NANOTECHNOLOGY INCORPORATION INTO ROAD PAVEMENT DESIGN BASED ON SCIENTIFIC PRINCIPLES OF MATERIALS CHEMISTRY AND ENGINEERING PHYSICS

[1]*Mrs.N.Sowjanya,*[2]*Mrs.D.Praveena*
Assistant Professor
Department of Physics
CVRT Engineering college, Tadipatri

ABSTRACT:
The use of naturally available materials not conforming to traditional specifications or standards, in the base and sub-base layers of road pavement structures, stabilised with New-age(Nano) Modified Emulsions (NME), have been tested, implemented and successfully verified through Accelerated Pavement Testing (APT) in South Africa. This was made possible through the development and use of a design procedure addressing fundamental principles and based on scientific concepts, which are universally applicable. The understanding of and incorporation of the chemical interaction between the mineralogy of the materials and a NME stabilising agent (compatibility between the chemistry of the reactive agents and material mineralogy) into the design approach is key to achieving the required engineering properties. Stabilised materials evaluation is done using tests indicative of the basic engineering properties (physics) of compressive strengths, tensile strengths and durability. This article describes the basic materials design approach developed to ensure that organofunctional nano-silane modified emulsions can successfully be used for pavement layer construction utilising naturally available materials, at a low risk. The enablement of the use of naturally available materials in all pavement layers can have a considerable impact on the unit cost and life-cycle costs of road transportation infrastructure.

Keywords: road pavement design; design based on materials science; material mineralogy; Newage (Nano) Modified Emulsions (NME); naturally available materials; material stabilisation; basic engineering requirements; Unconfined Compressive Strengths (UCS); Indirect Tensile Strengths (ITS); Retained Compressive Strengths (RCT) and; Retained Tensile Strengths (RTS).

INTRODUCTION:

Organofunctional nano-silane technologies have been used in Europe for the protection of stone buildings for more than 150 years [1,2]. The application of various nanosilane products has been used to protect buildings against the climatic effects of moisture, providing a hydrophobic protective layer preventing further decay due to chemical weathering. Initial work done by scientists to develop protective products relied on trialand-error testing and resulted in contradictorily results as reported by various scientists. Eventually, it was concluded that the successful application of a silane-based protective product depends to a large extent on the compatibility of the nano-silane product to the “type of stone” as well as the “condition of the stone” to be treated [3]. The technology developed in the built-environment, as well as the “lessons learnt” can find direct application and should form the basis for the successful introduction and treatment of available materials in road pavement engineering [4].

The potential impact of the use of nanotechnologies in the field of pavement engineering has been identified more than a decade ago [5]. However, in practice, the introduction of applicable and proven nanotechnologies has been slow to receive acceptance. This scepticism in the pavement engineering fraternity has its origin in a constant flow of "wonder" products (commonly referred to as snake-oils) that have been introduced into the market by suppliers for the improvement of naturally available materials. These products have invariably been found wanting in practice, not meeting the anticipated results and leading to a general scepticism, detrimental to the introduction of new technologies into the field of pavement material stabilisation. Both the suppliers of new products/technologies as well as the road pavement engineering fraternity are to blame for this situation. Pavement engineers mostly rely on archaic, empirically derived tests (some more than a hundred years old), not indicative of the scientific characteristics of materials [6].

These tests are found wanting in assessing new products and to evaluate their true potential and limitations in terms of sound engineering requirements. In the same vein, suppliers of new products invariably lack a scientific basis and the data to support their claims, often using marketing agents with little engineering knowledge. This situation is very similar to what scientists in the built-environment experienced more than 150-years ago with the development of stone protectors on a trial-and-error basis.

Over the last few decades considerable resources in pavement engineering have been allocated to the development of sound Mechanistic-Empirical design methods to improve the analysis of pavement structures. Transfer functions based on the stresses, strains and deformation characteristics of various materials have been developed to improve the scientific basis of pavement design, identifying failure mechanisms and developing failure theories for universal use and analysis. The same (with some notable exceptions such as in the field of asphaltic materials) cannot be said about the testing, evaluation and characterisation of the materials used in the construction of road pavement structures. Most of the material characerisation tests lack a scientific basis with little relation to potential bearing capacity and the theoretical analysis of pavement structures. This lack of sound engineering concepts for the characterisation of naturally available materials and the specification of engineering requirements in terms of basic physics, requires urgent attention.

