Compaction and Strength of Lime – Fly Ash Stabilized Collapsible Residual Sand

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ABSTRACT

Berea Red Sands are weakly bonded residual collapsible sands underlying significant portions of the west coastal plain of South Africa. Freshly quartered samples of Berea Sand mixed with 4% and 8% Lime as stabilizers and 0%, 6%, 12% and 18% Fly Ash as additive by weight of the dry soil, were compacted and cured for 7 days, 28 days and 56 days. At different stages of curing, some samples were tested to determine their Unconfined Compression Strength (UCS) and California Bearing Ratio (CBR). Similar but limited number of tests were conducted on visually identical, commercially used reconstituted road fill materials.

The stabilization of Berea Sand with Lime and Fly Ash results in significant improvement on the strength and bearing properties. Marginal difference in the magnitude of UCS and CBR of the 4% Lime and 8% Lime mixes for percent Fly Ash up to 12% for the 7 days curing period was indicated. Further addition of Fly ash result in lower strength of 4% Lime mixes and marginal increase in the strength of 8% Lime mixes over the extended curing period. The max UCS of Lime stabilized Berea Sand is however significantly lower than the UCS of Lime stabilized reconstituted road fill materials due to different particle and mineralogical constitution and thus may only be suitable for recompacted subgrades and sub base of low level municipal road projects.

KEYWORDS: Collapsible Sand, Unconfined Compression strength, California Bearing Ratio.

INTRODUCTION

Berea Sand is formed by the leaching of calcarenite that underlies it. It is part of a recent formation that forms unconsolidated red dune ridges along most of the Indian Ocean coastal plain and texturally consist of quartzite sand that is coated with iron oxide and weakly held together by mainly Kaolin Clay (Brink 1984). Because of the profile heterogeneity and inherent delicate macro structure, Berea Sand is known to exhibit collapse behavior that has resulted in failure of embankments; moisture induced slope failures, pavements and buildings and is thus considered as one the problem soils of Southern Africa (Jennings and Knight 1975 and McKnight 1999).

Although Berea Sand formation appears longitudinally alongside the entire coast of Kwazulu Natal and sporadically from Transkei coast to Morgan Bay in East London, deposits of naturally occurring intact granitic and doleritic rocks and aggregates are not widely spread in South Africa and are fast depleting, thus the high cost of processing and transporting these durable materials add to the ever growing cost of Expanded Public Works (EPW) driven Rural Development Projects (RDP) (Bennett et al, 2002).

Broad engineering geological profiling of Berea formation indicate that the physical and engineering properties vary rapidly both laterally and vertically, mainly in relation to changes in clay content and moisture content (Maud, 1968 and Brink, 1984). As plasticity, clay content, suction, binder potential and permeability are important parameters influencing the behavior of residual red soils, as dug lateritic sandy soils and naturally occurring gravels used as road bases in subtropical or tropical climate conditions (Toll, 1991), Berea Sands typically of fairly high permeability and low kaolin content may not take advantage of these beneficial properties and thus may benefit from stabilization.

The northern region of Kwazulu Natal where annual rainfall of 900mm and Weinert number of less than 2 is classified wet for pavement design purposes. Paige Green and Garryts, (1998) have detailed the failure of unpaved and graveled top municipal roads and settlement of old black tops in these vast regions. Bennets et al, (2002) investigated various low traffic volume surfaced road pavement carrying less than 400 vehicles per day, constructed with Lime and Cement stabilized Berea sands mixed with other aggregates, and noted low relative maintenance cost and higher durability of the lime stabilized sand pavement. In addition, the beneficial effects of stabilization of residual tropical soils with Cement, Cement and Fly Ash, Hydrated Lime and Lime and Rice Husk Ash are well document by Ali et al, (1992) and Bagherpour and Choobbasti (2003). For some residual soils, it was observed that higher strength was developed by the Lime - RHA mixtures at all stages of the curing period than the Cement- RHA mixtures.

In South Africa, power station Fly Ash is disposed of in one of two ways; by dry dumping or by hydraulic deposition into ash dams (Fourie and Blight, 1999). Series of geotechnical and chemical tests carried out on Fly Ash from some of the stations revealed the presence of significant quantities of quartz, alumina and iron oxide thus indicating high likelihood of pozzolanic hardening of the Ashes (Fourie et al, 1997 and Fourie et al, 1998). The availability of good quality Fly Ash provided the impetus for the study of strength improvement of Lime stabilized collapsible residual sand.

The main objective of this investigation is to evaluate the effect of Fly Ash on the strength in Lime stabilized Berea Sands. It is intended to use Fly Ash as a replacement for fines and also to take advantage of the pozzolanic cementation associated with Lime-Fly Ash reactions in the presence of pore water, thus reduce cost of RDP roads reserve the costly natural materials for the N1, N2, N3 and N4 interprovincial highways.

MATERIALS AND METHODS

Chemical Compositions of Test Materials

Fly Ash is a pozzolanic material, consisting of non – crystalline silicate and aluminates particles and rounded magnetic iron oxide (Fe3O4) grains, materials which when mixed with other chemicals like cement or lime containing calcium and in the presence of water can enhance cementation (O' Flaherty, 1974). Fly Ash possesses a wide quality range and this may be problematic.

