PRACTICAL APPLICATION OF NANO-TECHNOLOGY IN ROADS IN SOUTHERN AFRICA

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Abstract:

The high cost of the upgrading, maintenance and rehabilitation of the existing road infrastructure puts an ever increasing burden on available funds throughout the world especially, in developing countries which are struggling to compete in the global market. This scenario of high cost in the provision and improvement of transportation infrastructure makes it essential for design engineers to optimise designs using proven technologies and investigate, test and implement cost-effective new technologies (e.g. proven nano-technology modified stabilising agents) that have successfully being used all over the world. The Gauteng Province Department of Roads and Transport (GPDRT) in South Africa identified nano-technology applications as a potential game-changer that will dramatically improve cost-effective infrastructure service delivery (with reference specifically to roads). This paper give some details with regard to some of the first designs approved for implementation by the GPDRT and the Road Agency Limpopo (RAL) in South Africa and the Swaziland Ministry of Public Works and Transport in the sub-continent incorporating nano-modified emulsions for the construction of new roads and rehabilitation of existing roads. This technology is being implemented together with improved testing and characterisation of the naturally available road building materials on the basis of the inherent mineralogy of the materials. Research initiatives launched at the University of Pretoria in South Africa, use minerology characterisation as a basis to develop improved guidelines for pavement engineers to more cost-effectively match naturally available materials with appropriate stabilising agents for use in all pavement layers.

Keywords: Nano-modified Emulsion, material stabilisation, cost-effective road construction, naturally available materials

1. INTRODUCTION

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 and to any cost associated with and influencing production and delivery costs needs to be minimised – transportation cost is a crucial component of this competitive regime. In addition, basic services in terms of access to markets, schools and health facilities are either non-existent or in serious disrepair for large sectors of the population throughout the continent (SATCC, 2003). 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 proven available nano-technologies) that are available and that have been implemented successfully in many countries throughout the world.

The Gauteng Province Department of Roads and Transport (GPDRT) identified nano-technology applications as a potential game-changer that will dramatically improve cost-effective service delivery, specifically roads, in the province (and in effect the whole region) (Jordaan and Kilian, 2016). Consequently, the GPDRT has committed to the identification, laboratory testing and demonstration of cost-saving technologies on sections of roads in the Gauteng province of South Africa, both for the rehabilitation of existing roads and the construction of new high-order roads. Through intensive investment in research the GPDRT has also committed to demonstrate the cost-saving implications of these technologies applicable to all categories of roads varying from low-capacity township roads to high-order dual-carriage roads carrying high traffic loading.

The initiative of the GPDRT was followed by the Road agency Limpopo (RAL) in South Africa which approved the use of this technology for the rehabilitation of a 6 km section of township-road in the Thohoyandou urban area in Limpopo Province over the 2015/16 financial year. In addition to provinces in South Africa, the Swaziland Ministry of Public Works and Transport (SMPWT) has recognised the cost-saving potential of using nano-modified technologies to improve naturally available material to achieve the specified strength criteria, has approved the use thereof for the upgrading of an extensive road network, linking several villages, to the North of the City of Manzini.

This paper summarises the practical use of the available and proven nano-technologies in southern Africa (through a number of selected case studies) which enables the cost-effective use of naturally available materials for the provision and preservation of the road networks in the sub-continent. The use of these technologies is implemented using advanced material characterisation through X-Ray diffraction analysis (Ermrich and Opper, 2011)) which enables design engineers to take into account the minerology of the materials in identifying the most appropriate and applicable stabilising agent of material properties through the incorporation of mineralogy tests (Jordaan and Kilian, 2016) to enhance the use of naturally available materials – a need identified, initiated and launched by researchers (Jordaan, 2016) from the University of Pretoria, Department of Civil Engineering in South Africa. This initiative lead to the involvement of post-graduate students to match and test available stabilising agents, taking into account from the onset, the mineralogy and the potential weathering characteristics of the naturally available materials in order to address possible “problematic” materials to improve long term durability.

2. PAVEMENT DESIGN APPROACHES AND MATERIAL TESTING PROCEDURES

Design manuals and design catalogues generally used throughout the sub-continent (e.g. draft TRH14, 1985; draft TRH4, 1996: draft TRH12, 1997, etc.), are based on technology developed in the 1980s. These manuals, to a large extent, minimise risk through the use of freshly crushed stone from commercial sources in the upper pavement layers. These materials often come at a considerable cost to road authorities and are often imported over long distances at an additional haulage cost. In many of these cases naturally available materials are considered “unsuitable” due to potential (often unquantified) risks in terms of the possibility of containing "problem materials" (Jordaan and Kilian, 2016) and questions with regard to long-term durability and weathering characteristics.

