EVALUATION OF THE EFFECTS OF ENZYME-BASED LIQUID CHEMICAL STABILIZERS ON SUBGRADE SOILS

M B Mgangira

CSIR, Built Environment, P O Box 395, Pretoria, 0001

ABSTRACT

The purpose of this study was to asses the strength of enzyme treated soil material. Thus the aim of the paper is to present laboratory results on the effects of two enzyme-based liquid chemicals as soil stabilizers. Soil samples were prepared for standard geotechnical tests from two types of soils treated with the two enzyme-based products. One soil had a plasticity index of 35 and the other had a plasticity index of 7. The maximum plasticity index reduction after treatment of both soils was less than 5 % and therefore not significant. A slight improvement in the maximum dry density was obtained following treatment by one product on one of the soil samples. Unconfined compressive strength was evaluated after the samples were left to cure in plastic bags for 7, 14 and 28 days and revealed a mixed effect on strength. Those instances where there was increase in strength it was less than 50 % with increase in concentration level of the two enzyme-based stabilizers and age for both soils after treatment. More independent investigations on the effects of enzymes-based liquid stabilisers on the strength of treated soils are required if the level of their acceptance in road construction is to be enhanced

INTRODUCTION

Recently, enzyme-based liquid stabilisers have been introduced to the road construction industry. However evidence to support the effectiveness of these products as stabilisers is based on manufacturers' claims in their marketing brochures. Thus there is a need for independent assessment of these products. Since the goal of soil stabilization is to improve the properties of the treated materials, stabilisation should provide improvement in the material properties that contribute to better performance of the treated material compared to the untreated material. Thus assessment of the effectiveness of the method of treatment or used product in the soil stabilization can be achieved by determining change in the properties of the treated material. In this study the effectiveness of the enzyme-based products was determined through the measurement of Atterberg limits, and unconfined compressive strength.

While several independent studies have been reported, the acceptance to the use of enzyme-based products is still limited due to several factors. Rauch et al (2002) discuss these factors. In addition studies give mixed results. Some laboratory based studies demonstrate encouraging results, for example Valesquez et al (2006), while others did not find consistent significant change in the properties of the treated soils (Rauch et al, 2002).

Valesquez et al. (2006) tested the shear strength and resilient response of two soils treated with two enzyme products. One soil had a plasticity index of 9.4 while the other had a plasticity index of 52. They found that the resilient modulus for the treated samples was generally higher than the untreated. Due to the difference in the effect of the enzymes on the two soil samples, they concluded that the enzyme effect on resilient modulus of the material depended on many characteristics of the soil. The shear strength of the treated samples were found to be higher than the untreated although to a varying degree depending on the soil and the product. Rauch et al. (2002) tested three reference clays (kaolinite, illite, montimorillonite) and two high-plasticity natural clays with three liquid stabilisers, one of which was an enzyme-based product. They found that the enzyme product was among the stabilisers that showed no consistent increase or decrease in PI of the treated samples and they found no substantial improvement in both unit weight and the shear strength after treatment. In addition, treatment with the enzyme as was the case with the other products did not result in consistent, substantial reduction in soil expansiveness. In a further study reported by Tingle and Santoni (2003) treatment lead to minor improvement in wet unconfined compressive strength of low and high plasticity clay for one of the four enzyme products used in their study. Tingle et al (2007) report on studies on the effect of enzymes on granular soils. No effect in treatment was found.

The effectiveness of enzyme-based products in road construction is still unclear in particular with regard to long-term performance. Few field tests are reported in the public domain where enzymes have been used. Velasquez et al (2006) reports of a case study where better performance from enzyme treated roads was found. Visser (2007) carried out experimental field investigation to evaluate stabilization of road materials with non-traditional stabilizers which included an enzyme-based product. Enzyme treatment lead to an increase in the insitu CBR value as measured by DCP testing. At an insitu moisture content the DCP-CBR was 200 from a soaked CBR value of 43.

More studies are necessary to compliment the existing information on performance of enzyme-based products as stabilizers. Generally stabilization is considered to be an advantage in terms of improved strength and therefore the performance of the treated material. The purpose of this study was therefore to assess the strength of soil samples treated by enzyme-based liquid stabilizers using the unconfined compressive strength test.

