IMPROVEMENT OF MARGINAL MATERIALS BY FLY ASH IN ROAD WORKS

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The national road network continues to play a fundamental and catalytic role in the promotion of social and economic development of Botswana. However, a combination of adverse climatic and geologic factors, such as scarcity of conventional road building materials, near absence of a non saline surface water, and climatic extremes have dictated the need for innovative engineering approaches to highway design, construction and maintenance. In recent years application of fly ash has been considered in road construction with great interest. Fly ash is a pozzolanic material, which in the presence of water combines with lime to produce a cementetious material with excellent structural properties. Attempts have, therefore, been made at Botswana Roads Department in collaboration with University of Botswana to explore the feasibility of utilizing fly ash alone to improve the physical and strength characteristics of locally available non-standard marginal materials. The results indicate that with the addition of fly ash plasticity decreases while California Bearing Ratio (CBR) increases for calcrete and other locally available marginal materials for road construction. With appropriate amount of fly ash and an adequate curing the material can be improved to meet the requirements of base and sub-base coarse.

Keywords: Fly ash, Marginal materials, Calcrete, Plasticity Index, California Bearing Ratio, Road Works.

1 INTRODUCTION

The national road network continues to play a fundamental and catalytic role in the promotion of social and economic development of Botswana. To this end, substantial financial allocations have been made and would continue to be made to the roads sub- sector in order to promote further economic growth and development. However, a combination of adverse climatic and geologic factors, such as scarcity of conventional road building materials, near absence of a non saline surface water, and climatic extremes have dictated the need for innovative engineering approaches to highway design, construction and maintenance in Botswana. Since materials typically constitute approximately 70% of the total cost of the road construction in Botswana, probably the greatest cost for innovation has been in judicious use of marginal materials.

In Botswana materials like Kalahari Sand, and Calcrete are available in abundance. However, the specifications often preclude the use of such local soil and aggregates as a road pavement material due to their non- compliance with recommended standards. Such a situation results either in importing the materials from a long haul distance or to stabilize these materials with costly additives like cement. This makes the project prohibitively expensive especially in case of a low trafficked road.

In recent years application of fly ash in road construction has been considered with great interest. Fly ash is a pozzolanic material, which in presence of water combines with lime to produce a cementetious compound such as calcium silicate and calcium aluminate hydrates (ASTM, C 618-72). These compounds have improved structural properties like shear strength and CBR. The degree of pozzolanic property of a fly ash depends upon many factors, which include the amount of free lime and unburnt carbon, degree of pulverization and curing period. Recent work [1] has shown that if the amount of unburnt carbon is negligible, even a small proportion of free lime present in fly ash can initiate pozzolanic hardening. This study has also revealed that self-hardening of fly ash is further promoted by the formation of several other complex crystallined products including ettringite (needle like). Since the fly ash from Morupule Power Station contains about 7 % of free lime and less than 1% of unburnt carbon, it si expected to have a good self-hardening property. Attempts have, therefore, been made at Roads Department in collaboration with University of Botswana to explore the feasibility of utilizing local fly ash to improve the physical and strength characteristics of locally available non-standard marginal materials. The results of the present investigation indicate that calcrete and other marginal materials stabilized with fly ash may effectively be used for compacted fills, sub-base and base coarse in roads construction.

1 MATERIAL USED

2.1 Fly ash

Fly ash can be regarded as a non plastic silt which, when mixed with soils, can develop cementetious characteristics either due to pozzolanic effect or due to an inherent self hardening property under favourable conditions of moisture and compaction [2]. In Botswana, it is obtained from Morupule Thermal Power Station located at Palapye, about 300 km north of capital city Gaborone. It is produced at the rate of about 400 tons per day. Only less than 10% of the total production is being used by cement industry while the remaining more than 90% is dumped in the waste lagoons in the form of slurry. It has a gradation of uniform silt with a specific gravity of 2.1. The chemical composition of the fly ash used is shown in table-1.

Table 1: Chemical Composition of Fly Ash

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	Na_2O	P_2O_5
%	41.2	33.6	5.08	6.45	3.0	2.31	0.44	0.1	<0.05

2.2 Soils

Four types of soil samples representing different types of soil found in the Tswopong region were collected for laboratory testing. All these four soils were considered unsuitable for one or the other reason in their natural state for the use in constructing sub-base or base layers for the new road in that region.