Hydrated lime is dry powdered Lime, produced by adding to quicklime sufficient moisture, unlike slaking, to satisfy its affinity for water under hydration conditions. Details of the compounds and minerals constituent of a commercially available Hydrated Lime and Fly Ash used for this investigation, determined by x – ray diffractions at the Department of Geology, University of Kwazulu Natal, to ensure consistency with the requirements of TMH 10, are given in Table 1, as well as the major chemical constitution of Berea Sands.

The total constitution of active pozzolanas (SiO2 + AL2O3 + Fe2O3) is more than 70% for the commercially available Fly Ash (ASTM1987). Given the low content of pozzolanas in the Hydrated Lime, the additive role of the Fly Ash is crucial for the Berea Sand – Lime pozzolanic reaction.

Table 1: Compounds and Mineral Constitution of Berea Red Soil (BRS), Hydrated Lime (HL) and Fly Ash (FA)

	SiO_2	**AL_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**
BRS	62.68	19.48	13.56	0.1081	0.26	0.83	0.32	0.85	1.7223
HL	2.23	0.19	0.27	1.1288	1.65	93.87	0.00	0.06	0.00213
FA	83	8.	2.65	0.55	0.22	0.18	0.04	0	0.26

	P_2O_5	**Cr_2O_3**	**NiO**
BRS	0.013	0.0615	0.0061
HL	0.02	0.0015	00000
FA	0.4	0.005	0

Sample Preparation, Compaction and Curing

Bags of Berea Red sands were collected from the Agricultural farm of Mangosuthu University of Technology, 4.5 km from the Durban Airport. Batches of oven dried Berea Red Sand were prepared quartered out and required amounts of Lime and Fly Ash and then mixed thoroughly with water. The mix combinations are 4% and 8 % Lime stabilizer and 0%, 6% 12% and 18% Fly Ash additive. The samples are left to equilibrate for 24 hours prior to compaction. The Maximum Dry Density and Optimum Water Content for each mix is determined by ASSTHO compaction test in accordance with TMH1 (1996).

Compacted specimens were cured for 7 days, 28 days and 56 days at a relative humidity of 95 to 100 per cent and temperature of 220C to 250C in a curing room. The samples were covered by permeable hessian bags (foamed plastic bags) and water was sprinkled constantly on the cover over the selected curing period. Details of the test program are given in table 2.

The Unconfined Compression Strength (UCS) test was conducted on stabilized samples, compacted into the 50mm by 100mm mould to the respective Modified ASSTHO MDD and OMC, cured for the selected curing periods (7, 28 and 58 days) in samples in accordance with TMH1 (1996).

The California Bearing Ratio Tests was conducted on stabilized samples that were compacted into the ASSTHO mould at the OMC and 95% Modified ASSTHO MDD. Some of the samples were tested immediately while others were soaked for seven days before testing in accordance with TMH1 (1996).

All the tests were repeated on two samples and the results reflect the average determined from tests on identical sample.

Table 2: Unconfined Compression and California Bearing Ratio Tests

SOIL MIX	CURING (DAYS)			SOIL MIX	CURING (DAYS)		
	7	28	56		7	28	56
4% Lime 0% Fly Ash	UCS CBR	UCS	UCS	8% Lime 0% Fly Ash	UCS CBR	UCS	UCS
4% Lime 6% Fly Ash	UCS CBR	UCS	UCS	8% Lime 6% Fly Ash	UCS CBR	UCS	UCS
4% Lime 12% Fly Ash	UCS CBR	UCS	UCS	8% Lime 12% Fly Ash	UCS CBR	UCS	UCS
4% Lime 18% Fly Ash	UCS CBR	UCS	UCS	8% Lime 18% Fly Ash	UCS CBR	UCS	UCS

Results and Discussion

Result of Preliminary investigation on Commercial Aggregates

The road aggregate materials commonly used for some municipal and provincial roads construction in South African are reconstituted reddish soil, visually similar to Berea sands and other reddish sands in South Africa. These materials are laid and compacted as fills and subgrades and are also stabilized with cement and lime for base courses of major projects. The result of particle size tests of Berea red sands and the reconstituted road aggregate in accordance with TMH1 (1996) is shown in Figure 1. The reconstituted road aggregate is predominantly well graded clayey gravelly sands while the Berea Sand used is uniformly graded sand.

The plasticity index of the aggregate is 17% - 18% while that of Berea Sand is 6% – 8%.