It is acknowledged that southern Africa is almost unique in the world in terms of the weathering characteristics of the naturally available road building materials (Weinert, 1980). Southern Africa is renowned 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 1, 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.

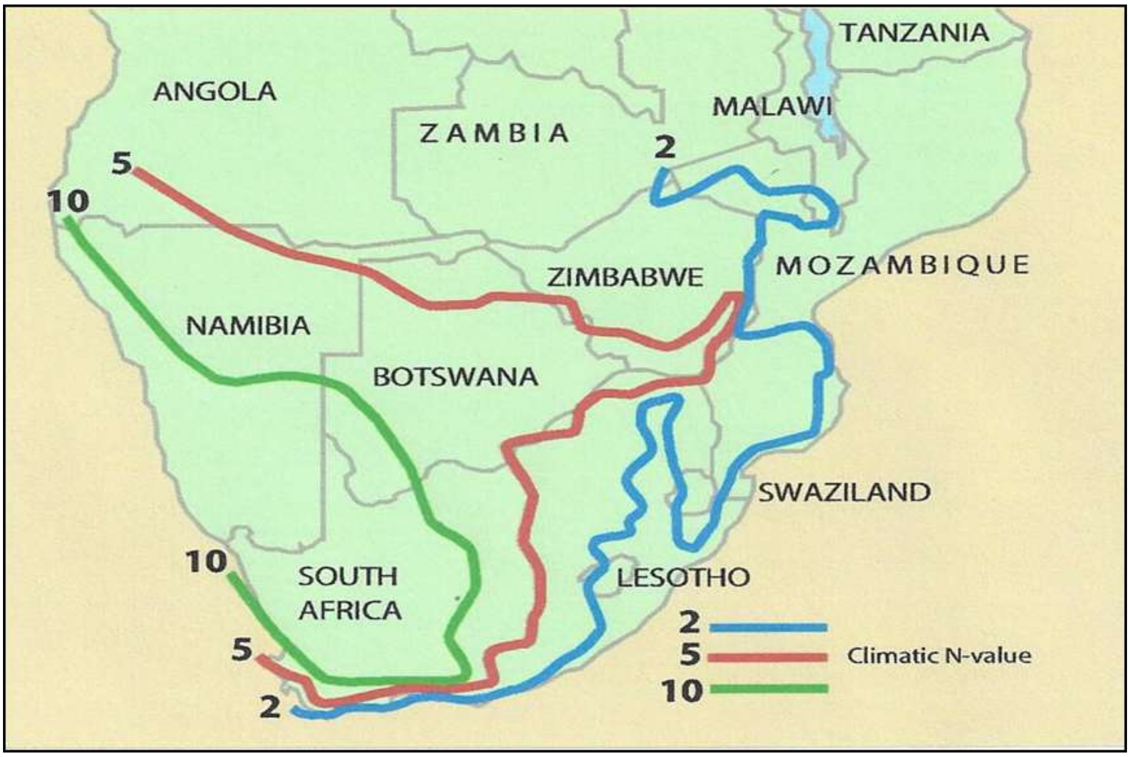


Figure 1
Weinert N-values for southern Africa (Weinert, 1980)

Unfortunately, the basic mineral composition of materials is seldom (if ever) taken into account when material suitability or the stabilisation of naturally available material 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 of materials only 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 mm sieve also (Jordaan, 2016), in addition to the tatal PI. 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 (clay) minerals – few road building practitioners currently are aware of or apply these basic principles in practice.

