Replacement of Cement in Concrete

P. Vipul Naidu¹ and Pawan Kumar Pandey²

¹Civil-SOT, Pandit Deendayal Petroleum University, Raysan, Gandhinagar, INDIA.
²Engineer, DMRC, Sector-18, Rohini, New Delhi, INDIA.

Abstract

Cement is a binding material, a substance that sets and hardens independently, and can bind other materials together. In ancient civilization the binding materials were of traditional type such as jaggery, lead, jute, rice husk etc, now in modern civilization cement is main binding materials. The use of concrete containing high volume fly-ash has recently gained popularity as a resource efficient, durable and sustainable option for variety of concrete application. The use of fly ash in concrete at proportions ranging from 30 percent to 65 percent of total cementitious binders has been studied extensively over the last twenty years. Due to some of its drawbacks we have replaced the cement by HIGH VOLUME FLY-ASH AND LIMESTONE. These two materials reduce green house gas emission proportionately and result in a more “green concrete”, through reduction of energy consumptions (energy required to produce cement) and prevent the depletion of natural resources. Our aim was to achieve the target strength of M40 grade, replacing cement by high volume fly ash and lime as per the normal mix design (using 53 grade of cement). We have achieved M40 target strength by replacing cement about 75 percent of its mass by fly-ash and lime.

In this context cost analysis of mix design and the properties of the design are also studied. As compared to original mix design of M40 grade concrete i.e. cent percent cement, we have reduced the cost up to 40 percent by 75 percent replacement of cement by HVFA and LIMESTONE.

Keywords: HVFA, Limestone, M40 grade concrete, Admixture, Mix Design.
1. Introduction
The production of Portland cement is not only costly and energy intensive, but it also produces large amounts of carbon emissions. The production of one ton of Portland cement produces approximately one ton of CO$_2$ in the atmosphere. Fly ash is a byproduct of the combustion of pulverized coal and is collected by mechanical and electrostatic separators from the fuel gases of thermal power plants, where coal is used as a fuel. Limestone (CaCO$_3$) is a raw material available in nature, it is primary need for production of cement material.

Fly ash is commonly used in concrete in replacement ranging from 0% to 30% by weight of the total cementitious material. Large quantities of fly ash and lime are available around the world at low cost and the use of high volume fly ash and lime seems to offer the best solution to rising cement demands. These two materials reduces green house gas emission proportionately and result in a more “green concrete”, through reduction of energy consumptions (energy required to produce cement) and prevent the depletion of natural resources.

Additional benefits include minimization of waste disposal (land filling these industrial byproduct). The use of HVFA in concrete has recently gained popularity as a resource –efficient, durable cost –effective, sustainable option for ordinary Portland cement (OPC) concrete application.

2. Materials
2.1 Cement
The cement used was Jaypee Cement (OPC-53 GRADE), because of its fine nature, good particle size distribution, optimal phase composition, imparts the properties of higher strength to the structures and the chemical and physical lab properties of Jaypee Cement (OPC-53 Grade) surpasses the properties of OPC 53 Grade as defined in IS: 12269–1987.

2.2 Fly-ash
Fly ash, also known as Pulverized Fuel Ash (PFA), is an industrial ash created when coal is burned to create electrical power. Fly ash, which is largely made up of silicon dioxide and calcium oxide, can be used as a substitute for Portland cement, or as a supplement to it. The materials which make up fly ash are Pozzolanic, meaning that they can be used to bind-or cement- materials together. Pozzolanic materials, including fly ash cement, add durability and strength to concrete Fly ash cement is also known as green concrete. Using fly ash cement in place of or in addition to Portland cement uses less energy, requires less invasive mining, and reduces both resource consumption and CO$_2$.

2.3 Aggregates
Aggregates are the major ingredients of concrete. They provide a rigid skeleton structure for concrete and act as economical space filters. Sizes of aggregates used were 20mm, 10mm and crushed aggregates.
Replacement of Cement in Concrete

2.4 Limestone
Limestone is calcareous sedimentary rocks formed at the bottom of lakes and seas with the accumulation of shells, bones and other calcium rich goods. It is composed of calcite (CaCO\(_3\)). The organic matter upon which it settles in lakes or seas are preserved as fossils. The limestone used acts as a basic binding material.

2.5 Admixture
Concrete admixture enhances the workability of concrete by its powerful deflocculating and dispersing effect on the cement particles which in turns helps to produce high workable concrete or enables in significant reduction in free water content. The admixture to IS 9103-199 (Amendment 2\(^{nd}\) August, 2007).

The admixture used was H & R Johnson P.C. Base 28 & 163 of Endura brand.

2.6 Water
Water is the most important and least expensive ingredient of concrete. It distributes the cement evenly. It lubricates the mix. The quantity of water is the most important parameter and is controlled by the w/c ratio. As the quantity of water in a mix goes up, the following effects are notices: the strength decreases, durability decreases, workability increases, cohesion decreases and the economy may increase at the expense of quality and reliability. Portable water is used in the study for both mixing and curing.