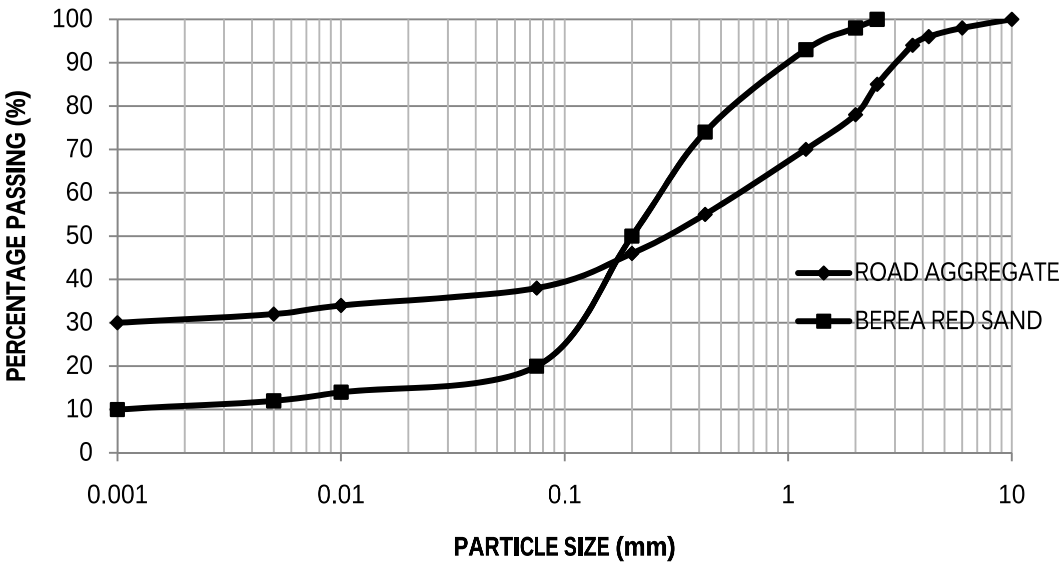

Figure 1: Particle Size Curve of Berea Sand and Reconstituted Aggregate.

The Modified ASSTHO compaction test was conducted on samples of the road aggregate stabilized with 3% and 6% Lime and Cement respectively by dry mass of soil materials in accordance with TMH1 (1996). The result are shown in Figures 2a and 2b and indicate that the Maximum Dry Density (MDD) of Lime stabilized and Cement stabilized soil decreases by the same magnitude, the Optimum Moisture Content (OMC) of lime stabilized soil is significantly smaller than the OMC of cement stabilized soil.

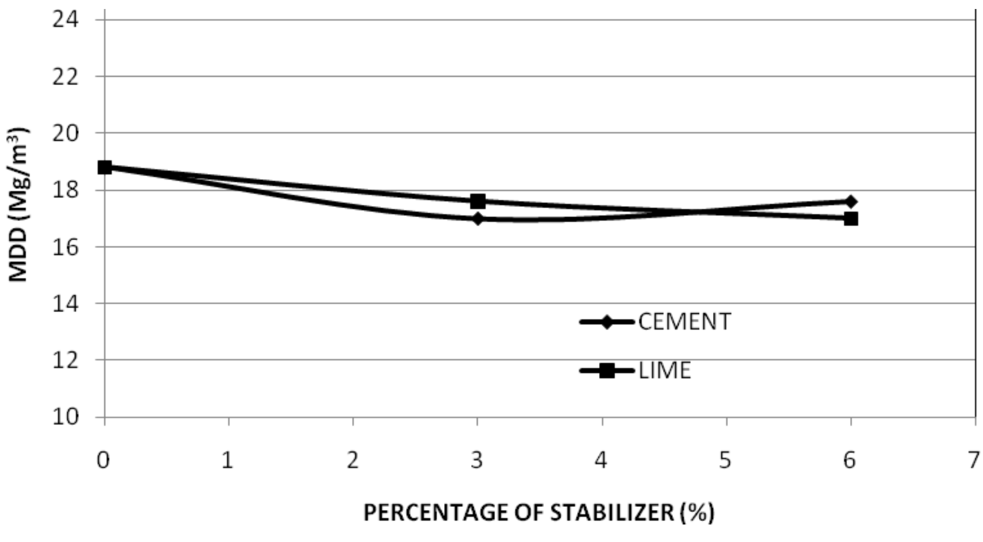

Figure 2a: MDD of Road Aggregate stabilized with Cement and Lime

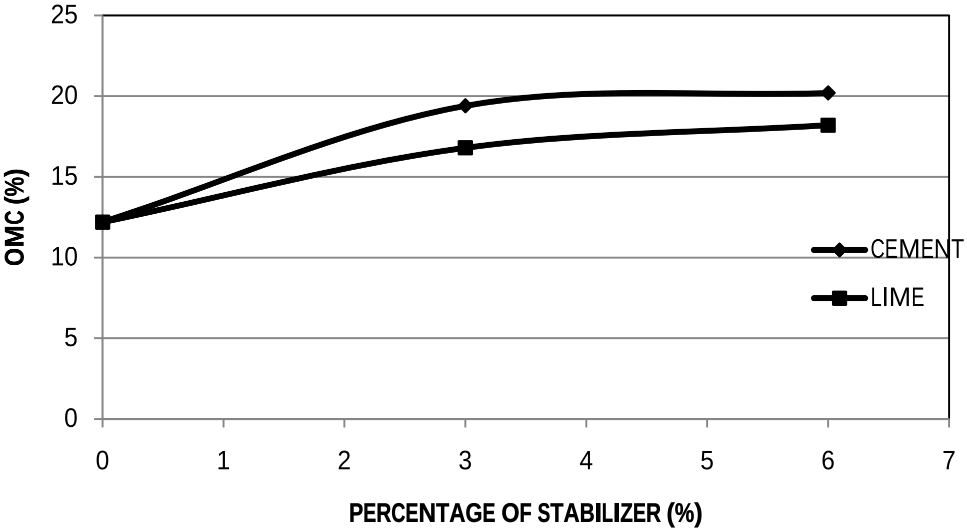

Figure 2b: OMC of Road Aggregate stabilized with Cement and Lime

The result of the Unconfined Compression Strength test conducted on samples of the road aggregate stabilized with 3% and 6% Lime and Cement respectively, compacted at the respective MDD and OMC, and cured for seven days in accordance with TMH1 (1996) are shown in Figure 3. The result indicate that the UCS of the aggregate can be significantly improved by Lime and Cement stabilization. Marginally higher strength was indicated by the cement stabilized material.

