The provision and preservation of good transport infrastructure is a prerequisite to economic growth. However, the high cost associated with this essential part of service delivery puts an ever-increasing burden on available funds.

Cost-effective upgrading, preservation and rehabilitation of roads

BY G J JORDAAN* AND A KILIAN**

AFRICA COMPARES POORLY with the rest of the world in terms of paved road infrastructure, as shown in Figure 1 – a reality that has a direct influence on the competitive potential of the sub-continent. Hence, it is imperative for road engineers in Africa to drastically impact on the provision of road infrastructure at a reduced cost.

The investigation of alternative, new roadbuilding products could potentially result in huge cost savings to road authorities. The Gauteng Province Department of Roads and Transport (GPDRT) has identified potential cost-saving nanotechnologies and has embarked on a programme to test these technologies on identified sections of its road network. Testing will be done on identified roads, involving the CSIR through accelerated pavement testing with the Heavy Vehicle Simulator (HVS) of the GPDRT and academics from the University of Pretoria (UP).

Common roadbuilding materials

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 roadbuilding materials. This can lead to the unexplained or unexpected deterioration of pavement layers that are often blamed on inadequate/poor construction practices.

Currently, material classification is done using empirically derived indicator tests developed more than half a century ago. These tests cannot identify the presence of problem minerals that are present in all natural roadbuilding materials throughout Southern Africa. Problem materials are usually defined as materials that react poorly when stabilised with stabilising agents traditionally used. These include materials containing mica minerals, smectite minerals, cohesion-less sands and organic material.

These, among others, could present problems resulting in severe premature distress on roads at considerable costs if not taken into account. The non-identification of these minerals is partly to blame for the conservative (and costly) approach generally followed when designing roads, even for relatively low traffic loadings such as those in residential areas.

However, the technology to identify the mineral composition of materials has been available for decades. X-ray diffraction (XRD) testing of material samples can enable road engineers to accurately determine the mineral composition of materials and should become standard practice. This test equipment has been generally available for some time at commercial laboratories.

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. It is believed 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 in all of the layers of the pavement structure, especially for the design of lower-category roads.

Stabilising agents

Usually, only cement, lime and bitumen are used for the stabilisation and improvement of materials for road construction in South Africa. Lime is mostly recommended for use in cases where the material has been tested to contain some clay. Cement, bitumen (in its pure form) and crushed stone or high-quality natural gravel (G4) are usually prescribed for use in the upper layers of a pavement structure for the various road categories.

The use of bitumen in a bitumen-stabilised base is comparatively costly and is normally only warranted for use in higher-order roads requiring a design catering for high traffic loadings.

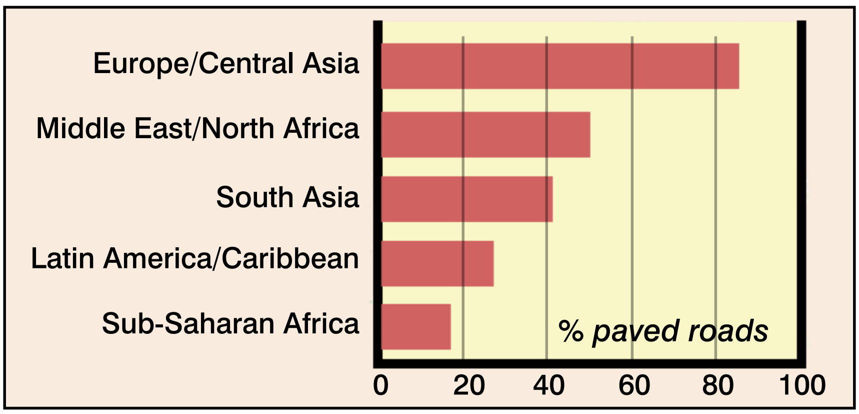

FIGURE 1 Sub-Saharan Africa compared with the rest of the world in terms of paved road infrastructure *(SATCC, 2003)*

Mixing of nanopolymer-modified emulsion into base layer using conventional equipment

Unfortunately, many bitumen-derived products, such as emulsions, are totally disregarded by many practitioners when considering design options.

Cement

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

The use of cement as a stabilising agent in the base layer 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 seldom considered by design engineers, is the behaviour of cement in the presence of some of the minerals associated with problem materials.

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 silica layers, known as mica. The presence of mica in materials and the effect thereof when using cement as a stabilising agent on such materials have been known for decades. More detailed studies recently done at UP have now quantified the detrimental impact of the presence of mica in weathered granite on the unconfined compressive strength (UCS) when stabilised with cement, as shown in Figure 2.

Smectite minerals

Smectite minerals are widely present in Southern Africa. 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; subsequent tests usually show carbonation to be absent and the reason for the distress goes unexplained. A typical XRD test scan will clearly show the presence of smectite, as illustrated in Figure 3.

