An experimental approach on Geopolymeric recycled concrete using partial replacement of industrial byproduct

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ABSTRACT

Geopolymer concrete is an advance technology in concrete technology by partial replacement of bonding material (cement) with fly ash after geopolymerization. The geopolymerization chemistry has been conducted by heating the mixture of a specified proportion of fly ash (carbon content <5\%), sodium hydroxide (NaOH) and water (H\(_2\)O) to a temperature of 60\(^\circ\)C to 80\(^\circ\)C. Fly ash sample collected from National Aluminum Company (NALCO) of Angul, Odisha having 0.5\% carbon content, has been polymerized as per Indian Standard to the referred degree of precision and different samples of different percentage of replacement has been prepared to produce geopolymer concrete. In the investigation, an attempt has been made in preparing concrete of M\(_{20}\) and M\(_{25}\) grade. This clearly reflects an ambience towards reutilization of industrial waste that creates environmental pollution to the society visa-vis reducing the cost of concrete due to replacement of cement by fly ash.

Keywords: Geopolymer, Fly ash, compaction factor, slump test.

1. Introduction

Concrete is a widely used material for various construction activities due to its versatile character. Binding material is an essential component of concrete. Cement, the most commonly used binding material is of high demand in developing countries like India, owing to rapid infrastructural and population growth. To accomplish the huge demand of binding material and simultaneously reduction in cost, alternate material as partial replacement to cement has been taken into consideration. As a result of de-carbonation of lime, manufacturing of one ton of cement generates about one ton green house gas (Davidovits, 1993). On the contrary, the use of waste byproducts reduces the piling of materials that may create an environmental problem in the future. A greener alternative inorganic polymer concrete (geopolymer) substitutes as an emerging class of cementious material that utilize ‘fly ash’ a byproduct of thermal power plant, as one of the most abundant industrial waste on earth, as a substitute for Portland cement (Malhotra, 1999).

2. Scope of Investigation

Fly ash geopolymer has been used for different activities in construction industry such as offshore structure, multi storied building, floating structure and manufacture of several building materials. Developed countries like China, UK have been using this material since years. The scope of geopolymer concrete is as follows:
1. Proper utilization of fly ash geopolymer is necessary to know about the characteristics and possible effects on the properties of concrete.
2. Design mix for $M_{20}$ and $M_{25}$ concrete with different percentage of replacement of cement with geopolymer concrete.
3. To study the effects of fresh concrete properties (slump test and compaction factor test) with different percentage of replacement of cement with geopolymer concrete.
4. To study the effect of hardened concrete properties (i.e. compressive strength, split tensile strength, flexural strength, modulus of elasticity and water absorption) with different percentage of replacement of cement with fly ash geopolymer.
5. The systematic study of the effect of curing methods on the strength characteristics is investigated for cement replacement.

3. Methodology

Additions of some alkali material such as NaOH with fly ash, the admixture is kept in an oven at $60^\circ C$ to $80^\circ C$ for 6 to 12 hours. After drying, it is then kept in open atmosphere for 24 hours, converting it to an alkali activated fly ash based geopolymer, which forms a pure substitute material to cement as binding material.

![Figure 1: Steps of Investigation](image)

Geopolymer binders and geopolymer cements are generally formed by reaction of an aluminosilicate powder with an alkaline silicate solution at ambient conditions. Metakaolin (Cassagnabere, 2010) is a commonly used material for laboratory synthesis of geopolymer,
and is generated by thermal activation of kaolinite. Geopolymer cements can also be made from natural sources of pozzolanic materials, such as lava or fly ash from coal. Most studies on geopolymer cements have been carried out using natural or industrial waste sources of metakaolin and other aluminosilicates. Industrial and high-tech applications rely on more expensive and sophisticated siliceous raw materials. It is well known that geopolymer have excellent performance with respect to fire resistance, acid resistance and stabilization/solidification of heavy metal waste (Duxson et al., 2007). The main objective of this research is to provide more information about the effects of various proportion of geopolymer cement as partial replacement of cement for which laboratory tests like slump test, compaction factor test, compressive strength and density of concrete have been analysed in the laboratory. This is an experimental study in which attempts have been made to investigate some property of geopolymer cement and discussion of the suitability of those properties to enable geopolymer cement as partial replacement material for cement.