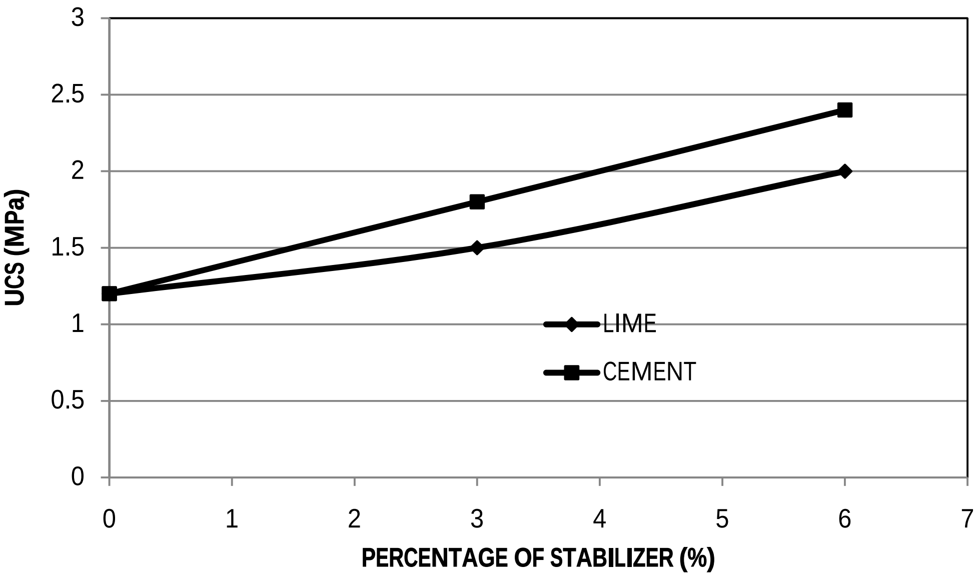

Figure 3: UCS of Road Aggregate stabilized with Cement and Lime.

Physical Properties of Berea Sands

The result of basic textural properties on samples of Berea Red Sands used in this investigation is shown in Table 2. The particle size analyses indicate that Berea Sand is uniformly graded sand with low fines content. The atterberg limit test revealed a nonplastic soil with very low shrinkage potential. The increase in specific gravity with decrease in particle size may be associated with the effect of iron oxide coating of the predominantly quartz sand, a trend noted by Toll (1988) in residual soils from Malawi and Kenya. The result of basic textural properties on samples of Berea Red Sands used in this investigation is shown in Table 2.

Table 2: The Index, Physical and Compaction Properties of Berea Red Soil

ATTERBERG LIMIT	SPECIFIC GRAVITY	ASSTHO COMPACTION
PI = 6% - 8% SL = 2%	$D_{2.0}$ = 2.68 $D_{0.075}$=2.71	MDD = 16.8 OMC = 10.20

Compaction Characteristics of Stabilized Mixes

The MDD of natural sample of Berea Sand is 16.8 Mg/m3 and the OMC is 10.2%. The result of series of tests conducted to examine the influence of 4% and 8% Lime content on the ASSTHO MDD and OMC and the effect of addition of Fly ash are presented in Figure 4a and Figure 4b. For the same comp active effort, the addition of lime alone result in a stepwise decrease the MDD and increase in the OMC. Further decrease in density and increase in moisture content was indicated by samples stabilized with increasing amount of Fly Ash. Ali et al (1992) indicated that the increase in optimum moisture content was due to water absorption by Fly ash and increase in amount of held water within the flocculent soil structure resulting from Lime - Clay interaction. The trend highlights the increased resistance offered by the flocculent stabilized sand structure to the compactive effort. Fly-ash particles contain significant electric charge that causes particle - particle repulsion and bulking of mixed materials. In addition, the specific gravity of Fly ash also contributes to the reduced dry density of the mix .

