CHAPTER-III
MATERIALS AND METHODS

3.1. Introduction
This chapter provides information on the materials, equipment and procedures used to optimize the process of converting the Class-F fly ash from power plant into a pervious material. This chapter divided into two parts. The first Chapter-III-A describe the preparation of cold bonded and sintered fly ash aggregate and the second Chapter-III-B elaborate the preparation of Pervious material. All the physical, chemical and engineering properties of the material were tested according to IS code and ASTM code. The details of this chapter described below.

CHAPTER-III-A
PREPARATION OF FLY ASH AGGREGATE

3.2. Raw Materials
The materials used for making cold bonding and sintered fly ash aggregate are fly ash as the source material, organic binder, coal dust, and some little amount of water.

3.2.1. Fly ash
Fly ash is the byproduct obtained from the thermal power plant by the combustion of coal. The materials used for making fly ash based pervious material are Class -F fly ash confirming ASTM C618 as source material. Raw material, Class F fly ash as shown in Figure 3A.1 from NALCO, Anugul being used for production of fly ash aggregates.

Figure 3A.1: Raw Class -F fly ash from NALCO
3.2.2. Organic Binder

The role of Organic binder is highly essential during the pelletization process. It helps to bind the fly ash particle and form pellet. It has been observed that various factor such as type of binder, moisture content, shape of aggregate, pelletization duration are affecting the efficiency of pellet. The following chemical such as Sodium hydroxide, Urea-Formaldehyde resin, bentonite power, Phenol-Formaldehyde resin, cement, metakaolin and sodium silicate were used during the peletization of fly ash aggregate. The chemicals used in the research are received from Finar Chemicals supplier ltd.

3.2.3. Coal Dust

Generally, coal dusts are added to the aggregate for proper generating exothermicity in sintering process so as to fabricate a strong sintered product. This process involves addition of coal dust during the preparation of raw mix proportion and secondly during firing of the aggregate to enhance surface molding.

3.2.4. Water

Water is a key ingredient in the manufacture of fly ash aggregate. Normal tap water is slightly added to which can influence workability and setting time of mixtures. The quantity of water used during pelletization process depends upon the fly ash and binder ratio.

3.3. Experimental setup & Procedure

3.3.1. Mix Proportion

The manufacturing process of fly ash aggregates requires raw material like fly ash, organic binder and some amount of water to be mixed in a suitable proportion. Totally seven different types of aggregates were produced for various binder and fly ash and the mix combination of each binder material is given in Table 3A.1. Manikandan R. and Ramamurthy K (2008), Initially the binder and fly ash were mixed in the ratio [10:90, 15:85, 17:83 and 20:80] homogenously in the pelletizer disc and then the calculated water (0.30) is sprayed during pelletization operation. During this process, small seeds grow and the growth of seeds increases upon time duration. Gesoglu M., Ozturan T. and Guneyisi E., (2007), finally the discharge of pellets has been collected in the disc. Quality of aggregates produced by this process depend on the following factors such as quality of raw materials, fineness of raw material, proportioning of raw materials, and handling and mixing of raw materials respectively.
Table 3A.1: Mix proportion of various type lightweight aggregates used in this study

<table>
<thead>
<tr>
<th>Aggregate type</th>
<th>Duration (Minutes)</th>
<th>Fly ash (gms)</th>
<th>NaOH (gms)</th>
<th>UF (gms)</th>
<th>Bentonite (gms)</th>
<th>PF (gms)</th>
<th>Cement (gms)</th>
<th>Slag (gms)</th>
<th>Water (gms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA-Na</td>
<td>15</td>
<td>850</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>FA-UF</td>
<td>15</td>
<td>800</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>FA-B</td>
<td>15</td>
<td>900</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>FA-PF</td>
<td>15</td>
<td>800</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>FA-C</td>
<td>15</td>
<td>850</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>150</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>FA-M</td>
<td>15</td>
<td>850</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>150</td>
<td>300</td>
</tr>
</tbody>
</table>

Mix proportion for Sintered Fly ash aggregate

| FA-SS          | 15                | Fly ash: Sodium Silicate: Water=830:170:300 |

3.3.2. Production of Fly ash aggregate by cold-bonding method

The manufacturing of fly ash lightweight aggregate was carried out using Class-F fly ash with the addition of binder. Manikandan R. and Ramamurthy K., (2007) a specially fabricated disc pelletizer shown in Figure 3A.2 was used in this study which has a disc diameter 500 mm and depth 250 mm. The angle of the disc can be adjusted between 45° -50° and speed 55 rpm.

