PILOT STUDY RESULTS OF THE STRENGTH BEHAVIOUR OF AGGREGATE-LIME-NATURAL POZZOLAN MIXES

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ABSTRACT

Rapid depletion of natural road construction material reserves and strict environmental laws has lead to the use of marginal materials in recent years. In Tanzania the use of natural pozzolans is becoming a technically viable option.

The paper determines the influence of moulding moisture content on the strength behaviour of aggregate-lime-natural pozzolan mixes in fresh and hardened states. The paper will determine the influence of the moulding moisture content on California bearing ratio (CBR) and the tensile and compressive strengths of laboratory-cured specimens.

In this study, two different mixes were prepared, one each from the individual pozzolans and one control sand-cement mix. The two pozzolans were obtained from separate sources in Tanzania, and were activated using hydrated lime. The fresh strength behaviour was evaluated by CBR test; UCS and Double Punch Tensile tests (DPTT) were done to evaluate the hardened state strength. Unconfined compressive strength and DPTT tests were done after 28, 90 and 180 days of curing under ambient conditions in the laboratory. Two moisture contents were used; optimum and 20 percent above optimum for all mix combinations. A trial mix was prepared using Mbeya pozzolan mix, moulded at 20 percent below optimum to determine the strength behaviour.

It was found that the natural pozzolan mixes provide engineering properties comparable with that of cement stabilised materials and are therefore a viable solution. Double punch tensile test method was also found to be a simpler and viable method for the tensile strength determination of lightly cement stabilised materials.

1. INTRODUCTION

1.1 Background

The current trends in the transportation sector show a growth in axle loads as well as vehicle numbers on all types of roads in highly industrialised countries as well as in developing countries. The increase in axle loads and number has forced road agencies to increase their design standards, adopting designs that provide roads with higher load bearing capacity during the design life of the road. This solution would have been feasible if the availability of the funds was certain and satisfactory. However, this is not the case in most developing countries that are running out of funds for road construction and maintenance. Consequently more cost effective but engineering feasible solutions must be found.

Currently, research is conducted worldwide to find road construction materials that will be both economically feasible as well as environmentally friendly. The use of in-situ materials in road construction was observed to be the best solution especially by including various stabilisation techniques and chemicals. This means that many agencies charged with the responsibility of designing and constructing highways must start using by-product pozzolanic materials (Sharpe *et al*, 1985). These low-strength binders (pozzolanic materials) have been used extensively as stabilising agents around the world especially in the USA, South Africa, Tanzania, France, Turkey and England where utilisation of industrial by-products such as granulated blast furnace slag and fly ash has been observed.

The abundant availability of natural pozzolanic materials of volcanic origin in many parts of Tanzania has led to research for its utilisation as a replacement of the granulated blast furnace slag already used in road construction (Eriksen, 2000).

1.2 Problem Statement

Although the use of pozzolanic binders are economically feasible in road construction, it was found that using such materials can result in failures such as premature cracking and breakdown of stabilised layers (Hoffman *et al*, 1976). Most of these failures have been related to factors such as poor construction techniques, slow strength development of pozzolanic materials and moulding moisture content that in turn influence the maximum dry density (Chikwira, 1999).

1.3 Objective of Study

The main objective of this study is to investigate the influence of moulding moisture content on the strength behaviour of aggregate-lime-pozzolan mixes and compare the results with control samples using conventional cement stabilisation.

1.4 Scope of the Study

In this study, the influence of moulding moisture content on the compressive and tensile strengths and CBR of laboratory prepared aggregate-lime-pozzolan mixes made from two natural pozzolan samples from Arusha and Mbeya regions in Tanzania is evaluated. A comparison is made with a series of cement-stabilised specimens moulded at the same moulding moisture contents, cured and tested under the same condition as the ALP mixes.

The study made use of an alternative tensile strength testing method, called Double Punch Tensile Test (DPTT) (Fang & Chen, 1971) after comparing it with the commonly used indirect tensile test (ITS) method.

2. POZZOLANS

The term pozzolan applies to the incoherent pyroclastic-sialitic rocks occurring in the neighbourhood of Pozzouli, and has subsequently been extended to include a wide range of both natural and inorganic materials differing in nature, composition and structure (Costa & Baroni, 1994).