4. Results and discussions

4.1 Results of properties of fresh concrete

Workability: The tests related to workability of fresh concrete are slump test and compaction factor.

Slump test: The measured slump values of fly ash based geopolymer with constant water/cement ratio 0.55 are 38, 39, 42, 49, 53, 61 mm for different mixes such as M_1(0% flyash+100% cement), M_2(40% flyash+60% cement), M_3(60% flyash+40% cement), M_4(75% flyash+25% cement), M_5(90% flyash+10% cement) and M_6(100% flyash+0% cement) respectively.

![Figure 2: Variation of Slump value of fresh concrete with fly ash contents (%)](image)

The variation of slump values with fly ash based geopolymer percentage is shown in Figure 2. It was observed that the slump value increases with increase in percentage of fly ash based geopolymer for the replacement of cement keeping w/c ratio constant. Fly ash does not absorb water as the cement does. Increased amount of fly ash based geopolymer results the bleeding of water so that the slump value increases. But in case of M_1 and M_2 it gives the same slump value i.e. 60% cement with 40% fly ash based geopolymer mix as workable as 100% cement concrete mix.
Compacting factor: The variation of workability (Yang and Song, 2009) is also measured in terms of compacting factor with constant w/c ratio of 0.55. The values are obtained for different mixes such as M₅ (0% flyash+100% cement), M₂ (40% flyash+60% cement), M₃ (60% flyash+40% cement), M₄ (75% flyash+25% cement), M₅ (90% flyash+10% cement) and M₆ (100% flyash+0% cement) are 0.9, 0.899, 0.851, 0.829, 0.802 and 0.71 respectively (Figure 3).

Figure 3: Variation of Compaction factor of fresh concrete with fly ash contents (%)  

The above value shows the compacting factor decreases with increases of addition of fly ash based geopolymer to the concrete instead of cement.

4.2 Results of properties of hardened concrete

4.2.1 Compressive Strength

The result of compressive strength of cubes for (7/14/28) days curing is shown in table 1 as per the references provided by (Yang K. and Song J., 2009). It can be observed that the compressive strength of cubes at 28 days curing for M₂₀ grade concrete mixture (M₁) is 29.7 MPa for 43 grade concrete. It can be assessed from the table that fly ash based geopolymer content increases the 40% the 28 days compressive strength increases to maximum of 29.9 MPa. As the fly ash based geopolymer exceeds 40% the compressive strength decreases.

<table>
<thead>
<tr>
<th>Mix. Identification (M₂₀ Grade Concrete)</th>
<th>Cubes at 7 days</th>
<th>Cubes at 14 days</th>
<th>Cubes at 28 days</th>
<th>Cylinder at 28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>M₁ (0% flyash+100%)</td>
<td>22.8</td>
<td>25.08</td>
<td>29.7</td>
<td>21.8</td>
</tr>
<tr>
<td>M₂ (40% flyash+60%)</td>
<td>22.7</td>
<td>25.46</td>
<td>29.9</td>
<td>22.1</td>
</tr>
<tr>
<td>M₃ (60% flyash+40%)</td>
<td>18.6</td>
<td>21.08</td>
<td>24.8</td>
<td>17.2</td>
</tr>
<tr>
<td>M₄ (75% flyash+25%)</td>
<td>14.5</td>
<td>16.0</td>
<td>19.3</td>
<td></td>
</tr>
<tr>
<td>M₅ (90% flyash+10%)</td>
<td>12.6</td>
<td>14.5</td>
<td>17.11</td>
<td>12.2</td>
</tr>
<tr>
<td>M₆ (100% flyash+0%)</td>
<td>8.14</td>
<td>9.35</td>
<td>11</td>
<td>9.3</td>
</tr>
</tbody>
</table>
The data cited above shows the compressive strength of cube is 29.7MPa after 28 days of curing for the mix M1 and the strength of geopolymer concrete having 40% fly ash and 60% cement can also achieve more than that much of strength i.e. 29.9MPa which is stronger. So a replacement of 40% cement by using fly ash based geopolymer in the concrete but surprisingly for mix M3, M4, M5 and M6 the strength decreases by 17%. Previous research has shown that curing time and curing significantly influence the compressive strength of Geopolymer concrete (Palomo et al.) in their study on Fly-ash based geopolymers have reported that the curing temperature and curing time significantly affected the mechanical strength of Fly-ash based geopolymers.