Figure 3A.2: Disc Pelletizer
The proportion was mixed in a disc pelletizer. Water was added to the mix by adoption the water binder ratio. The content were thoroughly mixed in the pelletizer until the complete formation of fly ash aggregates. This method of formation of fly ash aggregates is called pelletisation. The fly ash aggregates were taken out from the mixer and allowed to dry for a day. Finally the aggregates were cured in a water tank for 1 day, 3 days and 7 days respectively.

Figure 3A.3: Laboratory produced various types of Fly ash aggregate

In this method around six verities of cold bonded fly ash aggregates were produced by using different organic binder treatment. The laboratory produced fly ash aggregates is shown in Figure 3A.3. The whole process of formation of cold bonded fly ash aggregate is shown in Figure 3A.4.

Figure 3A.4: Fly ash aggregates by cold bonding method
3.3.3. Production of Fly ash aggregate by down-draft sintering method

Once the aggregate is formed in disc pelletizer, it is collected in tray allowed to dry for a day. Finally the aggregates are allowed for sintering for a temperature of 1150 °C for half hour duration in order to gain good strength.

![Downdraft sintering Machines](image1)

Figure 3A.5: Downdraft sintering Machines

Sintering of fly ash aggregate were done by down draft sintering method. Batch type suction grate sinter machine of 300×300 mm and cross section area 500 mm height hearth is used for prepare sintered fly ash aggregate from the pelletizer raw machine. The sintering experiment is being carried out by maintain 400 mm bed height of the granulated particle on a 50 mm thick hearth layer with suction pressure 400 mm WG below the grate to complete the preheating at 1150°C and cooling in 25-30 mins of time as shown in Figure 3A.5. The entire process of formation of sintered fly ash aggregate is shown in Figure 3A.6.

![Fly ash aggregates prepared by down-draft sintering method](image2)

Figure 3A.6: Fly ash aggregates prepared by down-draft sintering method
In the present study, lightweight fly ash aggregates are prepared by two methods such as cold bonding and sintering. There exist another method autoclaving but it has the following disadvantages

1) For curing a pressurized saturated steam is required at 140 °C for 30 mins.
2) Twenty four hours drying is required
3) Chances of heavy metal leaching during curing.
4) Low value of crushing strength
5) Less durability.

As the durability, strength and leachability are very essential for a building material, thus autoclaving process is discarded during the study.

**3.4. PHYSICO-CHEMICAL PROPERTIES OF FLY ASH**

The following section provides an outline of the various test methods employed in this study in order to determine the different properties and performance of fly ash.

**3.4.1. Particle size analysis**

Particle size of fly ash sample was analyzed by Malvern particle size analyzer (Model Micro-P, range 0.05-550 micron). The liquid dispersant containing 500 ml of distilled water was kept in the sample holder. Then the instrument was placed with pump speed 1800 rpm ultrasonic displacement at 10.00 micron.

![Particle size Analyzer Apparatus](image-url)
3.4.2. X-ray diffraction

The presence of crystalline element in a sample can preliminary is studied using x-ray diffraction technique. During the ash formation the morphology and crystal growth of minerals controlled. Practically fly ash being amorphous in nature containing ferro-alumino silicate. The XRD pattern shows that the presence of both crystalline and amorphous phases in fly ash. During sampling it was dried at 150 °C in its power form and this is used for qualitative analysis of mineral phase. This powered sample again analyzed by using Philips diffract meter as shown in Figure 3A.8 with a Cu Kα radiation source and a single crystal graphite monochromatic. An angular range of 10-60 of 2θ value in 0.10 increments was used throughout. The test has been carried out at CSIR-IMMT, Bhubaneswar.

Figure 3A.8: XRD Machine

3.4.3. Scanning electron Microscope

Scanning electron microscope shown in Figure 3A.9 is used in order to see the clear and close view of individual particle of fly ash scanning electron microscope which indicates that bottom ash is coarser then fly ash. The data represented the presence of cenosphere and pleosphere present in fly ash particles that needs to decrease in specific gravity. Cambridge Stereos scan 200 was used to study the morphology of the fly ash particles. The test has been carried out at CIPET, Bhubaneswar.
3.4.4. XRF

The chemical composition of the fly ash has been obtained with the help of X-ray fluorescence (XRF). A Siemens D-5000 XRF machine was used for the determination of chemical composition of fly ash which is shown in Figure 3A.10. This instrument is completely computer-controlled for data acquisition. The test has been carried out at Vedanta Aluminium Limited, Lanjigarh.
3.5. ENGINEERING PROPERTIES OF FLY ASH AGGREGATES

The given details provide the methodologies for characterization of fly ash aggregate. The morpho-chemico physic parameter is well studied and compiled using these methodologies.