Pozzolans are classified in many methods currently in practice. The differences commonly found in pozzolans includes composition (chemical, mineralogical, physical), geographic distribution, amount of processing required, properties (cementitious, pozzolanic), economic, methods of use and specification requirements (Phileo, 1989). However, pozzolans are generally classified according to Lea (Hewlett, 1998), into two major groups as artificial and natural pozzolans.

2.1 Pozzolan Activity

The term pozzolanic activity covers all reactions occurring among the active constituents of pozzolan, lime and water (Hewlett, 1998). The term pozzolanic activity includes two parameters, namely the maximum amount of lime that a pozzolan can combine with and the rate at which such combination occurs (Hewlett, 1998).

According to Hewlett (1998), a general agreement that the overall amount of combined lime essentially depends on the nature of the active phases, pozzolana contents, silica content, lime/pozzolana ratio in the mix and length of curing. The combination rate was also found to depend on the specific surface area (BET) of pozzolana, water/solid mix ratio and temperature. Each property has an effect in the durability and strength of the resulting mix.

2.2 Uses of Pozzolans

There is evidence that use of pozzolan in construction industry is reported to date back to the 1500-2000 B. C with the Minoan structures of Crete Island which contained potsherds (i.e., calcined clay) in a lime mortar (Lea, 1971).

Pozzolans are in worldwide use as cement replacement material. Pozzolans are also used in the road construction industry as a stabiliser in construction of aggregate-lime-pozzolan mix (ALP) pavements. This mix has successfully been used for road bases and shoulders in various parts of America especially in Pennsylvania (Hoffman *et al*, 1976). ALP mixes, in comparison with crushed stone aggregate, provide stiff bases that considerably reduce rutting. Furthermore, the PSI-value decreased much slower in the ALP pavement, and cracks developed much earlier and propagated much faster in the crushed-stone pavement (Wang & Kilareski, 1979).

2.3 Natural Pozzolans in Tanzania

The literature on pozzolans from various research institutions in Tanzania and other local contributors concentrates on the occurrence of natural pozzolans in two major areas surrounding the volcanic mountains (COWI, 2000), i.e. Mounts Kilimanjaro, Oldonyo Lengai and Meru in the north-eastern part of the country (Arusha and Kilimanjaro regions) as well as Mounts Rungwe and Ngozi in the southern highlands (Mbeya region).

In 1999, the Government of United Republic of Tanzania and Danish International Development Assistance (DANIDA) conducted a joint study for the feasibility of using volcanic ash in road construction. During the study, natural pozzolan samples from three sources were collected and strength tests were conducted on mixes.

The pozzolans were also classified based on mineralogy after Best, used by British Geological Survey in the VOLCON project as (COWI, 2000):

- Mbeya pozzolans are classified as Intermediate (52 – 66% SiO_2)
- Oldonyo Sambu pozzolans are classified as Basic (42 - 52% SiO_2)
- Kilimanjaro pozzolans are classified as Ultra basic (<45% SiO_2).

A microscopic investigation was done to determine the reactivity's of the pozzolan samples.

The following conclusions were made (COWI, 2000):

- Aluminosilicate glass phase in the pozzolan is the main reactive phase with lime,
- The more weathered (no or low alkali content) and fine-grained/porous this aluminosilicate phase, the more reactive with lime, forming mainly calcium aluminates (C_4AH_{13}), possibly gehlenite (C_2ASH_8) and calcium silicates (CSH-gel). Calcium to lime ratios between 1:1 and 3:1 in CSH were observed (ratio near 2:1 was the most frequent)
- Aluminosilicate glass phase (not weathered and containing alkalies, e.g. pumice of various types) seems to have a slower reaction rate but results in similar products as above,
- Calcium, iron, magnesium, titanium and other metals found in crystalline particles (with silica and/or alumina in plagioclase, augite, biotite and olivine). These crystalline particles were observed not to participate in the reactions with lime.

2.4 Engineering Properties of Aggregate-Lime-Pozzolan (ALP) Mixes

Road building materials are considered suitable if they can be used to make roads that can withstand all loads occurring routinely during the scheduled period of utilisation without any environmental repercussions. Generally, the performance of stabilised layers is evaluated by considering factors such as durability (Andres et al, 1976), strength (Cumberledge *et al*, 1976), volume stability and workability (Higgins et al, 1998).

