A Study on Effect of Fly Ash and Glass Powder on the Compressive Strength and Permeability of Concrete

Amarjeet Rathi¹, Naveen Hooda²

¹Student at M.R.I.E.M, Rohtak
²Assistant professor at Civil Department, M.R.I.E.M, Rohtak

ABSTRACT

Concrete production uses large quantities of natural resources as aggregates and contributes to the release of carbon dioxide during the production of cement. One ton of carbon dioxide is released into the atmosphere for the production of one ton of cement, which is approximately 7% of the world’s total yearly production of CO2. Concrete is a common construction material in India and its production causes the same environmental concerns as that of regular concrete. Most of developing country facing shortage of post consumers disposal waste site and it’s become very serious problems. In order to address environmental effects associated with cement manufacturing, there is a need to develop alternative binders to make concrete. Consequently extensive research is on going into the use of cement replacements, using many waste materials and industrial by products. Efforts have been made in the concrete industry to use mixture of fly ash and waste glass as partial replacement of coarse or fine aggregates and cement. In this study, finely powdered fly ash and waste glass powder are used as a partial replacement of cement in concrete and compared it with conventional concrete. This work examines the possibility of using mixture of fly ash and waste glass powder as a partial replacement of cement for new concrete. Mixture of fly ash and waste glass powder was partially replaced as 5%, 10%, 15% and 20% and tested for its compressive and permeability strength up to 52 days of age and were compared with those of conventional concrete; from the results obtained, it is found that mixture of fly ash and waste glass powder can be used as cement replacement material up to particle size less than 75µm to prevent alkali silica reaction.

1. INTRODUCTION

Concrete is the most widely used construction material in civil engineering industry because of its high structural strength, stability, and malleability. Recent technological developments have shown that these materials can be used as valuable inorganic and organic resources to produce various useful value-added products. The concrete industry is constantly looking for supplementary cementitious material with the objective of reducing the solid waste disposal problems i.e. Fly Ash and waste glass powder are among the solid wastes generated by industry. Substantial energy and cost savings can result when industrial by-products are used as partial replacements for the energy intensive Portland cement. Limestone is in short supply in India thus; an increased demand for cement and concrete can be met by partially replacing cement with fly ash (FA) and waste glass powder. This investigation attempts to study the feasibility of using locally available fly ash (FA) and waste glass powder as partial replacements for cement and mixture of concrete. The detailed experimental investigation is come to study the effect of partial replacement of cement by Fly Ash (FA) and waste glass powder in concrete. The huge quantity of concrete is consumed by construction industry all over the world.

According to the World Commission on Environment and Development sustainability means “Meeting the needs of the present without compromising the ability of the future generations to meet their own needs”. Sustainability is an idea for concern for the well being of our planet with continued growth and human development. For example, if we run out of limestone, as it is predicted to happen in some places, then we cannot produce Portland cement and, therefore, we cannot produce concrete; and, all the employers associated with the concrete industry go out-of-business, along with their employees.
The properties of fly ash contribute to strength gain and improved durability when used with Portland cement. India has vast resource of fly ash generation all across the country. This material if segregated, collected and used properly can resolved the major problems of fly ash disposal and reducing the use of cement, which consumes lot of energy and natural resources. Different grades of Portland pozzolana cement (PPC) are available depending on the respective country code classification. Bureau of Indian Standard (BIS) normally classify three grades of PPC namely; 33, 43 and 53, which are commonly used in construction industry. A wealth experimental study to evaluate the behavior of concrete properties both in plastic and hardened states with the inclusion of fly ash is available in the technical literature. However, no record could be found where comparative studies on the effect of concrete properties when cement of varying grades were partially replaced by fly ash and glass powder are addressed together. Thus, the present is to investigate the improvement of concrete properties when PPC of varying grades were partially replaced by fly ash and glass powder. The long-term contributions to strength gain and improvement in durability are the main objectives of this study.

