THE COST-EFFECTIVE UPGRADING, PRESERVATION AND REHABILITATION OF ROADS – OPTIMISING THE USE OF AVAILABLE TECHNOLOGIES

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ABSTRACT

The provision and preservation of a good transport infrastructure is a prerequisite to economic growth. To be competitive in a micro as well as macro economy, any cost associated with and influencing production and delivery costs needs to be minimised – transportation cost is a crucial component of this competitive regime. The high cost of the upgrading, maintenance and rehabilitation of the existing road infrastructure puts an ever increasing burden on available funds. This existing scenario of high cost increases makes it essential for design engineers to optimise designs using proven technologies and, together with client authorities, investigate, test and use improved seal, stabilisation and material enhancement technologies (e.g. through the use of available nano-technology) that are available and are continuously being developed all over the world. Unfortunately, new technology developed and successfully tested over the last decade in various parts of the world have, to a large extent, not been effectively utilised by the road building fraternity in South Africa. These developments, involving the use of nano-technology, enables the use of traditionally available stabilising agents at much lower application rates, achieving improved strength characteristics and more water resistant layers in roads at lower unit costs.

The Gauteng Province Department of Roads and Transport (GPDRT) has identified this technology as a potential game-changer that will dramatically improve service delivery, specifically roads, in the province (and in effect the whole region) at an affordable unit cost. Consequently, the GPDRT has committed to test the available products on sections of roads and scientifically prove the cost-effective use of the available technology. This technology will be used on the Route D1884 between Vereeniging and Heidelberg for the recycling of the existing in-situ base-course. Both the CSIR with Accelerated Pavement Testing using the Heavy Vehicle Simulator (HVS) together with academics from the University of Pretoria will be involved in the thorough testing and the evaluation of the rehabilitated road. The ultimate aim is to provide road engineers with improved guidelines for the effective use of available in-situ materials as related to the properties of appropriate cost-effective stabilising agents.

1. INTRODUCTION

Numerus previous studies have shown that the provision, preservation and rehabilitation of a good transport infrastructure are prerequisites to economic growth. Competitiveness in terms of the micro (metro, provincial) as well as the macro (regional, world) economies require that any cost associated with and influencing production and delivery costs be minimised – transportation cost is a crucial component of this competitive regime. However, the high increase in the cost of the provision, maintenance and rehabilitation of road infrastructure over the last few decades (higher than the inflation rate as measured by the Production Price Index (PPI)), puts an ever increasing burden on the available funds. This existing scenario of high cost increases, makes it essential for design engineers to optimise designs using proven technologies and, together with client authorities, investigate, test and use improved seal, stabilisation (e.g. new nano-technology developments) and material enhancement technologies that are available and are continuously being developed all over the world. Optimum use of generally available road building material through cost-effective enhancement should be the aim of road engineers.

The road pavement environment is traditionally very conservative, leaning towards the over-cautious. However, with current severe financial constraints client bodies need to encourage and invest in the investigation of “alternative” new road building products which could result in potentially huge cost-savings to the road authorities. In this regard, the Gauteng Province Department of Roads and Transport (GPDRT) has identified potential cost-saving technologies and has embarked on a programme to scientifically test these technologies on identified sections of their road network. These products will be tested (taking into account design needs and in-situ material properties) on identified roads, involving the CSIR through Accelerated Pavement Testing (APT) with the Heavy Vehicle Simulator (HVS) of the GPDRT and academics from the University of Pretoria (UP) using students to analyse the data for credits in furthering their qualifications.

Such an example is currently being pursued by the GPDRT for the rehabilitation design of the D1884 route between Heidelberg and Vereeniging. The existing base material on a section of this road is exhibiting severe distress, necessitating improvement. Traditionally, the existing base will be stabilised as a new sub-base and a new crushed stone base imported. In close co-operation with the GPDRT it was decided to test the effectiveness of an aqueous polymer additive (nano-technology) which is added to emulsion as a stabilising agent to improve the characteristics of the existing base material. These additives (of nano proportions) enable the use of lower percentages of residual bitumen which is needed to obtain the required strength results, resulting in considerable savings to the road authority. The accelerated testing and evaluation of the pavement structure with emphasis on the evaluation of the recycled base layer, is included as part of the project costing as a fixed item under “specialised testing” after construction. The advantage of this approach is that a full evaluation and detailed design of the road is done as part of the normal proceedings of the GPDRT and that the potential cost-saving new material technology is fully tested and evaluated in the field for immediate wider application if proved effective.

This paper discusses the identification of appropriate stabilising agents (traditional as well as new nano-technology) and their application as related to the properties of the material to be stabilised. As an end result the planned research programme aims to provide road engineers with improved guidelines for the cost-effective stabilisation of in-situ or generally available materials, based on the basic mineral composition of the materials. The mineral composition of road building materials are currently largely ignored by the traditional use and interpretation of empirically derived laboratory tests developed more than half a century ago.