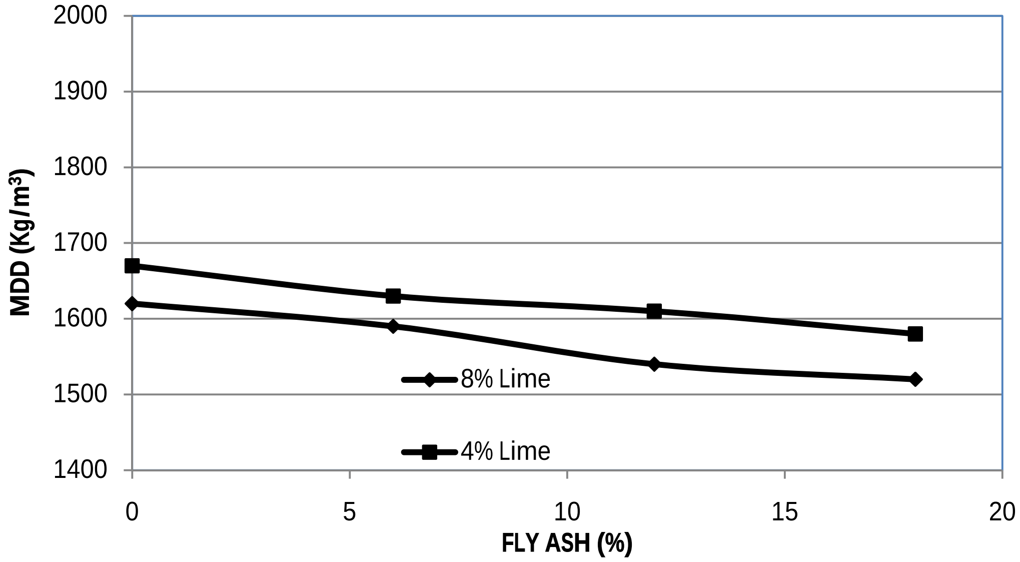

Figure 4a: MDD of Road Aggregate stabilized with Cement and Lime

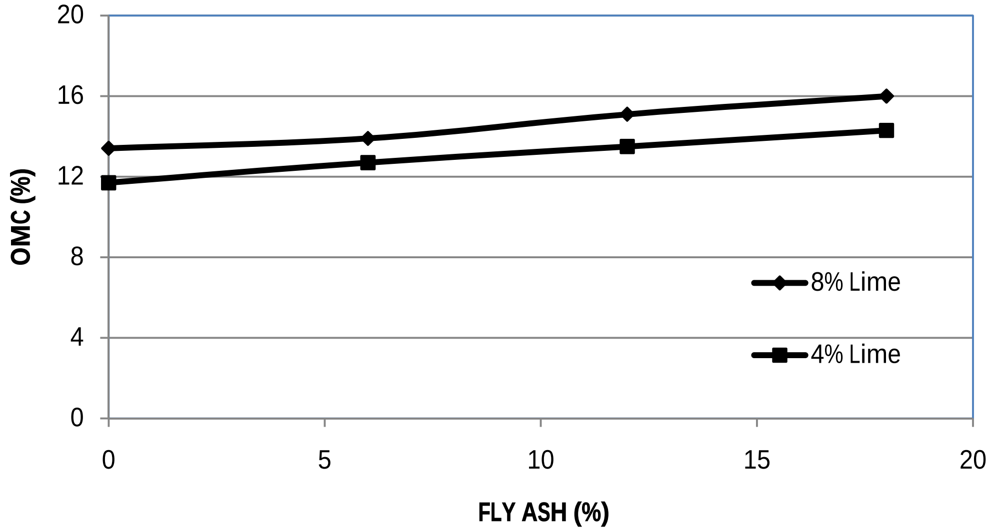

Figure 4b: OMC of Berea sand stabilized with Lime and Fly Ash

Unconfined Compressive Strength of Stabilized Berea Sand

The effect of curing and addition of Fly Ash on the UCS of the Sand stabilized with 4% Lime and 8% Lime is shown in Figure 5(a) and Figure 6(a) while Figure 5(b) and Figure 6(b) shows the rate of change in strength of stabilized mixes with curing periods.

For short duration i.e. 7days curing, the addition of 6% Fly Ash has significant incremental effect on the UCS and for this percentage of additive, extended curing however result only in marginal increase in UCS. For this percentage of Lime, increasing the amount of Fly Ash to 12% results in the maximum UCS for all the curing periods adopted. The increase in UCS resulting from increase in the additive from 6% to 12% is disproportionate i.e. increasing rate of increase in UCS. Subsequent increase in Fly Ash from 12% to 18% results in a decrease in UCS. Thus for all the curing time adopted, the UCS of Berea Sand stabilized with 4% Lime increases with increase in Fly Ash up to a limiting value above which further addition of Fly Ash result in decrease in UCS.

The increase in strength due to the addition of Lime is the result of pozzolanic reaction between the alumina and silica contents of Berea Red Sands and the hydrated Lime that results in the cementing agents. The addition of sufficient Fly Ash introduce additional amount of silica for the pozzolanic reaction. Further increase in Fly Ash beyond the optimum value results in decrease in strength because of the lower strength of the excess amount of Fly Ash that is not used up in the pozzolanic reactions.

Increasing the amount of Lime from 4% to 8% result in increase in UCS with increasing amount of Fly Ash for the curing periods adopted. This trend which is indicated in Figure 6a is also fundamentally different from Figure 5a because increase in Fly Ash from 12% to 18% result in even significant increase in UCS. The 8% Lime content supplied enough carbonates for the pozzolanic reaction that used up all the Fly Ash.

The rate of increase in UCS with curing period is higher for the 8% Lime mixes. However about 50% increases in the 7days strength was developed in 56 days for the two Lime mixes, and most of this increase occur between the 6% and the 12% Fly ash. Within this margin, the rate of increase in strength is independent on the percentage of fly ash in the mix.