2. LITERATURE

In this chapter, a brief review of the findings of earlier investigations on the important properties / parameters of fly ashes and waste glass powder; the available literature on the mechanisms of lime-fly ash and cement-fly ash hydration processes; influence of fly ash and waste glass powder addition on the properties of concrete, namely, workability and compressive strength , have been presented. A comprehensive review of the work of earlier investigators on blended cements; studies on the activation of low-calcium and high-calcium fly ashes and natural pozzolans, have also been presented. An attempt has also been made to critically evaluate the status of activation studies on fly ash. Apart form the above, literature relevant to the work carried out in this study, namely, on mix proportioning methods; effect of elevated temperature; influence of various aggressive environments on blended fly ash and glass powder concretes, have been briefly reviewed and presented.

Bilodeau(1994) have studied the air entraining HVFA concretes, the amount of air entraining agent required to attain the desired air content was greatly influenced by both the fly ash and the cement used in the mixture.

Cabrera and Atis (1999) discuss the major issues with abrasion testing. The authors present the fact that there are no guidelines on values from abrasion tests that ensure whether a concrete will perform adequately or not. Cabrera and Atis write that because of this, abrasion results may only be used on a comparative basis.

Dali J.S. and Tande S.N. (2012) studied the properties of concrete containing mineral admixtures, when it is subjected to alternative wetting and drying and high temperature and resulted that the compressive strength increment is upto 25% replacement of cement by waste glass powder, but the peak % increment is at 20% replacement in both the cases, i.e. concrete without subjecting to alternate wetting and drying, and concrete subjected to alternate wetting and drying.

Jangid Jitendra B. and Saoji A.C. (2012) resulted that the workability decreases as the percentage glass powder in the mix increases. 

Khatib J.M. et al (2012) in his study showed that there was a systematic increase in the slump as the glass powder content in the mix increases.

3. MATERIALS COLLECTION

3.1 Cement

The cement used was Portland pozzolana cement 43 (PPC 43).All properties of cement were determined by referring IS 12269 - 1987. The specific gravity of cement is 3.15. The initial and final setting times were found as 55 minutes and 258 minutes respectively. Standard consistency of cement was 30%.

3.1.1 Physical Properties of cement

Portland pozzolana cements are commonly characterized by their physical properties for quality control purposes. Their physical properties can be used to classify and compare Portland cements. The challenge in physical property characterization is to develop physical tests that can satisfactorily characterize key parameters.
1. Setting Time
2. Soundness
3. Fineness
4. Compressive Strength

3.2 Fine aggregates - Aggregate most of which passes 4.75-mm IS Sieve and contains only so much coarser material as permitted in 4.3.

3.2.1 Natural Sand - Fine aggregate resulting from the natural disintegration of rock and this has been deposited by streams or glacial agencies.  

2. Crushed Gruace1 Sand - line aggregate produced by crushing natural gravel.  

3.3 Coarse Aggregate -- Aggregate most of which is retained on 4 to 75-mm IS Sieve and containing only so much finer material as is permitted for the various types described in this standard.

NOTE - Coarse aggregate may be described as:

a) Uncrushed gravel or stone which results from natural disintegration of rock.

b) Crushed gravel or stone when it results from crushing of gravel or hard stone.

c) Partially crushed gravel or stone when it is a product of the blending of (a) and (b).

3.4 Water-Cement ratio

Water is the binding force of concrete and for the evolution of concrete a very low w/c ratio i.e. in the range of 0.20 - 0.34 is required. The acceptability of water for concrete is not a major problem if potable type water is used. Basically, the workability of concrete is controlled by use of super plasticizer in it. For production of concrete in the laboratory, in the present study three different water-cement ratios of 0.20, 0.22 and 0.24 have been considered. There is a diverse established effect of w/c ratio on the strength properties of concrete, the strength of concrete increases if the w/c ratio decreases.

