaOH solids in a solution varied depends on concentration of solution. Here the molarity of NaOH considered is 2M. NaOH solution with a concentration of 2M consisted of 2x40=80 grams of NaOH solids per litre of solution, where 40 is the molecular weight of NaOH. Super plasticizers: Super plasticizers are also known as high range water reducers. Conplast SP430 is a chloride free, superplasticising admixture based on selected sulphonated naphthalene polymers. It is supplied as a brown solution which is instantly dispersible in water. The quantity of super plasticizer added in concrete is 3% by weight of cementitious materials. Water: Potable clean drinking water conforming to the requirements of water for concreting and curing as per IS: 456-2009 was used. Extra water is added to improve the workability and the amount of water added is 15% by weight of binder materials (fly ash and GGBS). Polyester fibre: The polyester fibre which is a synthetic polymer made of purified terephthalic acid [PTA] of 0.06mm diameter is
used in the study as shown in Figure 2. Polyester fibre is very durable and hydrophobic in nature. It is very resistant to most chemicals. The properties of fibre are given in Table 3.

Table 3 Properties of polyester fibre

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Density</th>
<th>Diameter</th>
<th>Moisture content</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1370kg/m³</td>
<td>0.06mm</td>
<td>7%</td>
<td>8mm</td>
</tr>
</tbody>
</table>

![Figure 2 Polyester fibre](image)

2.2. Mix Design

The following assumptions are made in the design of geopolymer concrete mix: The unit weight of concrete is taken as 2400 kg/m³. Mass of combined aggregate is assumed as 77% of the mass of concrete. Fine aggregate is assumed as 30% of the total aggregate content. Alkaline liquid to fly ash ratio by mass is taken as 0.4 Binder is 70% fly ash and 30% GGBS. The ratio of sodium silicate to sodium hydroxide solution by mass is 2.5. Distilled water was used to dissolve the sodium hydroxide flakes to avoid the effect of contaminants in the mixing water. Extra water was added 15% by weight of cementitious material to get desired workability for all the mixes. The mix ratio used for casting paver blocks is given in Table 4.

Table 4 Mix proportions

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>276.01kg/m³</td>
</tr>
<tr>
<td>GGBS</td>
<td>118.29 kg/m³</td>
</tr>
<tr>
<td>NaOH</td>
<td>45.14 kg/m³</td>
</tr>
<tr>
<td>Na₂SiO₃</td>
<td>112.85 kg/m³</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>554.4 kg/m³</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>1293.6 kg/m³</td>
</tr>
<tr>
<td>Extra water -15%</td>
<td>59.14 kg/m³</td>
</tr>
<tr>
<td>Super plasticizer-3%</td>
<td>11.82 kg/m³</td>
</tr>
<tr>
<td>Polyester fibre</td>
<td>0% to 0.5% by volume of concrete</td>
</tr>
<tr>
<td>Molarity of NaOH</td>
<td>2M</td>
</tr>
</tbody>
</table>

2.3. Specimens and testing program

In the present investigation zig-zag paver blocks having a thickness of 80mm were cast. As per IS 15658:2006, minimum and maximum block thickness shall be 50mm and 120mm respectively. Paver block concrete contains fly ash, GGBS, fine aggregate and coarse
aggregate in the bottom half layer and in the top half layer of paver block same concrete mix is mixed with polyester fibres in 0%, 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% by volume of concrete. About 96 paver blocks were cast for determining the density, compressive strength, split tensile strength, flexural strength, water absorption and abrasion resistance as per IS:15658:2006 as shown in Figure 3.

The dimensions and plan areas of the specimens were determined as per IS 15658: 2006. Relevant testing procedures were followed for various tests. Density of the paver blocks were determined by dividing the mass of the block in kg to the volume of the block in $m^3$. For compression test, the paver block specimens were selected and 4 numbers in each mixes are tested for compressive strength in compression testing machine. The load shall be applied without shock and increased continuously at a rate of $15 + 3 N/mm^2$/min until no greater load can be sustained by the specimen or delamination occurs. For tensile split test it shall be ensured that the packing pieces and the axes of the bearers are in line with the splitting section of the specimen. The rate of loading is $48 + 3 kN/min$. The Flexural strength tests of concrete paver block specimens were determined at 28 days of age. The load shall be applied from the top of the specimen in the form of a simple beam loading through a roller placed midway between the supporting rollers. As per IS 15658:2006 the load shall be applied without shock and increased continuously at a uniform rate of 6kN/min. The water absorption test specimen shall be completely immersed in water at room temperature for 24 ± 2 h. The specimen then shall be removed from the water and allowed to drain for 1 min by placing them on a 10 mm or coarser wire mesh. Visible water on the specimens shall be removed with a damp cloth. The specimen shall be immediately weighed and the weight for each specimen noted in kg. For abrasion resistance sample size with 70.6x70.6 mm surface, properly dried in an oven was placed on disc rotating at 30 rpm with constant load of 300 N and 20 gram abrasive powder uniformly spread over disc at end of predefined constant revolution 22 and repeated for total 220 revolutions with 9 breaks. The wear shall be determined from the difference in readings obtained by the measuring instrument before and after the abrasion of the specimen.