As a stabilised material, the performance of ALP mixes is also evaluated based on the above criteria. Study has shown that the performance of these mixes is influenced mainly by aggregate gradation, lime plus fly ash content, ratio of lime plus fly ash to total fines, curing conditions and time, fly ash content, and moulding moisture content.

These properties tend to influence the performance of ALP mixes in terms of California bearing ratio (CBR), compressive and tensile strengths, shrinkage and frost resistance and permeability.

3. LABORATORY PROGRAM

3.1 Test Materials

During the study the following materials were used:

- Two different pozzolanic materials of volcanic origin from Mbeya and Arusha regions in Tanzania
- Commercially supplied Calcium Hydroxide (Supercalco 97) with 97.73% pure lime as an activator
- Commercially supplied CEM II/B-V 32.5N Portland fly ash cement conforming to SABS EN197
- Fine river sand specified to have 99% material finer than 4.75mm sieve
- Potable water without any dissolved salts or chemicals.

3.2 Experimental Design

Strength tests were conducted on design mixes shown in Table 1. A control cement-stabilised mix was also prepared for comparison purposes. All design mixes were moulded at moisture contents around the laboratory determined optimum moisture contents for each individual material.

Table 1. Design mixes.

Moulding moisture content	Lime:pozzolan:sand ratios by mass		Control mix
	Arusha	Mbeya	Percentage cement
20% Above OMC	1:3:21	1:3:21	4%
OMC	1:3:21	1:3:21	4%
20% Below OMC	N/A	1:3:21	N/A

The following tests were conducted:

- Sieve analysis and grading (Method A1 in TMH 1(1986)), was done on virgin pozzolan samples to determine if they adhere to the specifications as given by COWI (2000), where a minimum fines content (<0.075mm) of 30% and maximum grain size of 1mm (requirement 95% < 1mm) is specified
- OMC and MDD were determined using method A7 in TMH 1 (1986). The mixes were allowed to stand for 30 minutes to allow for even distribution of moisture

- CBR: The unsoaked CBR, without surcharge was determined 24 hours after mixing to allow initial strength to be developed. The decision to determine unsoaked CBR without surcharge was based on findings by Yoder & Witczak (1975) that for granular soils, the CBR is dependent on soil texture, moisture and density, rather than swelling. CBR was determined following Method A8 in TMH1 (1986)
- Compressive strength: The compressive strength was determined for all design mixes after 28, 90 and 180 days of curing following Method A14 in TMH1 (1986)
- Tensile strength: The tensile strength was determined for all mixes after 28, 90 and 180 days of curing. The test was done following the double punch tensile test developed at the University of Lehigh (Fang & Chen 1971)
- Split tensile strength was determined for duplicate specimens for tensile strength comparison following Method A16T in TMH 1 (1986).

3.3 Curing and Test Conditions

All specimens were wrapped in shrink-wraps to reflect actual uncured site conditions; placed in an ambient room maintained at 55% humidity and 30^0 Celsius, assuming the approximate operating conditions in the tropics (Tanzania) until prior to testing.

Plykkanen (1995) found that immersion of test specimens before testing is associated with a decrease in strength. In this study, the best test conditions were opted for where all specimens were dry tested with no prior immersion in water.

4. TEST RESULTS AND DISCUSSION

4.1 Indicator Tests

During the study, sieve analysis, compaction, chemical composition and Atterberg's limits were determined for both pozzolan mixes. A summary of indicator test results is given in Table 2. Table 3 gives the chemical composition of the two-pozzolan samples.

Arusha pozzolans were found to have the required minimum specifications. However, the Mbeya pozzolan sample required crushing in the laboratory prior to mixing.

Table 2. Indicator test results for the design mixes.

Type of Mix	Percentage <0.075mm	Percentage >4.75mm	Grading Modulus	Plasticity Index	MDD, kg/m3	OMC, %
Sand	1	0	2.02	NP	1956	6.5
Arusha mix	7	0	1.82	NP	1980	8.7
Cement mix	6	0	1.85	NP	1990	7.4
Mbeya mix	4	0	1.95	NP	2067	8.0

Table 3. Chemical composition of Arusha and Mbeya pozzolans, selected components.

