CAN METAKAOLINE REPLACE SILICAFUME?

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Abstract: This study focus on the effect of metakaolin on (1) workability (CF), (2) compressive strength at 7 days and 28 days, (3) Sorptivity and (4) percentage of porosity by water absorption of concrete. In this study, M60 grade concrete with and without metakaolin and activated class F fly ash were used. Cement was replaced at the levels of 0%, 5%, 7%, 9% and 11%. From the test results, it was observed that metakaolin concrete has shown better performance than conventional concrete and similar to silica fume concrete.

[10, 1] This shows that we can produce world class concrete by using locally available material at affordable price (metakaolin).

Keywords: - Compressive strength, workability, Sorptivity, water absorption, porosity.

I. INTRODUCTION

The global cement production rate is approximately 1.2 billion tons per year and it is expected to grow exponentially to about 3.5 billion tons by the year 2015[4]. The manufacture of ordinary Portland cement (OPC) is costly and energy intensive process, besides polluting the environment heavily. OPC production is associated with emission of carbon dioxide, which is a major source of global warming. Also, to produce one ton of OPC nearly 1.5 ton of earth minerals are being used and at the same time one ton of carbon dioxide is emitted to the atmosphere. Due to growing environmental concerns and to conserve energy and natural resources of our earth, efforts have been made to utilize industrial waste and byproducts in the construction industry as a pozzolonic admixture to replace OPC partially. Metakaolin, silica fume and activated class F flyash are one of such materials.

Presently, designer of the concrete structure has been mostly interested in the strength characteristic of material. In actual practice, service life of the structure is important. High strength concrete, M60 and above is difficult to manufacture without use of mineral or chemical admixtures.

Worldwide concrete technologist is recommending use of silica fume, along with super plasticizer for making high strength concrete with the lowest permeability. To fulfill the Indian requirement of silica fume, it is to be imported, hence it is costlier affair (price of silica fume is 10 to 20 times of OPC). Due to scarcity of SF, concrete technologist have tried out other Super pozzolonic [2] material like rice husk ash, metakaolin etc. In India commercial production of rice husk ash is limited.

II. SIGNIFICANCE OF RESEARCH

As silica fume is to be imported, it is dare necessity to find locally available material at an affordable price, substitute of it. Author tried out mixture of calcined china clay (metakaolin)-a superpozzolonic material and activated Flyash (class F).

Metakaolin is the product of processed heat treatment of natural Kaolin. It is the most recent mineral to be commercially introduced to the concrete and construction industry.

The metakaolin [5] is a low cost, locally produced, highly effective pozzolonic material, particularly for the early strength development, without appreciable loss in workability. It makes finish easier, reduces efflorescence, increase resistance to sulphate and chlorine attack. It maintains colour of concrete, especially in white concrete. So it can be very well used in Architectural work.

III. EXPERIMENTAL PROGRAMME

A. Properties of Materials

Ordinary Portland cement of 53 grade conforming to IS: 12269 – 1987 was used for the experimental investigation. Its specific gravity is 3.15. The cement was tested as per the Indian standards IS: 4031-1988. The results are given in table I

<table>
<thead>
<tr>
<th>Sr no</th>
<th>Property</th>
<th>Result</th>
<th>Permissible limit as per IS:12269-1987</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Normal consistency</td>
<td>31.5%</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Setting Times</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Initial setting time</td>
<td>98 min</td>
<td>&gt;30 min</td>
</tr>
<tr>
<td></td>
<td>Final setting time</td>
<td>219 min</td>
<td>&lt; 600 min</td>
</tr>
<tr>
<td>3.</td>
<td>Soundness (mm)</td>
<td>2.0</td>
<td>&lt; 10 mm</td>
</tr>
<tr>
<td>4.</td>
<td>Compressive strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 Days</td>
<td>28.7</td>
<td>&gt;27</td>
</tr>
<tr>
<td></td>
<td>7 Days</td>
<td>39.63</td>
<td>&gt;37</td>
</tr>
<tr>
<td></td>
<td>28 Days</td>
<td>55.94</td>
<td>&gt;53</td>
</tr>
</tbody>
</table>

TABLE 1

PHYSICAL PROPERTIES OF CEMENT
Fine aggregate: Natural river sand conforming to zone II as per IS 383-1987 was used. The physical properties of fine aggregates, coarse aggregates & grit are presented in Table II.