2. SCOPE

Africa compares poorly with the rest of the world in terms of paved road infrastructure as shown in Figure 1 (SATCC, 2003). The current unit cost for the upgrading, maintenance and rehabilitation of road infrastructure together with the limited available funds make it impossible for sub-Saharan Africa to establish the required transportation infrastructure to become competitive in the world market. Hence, it is imperative that road engineers in Africa undergo a mind shift and understand the basic need to provide and preserve roads using less funds. In this endeavour all available technologies pertaining to the road building fraternity have to be investigated, traditional concepts questioned and available new technologies which enables the use of generally available materials identified, investigated and where found to be cost-effective, immediately implemented to enable Africa to become a real role-player on the international market.

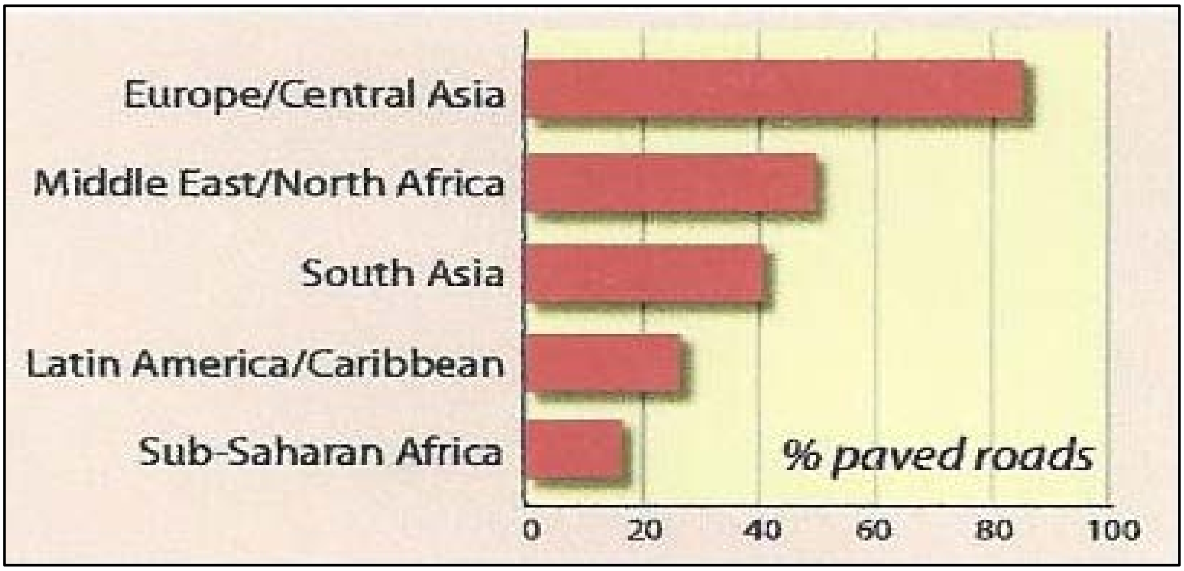

Figure 1
Sub-Saharan Africa compared with the rest of the world in terms of paved road infrastructure (SATCC, 2003)

The costs of road infrastructure are mostly controlled through two aspects, i.e.:

- Applicable geometry standards as related to the terrain and the communities it serves. Too often elaborate standards are applied to upgrade local collectors in rural areas, ignoring to a large extent, the basic needs of these communities in terms of safety (low speeds and separation of vehicles and pedestrians/non-motorised transportation systems), and

- Design of the pavement structure. Often locally available materials do not meet the minimum standards of a base-course of adequate strength properties (normally a G4 (draft TRH4 (1996) quality base or equivalent) for the relatively low design traffic loadings. This often leads to the adoption of a “safe” (but costly) design involving the stabilisation of available materials and the importation of a crushed stone base-layer.

Although of crucial importance, this paper does not deal with appropriate geometric standards which should take into account the needs of the communities it (as a basic principle) must serve. The scope of this paper is limited to the discussion of the cost-effective use of generally available materials and the identification of appropriate stabilising agents using existing as well as relatively newly developed technologies (e.g. nano-technologies) to substantially reduce the unit costs of the provision, maintenance and rehabilitation of the road transportation network. The basis for a research programme which will aim to provide design engineers with improved guidelines for the selection of appropriate stabilising agents are outlined. The emphasis on the re-use and enhancement of generally available materials simultaneously supports the concept of technology as a “first step” towards “green” designs (Jordaan, et al, 2015).

3. GENERALLY AVAILABLE ROAD BUILDING MATERIALS

3.1 General

The generally available road building (natural) materials strongly depend on the geology (basic rock formations) and the climate (Weinert, 1980). Southern Africa is renounced for the wide occurrence of basic crystalline rocks and argillaceous rocks of the late palacozoic (Karoo) age and younger (Weinert, 1980). These basic rocks together with warm temperatures and seasonal rain associated with Weinert n-values of less than n=5 as shown in Figure 2, must be assumed to contain minerals of the Smectite group (“until the contrary can be proven” (Weinert, 1980)) and more specifically, Montmorillonite as a result of decomposition. This wide occurrence of this Smectite minerals is shared by southern Africa with only a few other places in the world (Weinert, 1980).