Element	Elements composition by mass, %									
	Si	Al	Fe	K	Na	Ca	Ti	Mg	Cl	P
Arusha	48.19	22.06	12.61	6.58	4.08	3.58	2.19	0.57	0.08	0.07
Mbeya	61.43	17.25	7.98	8.26	2.30	0.94	1.47	0.23	0.13	0.01

4.2 Comparison of Tensile Strength Test Methods

Six identical specimens made of Arusha pozzolans were mixed and cured for 28 days in an ambient room. The tensile strength of three specimens was determined using the indirect tensile test (ITS) and double punch tensile test methods. The position of the test specimen in the double punch tensile strength test is as shown in Plate 1.

Plate 1. Position of specimen in double punch tensile test.

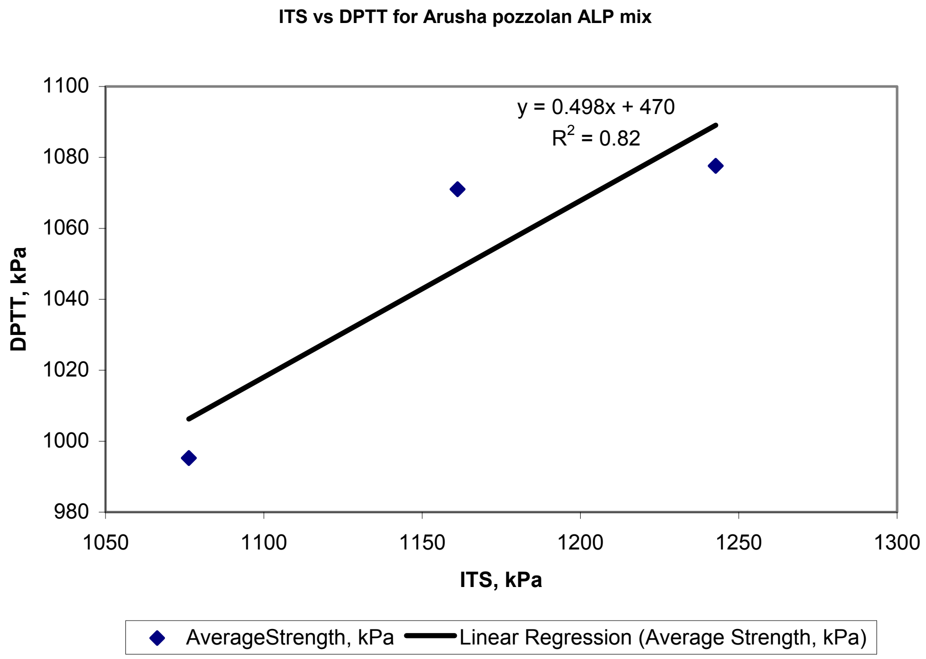

Figure 1. The tensile strengths relationship between ITS and DPTT.

The double punch test specimens were found to fail in three or two-planes. It was observed that the nature of the failure plane did not have any significant influence on the tensile strength as the replicate results were approximately the same and hence it was not considered further.

Note that the data shows a high degree of consistency. Statistical regression analysis of the data returns an average R^2 value of 0.82 indicating a reasonable correlation between the two test methods.

4.3 Strength Results

The compressive, tensile strength and CBR were determined for all design mixes. The tensile and compressive strengths were determined after 28, 90 and 180 days of curing in an ambient room. The CBR for all design mixes was determined 24 hours after mixing just for initial strength development regardless of different cement and pozzolan reaction rates.

4.3.1 Fresh Strength

CBR was used to evaluate the fresh strength for all design mixes moulded at OMC and 20% above OMC. CBR values at 97 and 100% of Mod AASHTO compaction efforts were measured and shown in Table 4. Low CBR values were recorded for all mixes moulded at 20% above OMC. A drop in CBR with an increase in compaction effort from 97 to 100 percent was observed for all design mixes in specimens moulded at 20 percent above optimum indicating a possible breakdown in strength at high compactions because of liquefaction of the mix. Results from a trial mix made of Mbeya pozzolan moulded at 20% below optimum show a slight increase in CBR compared to those moulded at OMC and above optimum. The low CBR values observed in ALP mixes can also be associated with a short curing time allowed.