MATERIALS TESTED

Stabiliser Products

Two commercially available enzyme-based products in South Africa (Permazyme 11X and Earthzyme/Roadstabilizor) were used for the study. However, in the paper no commercial names will be used. Reference will only be made to EBC1, EBC2 for the products and not necessarily in the order of the listing given.

The physical chemical parameters shown in Table 1 suggest high electrolyte activities with interactions with water through dipole-dipole, ionic and hydrogen bonds which should lead to surface interactions directly with chemical groups on soil particles when mixed. The interaction should play a role in the effectiveness of a given product in treated soils.

Table 1: Compositional physical-chemical properties of the products

Enzyme-based chemical stabilisers	pH	Conductivity (mS)	Turbidity (NTU)	Total dissolved solutes (TDS in mg/L)
EBC1	3.85±0.01	0.400±0.052	1.57±0.03	0.21±0.01
EBC2	4.31±0.02	1.016±0.017	0.58±0.03	0.51±0.03

Table 2 shows the concentrations of the metals in the products. The results show a difference in the order of the common metals, thus K > Ca > Mg > Si > Fe >Al > Mn for EBC1 and K > Mg > Ca > Si > Al > Fe > Mn for product EBC2. This order should affect the sorption of the products on the soil surfaces and therefore their effectiveness should be different.

Table 2: Compositional characterization (Metals)

Product	Cation content (mg/L)								
	K	Ca	Mg	Ba	Al	Mn	Fe	Ni	Si
EBC1	1103 ±10	983 ±12	321 ±4	568 ±30	9 ±1	2.26 ±0.13	35 ±2	1.6 ±0.3	39 ±1
EBC2	1672 ±10	4031 ±1	563 ±16	4609 ±113	20 ±2	1.00 ±0.10	6.72 ±0.15	ND	44 ±2

Four major inorganic anions were found in the enzyme-based products namely fluoride, chloride and nitrate and sulfate. Again the concentration levels are different. Relatively higher levels are found in product EBC1 than in product EBC2. Table 3 shows common anions in the following order of concentration levels: $Cl^- > F^- > SO_4^{2-} > NO_3^-$ for product EBC1 and $Cl^- > SO_4^{2-} > F^- > NO_3^-$ for product EBC2.

Table 3: Compositional characterization (Anions)

Product	**Anion content (mg/L)**			
	Fluoride (F^-)	Chloride (Cl^-)	Nitrate (NO_3^-)	Sulfate (SO_4^{2-})
EBC1	1336±51	1593±43	17±3	855±21
EBC2	579±13	649±15	207±7	601±14

According to Tingle et al. (2007) enzymes are organic molecules that catalyze very specific chemical mechanisms. The results shown in Tables 1 to 3 reveal that, while the products belong to the same family group, they have different compositional characteristics. While the stabilization mechanism of the products may be similar, as proposed in Tingle et al. (2007) the results give an indication that their effect on the same soil should be different**.**

Test Soils

Two soil samples were selected for the test program, black clay and a reddish brown chert, based on their plasticity characteristics. In the paper, the two soils will be referred to as soil A and soil B for the clay and the chert respectively. These soil samples were chosen as they provide examples of materials with differing plasticity index. The plasticity index values are mark the lower and upper boundary ranges recommended by the product suppliers for effective soil treatment. The applicable soil characteristics are given in section 4 below.

METHODS OF TESTING

Specimen Preparation

The soil samples were first crushed to pass the 4.75 mm sieve and dried in an oven at 105ºC for preparation. The dilution of the concentrated enzyme-based products used in the study was measured by mass, i.e mass of enzyme product to mass of water. Tap water was used in this study. After mixing the soil and the diluted chemicals, the mixtures were stored in plastic bags in a humidity controlled room prior to testing for compaction and making of specimens for the unconfined compressive strength.

Atterberg

The two soils were subjected to the Atterberg limit tests followed by the treated samples. Testing for Atterberg followed the standard methods A2 and A3 outlined in TMH1 (1986) for both the treated untreated samples.

Compaction

In order to establish the density-moisture relationship for both untreated and treated samples, the determination of the maximum dry density and optimum moisture content of both treated and untreated samples followed standard Method A7 in TMH1 (1986)**.** Samples were subjected to static compaction using the Baldwin machine.