3.5.1. XRD (X-Ray diffraction Study)

The X-ray diffraction of cold-bonded and sintered fly ash aggregate technique gives the idea about the possible phase’s formation. The sample is analyzed by passing through a Philips diffract meter with a Cu Kα radiation source and a single crystal graphite monochromator. An angular range of 10-60 of 20 value in 0.10 increments was used throughout. The test has been carried out at CSIR-IMMT, Bhubaneswar.

3.5.2. SEM (Scanning Electron Microscope) and Optical microscopy

Morphology study shows that the clear and close view of fly ash aggregate. The test investigations show that the fly ash aggregate are basically small porous in nature. The same instrument Cambridge Stereo scans 200 also used for morphology study of the cold bonded and sintered fly ash aggregate. The casting procedure was examined under the optical microscope to determine the case structure. A small section was cut from the castings. After that it is grinded properly till the formation of powered. The sample were washed and polished in clothes and then washed, dried and etched with Keller's solution and then examined though optical microscope.

3.5.3. Sieve analysis

Sieve analysis of coarse aggregate is determined by the help of sievers. The sieves were arranged in the decreasing order according to its size which is shown in Figure 3A.11. The samples were separated into fraction by sieving through set of sievers. It was sieved for 15 mins. After each sieving the material retained collected separately.

Figure 3A.11: Aggregate sieve analysis
3.5.4. Crushing strength

Crushing strength of individual pellet was carried out in California bearing ratio (CBR) testing machine shown in Figure 3A.12 according to IS:2386 (Part-4)-1963. A total of seven no’s of pellet have been collected from various binder treatment. The crushing strength (σ) is obtained by using the formula.

\[
\sigma = \frac{2.8 \times P}{\pi d^2}
\]  

(1)

Where "P" denotes the failure load "d" is the diameter of pellet used for testing

![CBR Testing Machine](image)

**Figure 3A.12: CBR Testing Machine**

3.5.5. Impact Test

This test is generally carried out in order to know about the strength, resistance of pellet to repeated impact loading. The impact strength of the aggregates was tested according to IS: 2386 (Part IV)-1963 using an impact test machine as shown in Figure 3A.13.

![Impact testing Machine](image)

**Figure 3A.13: Impact testing Machine**
Aggregate impact value $= \frac{W_2}{W_1} \times 100\%$ \hspace{1cm} (2)

Where, $W_1$ is the weight of the fly ash aggregate sample used for testing

$W_2$ is the weight of fraction passing through 2.36 mm sieve size

3.5.6. Abrasion Test

Abrasion value gives an idea about performance of aggregate. The test is carried out according to IS: 2386(Part IV)-1963 using los angels abrasion machine as shown in Figure 3A.14.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{abrasion_test_machine.jpg}
\caption{Abrasion Testing Machine}
\end{figure}

Abrasion value of aggregate $= \frac{W_1 - W_2}{W_1} \times 100\%$ \hspace{1cm} (3)

Where, $W_1$=Weight of the fly ash aggregate

$W_2$=Weight of the sample after 500 round revolution and sieved in 1.70 mm sieve

3.5.7. Specific gravity and Water absorption

The specific gravity and water absorption of fly ash aggregates can be carried out according to IS:2386(part3)1963 as shown in Figure 3A.15. The specific gravity of an aggregates is considered to be a measure of strength or quality of the material. Aggregates having low specific gravity are generally weaker than those with higher specific gravity value.

The Specific gravity of aggregate can be calculated with the help of glass vessel and air tight container and 10 mm size IS sieve.

$$\text{Specific gravity} = \frac{D}{C} - (A - B)$$

Where, $D =$ Wt. of oven dry sample, $C =$ Wt. of saturated surface dry sample

$A =$ Wt. of sample+ vessel+ water, $B =$ Wt. of vessel and water
The water absorption value of aggregate can be calculated with the help of Picnometer.

\[
\% \text{ of water absorption} = \frac{b - c}{a}
\]

Where, 
- \(c\) = Wt. of saturated surface dried aggregate
- \(b\) = Wt. of picnometer filled with water
- \(a\) = Wt. of picnometer containing aggregate and water