Table II

<table>
<thead>
<tr>
<th>Property</th>
<th>Fine Aggregate</th>
<th>Coarse Aggregate</th>
<th>Grit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness Modulus</td>
<td>3.061</td>
<td>7.45</td>
<td>6.33</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.67</td>
<td>2.85</td>
<td>2.81</td>
</tr>
<tr>
<td>Water Absorption (%)</td>
<td>2%</td>
<td>0.75%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Bulk Density (Kg/m^3)</td>
<td>1705</td>
<td>1673</td>
<td>1673</td>
</tr>
</tbody>
</table>

Coarse aggregate: Crushed coarse aggregate and grit conforming to IS 383-1987 was used. Coarse aggregate of size 20mm down and grit 10 mm down were used.

Properties of silica fume, metakaoline and flyash as shown in table III

TABLE III

<table>
<thead>
<tr>
<th>Chemical – physical properties</th>
<th>PERCENTAGE BY MASS</th>
<th>Cement</th>
<th>Flyash</th>
<th>Silica Fume</th>
<th>Metakaoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon dioxide, SiO₂</td>
<td>20.1</td>
<td>48.53</td>
<td>91.0</td>
<td>51.6</td>
<td></td>
</tr>
<tr>
<td>Aluminum oxide, Al₂O₃</td>
<td>4.51</td>
<td>24.61</td>
<td>0.58</td>
<td>41.3</td>
<td></td>
</tr>
<tr>
<td>Ferric oxide, Fe₂O₃</td>
<td>2.5</td>
<td>7.59</td>
<td>0.24</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Calcium oxide CaO</td>
<td>61.3</td>
<td>9.48</td>
<td>0.71</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Magnesium Oxide MgO</td>
<td>1.0</td>
<td>2.28</td>
<td>0.33</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>2.41</td>
<td>0.93</td>
<td>1.84</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Specific surface area (m²/kg)</td>
<td></td>
<td>250 – 400</td>
<td>20,000</td>
<td>2200 – 2500</td>
<td></td>
</tr>
</tbody>
</table>

B. Mix Proportioning

The mix proportions for the controlled concrete of M60 grade was arrived from the trial mix. M60 grade was selected based on the consideration of high strength concrete, which is generally used for prestressed concrete. The quantities of materials of concrete mixture are as follows per m³ of concrete.

Cement: Sand: CA (20mm): Grit (10mm): Water

562 : 560 : 723 : 482 : 174 kg/m³

1 : 0.996: 1.29 : 0.86 : w/b = 0.31

C. Preparation of test specimens

The ingredients for various mixes were weighed; required water was added and mixed by using a tilting drum type of concrete mixture. Precautions were taken to ensure uniform mixing of ingredients. The specimens were cast in steel mould and compacted on a table vibrator. The specimens of 150X150 X150 size of cubes were cast for the determination of compressive strength at 7 days & 28 days. The specimens of 100 mm dia and 50 mm thick were cast for Sorptivity test for durability. Curing of the specimens was started as soon as the top surface of the concrete in the mould was stiff enough. Spreading wet gunny bags over the mould for 24 hrs after the casting carried out for the initial curing. The specimens were later demoulded and placed immediately in water tank for further curing.

IV. TESTS CONDUCTED

A. Workability of Fresh Concrete

Workability is defined as per ACI: 116R-90, the properties of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. The workability property was measured by conducting compaction factor test in accordance with IS: 1199 – 1959.

B. Sorptivity test;

The Sorptivity [7] can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used as the test fluid. The specimen are drowned as shown in figure with water level not more than 5mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non absorbent coating. The quantity of water absorbed in a time period of 30 minutes was measured by weighing the specimen on atop pan balance weighing up to 0.1gm. Surface water on the specimen was wiped off with a dampened tissue and each weighing operation was completed within 30 seconds.

Sorptivity is a material property which characterizes the tendency of a porous material to absorb & transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time ‘s’.

\[ I = S \cdot t^{1/2} \]  
\[ S = \frac{I}{t^{1/2}} \]

Where \( S \) = Sorptivity in mm/√min  
\( t \) = elapsed time in min.  
\( I = \Delta W/Ad \)  
\( \Delta W \) = increase in weight  
\( a \) = surface area of the specimen through which water permeated. 
\( d \) = density of water

V. RESULTS AND DISCUSSIONS

A. Workability
Workability of concrete decreases as percentage of metakaolin or silica fume increases from 5% to 11% at intervals of 2% by replacement in OPC. By adding 10% activated flyash in both the mixes of silica fume and metakaoline workability is improved. Results of workability for all mixes were shown in Table IV & fig2.