This glaring omission of basic mineral properties by road engineers to identify suitable naturally available materials (at much lower costs) is mainly responsible for the relatively conservative approach adopted by most pavement engineers by basing designs on low risk (expensive) high quality materials. It was recognised (Jordaan, 2016) that the ability to accurately determine the minerology of naturally available materials will not only enable pavement engineers to use naturally available materials with more confidence, but also enable these minerals to be more closely matched with stabilising agents that will not adversely interact with these minerals. X-Ray Diffraction (XRD) scans of material samples will enable road engineers to determine the mineral composition of materials with the suitable level of confidence to enable naturally available materials to be utilised in road construction at an acceptable risk. This test equipment has been available for a couple of decades and is now more readily available for routine testing at an acceptable cost in commercial laboratories in southern Africa. Hence, the ability to take the mineral composition of materials into account by road engineers can no 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. THE USE OF NEW TECHNOLOGIES (NANO-TECHNOLOGIES) WITH OR WITHOUT TRADITIONAL STABILISING AGENTS

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 transportation/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 "nano-silanes" (down to < 5 nm in size) have been developed and successfully tested (CSIR-CRRI, 2010, 2015; NCAT, 2009, 2011) that interact with the free energy surrounding natural material molecules. This interaction changes the surface atom arrangements of aggregates to drastically reduce the susceptibility of these materials to water to effectively become water-repellent. In addition, variations of applicable nano-based polymers (70 – 80 nm in size) have been developed and are available as modifications/enhancements to bitumen emulsions (some available since the 1980s). These polymers with or without nano-silanes used as applicable modifications to existing emulsions greatly improve the distribution, coverage and hence, stabilisation characteristics of 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 all silanes and polymers do **NOT** exhibit the same characteristics and **NOT** all nano-based technologies will be effective as a stabilising/co-stabilising agent for road building materials. Normal laboratory testing (e.g. UCS and ITS(?) tests) (Asphaly Academy, 2009) of the modified stabilisation mix should be used to identify the most appropriate modification in line with the required criteria and the minerology of the material to be stabilised.

The following advantages are apparent from the use of nano-technology modified emulsions with or without applicable organo-silanes and/or applicable polymers (Jordaan and Kilian, 2016):

- 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/silanes modified emulsions are available in South Africa and have been tested on several roads, using various materials under different climatic conditions, including Gauteng, Limpopo province and Swaziland within the area with a Weinert n value of < 5 (high weathering probability). The addition of the scientifically based 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 (Jordaan and Kilian, 2016):

- 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, West-Africa and East-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 local roads, under local conditions using locally available naturally available materials 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. PRACTICAL IMPLEMENTATION OF NANO-TECHNOLOGIES IN ROAD DESIGN IN SOUTHERN AFRICA

4.1. General

Figure 2 shows the location of some roads where nano-technology have recently been approved for use since 2015 by official road authorities (one road already completed (May 2016)) and another in the process of being constructed.