The basic geology and associated minerals can play a crucial role in the selection of a suitable and cost-effective stabilising agent to enable in-situ materials to be used in the upper road pavement layers. Unfortunately, the basic mineral composition of materials is seldom taken into account when stabilisation is considered to improve the load-bearing characteristics of road building materials. This can lead to the “unexplained” or “unexpected” deterioration of pavement layers that are often blamed on inadequate/poor construction practices. This current situation is mainly due to the classification only of materials using empirically derived tests that were developed more than half a century ago. These tests will not identify the presence of “problem materials” that are present throughout southern Africa.

For example, materials in southern Africa within the Weinert n<5 area may often test as Slightly Plastic (SP). This may give no indication of the presence of Smectite. As a rule, with an Optimum Moisture Content (OMC) of more than 8 per cent and a fraction of the sample passing the 0.075 mm sieve of greater than 10 per cent, the Plasticity Index (PI) should be tested on the fraction passing the 0.075 per cent sieve only (SABITA, 1999). A marked difference between the total PI and the PI of the fraction passing the 0.075 mm sieve will usually be an indication of the presence of Smectite minerals – few road building practitioners currently are aware or apply these basic principles in practice.

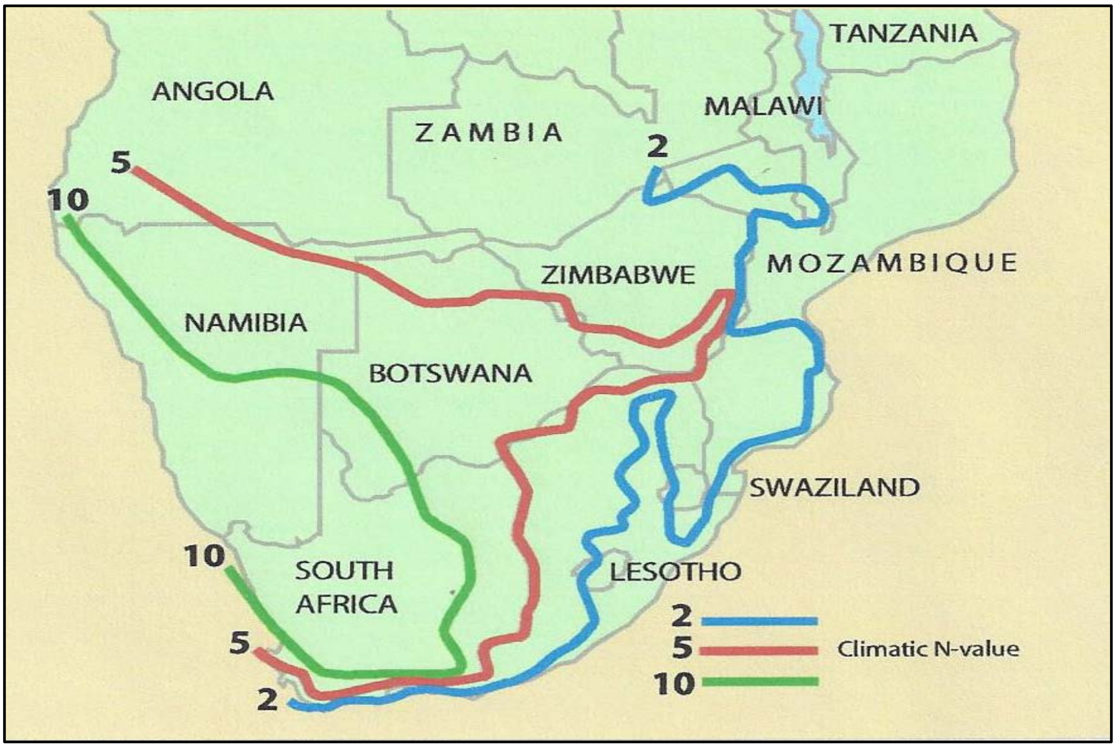

Figure 2
Weinert N-values for southern Africa (Weinert,1980)

X-Ray Diffraction (XRD) testing of material samples will enable road engineers to more accurately determine the mineral composition of materials that are available for road construction. This test equipment is now becoming more readily available at some commercial laboratories in South Africa. Hence, the ability to take the mineral composition of materials into account by road engineers cannot longer be considered as a problem. XRD scans of materials should become standard practice as part of the knowledge base of pavement/material engineers as a formal part of the road design process.

3.2 Problem materials

Problem road building materials are usually defined as materials that react poorly when stabilised with “traditionally” available stabilising agents. As previously discussed, part of the problem is that the empirically derived normally standard material tests will not identify potential problems associated with specific materials.

