Investigations on fly ash concrete for pavements
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doi:10.6088/ijcser.00202030015

ABSTRACT

The work reported through this paper is an experimental work conducted on High Performance concrete (HPC) with super plasticizer with the aim to report its suitability for concrete pavements. In this study, the effect of varying proportions of fly ash (30% and 40%) on compressive strength of high performance concrete has been evaluated. The mix designs studied were- M30, M40 and M50 to compare the effect of fly ash addition on the properties of these concrete mixes. In all nine concrete mixes have been designed, three as conventional concretes for three grades under discussion and six as HPC with fly ash with varying percentages of fly ash. The concrete mix designing has been done in accordance with Indian standard recommended guidelines i.e. IS: 10262:1982. All the concrete mixes have been studied in terms of compressive strength and flexural strength at 7 days, 28 days and 90 days. All the materials used have been kept same throughout the study to get a perfect comparison of values of results.

Keywords: High performance concrete, Fly ash, Concrete mixes, Compressive strength, Flexural strength, Concrete pavements.

1. Introduction

In the era of growth and development in all fields, construction industry can not afford to be an exception. Infact, concrete industry has undergone challenging advances since time immemorial. High performance concrete (HPC) in that series is quite young and is just 20 years old. High performance concrete is generally confused with high strength concrete. However, HPC is one which essentially possesses three characteristics namely high workability, high strength and high durability (Mehta and Gjorv, 1982). The misconception that high strength concrete will necessarily be highly durable has led to cracking and premature failure of many concrete structures (Mehta and Burrows, 2001). Though field data available tells about the success story of high performance concrete in many structures, the present study was aimed at analyzing the suitability of HPC with fly ash for concrete pavements. The whole world is producing a big reserve of fly ash through its thermal power plants but the fraction of fly ash being used for constructional purposes is not significant. The situation is even scarier in India. Currently, only 40 million tons of fly ash is being used in a variety of engineering works against a generation of 125 million tones of fly ash annually in India (Rao and Kumar, 1996). The use of fly ash in high percentages as a replacement to cement will address two global problems i.e. one, the problem of disposal of bulky volumes of fly ash in landfills and second, the CO$_2$ emissions in atmosphere causing global warming from cement industry (American Coal Ash Association, 1995). In short, we can say that the concrete industry, due to its large size, is the ideal home for economic and safe incorporation of million tones of industrial by-products such as fly ash. Therefore cement replacement in concrete by fly ash
will be highly advantageous from the standpoint of cost, economy, and durability, ecological and environmental benefits.

The present investigation includes the study of compressive and flexural strength of HVFC with two different proportions of fly ash contents. Long term Compressive strength (at age >90 days) and flexural strength of fly ash concrete has been found more as compared to concrete without fly ash. Moreover the rate of gain of flexural strength of fly ash concrete is more when compared to the same of compressive strength.

2. Research significance

The topic chosen for research is of importance especially in Indian scenario, as very small length of concrete pavements, here, is incorporating use of fly ash in it. The reason is either ignorance about the suitability of fly ash in HPC for concrete pavements or is lack of confidence in the test results available, as most of the research in the said area has been carried out abroad. Moreover, there is no consistency in the properties of fly ash available from different sources. So, the test results of one place can not be utilized as such for other places. The aim of the present research is to evaluate the performance of HPC with varying percentages of fly ash for concrete pavements. Compressive and flexural strengths are the most important properties that affect the performance of concrete pavements (Kumar, Tike and Nanda, 2007). Hence, these properties have been investigated in the present study for various concrete mixes with different percentages of fly ash. The objective of using fly ash as an admixture to concrete is to reduce heat of hydration, reduce cement content resulting in better economy, improved durability & workability and to safeguard environment from hazards of CO₂ emissions from cement industry and landfills of fly ash disposal. All fly ash mixtures exhibited substantially higher rates of strength gain as compared with non-fly ash control mixes (Mullick, 2006).

2.1 Experimental test details

For achieving the objectives of the present research, an experimental program was planned to investigate the effect of varying percentages of fly ash i.e. 30% and 40% by weight of cement, on compressive and flexural strength of concrete. The investigations for compressive and flexural strength on concrete with and without fly ash at different ages were conducted. The ingredients for HVFA concrete are cement, fly ash, fine aggregates, coarse aggregates and water. Laboratory tests were conducted on cement, fine aggregates, coarse aggregates, whereas test results of fly ash were performed through a professional laboratory.

The effect of replacing cement with fly ash in varying percentage (0%, 30% and 40%) on compressive strength of high volume fly ash concrete at moist curing was to be carried out by cube testing at the age of 7 days, 28 days and 90 days. However, the beam specimens were cast, cured and tested for flexural strength by two point loading system at 7 days, 28 days and 90 days of age. The test results were used for estimating the respective strengths at the age of one year.