3. Concrete Mix Design
3.1 Concrete mix design
The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as economically as possible is termed as the concrete mix design. The compressive strength of hardened concrete which is generally considered to be an index of its properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour.

3.1.1 Requirements of Concrete Mix Design
- The minimum compressive strength required from structural consideration.
- The adequate workability necessary for full compaction with the compacting equipment available.
- Maximum water-content ratio and/or maximum cement content to give adequate for the particular site conditions.

3.1.2 Factors to be considered for mix design
- The grade designation giving the characteristic strength requirement of concrete.
The type of cement influences the rate of development of compressive strength of concrete.

Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.

The cement content is to be limited from shrinkage, cracking and creep.

The workability of concrete for satisfactory placing and compaction is related to the size and shape of section.

Quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

3.1.3 Procedure

- Determine the mean target strength $f_t$ from the specified characteristic compressive strength at 28-day $f_{ck}$ and the level of quality control.
  $$f_t = f_{ck} + 1.65S$$
  Where $S$ is the standard deviation obtained from the table of contents given after the design mix.

- Obtain the water cement ratio for the desired mean target using the empirical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ratio. The water cement ratio so chosen is checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.

- Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.

- Select the water content, for the required workability and maximum size of aggregates (for aggregates in saturated surface dry condition) from table.

- Determine the percentage of fine aggregate in total aggregate by absolute volume from table for the concrete using crushed coarse aggregates.

- Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.

- Calculate the cement content from the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability, and greater of the two values is adopted.

- From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete.

- Determine the concrete mix proportions for the first trial mix.

- Prepare the concrete using the calculated proportions and cast three cubes of 150mm size and test them wet after 28 days moist curing and check for the strength.
• Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

3.2 Test Programs
• The Indian standard (IS 10262-1982) is followed to design the mix for m40 grade concrete with above parameter.
• In M40 grade, the control mix (without fly ash) was designed and further 30, 40, 50, 60 and 65% of cement was replaced respectively with the fly ash.
• And also the new control mix was designed in which 65 and 75% of cement was replaced with the fly ash + lime. (Lime was taken 5% to 10% of that cementitious material used)

4. Trial Mixes
Following the instruction of test programs we have designed M40 Grade concrete mix using 100% cement content as binding material. Now by keeping this design as a datum we have repeated the same design by making slight change in binding material, that means we are replacing the actual binding material i.e. cement to the another binding material i.e. by fly ash and lime.

TRIAL MIX - A: - Combination of Cement + Fly ash
TRIAL MIX–B:--Combination of Cement + Fly ash + Lime

Table 1: Trial mix - A: - Combination of Cement + Fly ash.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>For 1m3 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0% w/c - 0.30</td>
</tr>
<tr>
<td>Cement</td>
<td>440</td>
</tr>
<tr>
<td>Fly ash</td>
<td>0</td>
</tr>
<tr>
<td>C–Sand</td>
<td>805</td>
</tr>
<tr>
<td>10 mm</td>
<td>392</td>
</tr>
<tr>
<td>20 mm</td>
<td>705</td>
</tr>
<tr>
<td>Water</td>
<td>167</td>
</tr>
<tr>
<td>Admixture</td>
<td>4.20</td>
</tr>
<tr>
<td>Strength (Mpa)</td>
<td></td>
</tr>
<tr>
<td>7 Days</td>
<td>53.11</td>
</tr>
<tr>
<td>28 Days</td>
<td>71.11</td>
</tr>
<tr>
<td>56 Days</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: Trial mix - B: - Combination of Cement + Fly ash + Lime.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>For 1m3 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0% w/c - 0.30</td>
</tr>
<tr>
<td>Cement</td>
<td>440</td>
</tr>
</tbody>
</table>
5. **Cost Analysis**

Cost of concrete is depending upon the quantity, quality and proportion of materials used. As M40 Grade concrete is high grade concrete, use of cement is more to achieve early high strength. Replacement of cement by other material not only changes the strength properties of cement but also changes the cost of that particular design.

List of material used for trials and their respective cost as per market value is given below:-

1. Cement (brand Jaypee Cement)–350 Rs per 50kg bag (i.e. 1kg = 7lit).
2. Fly ash of F-grade–1000Rs per Ton (i.e. 1kg = 1Rs).
3. Admixture- H.R. Johnson P C base 163–32Rs per lit (consider 1kg = 1lit).
4. Crush Sand–1 brass = 2205Rs (i.e. 0.3rs/kg).
5. 10 mm aggregate–1 brass = 1572Rs (i.e. 0.202rs/kg).
6. 20 mm aggregate–1 brass = 1572Rs (i.e. 0.202rs/kg).
7. Lime–10Rs per kg.

Estimating of each trial for 1m$^3$ concrete is done by taking above cost of each material multiplied to the quantity used in it. Total estimation of each trial mix proportion will give exact differences of cost at the time of replacement.