3.5.8. Lechability Test

Generally, fly ash contains various hazardous material. Though; in this study pervious material is prepared from fly ash aggregate, so water quality check in terms of leachability study is necessary in order to know about the possibility of heavy metal leaching. In this test cold bonded and sintered fly ash aggregates were placed in a beaker filled with water as shown in Figure 3A.16.
The water sample were tested in different time interval such as 1 hour, 3 hours, 7 hours, 12 hours, 24 hours, 48 hours and 72 hours. Few important tests has been carried out on the outlet water, these are pH, TDS, Turbidity and heavy metal analysis.
CHAPTER-III-B
FABRICATION OF PERVIOUS MATERIAL

3.6. Raw Materials

The materials used for making Pervious concrete are sintered fly ash aggregate as the coarse aggregate, cement, admixture and some little amount of water.

3.6.1. Coarse aggregate

In this study, fly ash based aggregates was taken as the coarse aggregates for all the mixtures. All the aggregates used in this study are in spherical in shape, no other shape such as flaky, angular shape are not used. In order to get maximum compressive strength and minimum permeability, shape of aggregate is playing a vital role. The aggregate sizes chosen to prepare these mixtures were the following 4.75 mm, 9.5 mm and 12.5 mm size respectively is shown in Figure 3B.1.

Figure 3B.1: General Appearance of lightweight aggregates used.

The various strength properties of the aggregates were presented according to IS standard. The properties of fly ash aggregate are shown in Table 3B.1.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Crushing Strength</th>
<th>Impact Value</th>
<th>Abrasion Value</th>
<th>Specific gravity</th>
<th>Water absorption</th>
<th>Bulk density</th>
<th>Voids</th>
<th>Fineness modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash aggregate</td>
<td>6.50 MPa</td>
<td>5.4 %</td>
<td>25.4%</td>
<td>2.12</td>
<td>13.23 %</td>
<td>1.247 kg/ltrs</td>
<td>41%</td>
<td>7.96</td>
</tr>
</tbody>
</table>
3.6.2. Cement

The most common cement used is an ordinary Portland cement. The Ordinary Portland Cement of 43 grades as shown in Figure 3.2 is conforming to IS: 12269 (1987) is be used for the preparation of all the pervious concrete mixtures in this study.

![Figure 3B.2: Cement 43 grade](image)

Here, Ramco 43 Grade cement is used and the sample was analyzed in the Ramco concrete and Research Laboratory, Chennai. It seems that, the cement maintain its various properties as compared to standard value. The physical properties of cement are given in Table 3B.2.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Specific gravity</th>
<th>Consistency</th>
<th>Initial setting time(min)</th>
<th>Final Setting Time(min)</th>
<th>Soundness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value for cement (OPC)</td>
<td>3.15</td>
<td>31.5%</td>
<td>91</td>
<td>211</td>
<td>2.8</td>
</tr>
</tbody>
</table>

3.6.3. Admixture

Generally, chemical admixtures are used in porous concrete as well as conventional concrete for increasing strength. Due to the rapid setting time in pervious concrete mixtures, retarders or hydration stabilizing admixtures are commonly used. High range water reducing admixtures or medium range water reducers are commonly used depending on the w/c ratio. Admixture such as silica fume and super plasticizer are used in the mixture to enhance the strength of the concrete. Micro silica 920-U and Super plasticizer namely carboxylic ether (Glenium-110 P, BASF) with 1.1 g/cm³ specific gravity (at 20°C) in liquid form, supplied by Master Builder Technologies, Perth, Australia was used to the improvement of concrete properties.
3.6.4. Water

Water is a key ingredient in the manufacture of concrete. Water used in concrete mixes has two functions. The first is to react chemically with the cement, which will finally set and harden and the second function is to lubricate all other materials and make the concrete workable. Although it is an important ingredient in concrete, it has little to do the quality of concrete.

3.7. Experimental setup and Procedure

3.7.1. Mixture proportion

The specimens are obtained by mixing of cement, sintered fly ash aggregates, little amount of sand, water and admixture. In this experiment, mix design of 1:3, 1:4 and 1:6 are taken. In each ratio (Such as 1:3-FPC-1 to FPC-7, 1:4-FPC-8 to FPC-14 and in 1:6-FPC-15 to FPC-21) seven trial mixes were prepared by using single aggregate or mixed aggregate.