3. RESULTS AND DISCUSSION

3.1. Density

Density of the paver blocks were determined by dividing the mass of the block in kg to the volume of the block in $m^3$. The key for strong paver blocks is the density; high dense paver blocks can resist abrasion better and have better resistance to freezing and thawing. The density values of the standard paver block and paver block with polyester fibers in top layer thickness. Density value ranges from 1939 kg/m$^3$ to 2193 kg/m$^3$.
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![Graph showing density at 28 days for paver blocks with and without fibres.](image)

**Figure 4** Density at 28 days for paver blocks without and with fibres

From Figure 4 it is observed that the average density of concrete paver blocks without fibres is 2097.23 kg/m³. Density of paver blocks with 0.2% of polyester fibres is comparatively less as compared to other specimens. Density is maximum at 0.5% of fibre content. The next higher density is achieved for paver blocks with 0.4% of polyester fibres. The increment in density at 0.5% of fibres is 4.59% at 28 days as compared to paver blocks without fibres. The addition of fibres does not have any appreciable effect on density. This is due to the reason that the polyester fibres being light in weight did not contribute to increase in weight of paver blocks.

3.2. Compressive strength

The compressive strength of paver blocks were determined by as per the code procedure IS15658:2006. The compressive values of paver blocks with and without polyester fibres are shown in Figure 5. Compressive values ranges from 39.58 N/mm² to 50.87 N/mm². It is observed that the average compressive strength of geopolymer concrete paver blocks without fibres is 47.94 N/mm². From Figure 5, it can be seen that compressive strength of paver blocks with 0.2% of polyester fibre is comparatively less compared to other specimens. Maximum Compressive strength is attained for paver blocks with 0.5% of polyester fibres. The increment in the compressive strength at 0.5% fibre content is 6.11% at 28 days. The addition of fibre does not have any positive effect on compressive strength which implies that polyester fibres are not effective enough in resisting compression.

![Graph showing compressive strength with percentage of fibres.](image)

**Figure 5** Compressive strength
From the average compressive strength obtained it can be interpreted that, paver blocks without polyester fibre and paver blocks containing 0.3, 0.4, and 0.5% of fibres satisfy the compressive strength requirements of M40 grade of paver blocks as per IS 15658 :2006 and hence those paver blocks can be used for medium traffic conditions. On the other hand, paver blocks containing 0.1 and 0.2% of fibres satisfy the compressive strength requirements of M35 grade of paver blocks as per IS 15658 :2006 and hence those paver blocks can be used for light traffic conditions.

3.3. Split tensile strength

The split tensile test was carried out as per procedure given in IS 15658:2006. For each of the samples tested, failure load was noted. Failure length and failure thickness were also measured for each of the specimens from which the splitting tensile strength was calculated. The split tensile strength values of paver blocks at 28 days with and without fibres are also shown in Figure 6.

The Split tensile value ranges from 2.01 N/mm$^2$ to 2.42 N/mm$^2$. There is a nominal increase in split tensile strength due to the addition of polyester fibres. The increase in split tensile strength is about 4.5%, 11.4%, 15.9%, 17.9% and 20.4% respectively for 0.1, 0.2, 0.3, 0.4 and 0.5% of polyester fibres respectively. This increase in split tensile strength of geopolymer concrete may be due to the tensile strength of the polyester fibres which contribute to the increase in tensile strength of geopolymer concrete.

3.4. Flexural strength

The flexural strength test results are shown in Figure 7. The average flexural strength of paver blocks ranges from 3.41 N/mm$^2$ to 5.6 N/mm$^2$. The flexural strength of paver blocks without fibres is 3.41 N/mm$^2$. Due to inclusion of fibres in the top layer of paver blocks, flexural strength increases considerably as shown in Figure 7.
3.4. Flexural strength

As the content of polyester fibre increases the flexural strength also increases. There is an increase in flexural strength of about 13.8%, 20.8%, 31.4%, 55.4% and 64.2% for 0.1, 0.2, 0.3, 0.4 and 0.5% of polyester fibres respectively. According to IS15658:2006 specifications, the suggested minimum breaking load for heavy duty or industrial roads must be 7kN and for all the paver blocks tested, the breaking load value is greater than 7 kN.