Cohesion-less sand

The absence of the climatic factors often leads to the breaking down of the basic rock to form single graded sand with little variation in size. The stabilisation of material using economical percentages of cement usually requires material particles of different sizes to form a natural interlocking matrix to assist with the stabilisation process. Sand consisting of mostly single sized particles will usually require 5% 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.

Sand containing high percentages of organic material

- **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.

- **Sand containing pulverised (powdered) coral reef:** This material is usually very soft 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

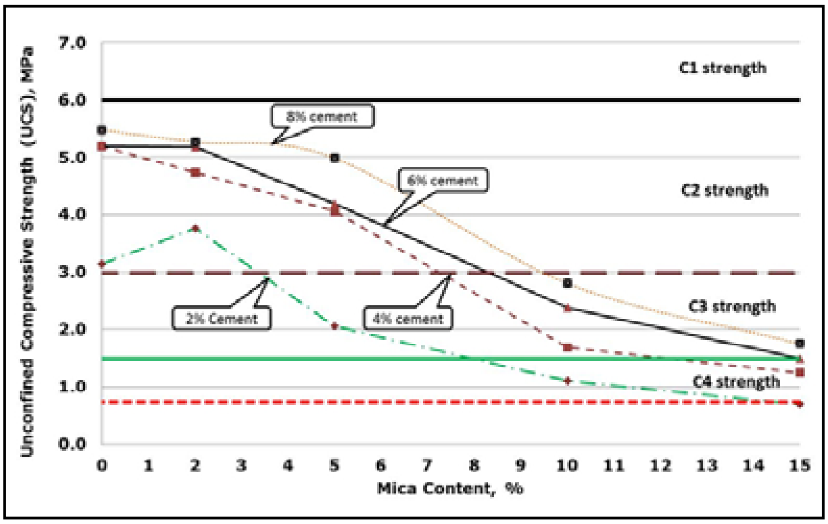

FIGURE 2 Influence of mica in weathered granite on the UCS, using cement as a stabilising agent *(Mshali and Visser, 2012)*

very well prove cost-effective in the use of this material in pavement layers.

Bitumen

Materials stabilised with bitumen products have more flexibility and waterproofing properties. Bitumen stabilisation includes many variations such as foam and emulsion stabilisation. Of these, emulsion has proved to be very cost-effective when used in relatively low percentages together with some cement (±1%) and a small percentage of lime in the presence of material with a PI in excess of 6.

This stabilisation recipe has been utilised for the in-situ reworking of many roads during rehabilitation throughout South Africa. HVS testing 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 break up the pavement layer.

Emulsions are 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 a need for cement to obtain a stable state and to meet the specified design criteria.

The use of new technology (nanotechnology)

New technologies developed over the last decade could prove a game changer in the cost-effective provision, maintenance and rehabilitation of road infrastructure.

New-generation, successfully tested organo-silanes interact chemically 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 have been developed that can be used to modify bitumen emulsions. These polymers with or without organo-silanes can be used as modifications to existing emulsions, greatly improving the distribution, coverage and, hence, stabilisation characteristics of bitumen molecules, allowing for the use of previously unheard of small quantities of residual bitumen to obtain the required design strength criteria.

However, not all polymers exhibit the same characteristics and not all polymers will be effective as a co-stabilising agent for all roadbuilding materials. Mineral identification through X-ray scans together with normal laboratory testing of the modified mix will be required to identify the most appropriate mixture to obtain the required strength criteria for the material being stabilised.

Nanopolymer-/organo-silanes-modified emulsions offer the following advantages:

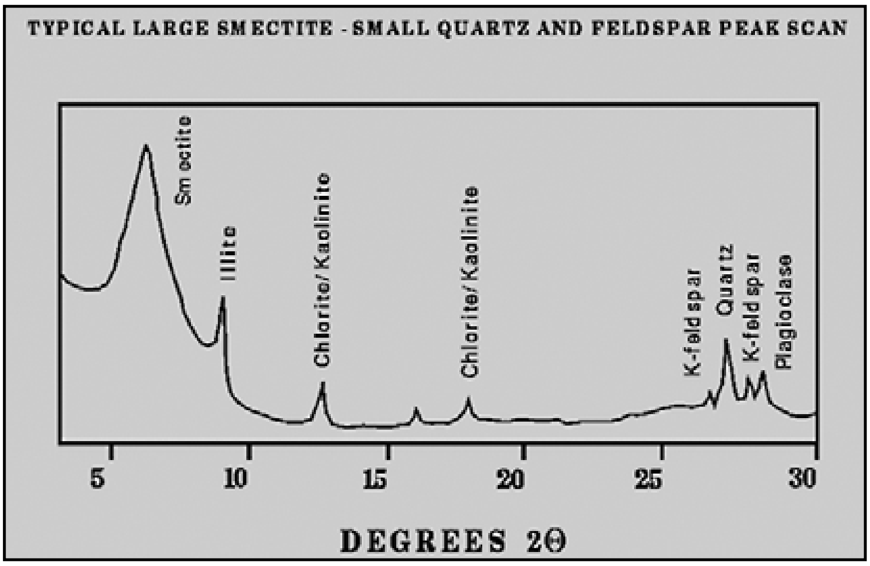

FIGURE 3 Typical large smectite, small quartz plus feldspar peak XRD scan

- reduced risk of cracking
- improved performance in terms of higher flexibility
- rapid increase in bearing capacity using low percentages of the stabilisation agent
- cost-effective use of locally available materials at a low risk
- improved resistance to water damage
- ease of construction.

The addition of the two nano-products results in several advantages over 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, requiring lower quantities of the stabilising agent needed to achieve the required strengths
- smaller particles and the water-repellent characteristics assist with the breaking of the emulsion and the rejection of the water from the bitumen-aggregate bonding process,

negating the need of cement to assist with the breaking of the emulsion
- smaller emulsion particles distribute much easier through the material, considerably reducing the construction complexity and effort needed to achieve the required mix and densities
- smaller particles pass much easier through the spraying nozzles of the construction equipment, reducing of the risk of clogged nozzles and the uneven distribution of the stabilising agent
- reduced risk of clogged nozzles in the distributing equipment, which lowers the risk of a pavement layer receiving an uneven distribution of the stabilising agent
- improved cost-effectiveness of the stabilisation process taking into account all the reduced risk factors.

These new nanotechnology-based products have been used successfully in many parts of the world, making the common use of marginal materials in the upper layers of pavements a reality on roads. The potential impact on the cost of road infrastructure is considerable and the GPDRT has embarked on a scientifically based programme to also illustrate the viability of this technology on its roads and to quantify the potential benefits. The already available track record of this technology and results from reputed research institutions make this a low-risk investigation with potentially huge returns.

GPDRT experimental sections

The rehabilitation of the D1884 road between Vereeniging and Heidelberg has been earmarked by the GPDRT as ideal for the introduction of nano-modified emulsion for the in-situ recycling of a severely distressed existing base layer.

Traditionally, the existing base (G7 quality) would be stabilised with cement as a new subbase and a new crushed-stone base imported. In this case, the base will be recycled using an aqueous polymer (nanotechnology) modified emulsion as a stabilising agent (0.7%) to improve the characteristics of the existing base material. This modification allows for the use of lower percentages of residual bitumen to obtain the required strengths, resulting in considerable savings for the road authority, The rehabilitation of the D1884 is now being preceded by the redesign of a number of roads and HVS test sections in Gauteng using nano-modified stabilisers. These road sections are aimed to provide pavement engineers with a range of designs suitable for low-volume residential streets to roads carrying high traffic loadings. All layers in these roads are designed using naturally available roadbuilding materials (G7 to G5) and tested using an array of nano-based modifiers to achieve the design strengths for the various pavement layers as matched to the mineral composition of the materials. The quantities of the stabilising agents added vary between 0.5% and 1.2%. Layers are being designed and tested for the various categories of roads and compared with the design criteria contained in the design manual for bituminous stabilised materials (BSM) for BSM1, BSM2 and BSM3 layer requirements.

LEFT The typical condition of the township road prior to rehabilitation

ABOVE Stabilision of the existing G7 quality base is done in situ with 0.7% nano-modified emulsion

RIGHT Surfacing of the nanopolymer-modified emulsion stabilised layer before applying a nano-prime

Test programme at the University of Pretoria

Using the previous mica/cement studies done at the university as a basis, 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 nanotechnology-based products.

The aim of this comprehensive study is to eventually provide road engineers with an improved guideline for the use of generally available roadbuilding materials in the various pavement layers, based on:
- basic minerals present in the material as stabilised through XRD scans
- identification of chemical reactions that take place (if any) using an array of different stabilising agents
- expected engineering properties to be achieved using different stabilising agents, including the latest nanotechnology-based products available
- testing of durability properties to be achieved as a function of the material and stabilising agent interaction
- 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.

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 that are available and continuously being developed all over the world. The following important factors need to be emphasised with the implementation of new technologies supporting the concept of green roads:
- cost factors: most materials are currently sourced from commercial sources, which significantly increases construction costs – the use of material of lesser quality will save on procurement costs and transport costs, as the lower quality materials are more readily available close to road construction sites
- environmental factors: lower quality materials require less energy for production i.e. blasting, transportation, crushing and screening is normally not required for the lower quality materials
- energy factors: the constructability of nano-based modified stabilisation is less complex and easier to construct (mixing as well as compaction) than the traditional high quality crushed stone base layers resulting in considerable energy savings. 3S

References available on request.

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