These materials, inter alia, include material containing:

- Mica minerals;
- Smectite minerals;
- Cohesion-less sands;

- Organic material, e.g.;
  - o Sands containing high percentages of crushed shell (prominent along some coastal regions along the West-coast of Africa (cold water)), and
  - o Sands containing high percentages of pulverised coral reef (powdered white sands), prominent along some coastal regions of the East-coast of Africa (warm water).

All of the above (and more) could present problems resulting in severe premature distress on roads at considerable costs if not taken into account. The non-identification of the basic composition of generally available materials and associated costly premature failures of "problem materials" are partly to blame for the conservative approach generally followed when considering design options, even when designing roads with relatively low design traffic loadings. However, the technology to identify the mineral composition of materials is generally available. This technology should be used effectively during the road design phase to more accurately identify appropriate and cost-effective stabilising agents to improve the characteristics of these materials for use in the upper road pavement layers.

If more than one stabilising agent is found to be applicable, laboratory tests to determine the required percentage of each stabilising agent, the associated costs and risks should be the determining factors in a life-cycle cost analysis (using the concepts of probability of failure (Jordaan, 2011(a))) to recommend the most appropriate stabilising agent to be used. It is the opinion that this approach will lower the risk to both the designer and the road authority and will, lead to the cost-effective use of generally available materials also in the upper layers of the pavement structure, especially for the design of lower category roads.

4. STABILISING AGENTS

4.1 General

Usually, only cement, lime and bitumen (with tar being outlawed) are used for the stabilisation and enhancement of materials for road construction in South Africa. These are also the stabilisation agents discussed and considered in the draft TRH4 (COLTO, 1996), which is the most widely used document in South Africa for the design of pavement structures. Lime is mostly recommended for use as a modifier in cases where the material to be used has been tested to contain some clay (high Plasticity Index (PI)). It follows, that the draft TRH4 (COLTO, 1996), only considers cement and bitumen in its "pure" form in the "Catalogue of Designs" together with the use of crushed stone or high quality natural gravel (G4) for use in the upper layers of a pavement structure for the various road categories identified.

The use of bitumen in a bitumen-stabilised base (BTB) is usually comparatively costly and is normally only warranted for use in higher order roads requiring a design catering for high design traffic loadings. Unfortunately, many bitumen derived products, such as emulsions, are currently not included in the draft TRH4 (COLTO, 1996), and consequently totally disregarded by many practitioners when considering design options. Although many good design documents have been published in

South Africa (e.g. by SABITA), addressing the use of these products, these options remain on the peripheral and are ignored by many practitioners.

The successful development of the "upside-down" pavement design approach in South Africa has led to the wide introduction of high quality crushed stone bases, able to carry relatively high traffic loadings. This approach required the sub-base to be stabilised, providing a basis against which the crushed stone base can be compacted to achieve the high densities specified. The sub-base is designed to crack and should not contain cement quantities that will result in reflection cracking propagating through the crushed stone layer and the surfacing. This could lead to water ingress into the pavement structure and premature distress appearing early in the life of a pavement structure. The use of cement in the sub-base also considerably reduces the "surfacing of problems" and covering of adverse reactions when dealing with some of the "problem" materials.

4.2 Cement

4.2.1 General

Cement at low percentages (usually < 3 per cent) is one of the most cost-effective and widely used stabilising agents traditionally used in road construction. However, strict quality control as adequately addressed in COLTO (COLTO, 1998) is important to achieve the required result.

These requirements, inter alia, include:

- Restrictions on mixing time for the completion of a construction section (cement stabilisation causes a chemical reaction and bonding develops quickly – prolonged working of a cement-stabilised layer will break the development of the chemical chains resulting in sub-standard effective strengths and low densities), and
- Properly controlled curing periods and methods (COLTO, 1998) must be adhered to in order to prevent the interaction of the top of the layer with the atmosphere and the subsequent chemical reaction resulting in carbonation and the forming of a loose layer on top of the cemented layer (Netterberg and Paige-Green, 1984).

The use of cement as a stabilising agent in the base is often also associated with cracking (shrinkage as well as fatigue cracking). Although these layers are able to still carry considerable traffic loading in a cracked state, the presence of open cracks on the pavement surface, if not sealed, will lead to the ingress of water from the top and considerable premature distress requiring early rehabilitation.

Not widely known and hence, seldom considered by design engineers, are the behaviour of cement as a stabilising agent in the presence of some of the minerals previously identified as "problem" materials.

4.2.2 Mica minerals

Acid crystalline rock decomposes and weathers under certain climatic conditions resulting in the rearrangement of atoms (in particular, silica chains) which could result in the formation of Mica (silica layers). Mica minerals are widely present in some southern African regions. The presence of Mica minerals in materials and the effect on using cement as a stabilising agent on such materials have been known for decades (Tubey and Bulman, 1964; Weinert, 1980).