![Figure 3B.3: Pervious concrete mixture at different water cement ratio](image)

All mixture were produced using Portland cement with different w/c ratio 0.30, 0.35 and 0.40 respectively is shown in Figure 3B.3. Additionally 7-10 % of silica fume and 5-10% of poly carboxylic ether were added to the mixture in order to get maximum strength. Fly ash aggregate of size 4.75, 9.5, 12.5 mm were used in this study. In order to investigate the effect of different size of fly ash aggregates and w/c ratio on the mechanical properties of FPC the mixture were made with three types of fly ash aggregates and three different w/c ratios. Table 3B.3 show the mix proportion of pervious concrete. PPC cement having specific gravity of 3.15 and conforming to the requirement of ASTM C150 was used for preparing all the concrete mixture. All mixture was proportioned on logical bases to achieve appropriate permeability, porosity and compressive strength. Apart from this mechanical properties such as compressive strength, flexural strength, split tensile strength were also investigated.
Table 3B.3. Mix design of Pervious concrete

<table>
<thead>
<tr>
<th>Concrete Mixes</th>
<th>Coarse aggregates Size (In mm)</th>
<th>Mixing of aggregates ratio (%)</th>
<th>Cement (kg/m³)</th>
<th>Aggregate (kg/m³)</th>
<th>W/C ratio</th>
<th>SF (%)</th>
<th>SP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM Standard</td>
<td>2mm, 4mm, 8mm, 12mm and 16 mm</td>
<td>1</td>
<td>270-415 kg/m³</td>
<td>1190-1480 kg/m³</td>
<td>0.27-0.40</td>
<td>5-15</td>
<td>5-7</td>
</tr>
<tr>
<td>FPC-1</td>
<td>4.75</td>
<td>1</td>
<td>420.93</td>
<td>1262.79</td>
<td>0.30</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-2</td>
<td>9.5</td>
<td>1</td>
<td>415.58</td>
<td>1246.74</td>
<td>0.30</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-3</td>
<td>12.5</td>
<td>1</td>
<td>411.62</td>
<td>1234.88</td>
<td>0.30</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-4</td>
<td>4.75+9.5</td>
<td>0.5+0.5</td>
<td>431.62</td>
<td>1294.88</td>
<td>0.30</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-5</td>
<td>9.5+12.5</td>
<td>0.5+0.5</td>
<td>428.37</td>
<td>1285.11</td>
<td>0.30</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-6</td>
<td>4.75+12.5</td>
<td>0.5+0.5</td>
<td>424.88</td>
<td>1274.65</td>
<td>0.30</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-7</td>
<td>4.75+9.5+12.5</td>
<td>0.2+0.4+0.4</td>
<td>434.88</td>
<td>1304.65</td>
<td>0.30</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>FPC-8</td>
<td>4.75</td>
<td>1</td>
<td>318.87</td>
<td>1275.51</td>
<td>0.35</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-9</td>
<td>9.5</td>
<td>1</td>
<td>315.88</td>
<td>1263.55</td>
<td>0.35</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-10</td>
<td>12.5</td>
<td>1</td>
<td>313.27</td>
<td>1253.08</td>
<td>0.35</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-11</td>
<td>4.75+9.5</td>
<td>0.5+0.5</td>
<td>326.72</td>
<td>1306.91</td>
<td>0.35</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-12</td>
<td>9.5+12.5</td>
<td>0.5+0.5</td>
<td>323.55</td>
<td>1294.20</td>
<td>0.35</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-13</td>
<td>4.75+12.5</td>
<td>0.5+0.5</td>
<td>321.12</td>
<td>1284.48</td>
<td>0.35</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-14</td>
<td>4.75+9.5+12.5</td>
<td>0.2+0.4+0.4</td>
<td>329.34</td>
<td>1317.38</td>
<td>0.35</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>FPC-15</td>
<td>4.75</td>
<td>1</td>
<td>217.56</td>
<td>1305.40</td>
<td>0.40</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-16</td>
<td>9.5</td>
<td>1</td>
<td>215.27</td>
<td>1291.62</td>
<td>0.40</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-17</td>
<td>12.5</td>
<td>1</td>
<td>213.64</td>
<td>1281.89</td>
<td>0.40</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>FPC-18</td>
<td>4.75+9.5</td>
<td>0.5+0.5</td>
<td>223.24</td>
<td>1339.45</td>
<td>0.40</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-19</td>
<td>9.5+12.5</td>
<td>0.5+0.5</td>
<td>221.62</td>
<td>1329.72</td>
<td>0.40</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-20</td>
<td>4.75+12.5</td>
<td>0.5+0.5</td>
<td>219.18</td>
<td>1315.13</td>
<td>0.40</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>FPC-21</td>
<td>4.75+9.5+12.5</td>
<td>0.2+0.4+0.4</td>
<td>225.40</td>
<td>1352.43</td>
<td>0.40</td>
<td>15</td>
<td>7</td>
</tr>
</tbody>
</table>
3.7.2. Specimen Preparation and Compaction

At first fly ash aggregates, cement and water were first mixed with in the 200 liter capacity laboratory pan mixer for about 3 minutes. The liquid component of the mixture (Admixture) was then added to the dry materials and the mixing continued for further about 4 minutes to manufacture the fresh concrete.