WORKABILITY AND COMpressive STRENGTH OF CONCRETE [8]

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Description of Mix</th>
<th>Average Compressive Strength in N/mm²</th>
<th>Compaction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal concrete Mix (NCM)</td>
<td>47.82 68.3</td>
<td>0.8038</td>
</tr>
<tr>
<td>2</td>
<td>Concrete mix with 5% Metakaoline(MK5)</td>
<td>45.6 66.25</td>
<td>0.792</td>
</tr>
<tr>
<td>3</td>
<td>Concrete mix with 7% Metakaoline(MK7)</td>
<td>47.54 68.35</td>
<td>0.7832</td>
</tr>
<tr>
<td>4</td>
<td>Concrete mix with 9% Metakaoline(MK9)</td>
<td>48.47 69.71</td>
<td>0.7787</td>
</tr>
<tr>
<td>5</td>
<td>Concrete mix with 11% Metakaoline(MDK11)</td>
<td>45.7 65.3</td>
<td>0.7606</td>
</tr>
<tr>
<td>6</td>
<td>Concrete mix with 5% Silica fume(SF5)</td>
<td>45.68 66.31</td>
<td>0.7642</td>
</tr>
<tr>
<td>7</td>
<td>Concrete mix with 7% Silica fume(SF7)</td>
<td>47.67 68.49</td>
<td>0.7563</td>
</tr>
<tr>
<td>8</td>
<td>Concrete mix with 9% Silica fume(SF9)</td>
<td>49 69.72</td>
<td>0.7542</td>
</tr>
<tr>
<td>9</td>
<td>Concrete mix with 11% Silica fume(SF11)</td>
<td>44.99 64.19</td>
<td>0.75</td>
</tr>
<tr>
<td>10</td>
<td>7% Metakaoline + 10% AFA (MK7 + FA10)</td>
<td>48.11 70.16</td>
<td>0.8028</td>
</tr>
<tr>
<td>11</td>
<td>9% Metakaoline + 10% AFA (MK9 + FA10)</td>
<td>49.26 71.72</td>
<td>0.7955</td>
</tr>
<tr>
<td>12</td>
<td>7% Silica Fume + 10% AFA (SF7 + FA10)</td>
<td>47.69 69.86</td>
<td>0.7852</td>
</tr>
<tr>
<td>13</td>
<td>9% Silica Fume + 10% AFA (SF9 + FA10)</td>
<td>48.54 70.84</td>
<td>0.7658</td>
</tr>
</tbody>
</table>

**B Compressive strength**

Results of compressive strength for 7 days and 28 days are shown in table 4 & fig3 for different proportions of silica fume and metakaoline by replacing OPC.

**C. Sorptivity**

Results of Sorptivity and percentage of porosity by water absorption is as shown in table V

**VI CONCLUSIONS**

1. Compacting factor (workability) decreases as the % addition of S.F/M.K increased Workability (Compaction Factor) increases by addition of Activated Flyash (AFA) in both cases.

2. 9% replacement levels is optimum for compressive strength. Beyond 9% compressive strength decreases. 10% addition of AFA increases compressive strength. (refer Table IV)

3. Sorptivity & water absorption decreases as the amount of S.F/Mk increases. i.e. permeability decreased. Decrease in permeability for metakaoline addition will be comparable to the silica fume addition. Cost of silica fume is approximately 3 times of metakaolin. This shows that we can produce world class concrete by using locally available material at affordable price (metakaolin).

<table>
<thead>
<tr>
<th>Sr no</th>
<th>Description of mix</th>
<th>Sorptivity % of porosity by water absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ordinary Portland concrete (OPC)</td>
<td>0.4880 3.773</td>
</tr>
<tr>
<td>2</td>
<td>Concrete mix with 7% Silica fume(SF7)</td>
<td>0.2354 2.891</td>
</tr>
<tr>
<td>3</td>
<td>Concrete mix with 7% Metakaoline(MK7)</td>
<td>0.2354 2.4745</td>
</tr>
<tr>
<td>4</td>
<td>Concrete mix with 9% Silica fume(SF9)</td>
<td>0.232 2.3447</td>
</tr>
<tr>
<td>5</td>
<td>Concrete mix with 9% Metakaoline(MK9)</td>
<td>0.2354 2.3447</td>
</tr>
<tr>
<td>6</td>
<td>9% Silica Fume + 10% AFA (SF9 + FA10)</td>
<td>0.232 2.1447</td>
</tr>
<tr>
<td>7</td>
<td>9% Metakaoline + 10% AFA (MK9 + FA10)</td>
<td>0.2354 1.9845</td>
</tr>
</tbody>
</table>

**VII. REFERENCES:**


[10] World Cement, April 2003, vol 34, no4 PP 42