Strength, Durability and Microstructural Analysis of Stabilized Fly Ash

Dharavath, Kishan
Assistant Professor
e-mail: kishand@manit.ac.in

Dindorkar, N.
Professor

Srivastava, R.
Professor
e-mail: kafley_2000@yahoo.com

Kafley, Tikaram
Research Scholar
e-mail: kafley_2000@yahoo.com

Department of Civil Engineering, MANIT, Bhopal

ABSTRACT
This paper presents the effect of lime and gypsum on specific gravity, Optimum Moisture content (OMC) and maximum dry density (MDD) upon stabilization with low lime fly ash. An extensive series of tests were conducted on the low lime fly ash adding varying percentage of lime and gypsum (lime: 5%,8%,12% and gypsum 0.4% and 8%). From the test results it is observed that the increase in percentage of lime results in the increase in the OMC, up to 8% and the rise between 8% to 12% of lime is not remarkable. Similar pattern was observed with the sample stabilized with gypsum. The UCS strength and the durability characteristics increase with lime percentage and longer curing period. This paper discusses the effects, reasons and the advantages of improved properties of fly ash stabilized with different percentages of lime and gypsum through the evaluation of strength deformation, durability characteristics and microstructural analysis.

1. INTRODUCTION
Coal combustion products are formed with the production of electricity in coal fired power plants all over the world. In India about 76% (NTPC, up to March 2009) of electrical energy is generated using coal as fuel in thermal power plants. Presently, in India more than 50-million tonnes of fly ash is being produced by 70 thermal power stations (NTPC, up to March 2009) which were spread across the country, out of which majority of fly ash having low lime content. Researchers have tried since sixties to transform fly ash from liability to asset. The solution of this problem may be achieved through bulk utilisation of the fly ash as a construction material in different civil engineering and infrastructural projects. Previous research works mainly consist of vast studies on strength of soil stabilized with fly ash or fly ash lime combination and limited research on the behaviour of stabilized fly ash. Fly ash is known to have self hardening characteristics depending upon the availability of free lime in it for pozzolanic reaction. In case of low lime fly ash, pozzolanic very low and gain in strength is low with slow rate. To enhance the strength, fly ash may be stabilized with proper additives (lime and gypsum) in suitable amount.

2. STRENGTH AND DURABILITY CHARACTERISTICS
Strength deformation and durability characteristics of any construction material are vital parameters to take care and to look in to them judiciously for their suitability. The test methods are usually chosen depending upon the field conditions. Stabilised fly ash has wide variety of application in Geotechnical and Geo-environmental engineering applications. These tests evaluate the strength deformation and durability characteristics of the specimen combinations. UCS gives the quick evaluation of the strength characteristics and the Slake Durability Indices give the idea if the resistance of the specimen to alternate cooling and heating and freezing and thawing.

3. MICROSTRUCTURAL ANALYSIS
In the similar manner as in the case of UCS and Durability Indices the samples combination were analyzed through the X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM). The XRD pattern for all the sample combination and for all the consecutive curing periods had been obtained. And for obtaining the SEM micrographs (images) of the specimen samples prepared at OMC, MDD and cured for 1
day, 7 days and 28 days were gold coated first so as to have proper conduction. The properly coated samples were then placed inside the SEM chamber for micrographs. The micrographs at different magnifications (X100, X300, and X500) were taken for close evaluation and analysis of the phisiomorphological changes that had occurred due to the curing and the fly ash – lime – gypsum interaction.

4. RESULTS AND DISCUSSION

The results obtained from the UCS tests for all the sample combinations that had been taken for the evaluation of strength deformation are shown in table 1.

Table 1: UCS for the Sample Combinations

<table>
<thead>
<tr>
<th>Combinations</th>
<th>UCS for 1 Day (Mpa)</th>
<th>UCS for 7 Days (Mpa)</th>
<th>UCS for 28 Days (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA +5L+0.4G</td>
<td>0.27</td>
<td>0.72</td>
<td>1.13</td>
</tr>
<tr>
<td>FA +5L+0.8G</td>
<td>0.29</td>
<td>0.75</td>
<td>1.25</td>
</tr>
<tr>
<td>FA +8L+0.4G</td>
<td>0.41</td>
<td>0.95</td>
<td>1.48</td>
</tr>
<tr>
<td>FA +8L+0.8G</td>
<td>0.42</td>
<td>1.05</td>
<td>1.54</td>
</tr>
<tr>
<td>FA +12L+0.4G</td>
<td>0.45</td>
<td>1.39</td>
<td>1.58</td>
</tr>
<tr>
<td>FA +12L+0.8G</td>
<td>0.50</td>
<td>1.42</td>
<td>1.62</td>
</tr>
</tbody>
</table>

It can be clearly seen from table 1 that the UCS for the specimen increases with curing periods as well as the percentage of lime and gypsum mixed. There is a clear increment in the compressive strength as the increased percentage of lime. For the sample combination (FA +5L+0.4G) the increment for 7 days is 116.6% and for 28 days it is 318.5%. The same trend of increment is observed in case of other combinations too. For Sample combination (FA+8L+0.8G) the increment in strength for 7 days is 150% and for 28 days it is 266.6%. The plot from the figure 1 shows the increment of all the sample combinations for different curing periods. The strength is significant in all the sample combinations with increase in lime percentage as well as increase in gypsum percentage.

The same trend in the case of the Durability Indices had been observed in the entire specimen through the evaluation of the Indices for two cycles. These durability indices had been calculated using the following relations:

\[ Id_1 = \frac{Y}{X} \quad \text{(For first cycle)} \]  
\[ Id_2 = \frac{Z}{X} \quad \text{(For second cycle)} \]

Table 2 shows the first and second cycle durability indices for all the sample combinations.