After mixing the fresh concrete were cast into mould 150×150×150 mm size cube and 500×100×100 mm size beams and 150×300 mm size cylinder were prepared by using Indian standard concrete mixing procedure shown in Figure 3B.5. For compaction of the specimen each layer was given to 25 manual stroke using a rodding bar and then vibrated for 1-2 minutes in a vibrating table. After 24 hours the samples were subsequently demoluded and placed to cure in 100% relative humidity conditions. The laboratory prepared fly ash based pervious material is shown in Figure 3B.6.
Cube shaped mould are allowed for compressive strength tests, beam shaped mould is test for flexural strength and cylinder shaped mould is tested for splitting tensile strength and water permeability test.

3.7.3. Curing of Specimen

The curing of pervious concrete samples followed ASTM C 19269. The samples were removed from their moulds and cured in a water tank at an age of 1 day, 7 days, 14 days, 21 days, and 28 days respectively which is shown in Figure 3B.7.

Figure 3B.7 : Curing of Specimens in different ages
3.8. MECHANICAL PROPERTIES OF PERVIOUS MATERIAL

3.8.1. XRD and SEM

The X-ray diffraction technique of pervious material gives the idea about the possible phase’s formation in various curing ages. The sample is analyzed by passing through a Philips diffract meter with a Cu Kα radiation source and a single crystal graphite monochromator. An angular range of 10-60 of 2θ value in 0.10 increments was used throughout. The test has been carried out at CSIR-IMMT. Scanning electron microscope. The study shows that the clear and close view of pervious material investigations show that the pervious materials are generally large porous in nature. The same instrument Cambridge Stereo scan 200 also used for morphology study of the cold bonded and sintered fly ash aggregate.

3.8.2. Slump test

A slump test is a method used to determine the consistency of concrete. The consistency, or stiffness, indicates how much water has been used in the mix. The stiffness of the concrete mix should be matched to the requirements for the finished product quality. Slump test of concrete was done according to IS: 7320(1974).

![Slump test of Pervious Concrete mixture](image)

**Figure 3B.8 : Slump test of Pervious Concrete mixture**

3.8.3. Paste thickness

The thickness of cement paste between any two aggregates of a pervious concrete specimen was measured using a digital stereo microscope. The same pervious concrete sections used for porosity determination were used to determine the paste thickness also. The ground and polished pervious concrete sections were placed on the stage plate of the microscope, which was connected to a personal computer. Figure 3B.9 shows the stereo microscope that was used to measure paste thickness of planar sections of pervious concrete specimens. The test has been carried out as RAMCO-Cement research laboratory, Chennai.
3.8.4. Density

The density of pervious concrete is a function of the mixture proportion and the consolidation of the mixture. In-place densities of pervious concretes were commonly found to be in the range of 100 lb/ft$^3$ to 125 lb/ft$^3$ (1,600 kg/m$^3$ to 2,000 kg/m$^3$). After the pervious concrete specimens solidified and were demolded, they were dried in an oven at 105 $\pm$ 5 °C until their weights were stable. The specimens were weighed and analyzed using a caliper to measure, calculate, and obtain their volumes. Dividing the weight by volume yields the weight of Pervious concrete per unit volume.

$$D = \frac{(M_c - M_m)}{V_m}$$

Where,
- $D =$ density or unit weight of concrete, lb/ft$^3$.
- $M_c =$ mass of mold filled with concrete, lb.
- $M_m =$ mass of mould, lb.
- $V_m =$ Volume of mould, ft$^3$.