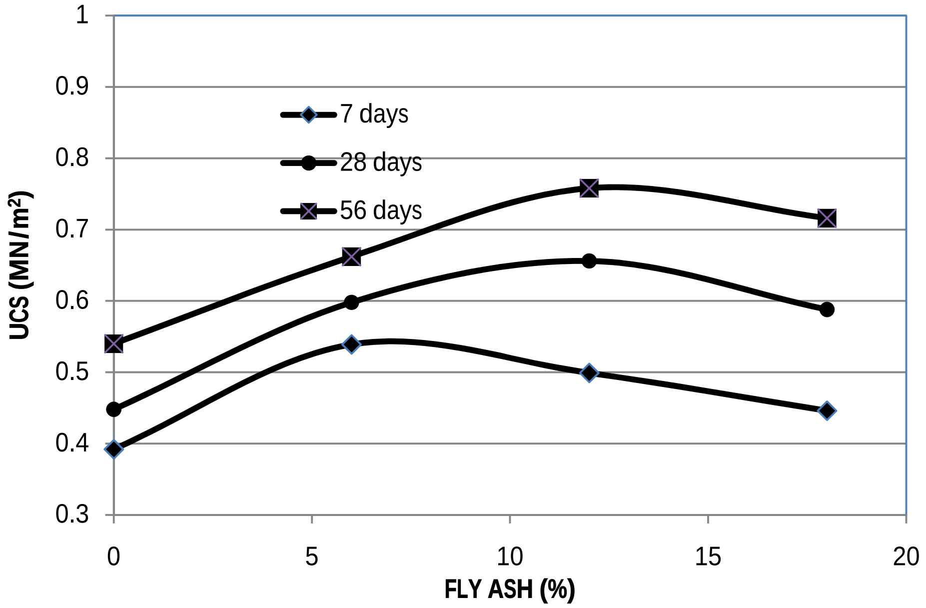

Figure 5a: UCS of Berea Sand stabilized with 4% Lime and 0 – 18% Fly Ash

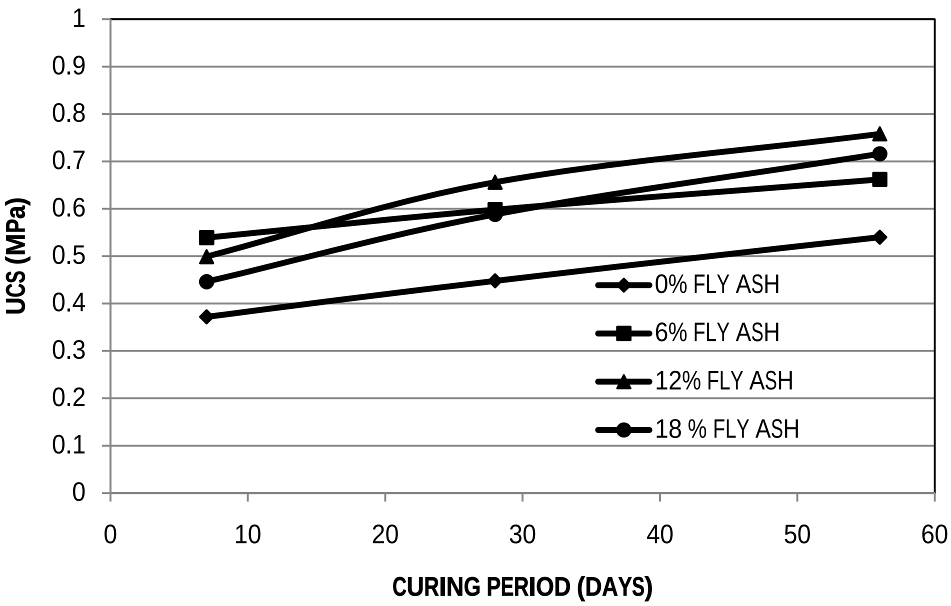

Figure 5b: UCS of Lime – Fly Ash stabilized Berea Sand at different curing peroids