4.2. Gauteng Department of Roads and Transport (GPDRT)

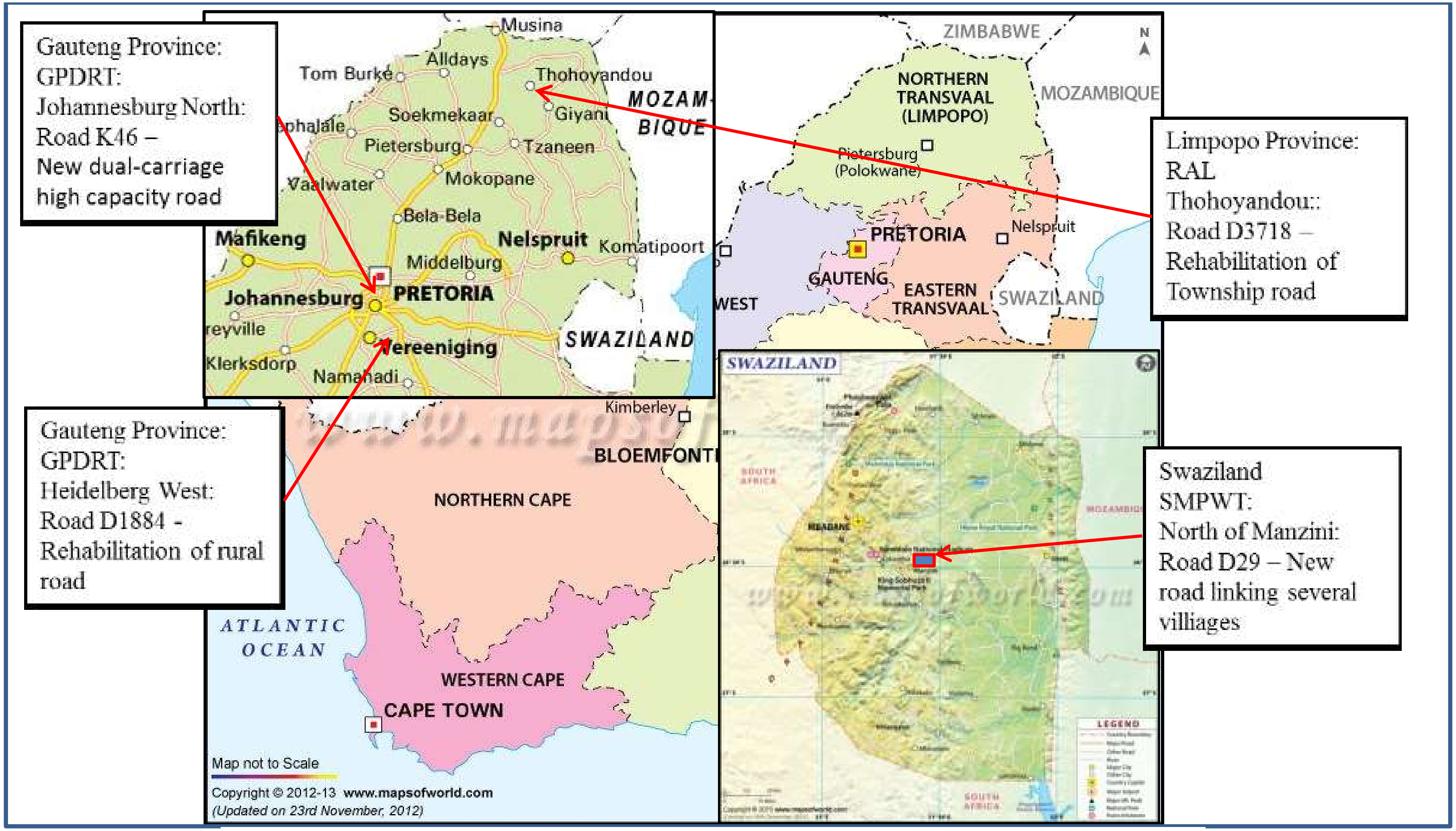
The GPDRT identify the need to initiate the study of the applicability and nano-technologies available and already proven in other countries in the world. Suitable roads were identified within the province to immediately demonstrate the applicability of the technologies with special emphasis on the cost-savings to be achieved. Rural Route D1884 between Vereeniging and Heidelberg in the South-East of the Gauteng province was the first road identified (2014/15) for the rehabilitation design of the road incorporating nano-technology modified emulsions. The second road (2016/17) where the technology has been used is to design an alternative cost-effective pavement structure is the K46, a major new dual-carriage road to the North of Johannesburg.

4.2.1. Rehabilitation of Rural Route D1884

This road was identified for rehabilitation in 2014. As shown in Photograph 1 (a) and (b) some sections of the road was found to be severely cracked, resulting in water-ingress and damage to the existing base-course. The detailed design showed these sections to have materials of inadequate shear strength to a depth of 150 mm. The normal practice for the rehabilitation of similar roads is to stabilise the in-situ base to a C4 (draft TRH14, 1985) quality cement-treated sub-base, to import a new 150 mm crushed stone base and to seal the road with a double seal.

(a) **(b)**

Photograph 1
Condition of sections of the D1884 showing open cracks which allowed water damage to the base-course and severe shear deformation of the layer.



Gauteng Province:
GPDRT:
Johannesburg North:
Road K46 –
New dual-carriage
high capacity road

Gauteng Province:
GPDRT:
Heidelberg West:
Road D1884 -
Rehabilitation of rural
road

Limpopo Province:
RAL
Thohoyandou::
Road D3718 –
Rehabilitation of
Township road

Swaziland
SMPWT:
North of Manzini:
Road D29 – New
road linking several
villiages

[redacted]

The damaged base layer material was tested to have deteriorated over the years to be of G7 quality (draft TRH14, 1985) at the time of the rehabilitation investigation. The rehabilitation design period for the D1884 is 20 years with a maximum estimated design traffic loading of 3.1 Million Equivalent 80 kN Standard Axles (MESA).

Using a nano-modified emulsion with 20 per cent polymer as a stabilising agent for the G7 material, Unconfined Compressive Strengths (UCS) tests and Indirect Tensile Strength (ITS) tests were done on both dry and wet laboratory prepared briquettes. The rapid curing test procedure prescribed for emulsion-treated materials were used to cure the prepared briquettes. The results of these tests are summarised in Table 1.