Table 4. Summary of CBR measurements.

Design mix	CBR Values, % Mod AASHTO					
	20% below OMC		OMC		20% above OMC	
	97%	100%	97%	100%	97%	100%
Arusha pozzolan	N/A	N/A	190	202	90	41*
Mbeya pozzolan	160	210	127	102	55	19*
Cement	N/A	N/A	140	187	100	90*

* At this moisture content, liquefaction took place resulting in a drop in CBR with an increase in compaction effort

From Table 4, the cement mix is found to have higher CBR as compared to other design mixes moulded at OMC and 20% above OMC. This shows that cement mix attain higher early strength as compared to the other mixes. Arusha pozzolan mix is also observed to have higher CBR than Mbeya pozzolan mix.

4.3.2 Hardened Strength

Figures 2 and 3 show the tensile and compressive strengths for design mixes moulded at OMC and 20% above OMC tested after 28, 90 and 180 days of controlled curing. Figures 2 and 3 show that Mbeya and Arusha pozzolan mixes develop higher compressive and tensile strengths compared with cement mixes at all curing durations. Low strengths at 28 days found in Mbeya pozzolan can be associated with the coarse nature of the material causing a delay in hydration compared with Arusha mix.

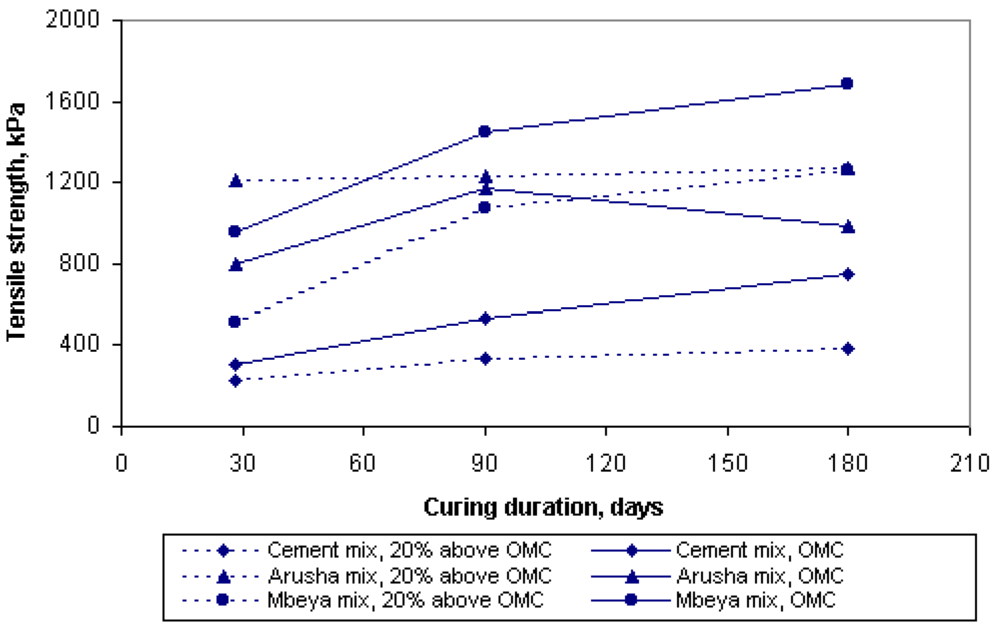

Figure 2. Double punch tensile strength for design mixes after 28,90 and 180 days of curing.