3. Experimental test setup

The specimens were tested on 0 – 100 ton capacity motorized UTM. Specimens were taken out from the curing tank at respective ages of testing and tested immediately on removal from the water, while they were still in the wet condition. The position of the cube when tested was at right angles of that as cast. The axis of the specimens was carefully aligned with the centre
of thrust of the spherically seated plate. The load was applied gradually and without shock and increased continuously at the rate of approximately 14N/mm²/minute till the failure of the specimen and thus the compressive strength was found out (Shetty, 2002). The flexural strength test was conducted on beams of standard size of 50cmX10cmX10cm by two point loading system (Neville and Brooks, 2009). The load was increased at the rate of 35 N/mm²/minute till the failure of beam specimen.

3.1 Materials used

3.1.1 Cement

Ordinary Portland cement of 43 grade conforming to IS 8112 (1989) was used. The cement was tested in accordance with the methods of test specified in IS: 8112 (1989).

3.1.2 Fine Aggregate

For preparation of concrete mix 4.75 mm (maximum) fine aggregates were used.

3.1.3 Coarse Aggregate

40:60 proportions of 10 mm and 20mm size coarse aggregates were adopted.

3.1.4 Fly ash

Fly ash was having bulk density 1000 kg/mm³ and specific gravity 2.25.

3.1.5 Potable water

Potable tap water was used for the preparation of all concrete specimens.

3.1.6 Chemicals used

Super plasticizer based on poly carboxylic technology was used for high strength concretes.

3.2 Concrete mix proportions

Cement is replaced by an equal weight of fly ash by 30% and 40% and the mix designs were done in accordance with IS:10262:1982.

Table 1: Mix Proportion for Different Specimens for M30 grade concrete (w/c=0.42)

<table>
<thead>
<tr>
<th>Mix designation</th>
<th>Water (liters)</th>
<th>Cement (Kg)</th>
<th>Fly ash (% of cementitious content)</th>
<th>Fine Aggregate (Kg)</th>
<th>Coarse Aggregate (Kg)</th>
<th>Compressive Strength (N/mm²)</th>
<th>Flexural Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 days</td>
<td>28 days</td>
</tr>
<tr>
<td>T – 1</td>
<td>172.2</td>
<td>410</td>
<td>--</td>
<td>564</td>
<td>1218</td>
<td>30.5</td>
<td>40.7</td>
</tr>
</tbody>
</table>
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<th>Mix designation</th>
<th>Water (liters)</th>
<th>Cement (Kg)</th>
<th>Fly ash (Kg)</th>
<th>Fine Aggregate (Kg)</th>
<th>Coarse Aggregate (Kg)</th>
<th>Compressive Strength (N/mm²)</th>
<th>Flexural Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T – 2</td>
<td>120.5</td>
<td>316</td>
<td>30%</td>
<td>564</td>
<td>1218</td>
<td>27.6 9</td>
<td>37.9 6 43.0 7 4.91 5.22</td>
</tr>
<tr>
<td>T – 3</td>
<td>103</td>
<td>271</td>
<td>40%</td>
<td>564</td>
<td>1218</td>
<td>25.4 6</td>
<td>34.8 6 45.5 3 4.21 4.56</td>
</tr>
</tbody>
</table>

Mix designation for M30

1. T – 1--Reference Mix for M30.
2. T – 2--30% cement replaced by fly ash for M30.
3. T – 3--40% cement replaced by fly ash for M30.

Table 2: Mix Proportion for Different Specimens for M40 grade concrete (w/c= 0.375)

<table>
<thead>
<tr>
<th>Mix designation</th>
<th>Water (liters)</th>
<th>Cement (Kg)</th>
<th>Fly ash (Kg)</th>
<th>Fine Aggregate (Kg)</th>
<th>Coarse Aggregate (Kg)</th>
<th>Compressive Strength (N/mm²)</th>
<th>Flexural Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T – 4</td>
<td>180</td>
<td>480</td>
<td>--</td>
<td>375</td>
<td>1263</td>
<td>39.5 51.3 53.1</td>
<td>5.52 5.85</td>
</tr>
<tr>
<td>T – 5</td>
<td>126</td>
<td>370</td>
<td>30%</td>
<td>375</td>
<td>1263</td>
<td>33.1 42.9 48.1</td>
<td>5.02 5.26</td>
</tr>
<tr>
<td>T – 6</td>
<td>108</td>
<td>317</td>
<td>40%</td>
<td>375</td>
<td>1263</td>
<td>30.7 40.9 53.2</td>
<td>4.92 5.16</td>
</tr>
</tbody>
</table>

Mix designation for M40

2. T – 5--30% cement replaced by fly ash for M40.
3. T – 6--40% cement replaced by fly ash for M40.
Table 3: Mix Proportion for Different Specimens for M50 grade concrete (w/c= 0.35)