Unconfined compressive strength (UCS)

In general terms, the determination of the unconfined compressive strength followed Method A14 in TMH1 (1986). However, the test method applies to non-traditional stabilizers. Modifications to the test are necessary when dealing with non-traditional stabilizers as the stabilizers may need more than 7 days to develop strength and the soaking process is deemed more severe than would be encountered in the field (Jones, 2007, Visser, 2007). The prepared samples were placed in large plastic bags and stored in a humid room at 100 % relative humidity at 25ºC. No soaking of samples was done prior to testing. Duplicate samples of size 100 mm in diameter and 115 mm high were used for the strength tests in this study.

RESULTS

Atterberg Limits

A series of tests were conducted on both untreated and treated samples to determine the effects of the enzyme-based chemicals and concentration level on the plasticity of the soils. For the untreated soils, soil A had a plasticity index of 35 and soil B had a plasticity index of 7 with linear shrinkage values of 11 and 5 respectively. Figure 1 shows the overall effect of the two enzyme-based stabilizers on the plasticity index of soil A. It can be seen that with increasing concentration level, product EBC1 slightly reduces the plasticity index of the soil. However, the reduction which is at 1.0cc/5l concentration is only by 2 %. On the other hand treatment with product EBC2 initially reduces the plasticity index to 31 at a concentration of 0.5cc/5l followed by a slight increase in the plasticity index with increasing concentration to a value of 37 at 1.5cc/5l, slightly higher than the untreated sample. The results show no consistence in the effect of the products on the plasticity index of the soil sample tested.

Figure 2 shows the variation of the plasticity index of soil B following treatment by the two products as a function of concentration level. It can be seen that the plasticity index of the sample slightly decreases following treatment by product EBC1. There is an initial slight increase in the plasticity index at 0.5cc/5l concentration following treatment by product EBC2. Product EBC1 shows slightly better results compared to EBC2. However, the plasticity index only reduces from 7 to a low of 5.4 for product EBC1 at a concentration of 1.0cc/5l and it reduces to a low of only 6.0 for product EBC2 also at 1.0cc/5l concentration. These values are considered to be insignificant to indicate improvement after treatment.