The observation is not new. The inconsistencies between a "petrological, geneticallybased classification" [7] and the engineering classification of materials for road construction had already been recognised by the British Standards Institution in 1954 [8] and also (inter alia) by the South African Bureau of Standards in 1976 [9], with little impact on traditional engineering practices.

The "lessons learnt" from the built-environment should form the basis of any design method aimed at the successful introduction of proven and available new-age nanotechnology solutions in the field of pavement engineering. Without an understanding of the basic science in terms of the mineralogy of the materials and the chemical interaction with organofunctional nano-silane based products and stabilising agents, the introduction and acceptance of the benefits to be achieved through the introduction of these technologies could be lost to the industry. This is mainly due to the risks and potential failures associated with the use of products that are not material compatible. A scientifically based materials design method for the appropriate use of applicable nano-silane products will limit these risks and overcome the limitations of an empirically derived materials classification system.

A scientifically based design method is universally applicable and does not require verification in different conditions. Such a method must be based on scientifically determine input values. A nano-silane modification of a stabilising agent of road building materials is reactive in nature, the influence of which is dependent on the chemical interaction with the minerals within the materials. Hence, to limit risks and address engineering requirements any design process must be based on the scientific identification of the primary and secondary minerals in the material [10] and an understanding of the basic chemistry involves in the use of nano-silane reactive agent with the minerals [11]. In order to address basic fears associated with new technologies fundamental principles and evaluation criteria need to be identified and adequately addressed [12]. Evaluation criteria should be based on fundamental engineering properties used to assess the adequacy of the future behaviour in a pavement structure in terms of compressive strengths, tensile strengths and durability (i.e. resistance to in-situ deterioration as a function of climate and loading conditions).

Over and above the technical merits, the successful implementation of new technologies is also a function of practical considerations, such as costs and ease of use and application (e.g. stability in often harsh conditions and constructability) [4]. All practical and functional factors need to be identified and accounted for [12] to ensure that the substantial benefits that can be realised through the introduction of applicable nanotechnologies in the field of pavement engineering, can be successfully introduced and find general acceptance for the benefit of society as a whole [4,6,13].

2. Background - Primary benefits of the introduction of new-age nanotechnology solutions (nano-silanes) in pavement materials design in pavement layers

Traditionally, materials for use in road construction are classified based on empirically derived archaic tests, aimed at the minimisation of the risk of failure during the design period, assuming future adequate preventative maintenance [6]. These classification systems mainly aim to ensure that the presence of secondary minerals (the result of chemical decomposition of the primary minerals), that could be harmful to the future performance of materials in pavement structures, is kept at a minimum. The resultant effect is that these criteria will mostly only be met by freshly crushed stone for use in the upper pavement layers (in pavement structures with thin asphaltic surfacings or chip seal surfacings) directly subjected to the high stresses/strains imposed by the traffic loading. The blasting and crushing of freshly crushed stone come at a considerable cost with an associated environmental impact and is a scarce commodity in many parts of the world. The result is that the unit costs of roads is considerable, making it highly improbable for the developing world to substantially increase their surfaced road network in support of economic development in the foreseeable future.

The only alternative available option currently used in the development of a surfaced road network in many sub-Saharan countries, is the stabilisation of quality naturally available materials using traditional stabilising agents. This practice usually involves stabilisation through the use of cement and/or lime with associated construction management (curing), material behaviour challenges (e.g. cracking) and material compatibility problems. These traditional stabilising agents (also containing nano-scale particles) are also reactive agents, often resulting in severe cracking and premature distress that cannot be explained using the results obtained from traditional test methods. In reality, the premature distress can often be associated with the mineralogy of the materials (e.g. the presence of mica [14]), which is not accounted for using traditional design material testing.