3.5 Fly Ash

Fly Ash is a by-product of the combustion of pulverized coal in electric power generation plants. When the pulverized coal is ignited in the combustion chamber, the carbon and volatile materials are burned off. However, some of the mineral impurities of clay, shale, feldspars, etc., are fused in suspension and carried out of the combustion chamber in the exhaust gases. As the exhaust gases cool, the fused materials solidify into spherical glassy particles called Fly Ash. Due to the fusion-in-suspension these Fly Ash particles are mostly minute solid spheres and hollow ecospheres with some particles even being peripheries, which are spheres containing smaller spheres. The size of the Fly Ash particles varies but tends to be similar to slightly larger than Type I Portland cement. The Fly Ash is collected from the exhaust gases by electrostatic precipitators or bag filters. Chemical makeup of Fly Ash is primarily silicate glass containing silica, alumina, iron and calcium. Color generally ranges from dark grey to yellowish tan for Fly Ash used for concrete. ASTM C 618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolana for Use as Mineral Admixture in Concrete has two designations for Fly Ash used in concrete - Class F and Class C.

3.5.1 Class F Fly ash

Fly Ash is normally produced from burning anthracite or bituminous coal that meets the applicable requirements. This class of Fly Ash has pozzolanic properties and will have a minimum silica dioxide plus aluminum oxide plus iron oxide of 70%.

1. Gives more flexibility to architects and engineers to design sleeker and economical sections.

2. Develops high early strength so that form work of slabs and beams can be removed much earlier resulting in faster speed of construction and saving in centering cost.
3. Produces highly durable and sound concrete due to very low percentage of alkalis, chlorides, magnesia and free lime in its composition.
4. Almost a negligible chloride content results in restraining corrosion of concrete structure in hostile environment.
5. Significant saving in cement consumption while making concrete of grades M15, M20 & M25 and pre-cast segments due to high early strength.

3.5.2 Class C Fly Ash

Fly ash is normally produced from sub bituminous coal that meets the applicable requirements. This class of Fly Ash, in addition to having pozzolanic properties, also has some cementitious properties and will have a minimum silica dioxide plus aluminum oxide plus iron oxide content of 50%. Most state and federal specifications allow, and even encourage, the use of Fly Ash; especially, when specific durability requirements are needed. Fly Ash has a long history of use in concrete. Fly Ash is used in about 50% of ready mixed concrete (PCA 2000). Class C Fly Ash is used at dosages of 15 to 40% by mass of the cementitious materials in the concrete. Class F is generally used at dosages of 15 to 30%.

3.6 GLASS POWDER

1. Glass is an amorphous (non-crystalline) that in essence, a super cooled liquid and not a solid.
2. Glass can be made with excellent homogeneity in a variety of forms and sizes from small fibers to meter-sizes pieces.
3. Primarily glass is made up of sand, soda ash, limestone and other additives (Iron, Chromium, Alumina, Lead and Cobalt).
4. Glass has been used as aggregates in construction of road, building and masonry materials

3.6.1 SOURCES OF WASTE GLASS

1. Glass food and beverages container.
2. Window repair shops
3. Glass decorative items
4. Old tube lights, electric bulbs
5. Glass polishing and glass window and door manufacturing shop

4. EXPERIMENTAL INVESTIGATION

Experiment were conducted on concrete prepared by partial replacement of cement by the mixture of fly ash and waste glass powder of particle size 75µm. The mixture of fly ash and waste glass powder was replaced by 5%, 10%, 15% and 20% of the binder and the mix design was prepared. The compression strength, permeability test and slump test were carried out on the mixture of fly ash and waste glass powder.

4.1 Mix proportion and of testing specimens

4.1.1 Mix Design: The concrete mix design was proposed by using Indian Standard for control concrete. The grade was M20. The mixture will be prepared with the cement content of 330kg/m3 and water to cement ratio of 0.53. The mix proportion of materials is 1:2.33:3.6 as per IS 10262-2009. Then natural fine aggregate was used. The replacement levels of cement with mixture of fly ash and glass powder were used in terms of 5%, 10%, 15% and 20% in concrete. Chemical admixture is not used here.