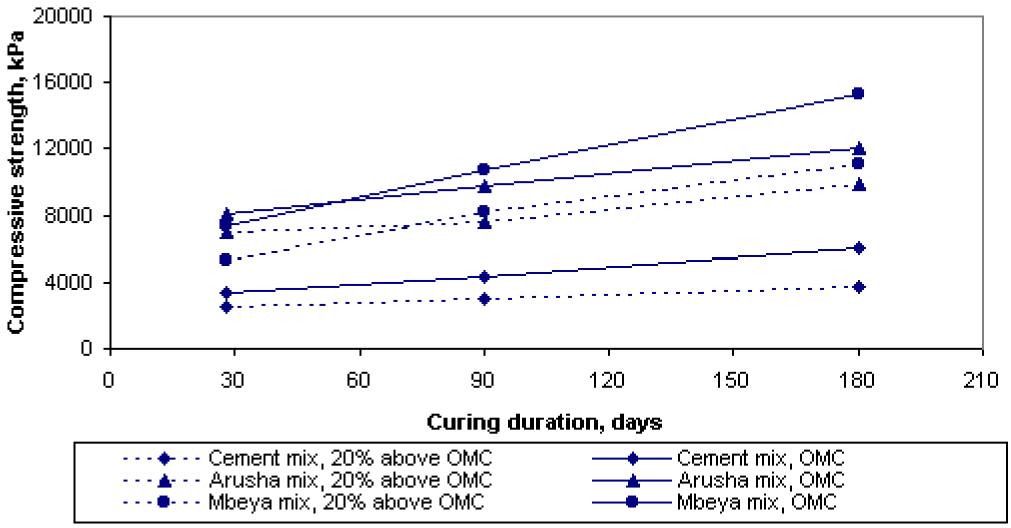

Figure 3. Compressive strength of design mixes after 28, 90 and 180 days of curing.

All design mixes attained most of the required strength after 28 days. A significant gradual strength increase was observed for all mixes between 28 to 180 days of curing except for the Arusha pozzolan mix moulded at 20 percent above optimum where a slight drop in tensile strength was noted between 90 and 180 days. Arusha pozzolan mix moulded at OMC was found to have the highest tensile and compressive strengths after 28 days of curing. However, Mbeya pozzolan mix moulded at 20 percent below optimum attained highest strengths at 90 and 180 days. The cement mixes were found to have the lowest tensile and compressive strengths at all curing times probably due to the low cement content (4%) as compared to the 16% binder used in ALP mixes.

4.3.3 Further Strength Investigations

A series of pilot specimens made from Mbeya pozzolan moulded at moisture contents below OMC were tested after 28, 90 and 180 days. It was observed that tensile and compressive strengths were higher on specimens moulded at OMC, a significant reduction in strength was found in specimens moulded below OMC compared with those moulded above OMC. This suggests that an increase in moulding moisture content for pozzolanic mixes has a positive effect since more high moisture content is necessary for hydration of the higher binder content (16%) as compared with cement mixes (4%). A lack of moisture results in a significant strength decrease. This contradicts the findings of various researchers that for cementitious materials moulding moisture contents drier of optimum result in a significant improvement in their strengths. Further tests are underway for the strength determination of remaining design mixes moulded at moisture contents drier of optimum. The tests are in progress and no strength results are available.

5. CONCLUSIONS

The long-term strength development as observed in Arusha and Mbeya pozzolan mixes was found to be higher than that observed in lightly cement stabilised material. This shows that the pozzolanic materials can be used in stabilisation of bases and sub bases in road construction. The two mixes were also found to behave similarly to the control cement mix in terms of 28 days strength development.

However, the following conclusions are drawn based on the laboratory investigations:

- The double punch tensile strength can be used to determine the tensile strength of lightly stabilised mixes
- Arusha and Mbeya pozzolan mixes were found to behave similarly to cement where most of the required strength (tensile and compressive) was achieved during the first 28 days

- All pozzolan mixes, Arusha and Mbeya showed high strength compared with cement mixes. This implies that the two mixes can be utilised as a cement substitute in stabilisation of bases and sub bases subject to further economical and environmental considerations
- All mixes developed high CBR when moulded at optimum moisture contents. A significant decrease in CBR was noted in all mixes when moulded at 20 percent above optimum implies a possible liquefaction in the mixes
- Mbeya pozzolan mixes develop higher long-term strength compared with Arusha mixes. However, the strength of Mbeya pozzolan mixes at 28 days is lower than that of Arusha pozzolan
- From the pilot investigations done on Mbeya pozzolan mix it was found that lower moulding moistures than OMC has negative influence on their strengths. However, the limiting of moisture content requires further investigations
- The low cement content used in this study (4%) was based on the maximum possible economical cement content required for stabilisation and was used only for comparison purposes. However, the ALP design mixes in this study were based on the recommendations from COWI (2000) and not economical considerations.

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BIOGRAPHY

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