3.8.5 Compressive Strength Test

Compressive strength of pervious concrete is usually found to be lower than conventional concrete due to its high porosity. Compressive strengths are in the range of 500 psi to 4000 psi (3.5- 28 MPa). For each series of tests, a set of standard size cube were made. The size of cube 150×150×150 mm was made for compressive strength measurement as shown in Figure 3B.10. The cube were tested in different curing days (1, 7, 21, 28-days) in accordance with the test procedures given in the Indian Standard IS: 516-1959.
For the experiment purpose the compressive testing machine of 2000KN capacity (CTM Digital) in the concrete laboratory of School of Civil Engineering, KIIT University at the loading rate of 0.2-0.4 N/mm² s. The compressive strength of the concrete specimens are calculated as follows.

\[
\text{Compressive strength (kg/mm}^2\text{)} = \frac{W_f}{A_p}
\]

Where \(W_f\) = Maximum applied load just before load (kg)

\(A_p\) = Plan area of the cube mould (mm²)

**3.8.6. Flexural Strength Test**

Flexural strength and dynamic modulus of elasticity are important for the structural behavior of pavements. Flexural strength of pervious concrete generally ranges between 1-3 MPa. Flexural strength is influenced by many factors, especially the degree of compaction and porosity. For each series of tests, a set of standard size of beam were made. The size of beam 500×100×100 mm was made for flexural strength measurement as shown in Figure 3B.11. The beam were tested in a flexural testing machine of 100 KN capacity at the concrete laboratory of School of Civil Engineering, KIIT University different curing days (1,7,21,28-days) in accordance with the test procedures given in the Indian Standard IS: 516-1959. The flexural strength of the concrete specimens are calculated as follows.

\[
\text{Flexural Strength (F)} = \frac{P_l}{lbd^2}
\]

Where, \(P\) = Failure/Ultimate load on the beam

\(l\) = Span of beam ,\(b\) = Width of beam ,\(d\) = Height of beam
3.8.7. Splitting tensile Strength Test

For each series of tests, a set of standard size of cylinder were made. The size of cylinder 150×300 mm dia was made for splitting tensile strength measurement as shown in Figure-3B.12.

\[
\text{Split tensile strength} = \frac{2P}{\pi L D} \text{ N/mm}^2
\]

Where, \(P\) = Compressive load of cylinder, \(L\) = Length of cylinder, \(D\) = Diameter of cylinder.
3.8.8. Water Permeability Test

The permeability is defined simply as the measure of the ease with which any fluid can pass through the voids present in a porous media. The interconnected voids present in a previous concrete specimen are responsible for the permeability of the specimen, which is directly dependent on the porosity, pore sizes, and pore roughness. Permeability as a unique ability for water to penetrate through porous concrete was expressed in millimeter per second (mm/s). The permeability is one of the most crucial characteristics to qualify pervious concrete. Because of the lack of standardized permeability test method, falling-head apparatus is adopted to determine permeability of Pervious concrete. The test apparatus shown in Figure 3B.13. In this test each specimen is sealed with petroleum jelly and put into a latex membrane to prevent leakage along their sides during testing. The sealed sample was placed into the specimen holder at the bottom of the standing pipe. Samples were then saturated with water to a level above the concrete specimen sample. Water was allowed to flow through the specimen by opening the bottom valve. Initial head was fixed at 305 mm above the specimen and the time needed to reach a final head of 50 mm was recorded. The measurement is repeated three times for each sample to determine a mean value.

Figure 3B.13: (a) Falling-head apparatus (b) Specimens for permeability test

The hydraulic conductivity k is then calculated according to the equation

$$K = \frac{a L}{A t} \ln \left( \frac{h_2}{h_1} \right)$$
Where,

- $a$ = Cross section of the graduated standing pipe above the sample in mm$^2$
- $L$ = Length of the sample in mm
- $A$ = Cross section of the sample mm$^2$
- $t$ = Time for head drop from $h_0$ to $h_1$ in sec
- $h_1$ = Initial head of 305 mm
- $h_2$ = Final head of 50 mm above the sample.
- $k$ = Hydraulic conductivity coefficient in mm/s

The hydraulic conductivity can be related to intrinsic permeability by using the relation

$$K = k \frac{\rho g}{\mu}$$

Where $\rho$ is the density of the fluid, $g$ is the acceleration due to gravity and $\mu$ is the dynamic viscosity of the fluid. When water is used as the permeating fluid, the Equation 3.3 can be simplified as

$$k \text{ (m}^2) = K \text{ (m/s)} \times 10^{-7}$$

### 3.8.9. Porosity Test

Porosity is regarded as one of the most important pore structure features of pervious concretes that dictate several of its mechanical and functional properties. Porosity or void content of a porous material is expressed as a percentage value and is defined as the volume of pores in the material to the total volume of the material. The porosity test was carried out at 28 days of age. A value of less than 15% is considered as low porosity while 30% is a high value of porosity for pervious concretes. A reasonable average value for preliminary structural and hydrological design is 20% . The total porosity in pervious concrete includes disconnected porosity and connected porosity, which is the primary influencing factor of water permeability.