4.2 Compressive Strength Test

Out of many test applied to the concrete, this is the most important which gives an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. For cube test two types of specimens either cubes of 15 cm X 15 cm X 15 cm or 10cm X 10 cm x 10 cm depending upon the size of aggregate are used. For most of the works cubical moulds of size 15 cm x 15cm x 15 cm are commonly used. This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of these specimens should be made even and smooth. These specimens are tested by compression testing machine after 28 days curing or 52 days curing.
4.3 Slump Test

Fresh concrete when unsupported will flow to the sides and sinking in height will take place. This vertical settlement is known as slump. The workability (ease of mixing, transporting, placing and compaction) of concrete depends on wetness of concrete (consistency) i.e., water content as well as proportions of fine aggregate to coarse aggregate and aggregate to cement ratio. The slump test which is a field test is only an approximate measure of consistency defining ranges of consistency for most practical works. This test is performed by filling fresh concrete in the mould and measure the settlement i.e., slump.

4.4 Permeability Test:

The miniature high pressure permeameter is used for studying the permeability characteristics of rock specimens, chemically solidified soils, & industrial products under high pressures.

Normally every material can be studied for its permeability characteristics. The small internal dimensions make it possible to perform tests on specimens which have been trimmed from large undisturbed block samples or undisturbed samples obtained by thin wall tube or piston sampling methods or on samples which have been trimmed from larger laboratory compacted specimens.

Pressure type test:

Develop pressure in the water reservoir. Connect the bottom of the permeameter assembly to the water reservoir. Apply required pressure by operating the regulator (10.5 kg/cm² pressure gauge indicates the water reservoir pressure & 7.0 kg/cm² pressure gauge indicates the test pressure.)

When constant flow is established, measure the discharge for a given time.

\[ K = \frac{QL}{hAt} \text{ cm/sec} \]

Where \( Q = \) discharge in ml.
\( A = \) area of specimen in cm²
\( t = \) time of discharge
\( h = \) head causing the flow
\( L = \) length of specimen

5. RESULT AND DISCUSSION

5.1 Compressive Strength

The results of compressive strength testing of laboratory-cured cubes are presented in Table below and for First series with 5% cement replacement, Second series with 10% cement replacement, third series with 15% cement replacement and fourth series with 20% cement replacement respectively. The strength values reported are the average of three test results.

<table>
<thead>
<tr>
<th>DESIGN MIX</th>
<th>28 days (N/mm²)</th>
<th>52 days (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 1</td>
<td>21.03</td>
<td>25.33</td>
</tr>
<tr>
<td>Mix 2</td>
<td>18.96</td>
<td>21.48</td>
</tr>
<tr>
<td>Mix 3</td>
<td>17.34</td>
<td>19.03</td>
</tr>
<tr>
<td>Mix 4</td>
<td>16.04</td>
<td>18.88</td>
</tr>
<tr>
<td>Mix 5</td>
<td>14.95</td>
<td>16.15</td>
</tr>
</tbody>
</table>
Where,
Mix 1 = mixture of pure cement concrete,
Mix 2 = mixture of cement with 5%fly ash and waste glass powder,
Mix 3 = mixture of cement with 10% fly ash and waste glass powder,
Mix 4 = mixture of cement with 15% fly ash and waste glass powder and,
Mix 5 = mixture of cement with 20% fly ash and waste glass powder.

### Table 5.2. Second series test of compression strength

<table>
<thead>
<tr>
<th>DESIGN MIX</th>
<th>28 days (N/mm²)</th>
<th>52 days (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 6</td>
<td>21.05</td>
<td>25.39</td>
</tr>
<tr>
<td>Mix 7</td>
<td>18.14</td>
<td>20.98</td>
</tr>
<tr>
<td>Mix 8</td>
<td>17.04</td>
<td>18.93</td>
</tr>
<tr>
<td>Mix 9</td>
<td>16.12</td>
<td>17.18</td>
</tr>
<tr>
<td>Mix 10</td>
<td>14.25</td>
<td>16.95</td>
</tr>
</tbody>
</table>

Where,
Mix 6 = mixture of pure cement concrete,
Mix 7 = mixture of cement with 5% fly ash and waste glass powder,
Mix 8 = mixture of cement with 10% fly ash and waste glass powder,
Mix 9 = mixture of cement with 15% fly ash and waste glass powder and,
Mix 10 = mixture of cement with 20% fly ash and waste glass powder.