Most work throughout the world on the use of nanotechnology solutions in pavement engineering has been concentrated on the improvement of binders for asphaltic materials [15,16]. This trend is no surprise due to the popularity of the concept of full-depth asphalt pavements, the vulnerability of asphalt binder characteristics to the effect of aging (and associated problems [4]) and the considerable investments needed in the construction of full-depth asphalt pavements. In order to reduce the costs of full-depth asphalt roads considerable investments in research have been made since the 1970s for alternative technologies and the use of freshly crushed stone as a high-quality alternative in combination with relatively thin asphaltic layers or even seal surfacings. This evolution in road pavement design has led to considerable cost-saving for high-end road as reported [17]. In later years the mis-use of this technology has led to unaffordable high unit costs, with high-quality crushed stone becoming the norm for all category roads. The unit costs for the provision of road infrastructure, even using crushed stone as an alternative to fulldepth asphalt roads has become a major obstacle to development and accessibility to markets [18]. However, material sciences have made some significant advances over the last few decades that should be the key to the next evolution in the use of available materials and pavement design.

Organofunctional nano-silane technologies have the ability to neutralise the presence of potentially harmful secondary minerals in materials. Through the application of a material compatible reactive nano-silane a chemical reaction [11] with each material particle can be activated to change the surface characteristics to become hydrophobic (water repellent) and prevent the possible negative impact of secondary minerals on the future performance of a road structure [4,12]. In addition, future weathering through chemical decomposition is prevented or, at least minimised, due to repelling of water or moisture within the pavement structure. The presence of water is a pre-requisite for weathering, due to chemical decomposition to occur [7]. It follows that durability of the materials within the pavement structure will be increased by minimizing chemical decomposition by limiting the effect of the influence of water submersion on test samples on the compressive and tensile strengths of materials. This aspect can also be key to the treatment of materials in regions of the world subjected to frost-freeze conditions.

3. Pavement design process based on scientific principles

3.1. Elements comprising the Design approach

In order to incorporate the basic principles of science into pavement materials design, engineers need to understand and recognise the influence of the chemical interaction between materials and the influence thereof on the end product [11]. For this reason, some effort is made to include the basic concepts of primary minerals and the process of weathering due to chemical decomposition as a foundation for the understanding of the need for a scientifically based materials design approach in pavement engineering. The main phases of the design approach presented to facilitate the successful implementation of applicable and proven nanotechnology solutions (or for that matter any traditionally used or future new reactive agent) in road pavement materials engineering, are shown in Figure 1.

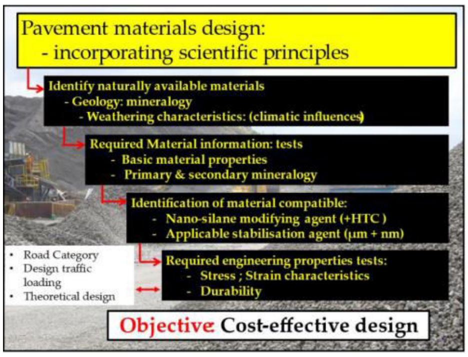

Figure 1: Recommended basic approach to road pavement materials design incorporating scientifically based concepts, developed for the selection of a material material compatible Newage (Nano) Modified Emulsion (NME) stabilising agent addressing the engineering requirements (physics) of a road pavement structure

Basic inputs such as traffic loading, required as part of pavement structural design, will, of cause, be part of the pavement design process and is not affected by the concepts discussed in this paper. Traffic loading is used to design a pavement structure with material layers meeting the engineering requirement to ensure that the predicted traffic loading will be carried, taken into consideration the risk profile of the category of road [21]. The main objective in the approach precented in Figure 1 is to ensure that the naturally available materials are utilised to their full potential using availabe, proven, safe and applicable material sciences in designing the most cost-effective road infrastructure at a minimum risk withour comprimising fundamental engineering principles.

3.2. Scientifically based material properties of naturally available materials

3.2.1. Mineralogy of naturally available materials

It is not the intention to replace the role of the geologist or to provide a comprehensive and detailed overview or description of all the various petrology and geology concepts as available in numerous sources. It is rather the intention to provide a simplistic approach with the emphasis on the basic concepts and understanding of the important role of mineralogy, in the successful implementation of proven and applicable nanotechnologies in the cost-effective use of naturally available materials in pavement engineering. The understanding of the roles of both the primary minerals (“type of stone”) as well as the secondary minerals (“condition of the stone”) are fundamental to the successful implementation of nanotechnologies through the incorporation of basic material science.