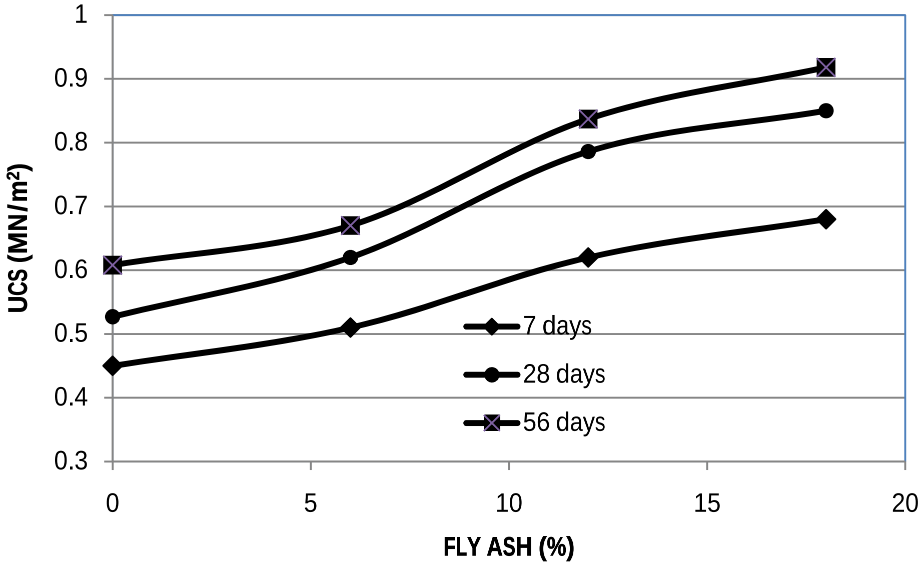

Figure 6a: UCS of Berea Sand stabilized with 8% Lime and 0 – 18% Fly Ash

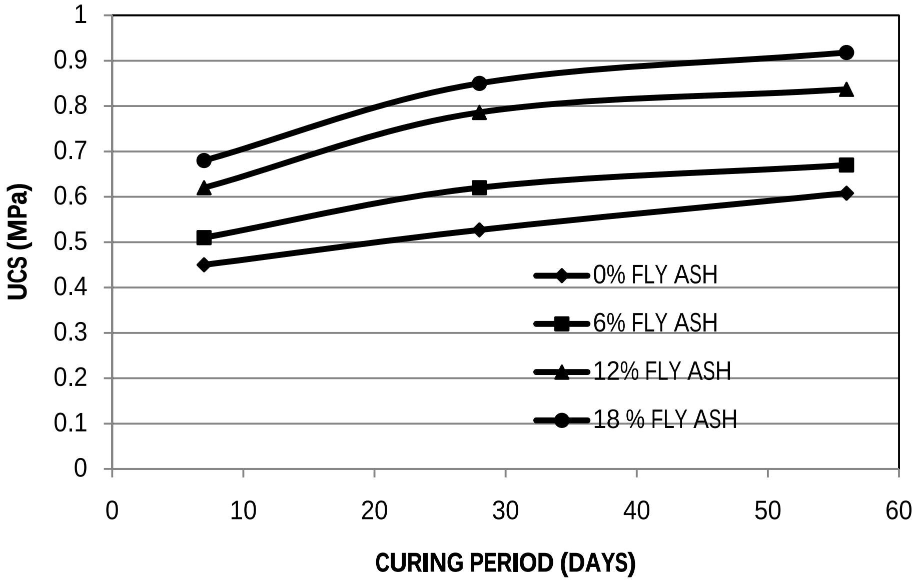

Figure 6b: UCS of Lime – Fly Ash stabilized Berea Sand at different curing periods

California Bearing Ratio of Stabilized Berea Sand

The results of the CBR tests on the 4% and the 8% Lime mixes are shown in Figure 7a and Figure 7b respectively. The CBR of samples that were tested after seven days of soaking increases with the addition of Fly Ash up to 12%, above which the value begins to decrease, while the result of the 8% Lime mixes shown in 7b indicate continuous increase in CBR with the addition of Fly ash. For the respective percentages of Fly ash additives, the CBR of the 8 % Lime mixes is higher than that of the 4% Lime mixes. This is similar in trend to that of the samples tested immediately after compaction although the respective magnitudes are lower. This behavior may be due to the availability of calcium from the lime for the pozzolanic cementations reaction with the silica and iron oxide from the soil and Fly Ash. The availability of water in the compacted mix facilitated the pozzolanic precipitation of carbonates, silicates and aluminates (Brewer 1964). The presence of Fly Ash that was not used up in the reaction would result in lower value of mobilized CBR.