![Figure 3B.14 Porosity test](image-url)
The equation for connected porosity $P_1$ is as follows

$$P_1 = \left[1 - \frac{(W_2 - W_1)}{V_1 \times \text{vol}}\right] \times 100(\%)$$

A caliper was used to measure and calculate specimen volume $V_1$, the specimen was immersed in water until it is filled with water before its weight in water $W_1$ is measured. Subsequently, the specimen was taken out of water and dried, and then its weight in air $W_2$ when its weight is stable was measured as shown in Figure 3B.14.

### 3.8.10. Abrasion Resistance Test

The abrasive wheel seen in Figure 3B.15 was used to measure the abrasion resistance of pervious concrete as recommended to standard IS: 1237 and IS: 1706. For this, test cut the concrete samples with 7.06 cm × 7.06 cm size and put on the place provided on the wheel. After that allow the wheel to run for 22 revolutions. This test is generally carried out in order to know about the percentage of weight loss of the specimens during the revolution time.

![Figure 3B.15: Abrasive wheel test apparatus](image)

### 3.8.11. Durability Test

It is well known that the durability of concrete is a vital concern for predicting its capability to meet the long term requirement. Durability test generally carried out in order to know about to change in both compressive strength and weight reduction. Generally durability test done by curing of cubes in the following solution such as 10% of $\text{Na}_2\text{SO}_4$ solution, 10% of $\text{H}_2\text{SO}_4$ and sea water for 7 days, 28 days and 56 days respectively as shown in Figure 3B.16.
For the durability test the oven dried specimens having known volume will be weighted on the digital weighing machine and calculated to the mass of specimen per unit volume.

Finally the losses in strength have been computed as follows

\[
\text{Compressive Strength loss} = (\sigma_{CB} - \sigma_{CA})
\]

Where, \(\sigma_{CB}\) = Compressive strength of the concrete specimens before chemical curing

\(\sigma_{CA}\) = Compressive strength of the concrete specimens after chemical curing

**Figure 3B.16: Specimens are Immersed in 10% of Na\(_2\)SO\(_4\), 10% of H\(_2\)SO\(_4\) and Sea water**

As discussed, the weight loss of the concrete specimen is regarded as another measure to assess the durability characteristics of the concrete. The weight losses of the concrete specimens have been observed by measuring the initial and final weight of concrete specimens before and after the chemical exposures. The loss in weight (%) are calculated as

\[
\text{Weight loss (\%) } = (W_{\text{initial}} - W_{\text{final}} / W_{\text{initial}}) \times 100
\]

Where, \(W_{\text{initial}}\) = Weight of the concrete specimen before chemical exposure

\(W_{\text{final}}\) = Weight of the concrete specimen after chemical exposure

All the weights are determined as the mean weight by taking the average of weight of three specimens.
3.8.12. Lechability Test

Though, in this study pervious material is prepared from fly ash, so water quality check is highly necessary in order to know about the possibility of heavy metal leaching during the contact with water. In this test a cube shaped size 150×150×150 mm FPC is placed in a chamber and water is continuously pass through it and collected the outlet water in different time interval such as 1 hour, 3 hour, 7 hour, 12 hour and 24 hour. After that, the outlet collected water is allowed for testing. Various tests has been carried out on the water such as pH, TDS, Turbidity, free chlorine and metal analysis. The schematic diagram of leachability tank is shown in Figure 3B.17.

![Schematic diagram of water quality tank](image)

**Figure 3B.17 : Schematic diagram of water quality tank**

3.8.13. Image analysis of Pervious concrete

Image analysis is a powerful tool to investigate inside the sample of a porous material and analyze the pore characteristics. In this study the Canon digital camera with the specification in Table 3B.4 were used to get the image of Pervious concrete sample. In the above experiment (150×300 mm) dia size cylinder and (150×150×150 mm) size cubes were taken. Scanned, cropped image of cylinder and square image of the cylinder samples photos were taken in order to know about the voids between the aggregates. Based on the results, the size of the pore inside the system can be determined.
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</table>
References


9) Kumar V., Mathur M. Sinha S.S. and Dhatrak S., Flyash Environmental Saviour New Delhi, India, Report Submit to Flyash Utilization Programme (FAUP) to TIFAC, DST, 2005.