More detailed studies done at the University of Pretoria as part of a Masters dissertation (Mshali and Visser, 2013) have, in more detail, quantified the detrimental impact of the presence of Mica in weathered granite on the Unconfined Compressive Strength (UCS) when stabilised with cement, An extract of some of the results from this study are shown in Figure 3 (Mshali and Visser, 2013).

4.2.3 Smectite minerals

Smectite minerals (clays) are widely present in southern Africa as discussed earlier in this paper. These minerals are very water sensitive and the presence of these materials could lead to the early failure of cement-treated layers if not adequately identified and addressed. When material containing even small quantities of Smectite is treated with cement alone, the expansion and contraction of the layer will lead to the breaking up of the layer. This distress is often misidentified as “carbonation” and subsequent tests usually show carbonation to be absent and the reason for the distress not explained. A typical XRD test scan showing the presence of Smectite among other minerals, is shown in Figure 4.

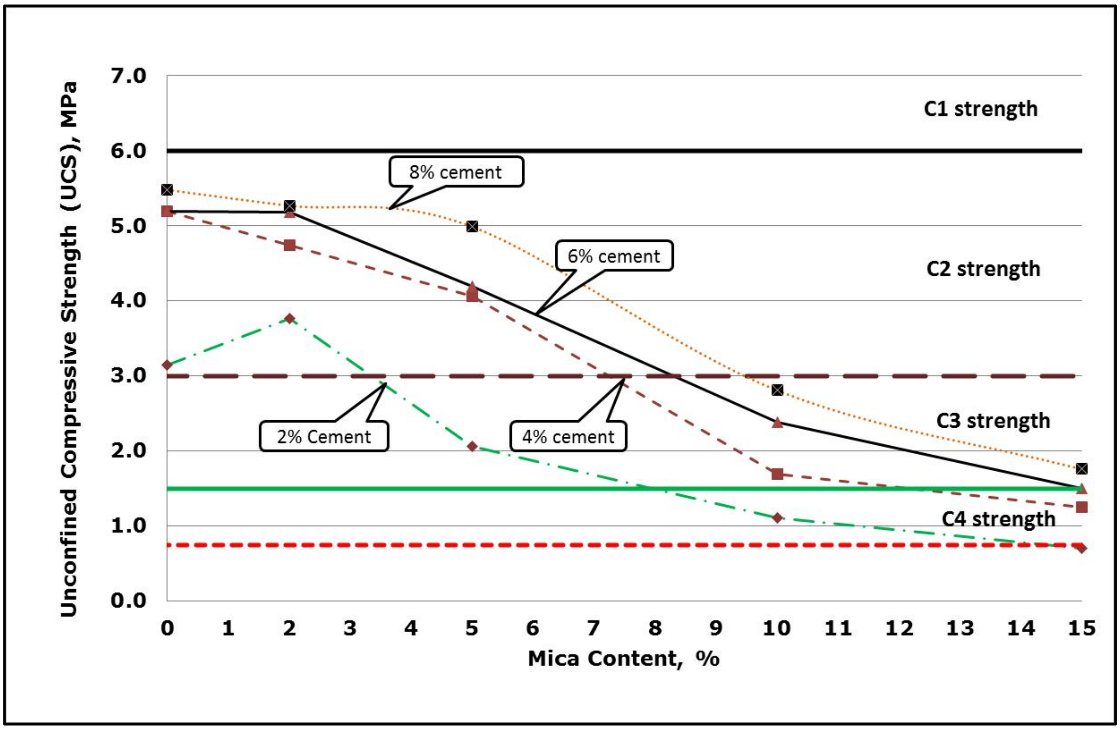

Figure 3
Influence of Mica in weathered granite on the UCS using cement as a stabilising agent (Mshali and Visser, 2012)