3.5. Water absorption

The water absorption test results are shown in Figure 8. The average water absorption of paver blocks ranges from 2.87% to 4.46%. The average water absorption of paver blocks without fibres is 2.87%. Water absorption values increases due to inclusion of fibres in the top layer of paver blocks as shown in Figure 8. As the content of polyester fibre increases the water absorption also increases. Water absorption increases by about 17.8%, 34.1%, 36.2%, 42.9% and 55.4% for 0.1, 0.2, 0.3, 0.4 and 0.5% of polyester fibres respectively. This increase in water absorption may be due to the presence of minute pores present on the surface of the paver blocks which might have allowed the penetration of water inside which is again due to the loss of homogeneity of concrete mix due to the addition of fibres. However, in all the mixes, the average water absorption is less than 6 percent by mass, the maximum value specified as per IS 15658: 2006. From the results, it can also be noticed that individual paver blocks at all fibre content absorbs water less than 7% which is the limit given in IS 15658: 2006. Hence the paver blocks are suitable for practical applications.
3.6. Abrasion Resistance Test

The abrasion resistance was measured by calculation the loss in volume after abrasion and the results are given in Table 5. Loss in volume ranges from 5201 mm³ to 10271 mm³. Abrasion resistance is higher for paver blocks with polyester fibres which is revealed through a decrease in volume loss. As the fibre volume is increased from 0.1% to 0.5%, the abrasion resistance also gradually increases which is indicated by minimum volume loss and minimum loss in thickness. According to ASTM C418 (9), for better abrasion resistance, specimens shall not have a greater volume loss than 15000 mm³ / 5000 mm² and the average thickness loss shall not exceed 3 mm. For all the specimens tested, the loss in volume after abrasion is less than 15000mm³ and the loss in thickness is less than 3mm.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Size of Paver Block (mm)</th>
<th>Weight of the Specimen (kg) (A)</th>
<th>Weight after abrasion (kg)(B)</th>
<th>Density of Specimen (kg/m³)(PR)</th>
<th>Difference in weight (kg) (∆m = A-B)</th>
<th>Loss in Volume ∆V=∆m/PR (mm³)</th>
<th>Loss in thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₀</td>
<td>71 x71 x 80</td>
<td>0.864</td>
<td>0.842</td>
<td>2142</td>
<td>0.022</td>
<td>10271</td>
<td>2.04</td>
</tr>
<tr>
<td>F₀₁</td>
<td>71 x71 x 80</td>
<td>0.871</td>
<td>0.851</td>
<td>2159</td>
<td>0.020</td>
<td>9264</td>
<td>1.84</td>
</tr>
<tr>
<td>F₀₂</td>
<td>71 x71 x 80</td>
<td>0.882</td>
<td>0.863</td>
<td>2186</td>
<td>0.019</td>
<td>8692</td>
<td>1.72</td>
</tr>
<tr>
<td>F₀₃</td>
<td>71 x71 x 80</td>
<td>0.876</td>
<td>0.859</td>
<td>2172</td>
<td>0.017</td>
<td>7827</td>
<td>1.55</td>
</tr>
<tr>
<td>F₀₄</td>
<td>71 x71 x 80</td>
<td>0.856</td>
<td>0.842</td>
<td>2122</td>
<td>0.014</td>
<td>6598</td>
<td>1.31</td>
</tr>
<tr>
<td>F₀₅</td>
<td>71 x71 x 80</td>
<td>0.853</td>
<td>0.842</td>
<td>2115</td>
<td>0.011</td>
<td>5201</td>
<td>1.03</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

Based on the experimental investigations carried out the following conclusions are arrived at:

- The addition of polyester fibres does not have any appreciable effect on density
- The addition of polyester fibres does not have any positive effect on compressive strength
- Paver blocks without fibres and paver blocks containing 0.3, 0.4 and 0.5% of fibres satisfy the compressive strength requirements of M40 grade of paver blocks as per IS 15658:2006 and hence those paver blocks can be used for medium traffic conditions and the application may include City streets, small and medium market roads, low volume roads, utility cuts on arterial roads, etc.
- Paver blocks containing 0.1 and 0.2% of fibres satisfy the compressive strength requirements of M35 grade of paver blocks as per IS 15658 :2006 and hence those paver blocks can be used for light traffic conditions
- There is a nominal increase in split tensile strength due to the addition of polyester fibres. Due to inclusion of fibres in the top layer of paver blocks, flexural strength increases considerably
- As the content of polyester fibre increases the water absorption also increases. Water absorption increases by about 17.8%, 34.1%, 36.2%, 42.9% and 55.4% for 0.1, 0.2, 0.3, 0.4 and 0.5% of polyester fibres respectively.
- Abrasion resistance is higher for paver blocks with polyester fibres which is revealed through a decrease in volume loss. Hence paver blocks with polyester fibres showed improved flexural strength and better abrasion resistance.
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- Geopolymer paver blocks are greener since the emission of carbon dioxide is prevented. By the application of geopolymer technique the problem disposal of fly ash can be solved to a certain extent.

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