Engineers traditionally assume that materials classified on the basis of various empirically derived tests, stay the unchanged during the design period of a pavement structure. However, due to the presence of moisture and temperature fluctuations, chemical weathering of materials is a natural continuous process, even within a pavement structure. The material chemical decomposition is independent of the role in which it is used as long as it has access to water (moisture or vapour) and subject to temperature variations during seasonal changes. These influences are more pronounced in areas around the world characterised by considerable fluctuation in temperature, humidity and rainfall, as mostly experienced between the Tropic of Cancer (North) and Tropic of Capricorn (South). Some primary minerals have a higher resistance to chemical weathering, and basic knowledge and an understanding of these characteristics are of importance in the identification of material compatible nanotechnology solutions.

The naturally available materials between the two Tropics are usually the result of considerable chemical decomposition, representing a classification often more closely associated with soils than with the original geology. It follows, that not only is the geology of importance, but also the identification of soil-types. Geological and soils maps can be of great assistance to identify variations in the characteristics and the mineralogy of the materials that may be naturally available in any specific region [18]. The following factors all contributes to the mineralogy of the naturally available materials:

- Original rock formation and primary minerals;
- Climatic factors including rainfall, temperature and humidity;
- Changes in the slope of the area and vegetation that both contribute to the removal of the top, most weathered materials, through the flow of water, and
- Human interference through deforestation and other activities.

The variation in these factors has a considerable influence on the expected chemical weathering of the materials and changes in the expected fundamental mineral properties pavement materials engineers have to deal with as summarized in Table 1 (summarized and based on [28]).

Table 1: Generalised material properties associated with different climatic regions of the world due to the effect of chemical weathering (based on [28])

Climatic conditions	Cold regions (little decomposition)	Warm regions (considerable decomposition)
Property	Materials: Conventional (Crushed rock base, river gravels, glacier outwash)	Materials: Pedogenic (laterites, calcretes, ferricretes, silcretes, etc.)
Climate	Temperate to cold	Arid, tropical, warm temperate
Material Composition	Natural or crushed	Varies from rock to sand to clay with considerable variation in each
Material Chemical Reactivity	Inert	Reactive
Material Variability	Homogeneous	Extremely variable

3.2.2. Primary minerals defining the type of stone

Stone/gravel/soil/clay consists of numerous minerals that are influenced in different ways through the differences in climatic variations. More than 4 000 minerals have been identified by scientists within the crust of the earth, resulting in countless variations and permutations that could influence material behaviour [29]. However, the understanding of mineralogy can be considerably simplified through the identification of the minerals that are in abundance and form most of the crust of the earth. It follows that these minerals will also be of particular importance in the identification of material compatible nanosilane technologies to be used together with an appropriate stabilising agent. Only a few elements form the bulk of these minerals (Table 2 [30]. A generalised composition of Igneous rocks (solidification of lava materials) found in the crust of the earth is shown in Figure 2 (Compiled from various similar figures in public domain e.g. [31]).

Table 2: Estimated percentages of the main elements found in the crust of the earth that constitutes most of the materials (estimates based on [30]) – some significant variances are precent around the globe

	Estimated % by Weight	Estimated Atomic %	Estimated Volume %
Oxygen (O)	~ 46.6 – 49.5	~ 62.3 - 66.2	~ 92 -94
Silicon (Si)	~ 25.3 - 27.7	~ 19.4 - 21.2	~ 8 - 6
Aluminium (Al)	~ 7.5 - 8.1	~ 6.0 - 6.5	
Iron (Fe)	~ 4.2 - 5.1	~ 1.6 - 1.9	
Calcium (Ca)	~ 3.2 - 3.6	~ 1.7 - 1.9	
Sodium (Na)	~ 2.4 - 2.9	~ 2.0 - 2.4	
Potassium (K)	~ 2.3 - 2.6	~ 1.2 - 1.4	
Magnesium (Mg)	~ 1.9 - 2.1	~ 1.6 - 1.8	
All Others	~ 2.5	~ 0.5	
Total	100	100	100

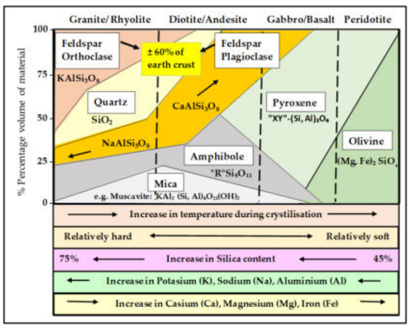

Figure 2: Generalised composition of Igneous rocks found in the crust of the earth (based on and compiled from various similar figures in public domain, e.g. [31])