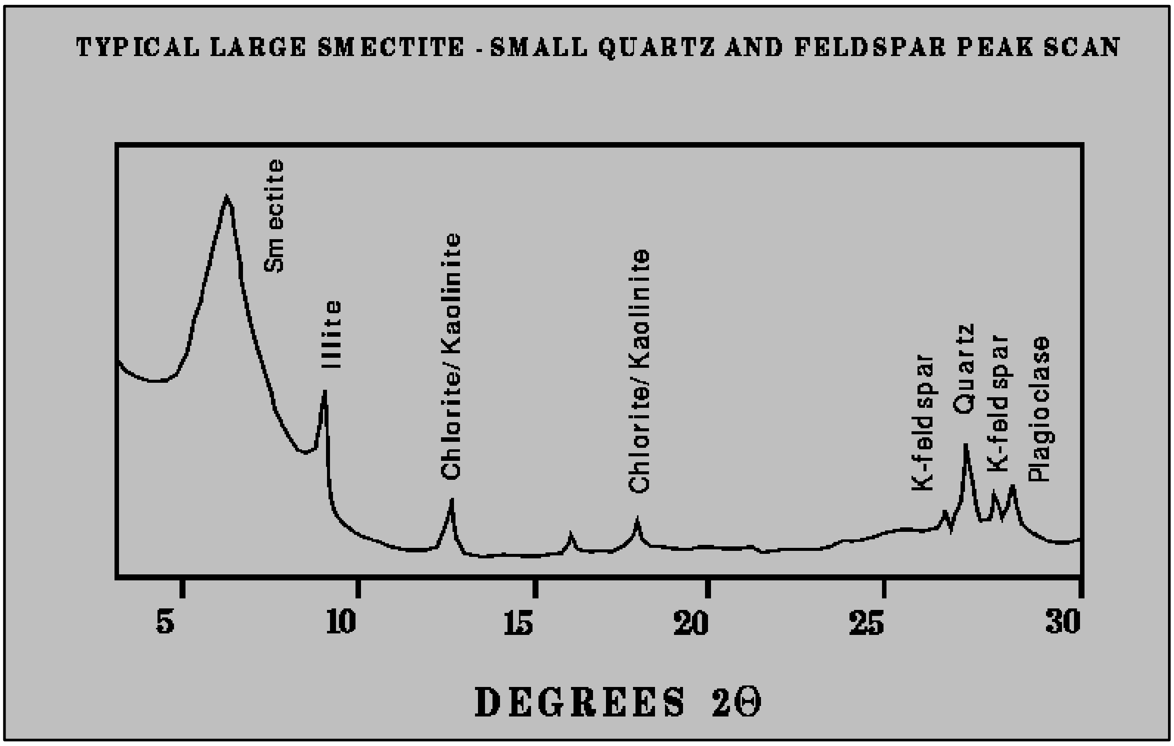

Figure 4
Typical large Smectite, small quarts plus feldspar peak XRD scan

4.2.4 Cohesion-less sand

The absence of the climatic factors previously discussed, often leads to the breaking down of the basic rock to form a single graded sand with little variation in size (most material passing the 2 mm sieve and very little material passing the 0.075 mm size sieve). The stabilisation of material using economical (low) percentages of cement (with an associated lower risk of severe shrinkage cracking) usually requires material particles of different sizes (also fines) to form a natural interlocking matrix to assist with the stabilisation process. Sand consisting of mostly single sized particles will usually require 5 per cent and more cement to meet minimum UCS specifications for use in pavement layers. This quantity of cement will inherently lead to a high risk of severe shrinkage cracking.

4.2.5 Sand containing high percentages of organic material

a Sand containing crushed sea shells.

The organic material comprised of the shell structure is relatively hard but, will continue to crush under the action of loading. If not bound properly, this will lead to the early deterioration of a pavement layer where this material is present in large quantities. Similar to cohesion-less sand, relatively high percentages of cement will be required to achieve specified strengths.

b Sand containing pulverised (powdered) coral reef.

This material is usually very soft (comparable to lime-stone) and will continue to break down with little load being applied to the material. Similar to the cohesion-less sand, high percentages of cement may be required to meet the required strength specifications. A combination of different stabilising agents may very well prove cost-effective in the use of this material in pavement layers.

4.3 Bitumen

4.3.1 General

The stabilisation of materials using bitumen products gives more flexibility and water-proofing capabilities to the stabilised layer. Stabilisation with bituminous products nowadays includes many variations (such as foam and emulsion stabilisation), none of which is included in the current draft TRH4 (COLTO, 1996). Of these, emulsion stabilisation has proved very cost-effective when using relatively small quantities of residual bitumen together with some cement (± 1 per cent) (to mainly assist with the "breaking" of the emulsion (SABITA, 1999)) and a small percentage of lime in the presence of material with a PI in access of 6. This stabilisation recipe has been utilised for the in-situ reworking of many roads during rehabilitation throughout South Africa. HVS testing (Jordaan, 2011(b)) has also shown that this stabilisation recipe can also be utilised cost-effectively on roads with relatively high traffic loading, providing a flexible pavement structure in harmony with the rest of the pavement layers. The successful use of this emulsion stabilisation recipe lies in the fact that the bitumen emulsion covers the clay particles such as Smectite and Mica and prevents the interaction with the cement and water that may lead to the breaking up of the pavement layer as previously discussed. At the same time the required specified strength criteria can be obtained following the material test procedures described in the appropriate design documentation (SABITA, 1999).

Emulsion as described, is also very suitable for the stabilisation of cohesion-less sands, providing the smaller particle fractions to bind the material together. However, the stabilisation of sands containing high percentages of pulverised coral reef material may prove problematic, resulting in an increased need of cement to obtain a stable state and to meet the specified design criteria.

4.4 The use of new technology (nano-technology) with or without traditional stabilising agents

4.4.1 General

The last decade has seen the development of new technologies that can prove to be a "game changer" in the pursuit of the cost-effective provision, maintenance and rehabilitation of road infrastructure. This technology may hold the key to sub-Saharan Africa becoming competitive in the word market by providing access to millions of people (and markets) at an affordable cost.