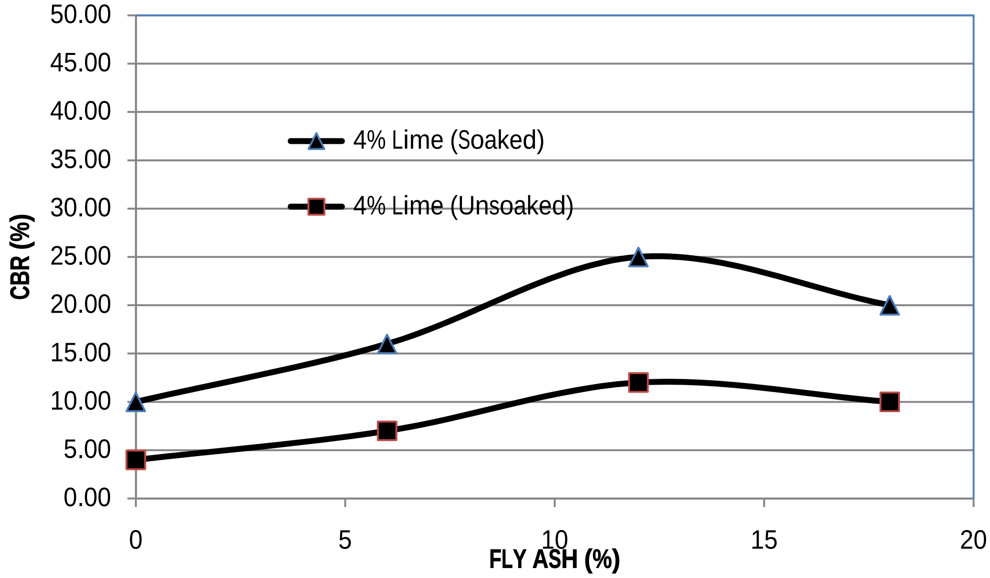

Figure 7a: UCS of Berea Sand stabilized with 4 % Lime and 0 – 18% Fly Ash

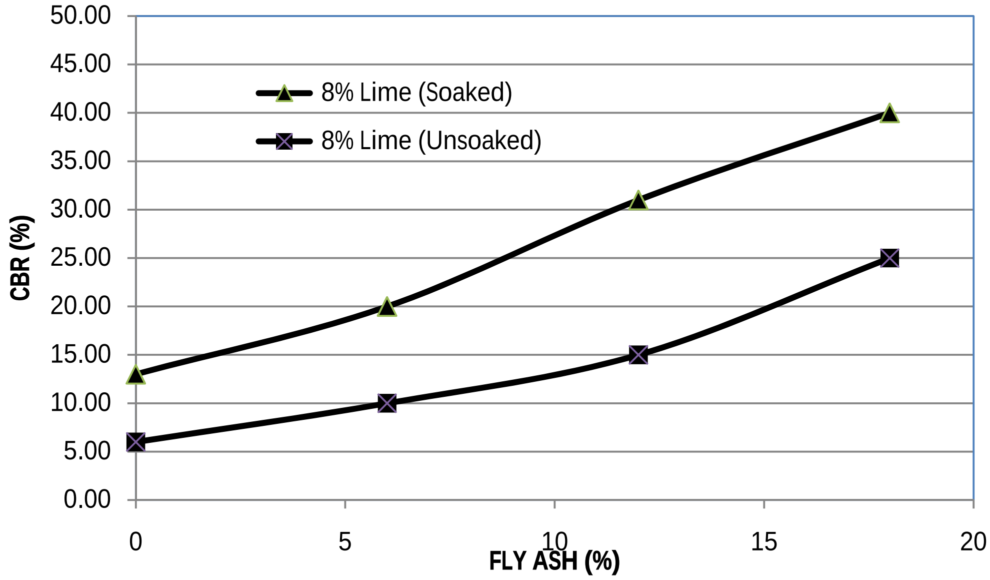

Figure 7b: UCS of Berea Sand stabilized with 8 % Lime and 0 – 18% Fly Ash

CONCLUSION

Deposits of naturally occurring intact granitic and doleritic rocks and aggregates are not widely spread in South Africa, thus the high cost of processing and transportation these durable materials add to the ever growing cost of municipal road development. The following conclusion can be drawn from the result of series of tests aimed at improving the pavement properties of collapsible Berea Sand with Lime and Fly Ash.

The stabilization of Berea Sand with Lime result in decreased MDD and increased OMC, as well as increase in UCS for sands stabilized with up to 8% Lime and 16% Fly Ash.

For the 4% Lime mix, maximum UCS is associated with 12% Fly Ash, the 56 days strength is 50% greater than the 7days strength, and the highest rate of increase in UCS is associated with increase in percent Fly Ash from 6% to 12%.

For the amount of additives used, 4% Lime mixes developed the highest CBR with 12% additive. For the 8% Lime mixes the CBR increases continuously with increase in Fly Ash.

The UCS of lime – Fly Ash stabilized Berea Sand is significantly lower than the UCS of the commercially used road aggregate because of differences in particle size and plasticity. The UCS and CBR of the 4% Lime and 12% Fly ash mixes however satisfy the requirement for compacted subgrade and sub base courses of municipal roads in accordance with TRH4 (1996).

Early UCS development and soaked CBR values are properties best suited for tropical environment conditions which has been poorly simulated by the 56 days curing.

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REFERENCES

1. Al-Khalaf M. N. and Yousif H. A. (1984) "Use of Rice Husk Ash in Concrete", The International Journal of Cement Composites and Lightweight Concrete, 6(4), p. 241-248.
2. Ali F. H. and Adnan A and Chew K.C. (1992) "Geotechnical properties of a stabilized chemically stabilized soil from Malaysia with Rice Hush ash as an additive" Geotechnical and Geological Engineering, Vol 10, p117-134.
3. American Standard for Testing Materials (1978) "Specification for fly ash and Raw or Calcium Natural Pozzolana for use as a mineral admixture in Portland Cement Concrete", ASTM C, pp.618-78.
4. Bagherpour, I. and Choobbasti, A.J. (2003) "Stabilization of fine grained soils by adding microsilica and lime or microsilica and cement", Electronic Journal of Geotechnical Engineering, Vol. 8
5. Bennett H E, Ducasse K, Payne GA and Sewlal S. (2002) " Innovations in Road Design and Construction in the Province of Kwazulu Natal, South Africa". 21st Annual South African Transport Conference South Africa, pp.21-41.
6. Brewer, R. (1964) " Fabric and mineral analysis of soils". Wiley, New York.

7. Brink, A.B.A. (1984) Engineering Geology of Southern Africa. Vol. 4. Building Publications. Silverton.
8. Fourie, A, Bhana Y and Blight G. (1998) "The contributions of matric suction to the stability of ash dump", Proceedings 2nd International Conference on Unsaturated Soils, Beijing, pp.225-230.
9. Fourie, A, Blight G, Bhana Y, Harris R and Barnard N. (1997) "The geotechnical properties of dry dumped and hydraulically placed power station flyash", Proc. 2nd International Conference on Mining and Industrial Waste Management. Midrand, South Africa, pp.10 – 17.
10. Fourie A and Blight G. (1999) " Erosion – resistant crusting of slopes of fly ash dams" Proceedings 6th International Conference on Tailings and Mine Waste '99. Fort Collins, U.S.A., p.189-195.
11. Jennings, J.E., and Knight, K. (1975) A guide to construction on or with materials exhibiting additional settlement due to collapse of grain structure. Proceeding of the 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering., Durban, Vol1, pp.99-105.
12. Maud, R.R. (1968) "Quartenary geomorphology and soil formation in Coastal Natal", Geomorphology. N.F16, pp 239-251.
13. McKnight, C.L. (1999) The stratigraphy and engineering geological characteristics of collapsible residual soil on the Southern Mozambique coastal plain. Proceedings of the 14th African Reg. CSMFE, Durban, Vol 1, pp. 633-646.
14. O' Flaherty C.A (1974) Highway Engineering, Volume 2, Edward Arnold Ltd, Leeds, London.
15. Paige -Green P and Gerryts E, (1998)"Innovative solution for township roads in Sandy areas" , The Civil Engineering and Building Contractor, p74 -76,.
16. TMH (1996) "Standard Methods of Testing Road Construction Material, Technical Methods for Highways" Vol. 1.
17. TRH4: (1996) "Structural Design of Flexible Pavements for Interurban and Rural Roads," Committee of Land Transport Officials, COLTO .
18. Toll, D.G. (1988) "The behaviour of unsaturated compacted naturally – occurring gravel", PhD Thesis, University of London.