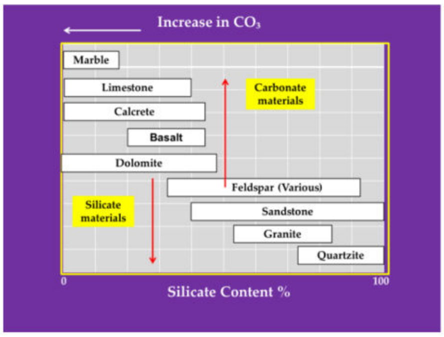

Figure 3: Silicon content variation versus Carbon-di-oxide content found in some typical and commonly known naturally available materials

The distinction between Silicate and non-Silicate and Silicon-poor materials is of importance as it forms the basis for the design and selection of an applicable effective NME stabilising agent. High percentages of other minerals such as Calcium Carbonates ($CaCO_3$) in the material to be stabilised will require a different modification in terms of a Hydroxy Conversion Treatment (HCT) [3,11] in order to provide high strength "permanent" bonding of the stabilising agent with the available elements in the material to meet engineering requirements.

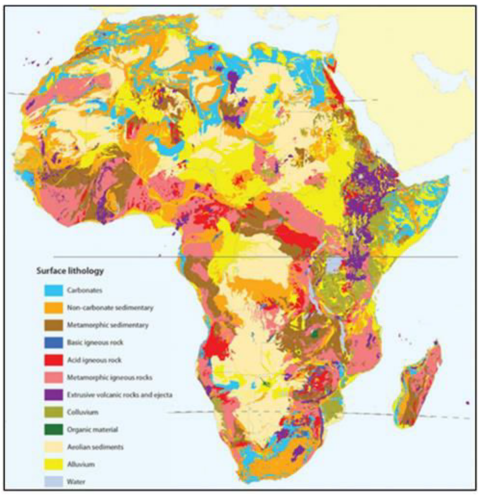

Figure 4 [32]: Example of the variation in surface geology of the continent of Africa showing large parts of the content that a general assumption of the presence of Silicate materials could have dire design and construction consequences

4. Typical pavement structural designs recommended for a variation of traffic loadings and traditionally defined subgrade materials

Recommendations for typical pavement structures for different traffic loadings and subgrade conditions [13] were originally based on fatigue criteria developed for bitumen emulsion stabilised materials as developed from APT loading [44]. At the time, the designs were considered conservative but suitable for the introduction of NME stabilising agents into a market known for its conservative approach. Subsequent APT loading done on two roads [26,27] have confirmed that the designs are conservative, with ATP loading exceeding the design traffic loadings by some considerable margins. Consequently, a more optimum design catalogue is now recommended, shown in Figure 26 for different design traffic loadings (up to 30 million E80s) and subgrade conditions varying from insitu CBRs of 3 per cent @ 93 per cent Mod AASHTO [22,23] and upwards. For comparisons with traditional designs recommended, typical designs are compared in Figure 27. Work done on the evaluation of thin chip seals, especially that done on a Cape seal with a variation of modified binders, has confirmed the potential use of this thin surfacing as a protective surfacing layer for roads carrying relatively high traffic loadings on base and subbase layers stabilised with a material compatible stabilising agent (with deformation characteristics comparable to that of asphalt surfacings specified for highways) [49].

Of particular importance is the fact that the behaviour of the NME stabilised material was found to be less sensitive to overloading than usually assumed for the assessment of pavement structures, with:

$$N = (P/80)^n \quad (2)$$

Where:

N = Equivalent 80 kN dual wheel standard axle load
P = Applied dual wheel axle load
n = Damage coefficient (normally considered as 4.2 [50])

In the case of the NME stabilised layers the damage coefficient has been found to be between 1.0 and 2.5. It follows that pavement layers stabilised with a NME stabilising agent is not as sensitive to high wheel loads a per normal pavement structures. Hence, these pavements will be very suitable in an environment where law-enforcement is a scarcity or non-existent. Life-cycle cost analysis [51] on a number of projects have shown initial material cost savings of 30 to 50 per cent with additional savings in construction time and considerable savings in periodic maintenance over the design period considered [25,26].

For comparative purposes, the recommended designs based on NME stabilised naturally available materials are compared with traditional designs using high-quality crushed stone layers and/or Cement (C)-treated layers [52] as shown in Figure 27. Material classifications are as per South African Technical Recommendations for Highways document TRH14 [53].

