Improvement in Strength Characteristics of White Kalahari Sands by Fly Ash

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Abstract

Botswana is a country of about 581 730 km² in area. Three quarters of which is covered by sands of the Kalahari Desert on the western side of the country. The Kalahari region is dry, sparsely populated and has undergone very little development. A major problem in providing an adequate road system in this region has been the scarcity of good road construction material. The loose single sized Kalahari sands are difficult to traverse, even in four-wheel vehicles, and any effort for prospecting a good road construction material in a vast featureless desert is an intimidating and costly exercise.

In the present investigation, effort has been made to improve the strength characteristics of white Kalahari sands by adding fly ash alone as a stabilizer. Investigations revealed that there is a significant increase in unconfined compressive strength as well as California Bearing Ratio (C.B.R) of sand. Both unconfined compressive strength and C.B.R were found to increase with the increase of fly ash proportion and the curing time. The gain in C.B.R of stabilized material was found to be high enough to make the white sand suitable for the construction of sub-grade and sub-base in the construction of low traffic roads. On the basis of limited laboratory testing, recommendations are made to conduct field tests on some test sections of a road in the Kalahari Desert before setting up the guidelines.

Keywords: Fly ash, White Kalahari sand, Unconfined Compressive Strength, California Bearing Ratio.

INTRODUCTION

Fly ash is a waste material of coal burning in thermal power stations. Several million tons of fly ash is being produced globally every day and its disposal presents a serious problem to the electricity industries using thermal power stations. Only a small portion of the amount produced is utilized and the majority is dumped on land. A nation wide pledge was made in 1997 in the News Bulletin by the President of Indian Geotechnical Society, which read as follows:

“Accumulation of fly ash has reached an alarmingly high levels requiring immediate attention for its disposal. Geotechnical Engineering activity is a primary mechanism of its bulk utilization and disposal. This requires a certain amount of basic and applied research both in the field and laboratories. I would urge members to contribute in this emerging area.”

The fly ash shows important pozzolanic properties which depend upon many factors including quality of coal, degree of pulverization of coal, proportion of free lime and unburnt carbon in the fly ash. Pozzolanic property of
a fly ash is directly proportional to the amount of free lime and indirectly proportional to the amount of unburnt carbon in the fly ash. It has been found that if the amount of unburnt carbon is negligible, even a small quantity of free lime can initiate pozzolanic hardening (Koo, 1991). Any deficiency of pozzolanic property of fly ash due to lack of free lime can be compensated by the addition of lime in the stabilizing admixture. Use of pozzolanic material in the construction material is very old. Romans used pozzolanic materials mixed with lime as cement in their enduring structures. Efforts have been made by the researchers, in the recent past, (Mateos and Davidson, 1962; Singh, 1967; Uppal and Dhawan, 1968; Ghosh et al., 1973; Gokhale and Prasad, 1975; Gokhale and Shukla, 1995) to utilize this material in conjunction with lime for soil stabilization. However very limited work has so far been done (Sahu and Vemullapalli, 1997 and 1998) on the stabilization of soil with fly ash only. The studies made by Sahu et al on the stabilization of various grades of soils with fly ash revealed an increase in unconfined compressive strength and C.B..R. of all the soils. The gains were more significant with silty sands than with finer soils.

Today, about 350 tons of pulverized fuel ash is produced daily at Morupule Power Station in Palapye. Only a small proportion of the amount produced is utilized by Cement Packaging plant in Gaborone for the production of cement, much of it is dumped in disused clay-pits, gravel pits, and ash lagoons after mixing with water. Disposal in this way fulfills a useful function but a considerable quantity is also placed on land, which might well be used for other purposes such as roads construction.

The general scarcity of conventional road construction materials in Botswana has been reported by several authors (Motswagole et al 1996). In many cases, particularly in the western parts of Botswana, the upgrading of available local marginal materials through the use of lime or other form of stabilizer is often the only economical alternative for road construction. The construction of roads necessitates the quarrying of materials, which also involves the abandonment of a large amount of land (Borrow pits). Any use of fly ash in roads construction would obviously be in the national interest in terms of reducing the quantity of a waste material and adding economy to the construction cost of the roads.