Table 1: Summary of UCS and ITS tests done on the in-situ G7 material sampled from the base layer of the D1884

Material Classification:	G7 (draft TRH14, 1987)							
Stabilising Agent:	GE- Nano 20P (silane modified SS60 anionic Emulsion with Polymer additive)							
% Stabilising agent added	0.7 % per mass (< 0.42% Residual bitumen)							
Test performed	**UCS* (Dry)**		**UCS*(Wet**)**		**ITS***(dry)**		**ITS***(Wet)**	
Unit of measurement	kPa		kPa		kPa		kPa	
Briquette diameter (mm)	150		150		150		150	
Compaction density (Mod. AASTHO)	100%		100%		100%		100%	
Test Protocol- Rapid Curing	48h @ 40°C		48h @ 40°C		48h @ 40°C		48h @ 40°C	
Test number	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Test results	**2269**	**2173**	**2139**	**2094**	**383**	**391**	**142**	**124**
Equavalent C****	C3	C3	C3	C3				
Equavalent BSM*****	BSM1	BSM1	BSM1	BSM1	BSM1	BSM1	BSM1	BSM1

* Unconfined Compressive Strength

** TMH1 Method A14 (COLTO, 1986)

***Indirect Tensile Strength - TG2 - NO PLASTIC BAGS - (Asphalt Academy, 2009)

**** Cement Stabilisation, draft TRH14 (COLTO, 1986)

***** Bitumen Stabilised Material - TG2 (Asphalt Academy, 2009)

Although the minimum criteria for a Bitumen Stabilised Material (BSM) - BSM2 (Asphalt Academy, 2009) is applicable to the road, the UCS and ITS results using only 0.7 per cent of the nano-modified emulsion (residual bitumen of about 0.4 per cent) exceed the criteria deemed appropriate for a BSM1 layer (> 6 MESA). The cost of the stabilising agent in this case would be in the order of South African Rand (R)160 /m^3, while crushed stone at the crusher source (without haulage) would cost in the order of R370/m^3. The alternative considered for the rehabilitation of this road involved the cement stabilisation of the in-situ base layer with an imported 150 mm G1 new base layer at considerable more costs. The savings in material cost savings alone for the materials exceed 50 per cent in this example. In addition, the construction process is limited to one layer, while the process of emulsion stabilisation is much less complicated resulting in considerable savings in time costs.

4.2.2. Design and construction of the dual carriageway K46 (William Nicol road to the North of Johannesburg

At the request of the GPDRT an alternative design was done for the pavement structure for the construction of the new dual-carriageway, the K46 (William Nicol Road) to the North of Johannesburg. The design traffic loading for this road is a maximum high scenario) of 9.6 MESA. The original and alternative design (incorporating nano-modified Emulsions with naturally available G5 (draft TRH14, 1985) quality materials are compared in Table 2.

XRD scans of the available G5 material are summarised in Table 3. Of importance is the result showing that the material weathers to contain approximately 17 per cent Mica (Muscovite) and approximately 43 per cent Kaolinite/Smectite. Laboratory testing using this material and the percentage of cement originally specified in the original design were unable to achieve the specified minimum ITS limits, mainly because of the presence of these minerals, especially Muscovite. Test results using a selection of Nano products and Emulsions with the G5 materials are summarised in Table 4.

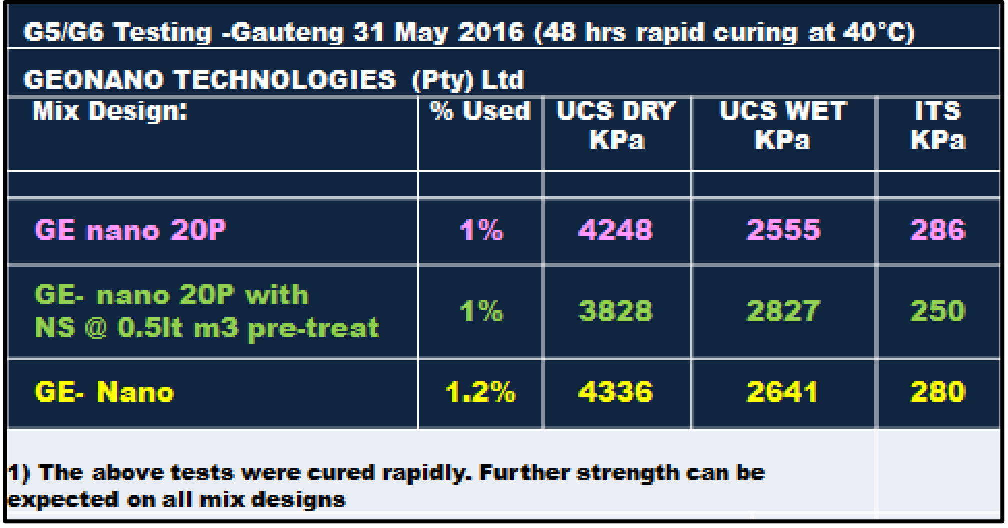
Table 2: Cost-comparison between original design and alternative design incorporating Nano-technology