**Figure 4:** Compressive Strength of mixes with age of varying fly ash contents (%)

Higher the percentage of geopolymerised fly ash lesser the water demand. The compressive strength of cylinder at 28 days curing for control mixture M1 is 21.8MPa and for M2 is 22.1MPa for M30 grade concrete, the strength of geopolymer concrete M2 increases by 1.4 % of normal concrete i.e. M1. The mixes M3, M4, M5 and M6 have shown the reduction of 21.1 %, 26.6 %, 40% and 57.3% of strength respectively in comparison with control concrete mix M1.

**Figure 5:** Variation of Compressive Strength of mixes with fly ash based geopolymer contents (%)

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For all mixes of 43 grade concrete the ratio of compressive strength of cylinder to compressive strength of cube at 28 days curing are calculated and is presented in figure 6.

\[ y = 0.8645x - 4.518 \]
\[ R^2 = 0.967 \]

**Figure 6:** Relation between 28-days compressive strength of cube & cylinder

The relationship between cylinder strength with that of cube strength for 43 grade can be expressed by the formula

\[ f_{ck\_cylinder} = 0.864f_{ck\_cube} - 4.518 \]

A line of best fit has been drawn for the given scattered points represented in figure 6. 28 days compressive strength of cube versus 28 days compressive strength of cylinder of M_{20} grade concrete are shown as the bi-variate plotting with respect to the linear equation \( y = mx + c \) and square of the regression coefficient \( R^2 \) located on the graph. The line of best fit produces positive co-relation \( R = 0.983 \) where maximum of points located very close to the line that depicts on extremely good co-relation co-efficient of the statistical values.

**Table 3:** Compressive strength of cubes and cylinders at different days of curing

<table>
<thead>
<tr>
<th>Mix. Identification (M_{25} Grade Concrete)</th>
<th>Cubes at</th>
<th>Cylinder at</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 days</td>
<td>14 days</td>
</tr>
<tr>
<td>M_1(0% flyash+100%)</td>
<td>24.8</td>
<td>28.91</td>
</tr>
<tr>
<td>M_2(40% flyash+60%)</td>
<td>25.73</td>
<td>29.498</td>
</tr>
</tbody>
</table>

The compressive strength in 28 days of M_{20} grade normal concrete cube i.e. M_1 = 29.7MPa and for geopolymer concrete cube M_2 = 29.9MPa. But the compressive strength in 28 days of M_{25} grade normal concrete cube i.e. M_1 = 33.375MPa and for the geopolymer concrete cube M_2 = 34.3MPa.

A line of best fit has been drawn for the given scattered points represented in figure 8. 28 days compressive strength of cube versus 28 days compressive strength of cylinder of M_{25} grade concrete are the bi-variate plotting with respect to the linear equation \( y = mx + c \) and
square of the regression coefficient ($R^2$) located on the graph. The line of best fit produces positive co-relation where maximum of the points located very close to the line that depicts an extremely good co-relation co-efficient of the statistical values.