Generally fill and sub-grade materials are readily available in the region, however, the problem is to locate the suitable materials with which to construct the base and the sub-base. Generally this is also fairly easy provided a careful selection is exercised while excavating the seams of gravels. Unfortunately in this region, most of the gravel seams are very thin, usually 500mm or even less, and are underlained by unsuitable clayey gravels. During borrow pit excavations, some of these underlaying clayey gravels get mixed with the upper selected gravel making them marginally unsuitable due to high plasticity index (Ip) and low CBR. In these cases the addition of fly ash can be considered as a good option to lower the plasticity index and increase the soaked CBR, thus making material suitable for base or sub-base.
To develop suitable specifications for the mixes of soil- fly ash and aggregate- fly ash, the soil and gravel samples were collected from a region (Tswapong North and South) where large amount of road construction activities are in progress and the roads are in the close proximity of the thermal power station. The following four types of soils/ gravels were collected for detailed investigations:

2.2.1 Clayey sand

The predominant overlying soil of this region is a ferroginous clayey sand (reddish in colour), which is generally marginally unsuitable because of their high plasticity indices and low CBR values.

2.2.2 Quartz - ferricrete schist

Many of the underlying gravels in this region are quartz/ferricrete mixtures. The ferricretes are generally found in thin seams with a mixture of ferricrete/quartz gravel at the top of the seam while clayey ferricretes are underlying the seams. The quartz/ferricrete gravels are extremely good materials for use as a sub-base and base in road constructions while the clayey ferricretes are unsuitable due to presence of clay. In the field, it is very difficult to excavate only the top layer of gravel/ferricrete as it gets mixed with the lower layer of clay ferricrete. This makes the material, as a whole, unsuitable for road works.

The quartz ferricrete gravel, chosen for the tests, would have been unsuitable for use as sub-base due to the high plasticity (Ip = 15% as against a value of 10%) and low CBR
(32%, as against a value of 45 % at 95% MOD. AASHTO) and unsuitable for base due to high plasticity (15 as against a value of 6) and low CBR (37% as against a value of 80% at 98% MOD. AASHTO).

2.2.2 Gneiss with calcrete

This particular calcrete appears to be weathered gneiss granules, which breaks down in hand and is not a typical calcrete of this region. It was however selected as being the lowest quality calcrete material, which was available around the area. The material in its natural state has a plasticity index of 14 which is marginally suitable for sub-base but has extremely low value of CBR in soaked condition (6.7% at 98% compaction and 4.5% at 95% compaction) which makes it totally unsuitable for its use either as sub-base/base or even as sub-grade and fill. However, it was selected to study the stabilizing effects of fly ash on perhaps the worst possible material.

2.2.3 Friable calcrete

Nodular calcrete, found throughout the region, are generally of good quality to be used for sub-base without any particular selection. This particular calcrete meets all of the specifications for a sub-base but the plasticity index of this material is too high and the CBR is too low for its consideration as a base. The grading modulus of this material is fairly high in its natural state, however, with little mechanical effort it breaks down too much smaller size particles. The grading modulus, therefore, could be a misleading parameter for this material.

2 LABORATORY TESTING:

The results of classification tests on all the soils are shown in Table-2. Various soil admixtures were prepared by mixing 4%, 8%, 16% and 24% of fly ash by mass. The modified AASHTO compaction tests and CBR tests on 4 days soaked samples were carried out on all the soils and its admixtures as per Technical Methods For Highways (TMH) specifications. The results of all the tests are shown in Table-2.

Table-2 Test results of all the soils and their admixtures

Soil + ash	Gravel %	Sand %	Silt %	Clay %	GM	MDD kg/m^3	OMC %	W_L %	I_p %	L.S %	C.B.R 98%	C.B.R 95%	C.B.R 90%
Fly ash	0	0	94	6	--	1310	20	NP	NP	00	--	--	--
Clayey Sand	1	69	16	14	1.08	2019	9	29	12	4.7	10	8	3
+4% ASH						1970	10.2	31	10	4.0	65	45	23
+8% ASH						1964	8.7	30	8	4.0	88	76	60
+16% ASH						1943	12.7	31	6	3.0	112	87	54
+24% ASH						1867	12.3	SP	SP	1.3	150	118	79
Quartz - Ferricrete	1	74	25	0	1.24	2043	10.9	30	15	4.4	37	32	23
+4% ash						2028	9.4	32	10	4.7	80	55	28
+8% ash						1992	9.9	25	7	3.3	102	63	23
+16% ash						1989	10.4	31	5	2.7	180	140	88
+24% ash						1960	8.7	SP	SP	0.7	191	148	115
Gneiss with Calcrete	56	24	20	0	1.99	1825	14.6	40	14	6.7	5	4.5	4
+4% ash						1815	14.2	41	12	5.3	17	15	7
+8% ash						1806	13.4	44	9	4.0	24	18	8
+16% ash						1674	14.4	42	4	2.0	32	29	25
+24% ash						1680	16.6	SP	SP	1.7	55	49	41
Friable Calcrete	62	30	8	0	2.3	1753	15.6	28	13	6.0	39	36	34
+4% ash						1687	19	23	9	4.7	49	39	30
+8% ash						1670	19.9	17	5	2.0	57	50	38
+16% ash						1665	23.4	SP	SP	1.7	66	60	52
+24% ash						1662	17	SP	SP	0.7	93	78	49

SP – The soils are slightly plastic. It was bit difficult to perform plastic limit tests. For academic purposes its plasticity index is assumed as 2 and plotted in Fig.2

3 RESULTS AND DISCUSSIONS

Particle size analysis of all the four soils used for investigation is shown in fig.1. All the soils are classified as coarse-grained soils. Clayey sand and quartz and schist are sands while gneiss with calcrete and friable clacrete are classified as gravels. It is also observed that clayey sand and quartz ferrecrete schist are well graded while gneiss with calcrete and friable calcrete are gap graded.