<table>
<thead>
<tr>
<th>Mix designation</th>
<th>Water (liters)</th>
<th>Cement (Kg)</th>
<th>Fly ash (Kg)</th>
<th>Fine Aggregate (Kg)</th>
<th>Coarse Aggregate (Kg)</th>
<th>Compressive Strength (N/mm$^2$)</th>
<th>Flexural Strength (N/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 days</td>
<td>28 days</td>
</tr>
<tr>
<td>T – 7</td>
<td>177.3</td>
<td>507</td>
<td>--</td>
<td>414</td>
<td>1298</td>
<td>40.2</td>
<td>53.5</td>
</tr>
<tr>
<td>T – 8</td>
<td>177.3</td>
<td>390</td>
<td>30%</td>
<td>414</td>
<td>1298</td>
<td>36.5</td>
<td>48.5</td>
</tr>
<tr>
<td>T – 9</td>
<td>177.3</td>
<td>334</td>
<td>40%</td>
<td>414</td>
<td>1298</td>
<td>33.6</td>
<td>44.4</td>
</tr>
</tbody>
</table>

Mix designation for M50

2. T – 8 --30% cement replaced by fly ash for M50.
3. T – 9 --40% cement replaced by fly ash for M50.

4. Results and discussions

Total number of 81 cubes were cast, cured and tested for compressive strength \(^{11}\) of various concrete mixes (IS: 456: 2000). Also 56 beams were cast, cured and tested for various concrete mixes for their respective flexural strengths (ASTM C78 / C78M - 10).

The following aspects were studied

1. The effect on compressive strength of concrete at age 7 days, 28 days and 90 days using fly ash in varying percentages as a partial replacement of cement for three grades of high strength concrete.
2. The effect on flexural strength of concrete at age 28 days and 90 days using fly ash in varying percentages as a partial replacement of cement for three grades of high strength concrete.
3. Projected compressive strength at age of 90 days for various mix designs is compared with that of actual values at 90 days.
The following graphs indicate the test results for compressive strength at 28 days and 90 days for M30, M40 and M50 grades of concrete. The test results of Flexural strength at 28 days have also been represented in form of a graph below.

It is clear from the values and graphs that the compressive strength at 28 days for fly ash concrete is less than that at 90 days. The compressive strength decreases with increase in fly ash content. The compressive strength at 28 days for fly ash concrete is also less than that for concrete without fly ash for all replacements levels. The reference mix achieves a compressive strength of 40.75 MPa at 28 days while the fly ash concrete with cement replacement of 30% and 40% attain strength of 37.96 MPa and 34.86 MPa respectively for M30 grade of concrete. Thus, the fly ash concrete with 30% and 40% replacement of the cement, gain 93.15% and 85.54% respectively in strength w.r.t. the strength of reference mix at the age of 28 days for M-30 grade of concrete. A similar test result pattern is observed for M40 and M50 grade of concrete.
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The lower compressive strength at the initial ages can be due to the reason of reduction of the quantity of cement by the replacement with fly ash, resulting in weakening the cohesion of the cement paste and adhesion to the aggregate particles. As stated in literature, approximately 75% strength rendering primary mineralogical phases\(^{13}\) is developed at the ultimate hydration of OPC. The balance Ca(OH)\(_2\) hardly contributes for strength as the fly ash replaced for cement do not contribute for chemical reaction, because of the reason that sufficient cementitious action of fly ash is not activated at the initial stages and thus the non reactive quantity of fly ash, at this stage, reflect insignificant effect on compressive strength. At the later ages, improvement in the strength is observed due to the reason that the surplus lime released from OPC hydration becomes the source for pozzolanic reactions, contributing for additional mineralogy as secondary hydrated mineralogy\(^{13}\), majority contributing for additional strength. Thus, the non reactive portion of fly ash fills up the matrix to render packing effect i.e. physical effect of improving the microstructure of the hydrated cement paste.

5. Conclusions

On the basis of the results and discussion of this investigation following conclusions can be inferred:

1. In all the concrete mixes, the compressive strength decreases with the increase in replacement level of fly ash for cement in comparison to reference mixes at all the ages.
2. The rate of development of compressive strength of fly ash concrete is more during the period from 28 days to 90 days than the corresponding values for the initial period up to 28 days.
3. The rate of development of flexural strength is more as compared to that for compressive strength of fly ash concrete mixes.
4. The projected compressive strength of concrete with fly ash is quite comparable to targeted strength at 90 days.
5. High volume fly ash concrete mixes for all grades of concrete are much more economical than reference mixes.

6. References


12. ASTM C78 / C78M - 10 Standard Test Method for Flexural Strength of Concrete.