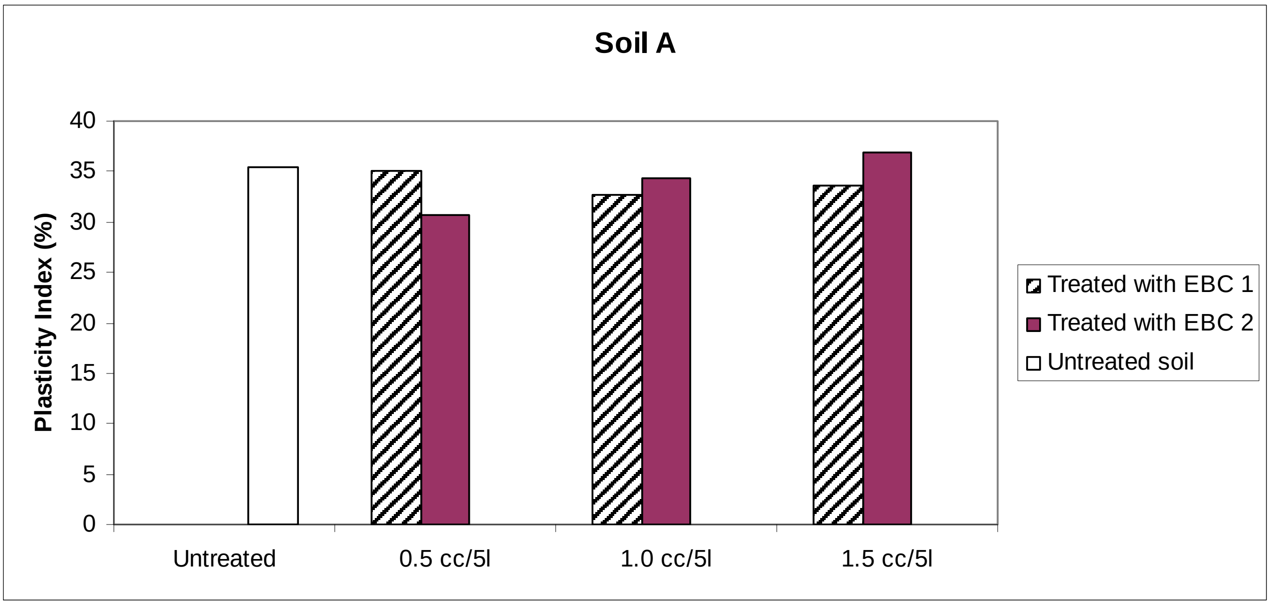

Figure 1: Plasticity index variation soil A with treatment

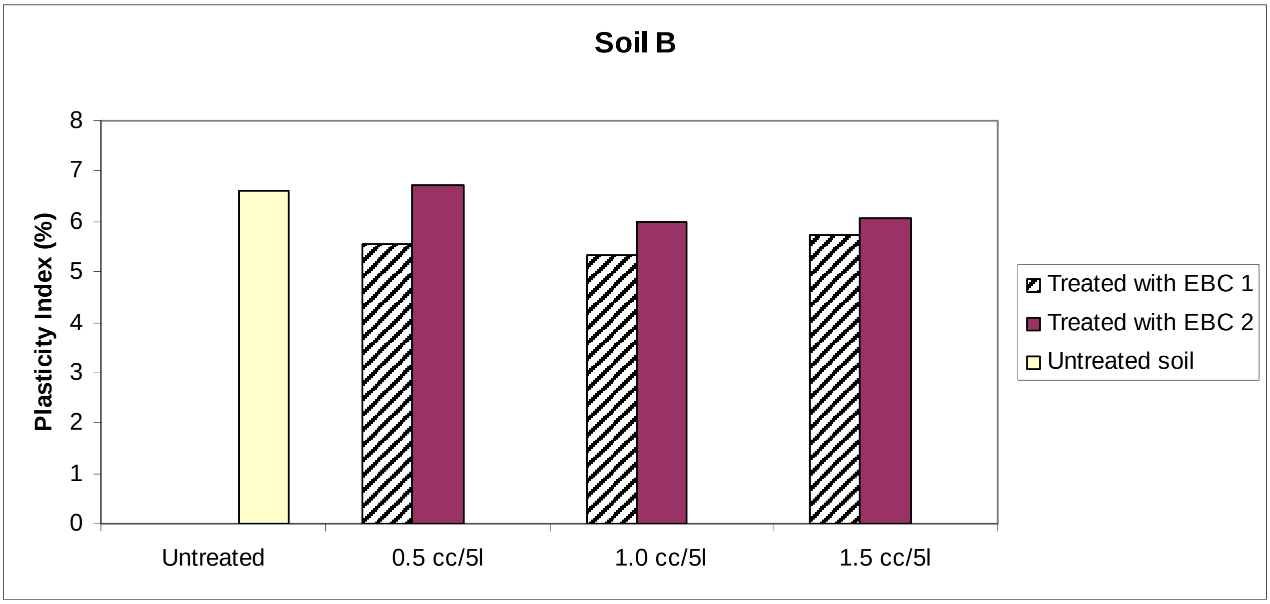

Figure 2: Plasticity index variation of soil B with treatment

Compaction

The effect of treatment with enzyme-based products on the maximum density and optimum moisture content of soil A and soil B is shown in Tables 4 and 5 respectively. It can be observed that for soil A, the maximum density values of the treated samples were lower than that of the untreated but the optimum water content was higher except for product EBC2 at a concentration of 1.5 cc/5l which was almost equal to that of the untreated soil. For soil B, practically the optimum moisture content does not change. Treatment with product EBC1 shows a slight decrease in the maximum dry density but a slight increase for samples treated with product EBC2. However, these values are less than 5 % to signify improvement in maximum density after treatment as proposed by Jones (2007). Thus changes of compaction characteristics of the treated soil are minimal.