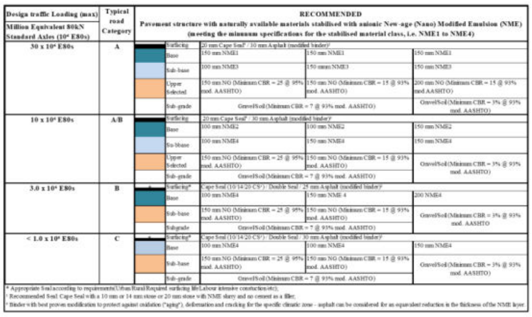

Figure 26: Typical recommended pavement structures developed for the construction of road pavements using a material compatible anionic New-age (Nano) Modified Emulsion (NME) stabilising agent with naturally available materials as per specifications (Figure 25)

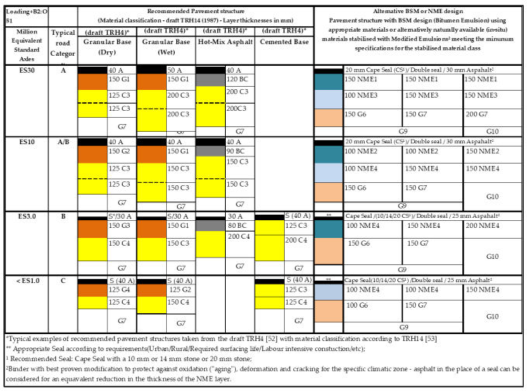

Figure 27: Comparative pavement designs based on high-quality crushed stone and/or cement-treated materials with relatively thin surfacings and the newly recommended NME stabilised designs using naturally available materials

5. Practical application and comparison of material design methods/approaches

5.1. Design method: comparison of results

The design approach as detailed was recently (2019) used on a road in South Africa to do an alternative design using locally available materials not conforming to standards traditionally prescribed. The original pavement design consisted of a 150 mm cement stabilised subbase with a UCS of 1500 to 3000 MPa and a 150 mm high-quality crushed stone base (G1 [53]) compacted to a minimum of 102% mod AASHTO [22,23] (88 per cent ARD) with a 40 mm asphalt surfacing. No high-quality stone is available in this part of the sub-continent and an alternative design was proposed using NME stabilised naturally available materials.

After discussions with the client, an alternative design was approved, specifying a 200 mm NME3 quality base layer (refer Figure 25) with a 40 mm asphalt surfacing (not recommended, but preferred by the client) with a modified binder. The naturally available material has a shortage in fines with little cohesion and a CBR of between 15 and 25 at 93 per cent mod-AASHTO [22,23]. Suppliers were invited to submit stabilising agents for testing and pricing using the naturally available materials, meeting the minimum requirements for a NME3 quality pavement layer. Three suppliers responded and their products were tested and evaluated by an independent laboratory against the engineering requirements contained in Figure 24. The three suppliers used different design approaches and provided different products to stabilise the materials. The test procedures previously referred to as standard test methods (refer Section 3.5.2) were followed to evaluate all the different products. The results and evaluation of the test results are given in Figure 28.

5.2. Discussion of results

The considerable advantage of the materials design approach based on the basic scientific approach as contained in this article, using materials of relative poor quality, is irrefutable. Of some interest is the Retained Compressive Strength (RCT) and Retained Tensile Strength (RTS) of more than 100 per cent show in Figure 28, using the design approach based on the scientific approach of mineralogy of the materials (last two line of results). These results are unheard of in pavement engineering, with an immediate reaction of erroueous and inaccurate laboratory work and/or recording from practitioners. However, these results are not unusual and easily explained and understood if the basis of the NME stabilisation process, the basis of the modification, the material characteristics and the test procedure as contained in Section 3.5.2 are well known.

With a scientifically based material compatible designed NME stabilising agent it is not unusual to achieve a 100 per cent hydrophobicity (or very close to 100 per cent) of your test sample. The effect is that the submersions of the test sample after completion of the rapid curing process in a water-bath will result in basically zero penetration of water into the sample, not negatively effecting the engineering properties to be tested.