### Table 5.3. Third series test of compression strength

<table>
<thead>
<tr>
<th>DESIGN MIX</th>
<th>28 days (N/mm²)</th>
<th>52 days (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 11</td>
<td>21.03</td>
<td>25.34</td>
</tr>
<tr>
<td>Mix 12</td>
<td>19.14</td>
<td>21.98</td>
</tr>
<tr>
<td>Mix 13</td>
<td>18.44</td>
<td>19.13</td>
</tr>
<tr>
<td>Mix 14</td>
<td>16.74</td>
<td>18.18</td>
</tr>
<tr>
<td>Mix 15</td>
<td>14.85</td>
<td>16.95</td>
</tr>
</tbody>
</table>

Where,
Mix 11 = mixture of pure cement concrete,
Mix 12 = mixture of cement with 5% fly ash and waste glass powder,
Mix 13 = mixture of cement with 10% fly ash and waste glass powder,
Mix 14 = mixture of cement with 15% fly ash and waste glass powder and,
Mix 15 = mixture of cement with 20% fly ash and waste glass powder.

### Table 5.4. Fourth series test of compression strength

<table>
<thead>
<tr>
<th>DESIGN MIX</th>
<th>28 days (N/mm²)</th>
<th>52 days (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 16</td>
<td>21.33</td>
<td>25.94</td>
</tr>
</tbody>
</table>
Where,
Mix 16 = mixture of pure cement concrete,
Mix 17 = mixture of cement with 5% fly ash and waste glass powder,
Mix 18 = mixture of cement with 10% fly ash and waste glass powder,
Mix 19 = mixture of cement with 15% fly ash and waste glass powder and,
Mix 20 = mixture of cement with 20% fly ash and waste glass powder.

5.2 Permeability Test Result

<table>
<thead>
<tr>
<th>Curing period</th>
<th>Permeability index (K) in cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>2.3 x 10-5</td>
</tr>
<tr>
<td>52</td>
<td>2.8 x 10-6</td>
</tr>
</tbody>
</table>

CONCLUSION

Based on limited experimental investigation concerning the compressive & split strength of concrete, the following conclusions are drawn:

1. Compressive strength reduces when cement replaced fly ash and glass powder. As fly ash percentage increases compressive strength and permeability strength decreases.
2. Use of fly ash in concrete can save the coal & thermal industry disposal costs and produce a ‘greener’ concrete for construction.
3. The cost analysis indicates that percent cement reduction decreases cost of concrete, but at the same time strength also decreases.
4. This research concludes that fly ash and glass powder can be innovative supplementary cementitious Construction Material but judicious decisions are to be taken by engineers.

All the experimental data shows that the addition of the industrial wastes improves the physical and mechanical properties. These results are of great importance because this kind of innovative concrete requires large amount of fine particles. Due to its high fines of quarry dust it provided to be very effective in assuring very good cohesiveness of concrete. From the above study it is concluded that the mixture of fly ash and glass powder may be used as a partial replacement material for cement. Mixture of fly ash and glass powder has been used for different activities in the construction industry such as for road construction and manufacture of building materials such as light weight aggregates, bricks, tiles and auto clave blocks. However its use as rigid payment is very much limited.

Thorough reaction with the concrete admixture, mixture of fly ash and glass powder, improved pozzolanic reaction, micro aggregate filling and concrete durability. As the properties are good as, the mixture of fly ash and glass powder is used as partial replacement of cement in the cement concrete.

REFERENCE


Cabrera, J. G., & Atis, C. D., Design and Properties of High Volume Fly Ash High* Performance Concrete. In High Performance Concrete: Performance and Quality of Concrete Structures (pp. 21*31). ACI.


Jangid Itendra B. and Saoji A.C., “Experimental investigation of waste glass powder as the partial replacement of cement in concrete production” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X [International Conference on Advances in Engineering and Technology –(ICAET-2014)].