Table 4: Maximum dry density and optimum moisture content of untreated and treated samples for soil A

Treatment	Soil A		Product EBC1		Product EBC2	
	MDD	OMC	MDD	OMC	MDD	OMC
0	1655	14.3	-	-	-	-
0.5 cc/5l	-	-	1555	17.6	1609	16.3
1.0 cc/5l	-	-	1569	18.7	1576	17.6
1.5 cc/5l	-	-	1557	18.3	1619	14.2

Table 5: Maximum dry density and optimum moisture content of untreated and treated samples for soil B

Treatment	Soil B		Product EBC1		Product EBC2	
	MDD	OMC	MDD	OMC	MDD	OMC
0	2095	7.8	-	-	-	-
0.5 cc/5l	-	-	2079	8.0	2101	7.5
1.0 cc/5l	-	-	2078	7.9	2096	7.4
1.5 cc/5l	-	-	2074	8.1	2097	7.4

Unconfined compressive strength (UCS)

The unconfined compressive strength test was used as an indicator to assess the strength improvement following the soil treatment with the stabilizers. The effects of the treatment on the unconfined compressive strength are shown in Figures 3 and 4 for soil A and soil B respectively. It can be observed that the treatment leads to some increase in unconfined compressive strength especially for product EBC1 on soil A. The results of the testing on soil A show some consistence in the effects of treatment based on product, age and concentration. It can be observed that product EBC1 generally gives better results than product EBC2 at the same age and concentration level. As a control to assess relative improvement with age, untreated samples cured the same way as the treated samples were tested at the same age. They show an increase in strength over time an indication of drying out. Unfortunately no moisture variation was assessed over the curing period. The results show an optimum concentration of 1.0 cc/5l for product EBC1 for soil A. Although the effect of product EBC2 is that of reduced unconfined compressive strength after treatment, the results indicate an improvement with age at concentration rates of 0.5 and 1.0 cc/5l, a possible indication of long-term increase in strength as suggested by Velasquez et al (2006) and Visser (2007). This requires further studies.

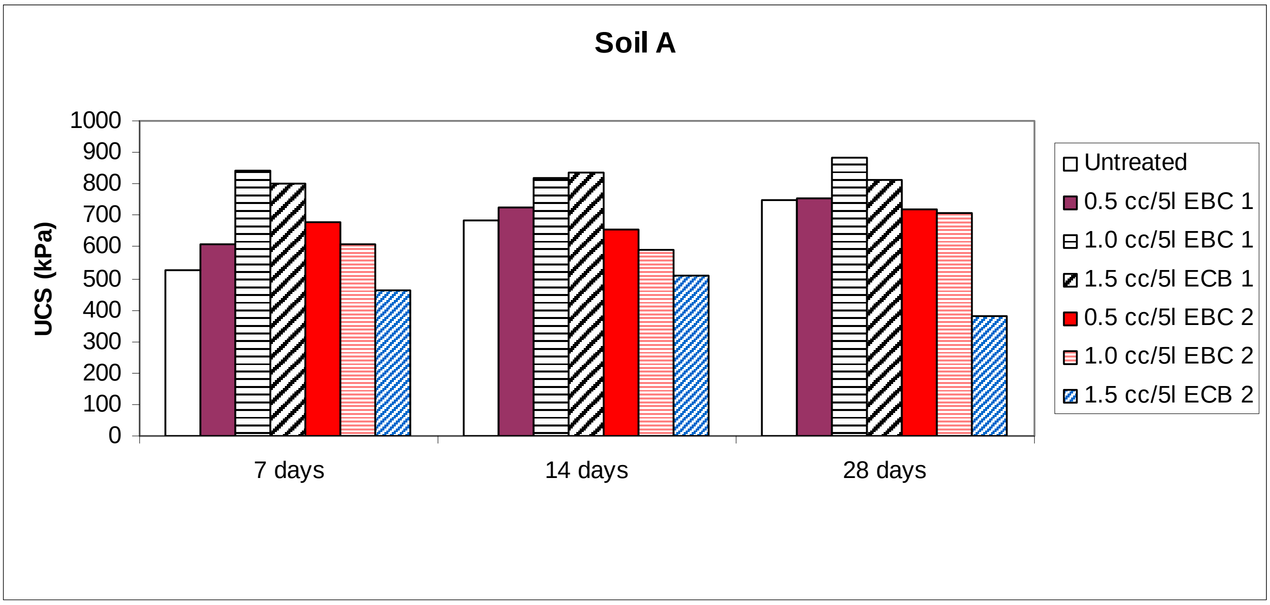

Figure 3: Change in unconfined compressive strength after treatment for soil A

In the case of soil B, the results generally indicate that the two products affect the soil nearly in the same way with respect to strength. Except for samples tested at day 14 of curing period for the 1.5 cc/5l concentration for product EBC1 and 1.0 cc/5l for product EBC2 as well as at day 28 for product EBC2 at 1.5 cc/5l concentration there is no significant increase in the unconfined compressive strength of the soil. In addition the results show no consistency in the effect of the products on the unconfined compressive strength for soil B.