MATERIAL USED

Soil

The soil used in this investigation was the “White Kalahari Sand”. The sand was collected from Tsabong, a town situated at a distance of about 700 km south-west of Gaborone. The Kalahari area constitute about three quarters of the country’s total area. The white Kalahari sand belongs to a family of arid soils. Arid soils are those soils, which are conditioned by an arid climate. The typical characteristics of arid soil strata are;

- Low water content and low water table resulting in them being unsaturated and having relatively large pore water suctions.
- They have a crust, which is rich in salts. This arises largely from the upward moisture loss at the top of the profile by evaporation. It often results in arid soils which get cemented or bonded by the precipitation of salts.
- They are often cemented by calcium carbonate to form calcrete.
- These soils are usually sorted and deposited by wind resulting into the formation of poorly graded (single sized) soils having very loose soil structure
Fly Ash

The fly ash used in this investigation was supplied by the operation manager of the Morupule Thermal Power Station, Palapye. The chemical and fuel analysis of the fly (supplied by the power station) is shown in tables 1 and 2.

**Table 1: Chemical Analysis of Fly Ash from Morupule Power Station.**

<table>
<thead>
<tr>
<th>Fly Ash Analysis</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>41.2</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>33.6</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>5.08</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>2.31</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.1</td>
</tr>
<tr>
<td>CaO</td>
<td>6.45</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.44</td>
</tr>
<tr>
<td>MgO</td>
<td>3.0</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

**Table 2: Fuel Analysis of Fly Ash from Morupule Power Station.**

<table>
<thead>
<tr>
<th>Ultimate Analysis</th>
<th>Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>60.94</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>3.05</td>
</tr>
<tr>
<td>Sulphur</td>
<td>1.06</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>--</td>
</tr>
</tbody>
</table>

Laboratory tests

Various laboratory tests carried out included classification tests, Modified AASHTO Compaction, C.B.R. and unconfined compression tests. All these tests were performed as per the standard method of testing construction materials (TMMH). Gradation curves of sand and fly ash are shown in fig.1.

![Gradation curve for fly ash and Kalahari sand.](image)

From the gradation curve it is seen that the fly ash is a well graded silt while the sand used is a poorly graded material. The white Kalahari sand was stabilized with 20%, 28% and 32% of fly ash. These proportions were based on the previous work (Sahu et al 1998) which indicated that strength characteristics of coarse grained soils were significantly improved with fly ash more than 20%. The amount of fly ash was added on the basis of mass calculated as replacement (i.e. soil mixture with 20% of fly ash means, 80% of sand and 20% of fly ash).
Sample preparation

(a) Unconfined Compression Test: All the samples were prepared by static compaction with a dry density of 1765 kg/m$^3$ and moisture content of 5% which corresponded to the maximum dry density and optimum moisture content of sand. Knowing the dry density and the moisture content of the compacted samples, amounts of sand, fly ash and water was calculated for a given length (90mm) and diameter (38mm) of compacted samples. The loose soil was filled in the tube and compressed from either end using aluminum spacers (fig.2). These samples were then extruded and cured before testing.

(b) California Bearing Ratio Test: All the samples were compacted with 100% compactive effort at their respective optimum moisture contents as determined by Modified AASHTO Compaction tests. C.B.R. tests were performed on 4 days soaked samples.

Curing of samples:

(a) Unconfined Compression Test Samples: The samples extruded from the tube were carefully wrapped in a greased polythene sheet and stacked in a 50mm diameter PVC pipe. Both the ends of the pipe were then sealed with a sealing cap to make it water tight. These sealed tubes were kept submerged in a water tank for curing at room temperature.

(b) C.B.R. Samples: The compacted samples were carefully wrapped with wet gunny bags. These gunny bags were kept wet all the time by sprinkling water at regular intervals.

RESULTS AND DISCUSSIONS

The results of all the tests are shown in table 3.