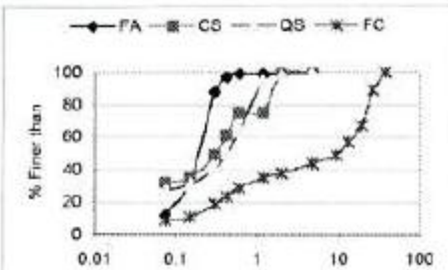

Fig.1 Gradation Curves

FA – Fly Ash; CS- Clayey Sand; QS – Quartz Ferricrete Schist; GC – Gneiss with Calcrete; FC – Friable Calcrete.

4.1 Atterberg Limits

Variation of plasticity index of all the soils with varying proportion of fly ash are shown in fig.2. While the liquid limit was determined by cone penetrometer the plastic limit was determined by rolling moist soil to 3mm diameter threads. All the tests were performed on the soil fraction passing 425µm size sieves. It is observed that plasticity index of all the soils decreases with the addition of fly ash.

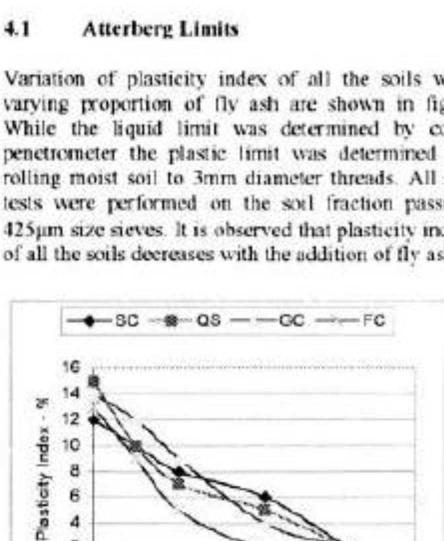

Fig.2 Variation of Plasticity Index with Fly Ash

The decrease is bit more rapid up to about 8 % of fly ash for quartz - ferrecrete schist and friable calcrete and up to 16% for gneiss and calcrete, while for clayey sand the decrease in plasticity index is almost linear with the proportion of fly ash. It is noted that only 8 % of fly ash is enough to lower the plasticity index of all the soils to less than 10 which satisfies the criterion for its use in sub-base. However, 16% of fly ash would be required to lower the plasticity index to less than 6% (required for base coarse) for all the soils except clayey sand for which it is about 20%.

Variation of linear shrinkage with fly ash is shown in fig.3. It is observed that the decrease in linear shrinkage is almost linear with the increase in fly ash content for all the soils except for friable calcrete for which the decrease is more up to about 8% of fly ash. On the whole the effect of fly ash is to decrease both plasticity index and linear shrinkage of all the soils.

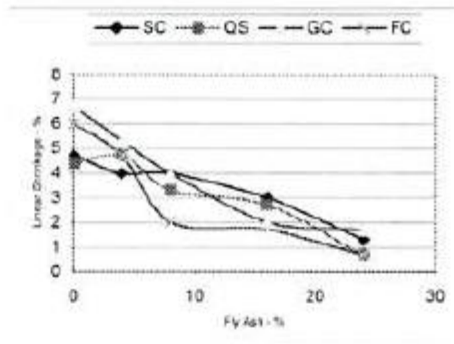

Fig.3 Variation of Linear Shrinkage with Fly Ash

4.2 Maximum Dry Density & Optimum Moisture Content

Variation of MDD and OMC with fly ash content for all the soils is shown in figs.4. & 5.