b. Density of fly ash based geopolymer concrete

**Figure 7:** Compressive Strength of M25 grade concrete with age of varying fly ash contents (%)

**Figure 8:** Relation between 28-days compressive strength of cube & cylinder of M25 grade concrete

**Table 4:** Density of the cube at 28 days of curing

<table>
<thead>
<tr>
<th>Mix. Identification (M20 Grade Concrete)</th>
<th>Concrete density (gm/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1 (0% flyash+100% cement)</td>
<td>2.5</td>
</tr>
<tr>
<td>M2 (40% flyash+60% cement)</td>
<td>2.504</td>
</tr>
<tr>
<td>M3 (60% flyash+40% cement)</td>
<td>2.32</td>
</tr>
<tr>
<td>M4 (75% flyash+25% cement)</td>
<td>2.1</td>
</tr>
<tr>
<td>M5 (90% flyash+10% cement)</td>
<td>1.87</td>
</tr>
<tr>
<td>M6 (100% flyash+0% cement)</td>
<td>1.81</td>
</tr>
</tbody>
</table>
It was observed that the density of concrete increases slightly with increase in percentage of fly ash based geopolymer content is 40% and cement is 60%. As the percentage of fly ash based geopolymer increases the mass of the concrete decreases due to the less weight of the fly ash, so that the density of the geopolymer concrete decreases as comparison to normal concrete. But in case of M1 and M2 mix, the density of the concrete gives same result. The variation of density of concrete with fly ash based geopolymer for M20 grade concrete mix percentage is shown in figure 9.

![Density of concrete vs fly ash geopolymer contents](image)

**Figure 9:** Variation of density of concrete with fly ash based geopolymer contents (%)

A line of best fit has been drawn for the given scattered points represented in figure 10. 28 days compressive strength versus density of concrete cube are the bi-variate plotting with respect to the linear equation \( y = mx + c \) and square of the regression coefficient \( (R^2) \) located on the graph. The line of best fit produces positive co-relation \( (R=0.978) \) where maximum of the points located very close to the line that depicts an extremely good co-relation co-efficient as far as statistical analysis is concerned.

5. Summary and conclusion

Fly ash based geopolymer can be used as binding material as partial replacement to cement in the geopolymer concrete. A comparative study through detailed technical parameters between cement concrete and geopolymerised concrete results with a conclusion that the geopolymer concrete (GPC) has better resistance to corrosion and fire (up to 2400°F), high compressive and tensile strengths, a rapid strength gain, and lower shrinkage. As per recent researches conducted GPC reduces the cost of binding material as compared to standard cement. From the various laboratory investigations made for characteristics study of fly ash based geopolymer concrete, following conclusions are drawn.

1. The measured slump values of fly ash based geopolymer with constant water/cement ratio .55 are 38, 39 42.49,53.61 mm for different mixes such as M1 (0% flyash+00% cement), M2 (40% flyash+60% cement), M3(60% flyash+40% cement), M4(75% flyash+25% cement), M5(90% flyash+10% cement) and M6(100% flyash+00% cement) respectively.
2. It was observed that the slump value increases with increase in percentage of fly ash based geopolymer for the replacement of cement with the same w/c ratio.
3. The compacting factor decreases with increase of addition of fly ash based geopolymer to the concrete instead of cement.

4. The compressive strength of geopolymer concrete produced by 40% replacement of cement is more than the characteristic compressive strength of (71,428) days curing of cement concrete (M20, M25).

5. For all mixes of 43 grade cement, the ratio of compressive strength of cylinder to compressive strength of cube at 28 days curing are found to be 0.734, 0.739, 0.69, 0.81, 0.82 and 0.84 respectively for mixes M1, M2, M3, M4, M5 and M6.

6. The relationship between cylinder strength with that of cube strength for 43 grade can be expressed as

\[ f_{ck\,cylinder} = (0.864 \times f_{ck\,cube}) - (4.518) \]

with co-relation co-efficient \( R^2 \) as 0.967

7. The density of concrete increases slightly by 40% replacement of cement with geopolymer concrete and the density of concrete decreases if the percentage of cement replacement is increased.

5. References