New generation organo-silanes (down to 5 nm in size) have been developed and successfully tested (CSIR-CRRI, 2010, 2015; NCAT 2009, 2011) that chemically interacts with natural material molecules to change the surface atom composition of aggregates to drastically reduce the susceptibility of these materials to water. In addition, a variation of nano-based polymers (70 – 80 nm in size) have been developed and are available that can also be used as modifications to bitumen emulsions. These polymers with or without organo-silanes can be used as a modification of existing emulsions, greatly improving the distribution, coverage and hence, stabilisation characteristics bitumen molecules (± 5000 nm in size), allowing for the use of previously unheard of small quantities of residual bitumen to obtain the required design strength criteria. However, it should be noted that not all polymers exhibit the same characteristics and not all polymers will be effective as a co-stabilising agent for road building materials. Normal testing of the modified mix should be used to identify the most appropriate modification in line with the required criteria and the minerology of the material which is being stabilised.

The following advantages are apparent from the use of nano-polymer modified emulsions with or without organo-silanes:

- Reduced risk of cracking;
- Improved performance in terms of higher flexibility;
- Required bearing capacity is obtained in a relatively short time using low percentages of the stabilisation agent;
- Enables the cost-effective use of locally available materials at a low risk;
- Improved resistance to water damage, and
- Ease of construction.

The nano-polymer modified emulsions are available in South Africa and have been tested on several roads, using various materials under different climatic conditions, including Gauteng and the Limpopo province within the region with a Weinert n value of < 5 (high weathering probability). The addition of the two nano-products as discussed, results in several advantages obtained when compared to the use of traditional stable mix emulsion as a stabilisation agent. These advantages include:

- Improved distribution of the stabilising agent throughout the pavement layer during the stabilising process, resulting in lower quantities (percentages) of the stabilising agent being needed to achieve the required strengths;
- Smaller particles and the facilitation of water resistant characteristics assist with the “breaking” of the emulsion and the rejection of the water from the bitumen-aggregate bonding process, not requiring the addition of cement to assist with the “breaking” of the emulsion (i.e. the shedding of the water in the emulsion mix separating the bitumen from the water and allowing it to bind to the material particles and to fully act in its role to increase the material properties in line with the design requirements);
- Smaller emulsion particles distribute much easier through the material, considerably reducing the construction complexity and effort needed to achieve the required mix;
- Smaller emulsion particles pass much easier through the spraying nozzles of the construction equipment (i.e. water bowser or recycler) resulting in the considerable reduction of the risk of clogged nozzles and the uneven distribution of the stabilising agent;

- Reduced risk of clogged nozzles in the distributing equipment which ultimately also results in a lower risk of a pavement layer receiving an uneven distribution of the stabilising agent, and
- Improved cost-effectiveness of the stabilisation process taking into account all the reduced risk factors.

These new nano-technology based products have been used successfully in many parts of the world (including India, the USA and West-Africa) making the common use of marginal materials in the upper layers of pavements a reality on many roads. The potential impact on the cost of road infrastructure is considerable and the GPDRT has embarked on a scientifically-based programme to also prove the viability of this technology on their roads and to quantify the potentially recognised benefits. The already available track record of this technology and results from reputed research institutions (CSIR-CRRI, 2010, 2015; NCAT, 2009, 2011) make this a low risk investigation with potentially huge returns.

4.4.2 GPDRT experimental sections

The D1884 between Heidelberg and Vereeniging has been identified for rehabilitation. The design of the section requiring strengthening is done based on laboratory tests utilising a mixture containing emulsion and nano-polymers. A typical sample of the basic material results from the D1884 to be stabilised are given in Table 1. The material was tested using 0.3 to 0.7 per cent of the polymer modified emulsion (GE-20) to the material. The UCS and ITS test results using the material with 0.7 per cent of the polymer modified emulsion mixture are given in Table 2. It is seen that even at the very low percentages, using the accelerated curing procedure of 48 hours in an oven at 40° C (SABITA, 1999) the strength criteria for an equivalent C4 layer as a base-course is exceeded.

Table 1: Basic material results of the material to be stabilised as taken from the D1884 (typical sample).

Test Report :	**HEIDELBERG WEST - MATERIAL TEST RESULTS**	
SAMPLE INFORMATION & PROPERTIES		
CONTAINER USED FOR SAMPLING		Black Sampling Bags
MOISTURE CONDITION OF SAMPLE ON ARRIVAL		Slightly Moist
HOLE No. / Km. / CHAINAGE		CH 4-950 LHS
ROAD No. OR NAME		D1884
LAYER TESTED / SAMPLED FROM		TP4-50+170(1st layer)
GRADING ANALYSES - % PASSING SIEVES (TMH1 1986 : METHOD A1 (a)		
SIEVE ANALYSES (mm)	75.0	100
	63.0	100
	53.0	100
	37.5	87
	26.5	78
	19.0	74
	13.2	68
	4.75	59
	2.00	54
(TMH A1a)	0.425	32
	0.075	17