It is observed from the table that durability indices for the specimens with longer curing periods and with higher percentages of lime and gypsum are in the increasing order. The indices are compared with the values given by the International Society for Rock Mechanics (ISRM).

From the tables of the obtained values of the Durability Indices (Table 2) and the Values of Durability Index Classification, it is clearly observed that the indices are in the incremental order with that of curing periods and percentage of lime and gypsum. Figure 2 and Figure 3 support the increment in the durability characteristics with increase curing periods.

Table 2: 1st and 2nd Cycle Durability Indices with Curing Period

<table>
<thead>
<tr>
<th>Combinations</th>
<th>1 Day</th>
<th>7 Days</th>
<th>28 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( Id_1 ) (%)</td>
<td>( Id_2 ) (%)</td>
<td>( Id_1 ) (%)</td>
</tr>
<tr>
<td>FA +5L+0.4G</td>
<td>39.8</td>
<td>32.3</td>
<td>62.2</td>
</tr>
<tr>
<td>FA +5L+0.8G</td>
<td>40.9</td>
<td>34.3</td>
<td>65.9</td>
</tr>
<tr>
<td>FA +8L+0.4G</td>
<td>49.7</td>
<td>40.4</td>
<td>69.8</td>
</tr>
<tr>
<td>FA +8L+0.8G</td>
<td>56.2</td>
<td>45.4</td>
<td>67.1</td>
</tr>
<tr>
<td>FA +12L+0.4G</td>
<td>55.2</td>
<td>47.3</td>
<td>70.6</td>
</tr>
<tr>
<td>FA +12L+0.8G</td>
<td>58.3</td>
<td>49.1</td>
<td>71.2</td>
</tr>
</tbody>
</table>

Note: \( Id_1 \) - First cycle durability index, \( Id_2 \) – Second cycle durability index.
Fig. 3: 2nd Cycle Durability Index (I_d2)

It is concluded that the durability characteristics for all the sample combinations increase with increase in the lime percentage and also with the increase in the curing periods. Further increment would surely be demonstrated if the curing periods are extended to longer durations.

The microstructural analysis on each sample combination show that due to increased curing period in days there occurred the formation of the hard gelatinous substance known by the name ettringite inside the pores. Through the XRD patterns analysis in comparison to the standard pattern of it the pattern for specimen combination with higher percentage of lime and with longer curing period show close conformity with the standard ettringite pattern. The closeness increases with longer curing periods. Figure 4, Figure 5 and Figure 6 show the samples pattern and their comparison with the standard pattern of ettringite.

Pattern with the combination of (FA+12L+0.4G) and the combination (FA+12L+0.8G) as shown in the figures 4 and 5 show very close resemblance to that of the standard ettringite pattern. Hence it can be concluded that the close resemblance of these XRD patterns with that of the standard ettringite pattern show the formation of the hard gelatinous substances inside the pore spaces. The formation densifies as the curing period is increased.

The Scanning Electron Microscope give us the idea that the formation of a new gelatinous skeleton really had taken place. The formation does not appear in the 1 day cured samples whereas the morphological changes in the 7 days and 28 days cured sample appear significant. More significant is the changes with longer curing period. Figure 6 and 7 show the comparable changes in the in the specimens with increased curing period and variable percentage of lime and gypsum used.

Figure 6 shows the changes of the same combination of lime and gypsum but cured for different days. It can be clearly observed that there certainly have occurred changes in the arrangement of the particles and dominantly the formation of the new substance is observed inside the pores. The increase in the lime percentage and the curing days (Figure 6 and Figure 7) has helped and given the sample sufficient time and the required lime percentage for the reaction to happen. In the mean time the reaction product formed is the hard skeleton of the ettringite (Calcium Aluminium Sulphate Hydroxide Hydrate). The stabilized fly ash with lime and gypsum gains strength with the increase in curing period.

5. CONCLUSION

Based on the experimental findings and discussions through various tests series presented in this paper, the following conclusion can be drawn:
1. Addition of lime up to (up to 12 %) increases the maximum dry density as well as there is increase in optimum moisture content.

2. Addition of lime alone or in combination with gypsum increases the strength of the fly ash. Gypsum is to be added along with lime to achieve higher strength within short curing period. For only lime stabilised fly ash higher lime content and longer curing period are to be provided so as to attain high strength.

3. Addition of lime along with gypsum is useful in increasing the strength of the fly ash. The unconfined compressive strength increases with longer curing period.

4. The addition of lime along with the gypsum increases the durability characteristics of the low lime fly ash.

5. From Scanning Electron microscope the physiomorphological changes is observed due to the formation of the hard skeletal gelatious matter. The formation interlocking network is observed to form with longer curing period and higher lime percentage.

6. The XRD patterns with longer curing period and higher percentage of lime ( up to 12%) and gypsum shows the compatibility of the curves to that of the standard pattern of the ettringite. With this it is confirmed that the hard skeletal crystalline product is being formed inside the solid particles of the stabilized fly ash. Complete formation of the hard material depends upon the higher curing period.

7. The formation of the new product network through pozzolanic reaction may be the reason for the enhancement of strength due to stabilization. This network of skeletal product may resist the formation of cracks in stabilized specimens while slaking in durability test. This may be the reason for higher strength and higher durability fly ash specimen stabilized with lime and gypsum and cured for longer period.

From the findings and the evaluations of the strength deformation, durability characteristics and the microstructural analysis it can be recommended that the low lime stabilized fly ash can be used for the fill of low lying areas and the mine voids. It can even be used as the filler materials in areas where there occur regular temperature fluctuations.

**REFERENCES**