**Table 3**: Estimation cost of each trial carried in Trial Mix Design A.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>0% Rep</th>
<th>30% Rep</th>
<th>40% Rep</th>
<th>50% Rep</th>
<th>60% Rep</th>
<th>65% Rep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rs.</td>
<td>Rs.</td>
<td>Rs.</td>
<td>Rs.</td>
<td>Rs.</td>
<td>Rs.</td>
</tr>
<tr>
<td>Cement</td>
<td>3080.00</td>
<td>2156.00</td>
<td>1848.00</td>
<td>1540.00</td>
<td>1232.00</td>
<td>1078.00</td>
</tr>
<tr>
<td>Fly ash</td>
<td>0.00</td>
<td>132.00</td>
<td>176.00</td>
<td>220.00</td>
<td>264.00</td>
<td>286.00</td>
</tr>
<tr>
<td>C-Sand</td>
<td>234.25</td>
<td>234.25</td>
<td>234.25</td>
<td>234.25</td>
<td>234.25</td>
<td>234.25</td>
</tr>
<tr>
<td>10 mm</td>
<td>78.39</td>
<td>78.39</td>
<td>78.39</td>
<td>78.39</td>
<td>78.39</td>
<td>78.39</td>
</tr>
<tr>
<td>20 mm</td>
<td>142.09</td>
<td>142.09</td>
<td>142.09</td>
<td>142.09</td>
<td>142.09</td>
<td>142.09</td>
</tr>
<tr>
<td>Water</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Admixture</td>
<td>134.40</td>
<td>134.40</td>
<td>134.40</td>
<td>134.40</td>
<td>134.40</td>
<td>134.40</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td>3669.13</td>
<td>2877.14</td>
<td>2613.14</td>
<td>2348.66</td>
<td>2084.45</td>
<td>1953.03</td>
</tr>
</tbody>
</table>
Table 4: Estimation cost of each trial carried in Trial Mix Design B.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>0% Rep Rs. P.</th>
<th>65% Rep Rs. P.</th>
<th>70% Rep Rs. P.</th>
<th>75% Rep Rs. P.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3080.00</td>
<td>1078.00</td>
<td>924.00</td>
<td>770.00</td>
</tr>
<tr>
<td>Fly ash</td>
<td>0.00</td>
<td>264.00</td>
<td>286.00</td>
<td>286.00</td>
</tr>
<tr>
<td>Lime</td>
<td>0.00</td>
<td>220.00</td>
<td>220.00</td>
<td>440.00</td>
</tr>
<tr>
<td>C-Sand</td>
<td>234.25</td>
<td>234.25</td>
<td>234.25</td>
<td>233.67</td>
</tr>
<tr>
<td>10 mm</td>
<td>78.39</td>
<td>78.39</td>
<td>78.39</td>
<td>78.39</td>
</tr>
<tr>
<td>20 mm</td>
<td>142.09</td>
<td>142.09</td>
<td>142.09</td>
<td>142.09</td>
</tr>
<tr>
<td>Admixture</td>
<td>134.40</td>
<td>144.00</td>
<td>144.00</td>
<td>144.00</td>
</tr>
<tr>
<td><strong>Total cost =</strong></td>
<td><strong>3669.13</strong></td>
<td><strong>2160.73</strong></td>
<td><strong>2028.73</strong></td>
<td><strong>2172.82</strong></td>
</tr>
</tbody>
</table>

6. Conclusions

6.1 General conclusions
- Using fly ash reduces the expenses on (energy & cost) cement.
- Reduce leaching of lime from concrete.
- Make cement structures more dense and thus improve their durability.
- By adding fly ash rate of hydration get reduced therefore expected results achieve later than 100% cement is used.
- Replacing cement by Lime and fly-ash gives arises to Green Concrete Technology, which has low emission of CO$_2$ and CO directly or indirectly in the environment.
- Using proper admixtures in mix gives high variations in there result, like early strength, high workability and water reducer.
- Addition of other binding material in place of cement reduces the w/c ratio. Only sufficient water is used to hydrate the cement to gain whole strength from it.

6.2 Conclusions by Trial Mix A
- From the various trials testing taken by us, we have concluded that replacement of cement by only fly ash can be done up to 65%.
- We have observed that, as we go on adding fly ash in mix design workability gets increased.
- Replacing cement by fly ash up to 65% gives about 46.77% cost beneficial to that of original mix cost. Hence it is more economical.
- By overlooking all the results we have come to know that, cement content in mix gets completely hydrated to achieve the target strength M40.

6.3 Conclusions by Trial Mix B
- Using Lime in mix design increases the strength about 5-10% to that of Trial Mix A.
Lime has a property of hydration and also acts as a binding material, so the results of combined mixture of cement and lime get desired results.

As the combination of lime and fly ash increases the strength, so we can replace the cement about 75% to that of cementitious material.

Replacing cement by fly ash + lime up to 75% gives about 40.78% cost beneficial to that of original mix cost. Hence it is more economical because only 25% of cement is used to get M40 grade cement.

As we observed that hydration of cementitious material performs in two types of hydration, primary hydration- by cement content and secondary hydration- by lime content.

References