Original Design				**Alternative design (nano-technology)**		
Layer	**Layer Thickness**	**Material**	**Material cost/ m2**	**Layer Thickness**	**Material**	**Material cost/ m2**
	(mm)			(mm)		
Sufacing	40	Continious graded (medium) asphalt	R 115.00	30	UV protective polymer + 3% Sasobit modified medium 50/70 pen asphalt	R 96.00
Tack-coat		Tack coat of 30% stable-grade emulsion	R 6.25		Nano-Tak" tack coat (1.4 L nano-tak + 100 L Cat 60 Emulsion + 200 L Water mixture) - application at 0.5 L/square meter	R 4.73
Prime		MC 30 cut-back bitumen	R 9.55		Nano -Prime (1 L Nano prime + 100 L Cat 60 emulsion+ 200 L Water mixture - Application at 1 L/square meter)	R 5.90
Base	150	G1 crushed stone	R 55.50	150	G5 + 1.2% GE-Nano at 100% mod AASHTO	R 57.65
Upper sub-base	150	C4 layer	R 37.17	150	G5 + 0.7% GE-Nano at 97% mod AASHTO	R 47.25
Lower sub-base	150	C4 layer	R 37.17			
		Total material cost/m2	R 260.64		Total material cost/m2	R 211.53
Saving of almost 20% in material costs (with currently high transportation costs of nano-technology)						
Additional savings - time and effort (no curing of cemented layers; no G1 layer; elemination of lower sub-base, etc)						
Total saving - estimated in the order of 30 - 40 %						

Table 3: Summary of the XRD scans of the G5 material for the K46

XRD IDENTIFIED MINERAL	% of Mineral Present in Total Material Sample	% of Mineral Present in percentage of material passing the 0.075 mm sieve
Kaolinite	5.69	40.05
Microcrine	15.11	5.93
Muscovite (Mica)	10.79	17.05
Plagioclase	24.55	15.12
Quartz	43.85	14.85
Smectite	trace	7.05

Table 4: K46 laboratory test results using nano-modified emulsions



G5/G6 Testing -Gauteng 31 May 2016 (48 hrs rapid curing at 40°C)

GEONANO TECHNOLOGIES (Pty) Ltd

Mix Design:	% Used	UCS DRY KPa	UCS WET KPa	ITS KPa
GE nano 20P	1%	4248	2555	286
GE- nano 20P with NS @ 0.5lt m3 pre-treat	1%	3828	2827	250
GE- Nano	1.2%	4336	2641	280

1) The above tests were cured rapidly. Further strength can be expected on all mix designs

Photographs 2 and 3 show the successful construction of the first trail section of the sub-base on the K46 dual carriageway (25 October 2016) in the Gauteng Province. This section was constructed using conventional equipment with graders and a water cart.

Photograph 2
Mixing of stabilising agent using a water cart and two graders

Photograph 3
Condition of trail section just before final roller passes

Photographs 4 show the condition of the exposed layer constructed on the 25 October 2016 as taken on 23 January 2017 after heavy rains during the November 2016 to January 2017. Photograph 5 shows the distribution achieved through the layer on the 25 October 2016 using conventional construction equipment and 0.7 per cent stabilising agent with less than 0.42 per cent residual bitumen

4.3. Road Agency Limpopo (RAL)

Nano-technology modifications were approved by RAL for the rehabilitation of a township road in Thohoyandou in the Limpopo province of South Africa. The in-situ base-layer was tested to be of G7 quality and results using 0.7 per cent GE-Nano-20P were similar to that shown in Table 1, meeting the BSM1 minimum specifications. The condition of the road before rehabilitation is shown in Photograph 5. A recycler was used to mill the existing surfacing and base -layer and adding the nano-modified

Photograph 3
Condition of the exposed sub-base after 3 months of heavy rains

Photograph 4
Distribution of 0.7% Nano-modified emulsion through the sub-base layer

emulsion stabilisation in one operation. The minimum specification of 100 per cent mod AASHTO compaction was achieved without any problems. Most of the road was in-situ recycled on 3 December 2015 and primed 4 days later. This section of road was left open to traffic until 25 January 2016. Photograph 6 shows the condition of the exposed road after almost two months (over the December 2015/January 2016 period) at which time it was treated with a nano-tack coat and overlaid. The whole project with added drainage facilities and walk-ways was completed successfully in May 2016.