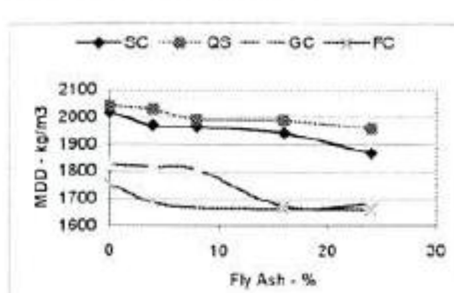

Fig.4 Variation of MDD with Fly Ash

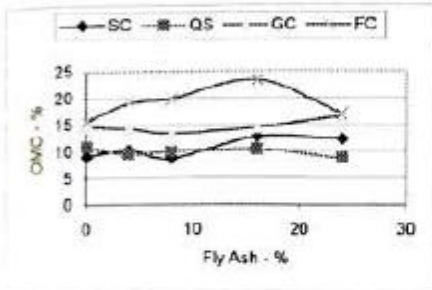

Fig. 5 Variation of OMC with Fly Ash

It is observed that while the MDD of all the soils decreases with the addition of fly ash the OMC increases for all the soils except for quartz-ferrecrete schist for which it remains more or less the same. The behaviour is in accordance with the general observation of the effect of soil gradation on OMC and MDD. All the soils used are coarse-grained soils while the fly ash is a fine-grained one (silt size particles). Any addition of fly ash would change the gradation towards finer side, which would reduce the MDD and increase OMC. The reduction in MDD with the increase in fly ash in the admixture is also due to fact that the specific gravity of the fly ash is lower (2.1) than that of soils (about 2.65)

4.3 California Bearing Ratio

The CBR of all the soils and its admixtures with fly ash were determined at 98%, 95% and 90% of Modified AASHTO Compaction and are shown in figures 6,7 and 8.It is observed that the CBR of all the soils increases with the increase of fly-ash proportion. The gain is significantly high for quartz ferrecrete schist and clayey sand (about 190% for quartz-ferrecrete schist and about 150% for clayey sand) while for gneiss and calcrete and friable calcrete it increases to 90% and 60% respectively at 98 % compaction. The variation in the gain of CBR appears to be dependent on the gradation of the soils.

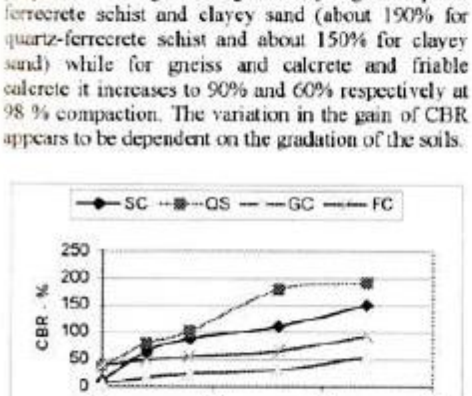

Fig.6 Variation of CBR at 98% Compaction

It is more for well-graded soils than gap graded soils. Similar trends were observed at 95% and 90% compaction.

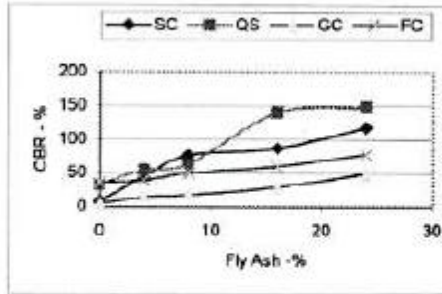

Fig.7 Variation of CBR at 95% Compaction

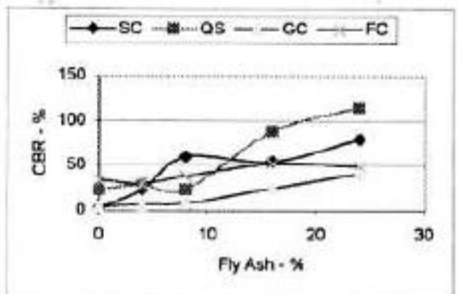

Fig. 8 Variation of CBR at 90 % Compaction

The increase in CBR depends upon the amount of fly ash, gradation of soil and the degree of compaction. It was noted that the soils, which were marginally unsuitable for base and sub-base, are improved to a level where the CBR values are much higher than the required specification (>80%) requirement [3]. The amount of fly ash required to increase the CBR for (i) base courses varies from 5 to more than 24 % and (ii) for sub-base courses varies from 0 to 20%, depending upon the type of soil and the degree of compaction. Similar trends were found with silty sand and soils of low and intermediate plasticity [4]. This limited study suggests that a fly ash with very small content (<1%) of unburnt carbon can be used to stabilize the coarse grained soils for road construction without mixing with lime even if it is a class F fly ash (free lime < 10%). These findings support the previous findings by Koo and Toth [1,2], which suggest that if the amount of unburnt carbon is negligible, even a small proportion of free lime present in fly ash can initiate pozzolanic hardening. However the amount of fly ash required for improving CBR to a desired level should be determined from the laboratory tests as it depends upon the chemical composition of fly ash, soil grading and the degree of compaction.

CONCLUSION

1. Both plasticity index and linear shrinkage of the soil decreases with the increase in fly ash.
2. With the addition of fly ash MDD decrease while the OMC increases.
3. CBR is increases with the increase in fly ash.
4. The effect of fly ash on CBR is more in well-graded soils than in gap-graded soils
5. The fly ash improves the marginally unsuitable material for base course in road construction.

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