PROJECT: UPGRADING OF GRAVEL ROAD: South Africa

TEST RESULTS: UPGRADING OF GRAVEL ROAD USING IN-SITU MATERIAL CBR @ 93 % mod AASHTO between 15 and 45

MATERIAL REQUIREMENT: NME3

REQUIRED CRITERIA:

UCS_{wet} > (kPa)	1000	Retained Compressive Strength (RCS) (% (UCS_{wet}/UCS_{dry})) >	70
		RCS in relation to minimum criteria in a wet condition (RCS-MC) (RCS x ($UCS_{wet}/UCS_{wet-criteria}$) (%)) >	100
ITS_{wet} > (kPa)	160	Retained Tensile Strengthcohesion (RTS) (% (ITS_{wet}/ITS_{dry})) >	70
		RTS in relation to minimum criteria in a wet condition (RTS x ($ITS_{wet}/ITS_{wet-criteria}$)) >	100

No	Product tested	Design Methodology	Supplier	UCS_{dry} kPa	UCS_{wet} kPa	RCS %	RCS-MC %	ITS_{dry} kPa	ITS_{wet} kPa	RTS %	RTS-MC %	Comments	Cost/m3 (Product)*
1	2% Roadcem + 2.5% SS60 (55lts/m3) (BSM)	BSM¹	1	2351	1790	76	136	289	217	75	102	Pass	US$ 49.40
2	2% Roadcem + 1.5 % SS60 (33lts/m3) (BSM)	BSM¹	1	1585	1166	74	86	171	105	61	40	Fail	
3	2% Roadcem + 1.0 % SS60 (22lts/m3) (BSM)	BSM¹	1	1409	887	63	56	121	48	40	12	Fail	
4	1.0 % Cationic NME (22 lts/m3)	T & E²	1	1238	705	57	40	108	29	27	5	Fail	
5	1.5 % Cationic NME (33 lts/m3)	T & E²	1	1308	739	56	42	112	27	24	4	Fail	
6	2.5 % Cationic NME (55 lts/m3)	T & E²	1	1370	798	58	46	138	37	27	6	Fail	
7	2% Roadcem + 2.5 % SS60 (55lts/m3) (BSM)	BSM¹	2	2086	1515	73	110	233	166	71	74	Fail	US$ 52.50
8	2% Roadcem + 1.5 % SS60 (33lts/m3) (BSM)	BSM¹	2	1565	971	62	60	139	86	62	33	Fail	
8	2% Roadcem + 1.0 % SS60 (22lts/m3) (BSM)	BSM¹	2	1396	823	59	49	132	45	34	10	Fail	
10	1.0 % Cationic NME (22 lts/m3)	T & E²	2	1253	707	56	40	105	23	22	3	Fail	
11	1.5 % Cationic NME (33lts/m3)	T & E²	2	1329	746	56	42	135	29	21	4	Fail	
12	2.5 % Cationic NME (55lts/m3)	T & E²	2	1396	769	55	42	162	39	24	6	Fail	
13	1.0 % Anionic NME (22lts/m3)(Double Emulsification)	Mineralogy³	3	3110	3120	100	313	281	356	127	282	Pass	US$ 24.00
14	1.0 % Anionic NME (22 lts/m3)(Single Emulsification)	Mineralogy³	3	2090	2840	136	386	181	283	156	277	Pass	US$ 23.40

BSM¹ = Bituminous Stabilased Material (BSM) design approach - Industry Manuel - TG2 [54]

T & E² = Trail and Error design adding different percentages of stabilising agents as per supplier

Mineralogy³ = Design based on mineralogy of materials and chemical interaction with Nano-Modified Emulsion (NME) Stabilising agent

*Price provided by contractor on site South African Rand conversion: 1 US$ = R16 South African Rand

Figure 28: Results of the testing of stabilised materials as per design criteria for a NME3 (Figure 24) layer using different stabilising agents and different design methods/approaches as detailed at the bottom

However, during the last phase of the rapid curing process the test samples are left in the oven for 24 hours at 30°C to allow the samples to "cool down" (as per current test recommendations). The modified NME stabilising agent has as a basic ingredient of bitumen (or equivalent polymer) that is added to the material in the form of a modified emulsion. During the rapid curing process the bitumen (or equivalent polymer) in the emulsion separates from the water and the water is effectively repelled from the test sample by the nano-silane modification that attaches the bitumen particle "permanently" to the material particles in the material test sample and effectively coats every material particle to be hydrophobic.

5. CONCLUSIONS

The use of nanotechnology solutions in the built environment is nothing new. Scientists in Europe have been tasked to developed products to protect stone buildings against the effect of water and pollution since the early 1800s. Initially, these scientists were faced with contrasting results and success. The variation in the results, applying various silane-based (nano-size) treatments that was developed at the time, soon led the scientists to conclude that the type of stone and the condition of the stone are crucial information required to take into consideration when using and applying any specific product. The products developed and the lessons learnt over more than 150 years in the built environment for the protection of buildings, monuments and statues, are also directly applicable to the field of road pavement materials design.

This article details a material design approach incorporating basic science in terms of the chemical interaction between the mineralogy of naturally available materials and available, proven nanotechnology solutions, enabling the use of traditionally classified "marginal" materials in the upper layers of a road pavement structures at a low risk.

Naturally available materials normally do not conform to the criteria that are traditionally applied for the evaluation of materials considered suitable for use in these layers. These traditional material classifications are, to a large extent, based on empirically derived tests far removed from the basic petrological genetics of materials. These inconsistencies have been recognised and pointed out by geologists since the 1950s, with little impact on traditional approaches used by pavement engineers for the classification of road building materials.

The successful implementation of new-age nanotechnologies in road pavement materials design will depend on the scientific analysis of the primary minerals (type of stone) as well as the secondary minerals (condition of the stone) comprising the naturally available materials. In order to minimise risk, a materials design approach enabling the use of naturally available materials is presented, based on the mineralogy of the materials and the chemical interaction thereof with any modified stabilising agent is presented in full. The scientifically based material design method/approach ensures that the NME stabilising agent is material compatible and that it will be able to develop strong chemical bonds with the material particles as well as the stabilising agent. The implementation of a scientifically based materials design approach is universally applicable, in contrast to empirically derived methods that require verification under different conditions.

The materials design method bases the selection of a material compatible NME stabilising agent on the primary as well as the secondary minerals. Adjustments in the various volumes and use of various applicable new-age nanotechnologies are done using a few, easily obtainable material parameters. The aim of the nano-silane modification is also to neutralise any possible negative impact of the possible presence of secondary minerals in the naturally available materials on the future behaviour of the pavement structure. The secondary minerals are neutralised by ensuring that the material particles are chemically changed to become hydrophobic, not allowing water access to these minerals. Chemical decomposition of materials is only possible in the presence of water. If water is largely repelled from the material particles, further chemical weathering is limited and durability improved.

The NME stabilised material properties are assessed against engineering criteria indicative of the physics of the material behaviour, i.e. the stresses and strains that need to be tolerated by the stabilised materials, as well as the future required durability, i.e. the level to which these properties will be maintained within the NME stabilised material over time. These criteria are specified using a classification system for the NME stabilised materials as a function of the required bearing capacity within the pavement structure in terms of the required engineering stresses and strains, in line with modern Mechanistic Empirical pavement design methods.

This approach requires pavement engineers to have a basic understanding of mineralogy, chemical weathering and the influence thereof on the materials and the selection of a material compatible NME stabilising agent. These aspects are addressed within this article. Chemical weathering is directly associated with the higher temperature and high rainfall areas of the world, especially concentrated, but not exclusive to, areas within the Tropics, on either side of the Equator. These regions are also associated with the majority of the developing world, urgently in need of improved transportation infrastructure in support of developing economies.

Practical implementation of the presented design approach has shown material cost savings of between 30 and 50 per cent with similar savings in construction times when compared to traditionally used pavement designs. The alternative designs using naturally available materials stabilised with material compatible NME stabilising agents, have been evaluated using numerous laboratory tests as input into the recommended material classification system of NME stabilised materials. An updated catalogue of designs, initially developed using Mechanistic-Empirical design methods, were refined using these laboratory tests in combination with full-scale APT results, enabling the designs to be optimised and a revised design catalogue to be compiled.

The implementation of the material design approach has recently been evaluated in practice against traditional design approaches. The use of the mineralogy-based NME stabilisation of the available materials not only far exceeded the required engineering criteria, but also realised a comparative saving in material costs of more than 50 per cent.

Similar savings in the construction time can be realised. Additional requirements addressed in project specifications to further reduce possible associated risks during construction will make the scientifically-based materials design method/approach as detailed, an attractive alternative.

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