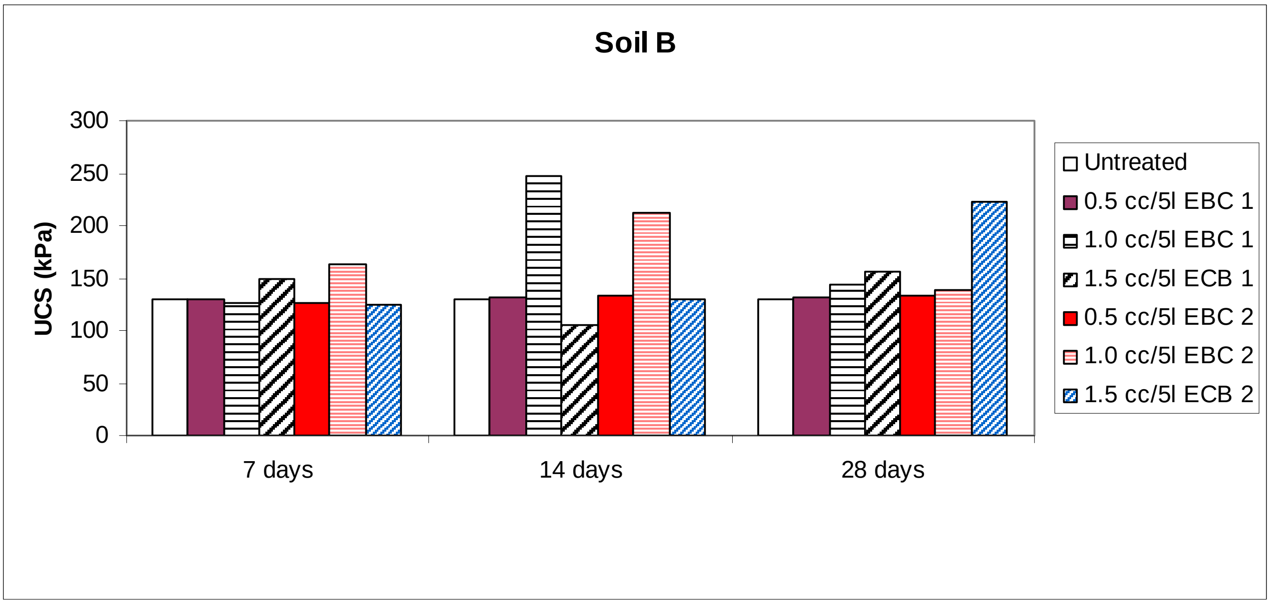

Figure 4: Change in unconfined compressive strength with treatment for soil B

CONCLUSIONS

The aim of the paper was to present laboratory results on the effects of two enzyme-based liquid chemicals as soil stabilizers. The presented laboratory test results included some of the characteristics of the enzyme-based products, Atterberg limits, standard proctor and unconfined compressive strength. Based on these results, the following conclusions are drawn:

- While the chemicals belong to the same family products, they differ in their physical and chemical composition. This will influence their effect at the microstructural level resulting in the observed differences in their effects on the different soil properties.

- Treatment with the enzyme-based products to lead to a slight decrease in the plasticity index of both soils.

- The treatment of the soils with the enzyme-based products generally increased the optimum moisture content of soil A with high plasticity and slightly decreased the maximum dry density. For soil B with low plasticity the there was a slight increase in maximum dry density following treatment with product EBC2 but a slight decrease with product EBC1. For all practical reasons there was no change in the optimum moisture content.

- Enzyme-based chemical treatment of the two soils using the two products showed a mixed effect on the unconfined compressive strength. No consistence significant improvement in the unconfined compressive strength could be attributed to treatment.

- The results confirm the findings of previous studies that enzymes would be expected to be soil specific. This raises the question of how effective can these products be utilized on a large project?

Further independent investigations on the effects of enzymes-based liquid stabilisers on the strength of treated soils are essential if the level of their acceptance in road construction is to be enhanced.

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