ATTERBERG LIMITS ANALYSIS (TMH1 1986 : METHOD A2 & A3 ; TMH1 1986;TMHA4 1974)		
ATTERBERG LIMITS **(TMH A2&A3)**	LL%	24.1
	P.I.	**2.5**
	LS%	1.2
GM		2.00
CLASSIFICATION	H.R.B.*	A-1-b(0)
	COLTO*	G7
	T.R.H. 14*	G7
MOD AASHTO **(TMH A7)**	OMC%	8.8
	MDD(KG/M^3)	2126
	COMP MC %	8.0
	% SWELL	0.36
CBR **(TMH A13T)**	100%	33
	98%	29
	97%	27
	95%	23
	93%	17
	90%	8

Table 2: Results from the stabilisation of the material from the D1884 using low percentages of the polymer-modified emulsion as a stabilising agent

UCS /ITS TG2 L1 - TMH 1 Method A14/ A16T		
SECTION 1 - IN LABORATORY DESIGN		
ROAD NAME	D1884 (4+950 LHS)	D1884 (4+950 RHS)
LAYER	1st layer	1st layer
DATE RECEIVED	24/03/2015	24/03/2015
CLIENT MARKINGS	N/A	N/A
Maximum dry density (MDD)	2126	2084
Optimum moisture content (OMC)	8.8	8.6
Date tested	02/04/2015	02/04/2015
ITS - STRENGTH OF BRIQUETTES (DRY)		
Binding Agent Content	0.7% GE-20	0.7% GE-20
Cement Content		
Compaction effort (%)	100%	100%
Dry Density (kg/m³)	2135	2101
Maximum load applied (kN)	4.32	3.78
Indirect Tensile Strength (ITS) (kPa)	383	391
UCS - STRENGTH OF BRIQUETTES (DRY)		
Binding Agent Content	0.7% GE-20	0.7% GE-20
Cement Content		
Compaction effort (%)	100%	100%
Dry Density (kg/m³)	2126	2092
Maximum load applied (kN)	41.38	39.64
UCS TMH1 A14 (kPa)	2269	2173
ITS-STRENGTH OF BRIQUETTES (SOAKED)		
Binding Agent Content	0.7% GE-20	0.7% GE-20
Cement Content		
Compaction effort (%)	100%	100%
Dry Density (kg/m³)	2139	2094
Maximum load applied (kN)	-	-
Indirect Tensile Strength (ITS) (kPa)	142	124
UCS-STRENGTH OF BRIQUETTES (SOAKED)		
Binding Agent Content	0.7% GE-20	0.7% GE-20
Cement Content		

Compaction effort (%)	100%	100%
Dry Density (kg/m³)	2115	2080
Maximum load applied (kN)	6.98	7.14
UCS TMH1 A14 (kPa)	2139	2094
BSM Classification	BSM3	BSM3
Test Type	48 hour curing	48 hour curing

4.4.2 Test programme at the University of Pretoria

Using the previous studies done at the university as a basis (Mshali and Visser, 2013), a test programme will be embarked upon, testing an array of marginal materials (G5 to G7) generally available in southern Africa to evaluate the impact of various available stabilising agents, including the newly developed nano-technology based products.

The aim of this comprehensive study is to eventually provide road engineers with an improved guideline for the use of generally available road-building materials in the upper pavement layers, based on:

- Basic minerals present in the material to be stabilised (XRD scan);
- Identification of chemical reactions to take place (if any) using an array of different stabilising agents;
- Expected engineering properties to be achieved (e.g UCS, ITS, Shear, etc.) using different stabilising agents (including latest nano-technology available);
- Testing of durability properties to be achieved as a function of the material and stabilising agent interaction, and
- Life-cycle cost-comparison of the various stabilising options taking into account associated risks during the construction process and the probability of achieving the required results during construction and over the design period.

5. CONCLUSIONS

The high cost of the upgrading, maintenance and rehabilitation of the existing road infrastructure puts an ever-increasing burden on available funds. This existing scenario of high cost increases makes it essential for design engineers to optimise designs using proven technologies and, together with client authorities, investigate, test and use improved seal, stabilisation and material enhancement technologies (e.g. through the use of available nano-technology) that are available and are continuously being developed all over the world.

These new nano-technology based products have been used successfully tested and used in many parts of the world (including India, the USA and West-Africa), making the common use of marginal materials in the upper layers of pavements a reality on many roads. The potential impact of the use of new technologies on the cost of road infrastructure is considerable and GPDRT has embarked on a scientifically based programme to also prove the viability of this technology on their roads and to quantify the potentially recognised benefits.

Full-scale HVS testing of a road rehabilitation using small quantities of modified emulsions are to be done during 2016/17, involving the CSIR and the University of Pretoria. The research programme is aimed at providing improved guidelines to road engineers for the identification of suitable stabilising agents to enable the more cost-effective utilisation of “marginal” materials in the upper pavement layers at an acceptable risk.

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