Photograph 5
Road condition with recycler in back ground, ready to start in-situ recycling

Photograph 6
Surfacing of the recycled base after being opened to traffic for two months

4.4. Swaziland Ministry of Public Works and transport (SMPWT)

The detailed design of the road D29 Lugaganeni – Luve road to the North of Manzini, was commissioned in 2015. The original preliminary design recommended a pavement structure consisting of an imported 150 mm G1 base layer on top of a C4 cement-treated sub-base with a double seal surfacing. The design traffic loading for upgrading of this road is estimated to be between 0.5 and 0.8 MESA. Adequate quantities of G6 quality of naturally available material was found in close proximity of the proposed road – enough to construct all the layers of the new road.

The SMPWT considered the recommended design as being too expensive and requested alternatives to be investigated. The available materials were tested using nano-modified emulsions. A summary of the test results are summarised in Table 5.

Table 5: A summary extract of comparative laboratory test results using naturally available G6 quality material stabilised with both "traditionally" specified cement and as an alternative, Nano-modified Emulsions (GE-Nano-20P))

Material	**G6 material obtained from the borrow pit at the D29 Testing done: 15 October 2015 - Mbabane**					
Stabilising agent	**Afrisam Cement**			**GE-NANO-20P – Nano-polymer modified Emulsion**		
Stabilising Percentage	2.0%	2.5%	3.0%	0.3%	0.5%	0.7%
Curing time	**7 days**			**48 hours**		
UCS (kPa)	1120	1340	1580	2930	2440	2930
ITS (kPa)	85	106	120	154	131	161

UCS = Unconfined Compressive Strength measure in kPa
ITS = Indirect Tensile Strength measured in kPa

The results shown in Table 5 show that the minimum ITS specifications for a C4 layer is not met, even with 3 per cent cement. However, all requirements of a BSM3 layer (Asphalt Academy, 2009) (and more), is easily met, even with only 0.3 per cent of the stabilising agent. An alternative design using available G6 material stabilised with 0.5 per cent nano-modified emulsion was approved by the SMPWT for use in the construction of the new surfaced D29 rural road. This alternative design, using a nano-modified emulsion stabilising agent with naturally available G6 quality material, was shown to result in a saving of more than R 50 million on this project.

5. CONCLUSIONS

The use in practice of Nano-technology modifications together with traditionally used stabilising agents have been proven to provide cost-effective alternatives to tradition design approaches, mainly using newly crushed stone materials from commercial sources. These Nano-modified stabilising agents enables the use of naturally available road building materials in the cost-effective rehabilitation of existing roads as well as the construction of new roads as demonstrated in the paper. These technologies together with improved characterisation of available materials through XRD minerology scans enabled designers to use naturally available materials and manage risks in an acceptable process to lower the costs of the provision and rehabilitation of transportation infrastructure. Several road authorities in southern Africa have approved the use of these technologies on selected roads. The approval of these technologies is supported on the basis of advantages in terms of (all in support of the concept of "Green" technology):

- **Cost-factors:** most materials are currently sourced from commercial sources which significantly increases construction costs - the use of naturally available materials results in the saving of procurement costs and transportation costs, as these naturally available materials are usually more readily available closer to road construction sites – even when materials of lower quality are sourced from commercial sources, these materials are often less than half the cost of crushed stone materials;

- **Environmental factors:** lower quality materials require less energy for production i.e. the blasting, transportation, crushing and screening is normally not required for the lower quality naturally available materials, and
- **Energy factors:** the construction of a nano-based modified stabilised layer is less considerably less complex and easier to construct (mixing as well as compaction)(equated in practice to the mixing in of "dirty water" by operators = a process normally done during the construction of granular pavement layers to obtain material at Optimum Moisture Content (OMC) before compaction of the layer) than the traditional high quality crushed stone base layers resulting in considerable energy savings.

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