<table>
<thead>
<tr>
<th>Fly ash%</th>
<th>MDD kN/m$^3$</th>
<th>OMC%</th>
<th>UCS kN/m$^2$</th>
<th>CBR%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7days</td>
<td>14days</td>
<td>21days</td>
<td>0 day</td>
</tr>
<tr>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>20</td>
<td>1640</td>
<td>5</td>
<td>--</td>
<td>60</td>
</tr>
<tr>
<td>28</td>
<td>1552</td>
<td>8</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>32</td>
<td>1546</td>
<td>9.5</td>
<td>90</td>
<td>130</td>
</tr>
<tr>
<td>100</td>
<td>1310</td>
<td>20</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Variation of MDD with Fly Ash content

Variation of Maximum Dry Density with the proportion of fly ash is shown in fig. 3. It is observed that with the increase of fly ash the maximum dry density decreases linearly. It is due to the fact that the proportion of solids (fly ash) with lower specific gravity (2.2) increases in the soil admixtures with the increase in fly ash proportion.

![Fig. 3: Variation of MDD with Fly Ash](image1)

**Fig. 3: Variation of MDD with Fly Ash**

Variation of OMC with Fly Ash content

Variation of Optimum Moisture Content with the proportion of fly ash is shown in fig. 4. It is observed that it increases with the increase of fly ash content. It is in accordance with the general observation where Optimum moisture content increases and maximum dry density decreases as the gradation of soil changes from coarse to fine.

![Fig. 4: Variation of OMC with Fly ash content](image2)
Variation of UCS with Fly Ash content

Unconfined compressive of all the admixtures was determined at various curing periods. The variation of UCS with curing period has been shown for all the admixtures in fig. 5. It is observed that UCS increased both with the proportion of fly ash as well as with curing time. The unconfined compressive strength of pure sand is zero as it is difficult to make any cylindrical sample. In the absence of any cohesion, the shear strength of sand is zero. But with the addition of fly ash the UCS increased to a limit of about 240 KN/m² for 32% fly ash after 21 days of curing. This is a fairly good strength of the admixture. It is noted that the gain in strength with time is low at lower proportion of fly ash, which is indicated with no gain in UCS up to 7 days for soil admixture with 20% of fly ash.

![Fig. 5: Variation of UCS with fly Ash Content](image)

Variation of CBR with Fly Ash content

CBR of all the soil admixtures after four days soaking is shown in fig.6. It is noted that like UCS, CBR also varies with curing period. The gain is significantly high after 21 days of curing. While the CBR of sand alone was found to be 30%, it increased to 60% for the admixture with 20% of fly ash and to 75% for the admixture with 32% of fly ash. It demonstrates that the material, which was unsuitable even for sub-base, was improved to a level of suitability for base coarse with 32% of fly ash as per minimum requirement of Botswana Roads Design Manual (Stabilized natural materials for base coarse – 5-110.6.2). This is a very significant improvement by any standard.
The investigation suggests that white Kalahari sand can be stabilized with fly ash and used for the construction of roads. However, since it would need relatively larger amount of fly ash (more than 30%) to be mixed with sand and water for curing, it might be an economical proposition only to locations where the haulage distance for fly ash are not large and water is not scarce.

CONCLUSIONS

1. With the addition of fly ash with white Kalahari sand the MDD decreases while OMC increases.
2. Both unconfined compressive strength and C.B.R. of white Kalahari sand increase with the addition of fly ash.
3. The gain in both unconfined compressive strength and C.B.R. with curing time is initially slow but picks up after 7 days.
4. With fly ash more than 32% and 21 days of curing both unconfined compressive strengths and C.B.R. are increased to a level which makes the material suitable for sub-base and base coarse of a low traffic road.

RECOMMENDATIONS

It is noted that the gain in strength characteristics of sand with the addition of fly ash is rather slow initially and picks up after 7 days. This may not be a desirable behaviour in the areas like Kalahari desert where one encounters the scarcity of water. It suggests a need for further research to find an answer to this problem.

Before setting any standard on the use of fly ash in road construction in Kalahari desert, there is a need to make trial sections and to monitor its performance.

REFERENCES:


