MERGING PROCUREMENT AND ENGINEERING REQUIREMENTS WITH THE INTRODUCTION OF NEW (NANO) MODIFIED EMULSION (NME) TECHNOLOGIES THROUGH "END PRODUCT SPECIFICATIONS"

GJ JORDAAN[1] and WJ vdM STEYN[2]

[1]Jordaan Professional Services (Pty) Ltd t/a JPS & Department of Civil Engineering, University of Pretoria, PO Box 33783, Glenstantia, Pretoria 0010;
Tel: 082 4164945; Email: jordaangj@tshepega.co.za
[2]Faculty of Engineering, Built Environment and Information Technology, University of Pretoria, Private Bag X20, Hatfield, Pretoria 0028, South Africa;
Tel: 082 2199704; Email: wynand.steyn@up.ac.za

ABSTRACT

Introducing New (Nano) Modified Emulsions (NME) into the road industry has been shown to have considerable advantages in terms of road pavement durability and the delivery of climate-resilient, cost-effective road infrastructure. However, the introduction of new stabilising agents for granular materials has the potential to also open the door to the so-called "snake oils" or sub-standard stabilising agents with resultant dire consequences to perceptions regarding the introduction of new technologies for the improved utilisation of naturally available granular materials in the road environment. Procurement rules often prevent authorities from specifying any specific product. However, the industry can specify "End Product Specification," where the contractor can use any supplier with products that meet basic engineering material and practical specifications beneficial to road projects. This paper discusses some basic requirements, introducing typical clauses that should be incorporated into an "End Product Specification". To ensure successful application in practice, practical aspects related to material stability in harsh environmental conditions, water quality, material quality control test procedures, reworking of materials in case of failures and equipment requirements as related to the application of NME materials should all form part of such "End Product Specifications". The primary purpose of these specifications is to reduce risks to road agencies, ensuring that sub-standard stabilising agents are not introduced under the cover of NME.

1. INTRODUCTION

An essential undertaking in the "Code of Ethics" of professional engineering registration is to optimise available resources in design and construction. In terms of road pavement engineering, that could directly be related to the optimum utilisation of Naturally Available Granular Materials (NAGM) in the general area of any road project. However, NAGM often does not have the inherent bearing capacity to be utilised in the upper road pavement structure to accommodate and withstand the high traffic-induced stresses and strains close to the surface of the road structure. Traditionally, this "problem" has been overcome through the introduction of full-depth asphalt pavement structures or the construction of high-quality crushed stone layers supported by cement-treated sub-layer(s) (Jordaan & Steyn, 2019a; Jordaan et al., 2023). Although the latter has proven cost-effective when compared to full-depth asphalt pavements (Rust et al., 1998), it can come at considerable costs to authorities, especially using commercial sources and the haulage of high-quality

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materials over significant distances, which has, unfortunately, also become the norm for roads carrying even relatively low traffic loadings.

In many parts of the world, high-quality NAGMs are scarce, often resulting in high unit costs for providing basic all-weather road infrastructure. Due to climatic influences, high-quality granular materials are especially scarce near the equator (Weinert, 1980). Using high quality crushed stone, costs may vary from US$ 0.7 million/km for basic township roads with a relatively low required bearing capacity to a unit cost as high as US$ 10 million/km in some developing regions of the world for higher-order roads. The lack of available funds for developing all-weather, climate-resilient road infrastructure makes this high unit cost unsustainable (Jordaan & Kilian, 2016; Jordaan et al., 2017).

The introduction of nano-particle size organofunctional-silane modifications of emulsions for the stabilisation and increasing the bearing capacity of NAGM have been proven in laboratories [e.g., Jordaan et al., 2017a; Jordaan et al., 2017b; Akhalwaya & Rust, 2018; Jordaan & Steyn, 2019a; Kidgell et al., 2019), through Accelerated Pavement Testing (Rust et al., 2019; Rust et al., 2020; Jordaan et al., 2021a) and in practice (Jordaan & Steyn, 2019a; 2022a; 2022b). These nano-technology solutions, generally referred to as New (Nano) Modified Emulsions (NME), have all the characteristics of disruptive technology (Steyn, 2021), requiring a mindset change in the use of granular materials as defined by traditional material classification systems used in pavement engineering (e.g., COLTO, 1985; AASHTO, 1995). The potential engineering properties of granular materials using NME technologies are firstly a function of the generic fingerprinting (British Standards, 1954; SABS, 1976; Weinert, 1980; Jordaan & Kilian, 2016; Jordaan & Steyn, 2019) of the NAGM as defined by the primary and secondary minerals comprising the granular materials. The generic fingerprints of granular materials are often independent of traditionally used material classification systems. The successful introduction of nanotechnology solutions to improve the properties of NAGM depends on the chemical bonds (Jordaan & Steyn, 2021c) that can be enacted between the modifying agents (nano-silane (NS)) and the primary minerals within a NAGM. NAGM with different mineralogy compositions will require different chemical bonds to improve the NAGM and create a durable material effectively.

However, procurement procedures in many parts of the world prevent the specification of any specific modifying agent and binder, requiring generic specifications regarding the type of stabilising agent to be used. Tenders are usually awarded based on costs, assuming all products have the same end product. This procurement concept allows for the implementation of the lowest-cost products, often related to the less effective products of questionable quality and origin. The general specifications may also open the door to so-called “snake oils”, which have a history of failures within the pavement engineering environment. General specifications with regards to NME stabilising agents could lead to disastrous consequences, resulting in the rejection of NME technologies, with dire consequences in the following:

- Evolution of pavement engineering principles from a “trial and error”, empirical nature of granular material utilisation to a scientifically based materials design method (Jordaan & Steyn, 2019, 2021a); and
- Provide cost-effective transportation facilities and essential service delivery, especially in developing regions.

Although procurement procedures prevent the specifications of specific products, the specification of technical requirements is permitted. These technical requirements can be utilised to ensure that the end product will meet all basic engineering and practical requirements and limit risks to the implementing agencies. This paper discusses the background and some main aspects that should be addressed in such an "End product Specification" (EPS) (Jordaan & Steyn, 2019; Jordaan & Steyn, 2020). Recommendations address some of the most critical technical engineering requirements and some essential practical requirements for application in harsh environmental and political volatile conditions.

2. DEFINING A MATERIAL COMPATIBLE NEW (NANO) MODIFIED EMULSION (MC-NME)

MC-NME stabilising agent consists typically of a:

- Binder, e.g., a bitumen emulsion or equivalent Micro-Polymer (MP) or appliable Nano-Polymer (NP) or a combination thereof, and
- Nano-Silane (NS) modification to the binder or equivalent.

In terms of a general definition for an "End Product Specification" (EPS), a NME stabilising agent is defined as any additive to a granular material in the form of a solution, including any additive added to the construction water, including (but not limited to):

- Bitumen emulsions with/without a modified emulsifying agent (e.g., an aggregate adhesive, water-repellent agents (e.g., NS) and/or with the addition of polymers (MP- and/or NP-);
- Material-compatible polymers (MP and/or NP) with/without an NS modifying agent, and
- Any "alternative" rock/aggregate/soil stabilising agent.

In the context of an EPS, an NME may be considered an abbreviation covering the use of any or all of the stabilising mentioned above or material improvement additives. Numerous modifiers have been in use since the 1970s. These modifiers have improved considerably since the ability was developed in the 1990s to see and observe (with the development of electron microscopes) the impact of these modifiers on engineering characteristics unless specifically otherwise identified or separately specified. However, in terms of the evaluation of these products, the engineering requirements in terms of strength criteria (limiting criteria for tests indicative of basic engineering properties such as compressive stress and tensile strain), durability and long-term stability, sample preparation and test protocol as contained in an EPS must be met in all cases.

The EPS requires an NME to be verified before usage, and the contractor guarantees the use thereof through his supplier. It is important to note that the NME stabilising agent (or equivalent) should be costed in a Bill of Quantities (BOQ) in terms of cubic metre of the material that is being stabilised and compacted to the specified pavement layer requirements and NOT by the volume (quantity in terms of litres or m^3) of the stabilising agent needed to meet the engineering requirements. Volumes may vary considerably as a function of any NME and are product-specific.

3. RECOMMENDED END PRODUCT SPECIFICATION (EPS)

An applicable EPS will normally address the engineering requirements that must be achieved. However, to verify the specifications, it is necessary also to address and specify the tests that will be used, the test criteria that will be applied, and the test protocols that will be followed. In terms of practical application, minimum requirements need to be specified for the MC-NME in terms of stability on site and the construction water quality, similar to normal specifications for any road construction project. Many specifications applicable to MC-NME stabilisation are generic and are addressed in generally applicable required construction specifications applicable to unmodified bitumen emulsion stabilised materials. This paper only concentrates on aspects specific to MC-NME stabilisation of NAGM and the rationale behind the recommendation. A complete Project Specification (PS) applicable to the application of MC-NME stabilising agents (Jordaan & Steyn, 2019; Jordaan & Steyn, 2021a) will include:

I. Scope
II. Materials and material specifications
III. Composition of recycled mixes
IV. Plant and equipment
V. Setting out and control of the works
VI. Construction
VII. Weather limitations
VIII. Operational limitations
IX. Protection and maintenance
X. Construction tolerances and finishing requirements
XI. Trail sections
XII. Work outside normal working hours
XIII. Testing
XIV. Treatment of gravel roads to protect the gravel layer and reduce dust
XV. Measurement and payment

Only item (II) as related to an ESP and the rationale behind the recommendations are covered in this paper, i.e.:

- Material and Material Specifications, including:
    - Stability requirements for practical application, and
    - Additional aspects with specific reference to NME stabilisation, i.e.:
        - Test protocols to be followed related to the material specifications;
        - Construction with specific reference to reworking of pavement layers not meeting specifications, and
        - Measurements and payments.

4. UNDERSTANDING MC-NME STABILISATION

4.1 Background

Organofunctional-silanes (Nano-silanes (NS)) were developed in the early 1800s (Von Ebelman, 1846; Von Hoffman, 1861) for the protection of stone buildings against the detrimental effects of the environment. Lessons learnt over almost two centuries in the built environment (Wheeler, 2005) are just as applicable to adjusting these technologies for using granular material treatment in road pavement structures. These include that the effective protection of stone buildings using a specific organofunctional-silane is a function of the:

- Type of stone, i.e., the primary minerals constituting the granular material, and

- Condition of the stone, i.e., the secondary minerals contained within the granular material that have developed due to weathering as a result of the chemical decomposition of the primary minerals in the presence of water

The NS attaches chemically to the stone/aggregate/soil particles to provide a three-dimensional coating around each granular material particle to change the polarity thereof and make it hydrophobic (water-repellent) (Jordaan & Steyn, 2019, 2021b, 2021c; Jordaan et al., 2017). The applicable NS is selected based on the primary minerals of the NAGM to create strong chemical bonds (some of the strongest found in nature (Jordaan & Steyn, 2019, 2021b)), creating a durable product protected from future chemical decomposition. In contrast to the protection of buildings in the built environment, in pavement engineering, the NS is also used to chemically attach the binder to the stone as a modification to the binder. The nano-size of the NS particles is too small to bind granular particles together, and a binder is required to bridge the gaps between the granular particles, as demonstrated in Figure 1 (Jordaan & Steyn, 2019, 2021d). It follows that the determination of the mineralogy of the materials will form a cornerstone for an MC-NME stabilising agent to meet the required engineering properties as a function of the required bearing capacity. In addition, the modifier must be compatible with the binder to chemically bind with it and meet the specified engineering specifications. The quality and type of the NS and the binder directly relates to the stability of the NME and could influence the engineering properties to be achieved.

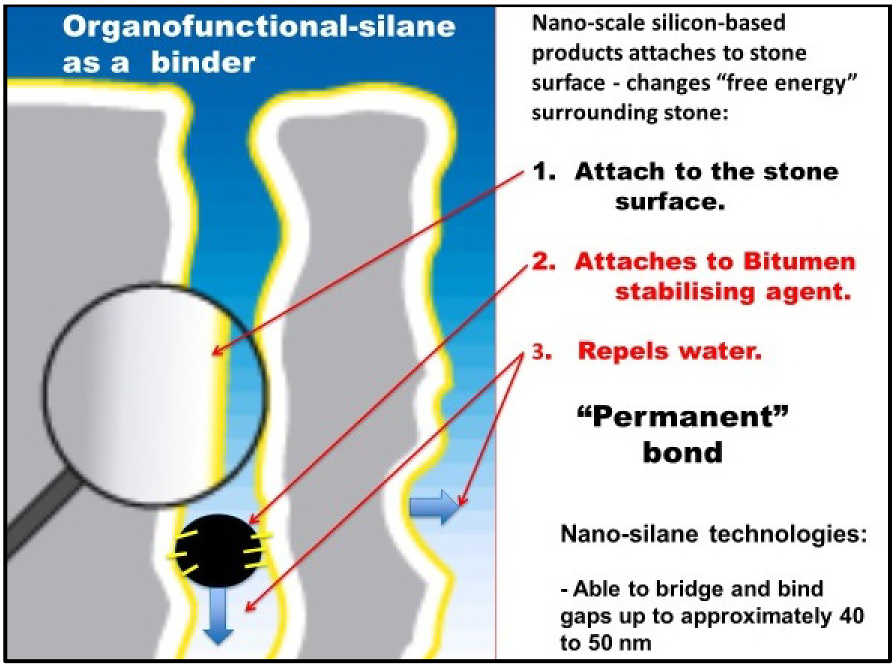

Figure 1: Illustration of the role of an organo-functional-silane modification of an emulsion stabilising agent as applied to granular materials

The quantity of the NS added as part of an MC-NME must be sufficient to cover all particles within the granular material that are being stabilised. The incorporation of dry versus wet tests in an EPS will enable different products to be evaluated in terms of their ability to prevent water access to the granular particles and to assess the level of hydrophobicity achieved within the stabilised mix and, hence, their applicability for use with a specific NAGM. The hydrophobicity achieved during stabilisation is directly related to the durability of the stabilised layer. Chemical weathering can only take place in the presence of water, hence denying the NMGM direct access to water will influence the long-term durability of the NAGM.

4.2 Influence of the Binder in an MC-NME Mix

As illustrated in Figure 1, modifiers alone cannot bind granular particles together due to the very small particle sizes. Hence, a larger particle-size binder is required to create a cohesive product with the NAGM for use in any specific layer within a pavement structure. Ordinary binders, such as a bitumen emulsion, contain particle sizes from 1 µm to 5 µm (± 1000 times larger than an NS). Polymers of similar sizes are available in the market that could fulfil the same role.

A bitumen emulsion's quality depends on several aspects, including the manufacturing process and the quality of the emulsifying agent (James, 2006; Baumgardner, 2006). Different emulsifying agents could have a meaningful impact on the test results of granular material stabilised with an emulsion, as illustrated in Figure 2 (Jordaan & Steyn, 2021c). Figure 2 shows the results of the Retained Compressive Stress (RCS = $\%(UCS_{wet}/UCS_{dry})$ (Jordaan & Steyn, 2019, 2021a) and Retained Tensile Strength (RTS = $\%(ITS_{wet}$/ITSdry) (Jordaan & Steyn, 2019, 2021a) of eight different anionic bitumen emulsions supplied by five different suppliers within the Gauteng area of South Africa. The only difference between the different products, all manufactured within the SANS specifications (SANS, 2014), is the type and quality of the emulsifying agent used. It is seen that the use of a lesser quality emulsifying agent (usually also the less expensive product) could result in a reduction of more than 60 per cent in the RCS and up to 40 per cent in the RTS. It follows that implementing an EPS, with the risk being put on the contractor and his supplier, could also benefit traditionally available stabilising agents to ensure that the best quality products are constantly being supplied and used as a basis for tendering for the provision of transportation infrastructure. In the absence of an EPS, where price will be the only criterion used to evaluate tenders, the lowest cost (usually also based on the worst product in terms of potential bearing capacity) will be the most competitive, with dire consequences regarding required engineering criteria.

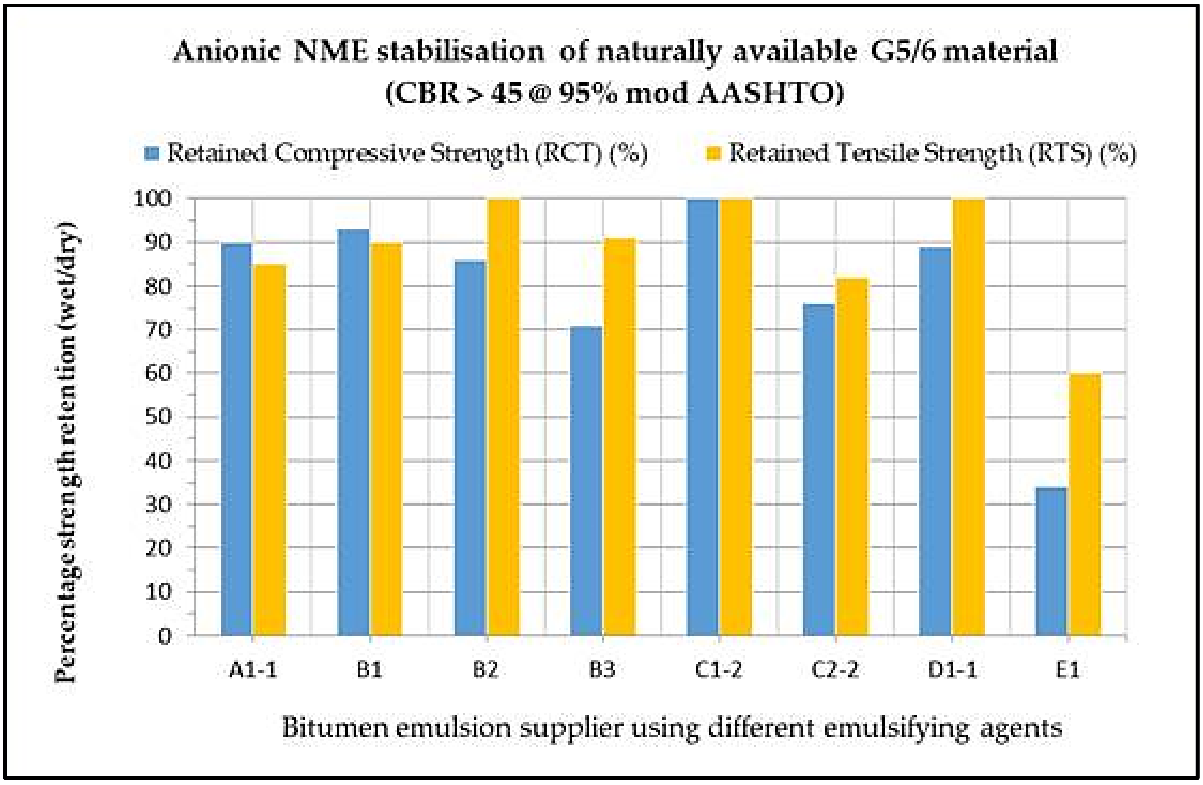

Figure 2: Comparison of the RCS and RTS test results of eight different emulsions as supplied by five different suppliers using different emulsifying agents

5. MATERIALS AND SPECIFICATIONS

5.1 Materials Specifications

The recommended EPS criteria for material test results are given in Table 1. The generally available material tests indicate engineering requirements, i.e., the Unconfined Compressive Strength (UCS) indicates the compressive strength and the Indirect Tensile Strength (ITS) indicates the material's tensile strength. The durability of the MC-NME stabilised material is increased through the level of hydrophobicity achieved (Jordaan and Steyn, 2021b), denying water access to the granular material and, hence, preventing or at least limiting, the possibility of in-situ weathering of the NAGM through chemical decomposition. The material's durability is a function of the Effective Retained Compressive Strength ($RCS_{effective}$) and the Effective Retained Tensile Strength ($RTS_{effective}$), as shown in Table 1. Although only the UCS and ITS wet criteria are specified in Table 1, both the dry (after the rapid curing process) and the wet UCS and ITS tests need to be done as discussed under the "Test protocols".

The compilation of Table 1 (Jordaan & Steyn, 2019; 2020; 2021a) considers several aspects concerning MC-NME stabilisation to be included in an EPS. Only the following items are addressed in this paper, i.e.:

- Identification of different material classes (NME1 to NME4) to be used in a pavement structure as a function of the required bearing capacity in terms of the design traffic loading;
- Specification of the required engineering properties in terms of tolerable stresses and strains (UCS and ITS minimum criteria) for the different material classes (NME1 to NME4); and
- Stability of the MC-NME on site.

Table 1: Minimum criteria specified as indicative of engineering requirements for different quality materials as an output from the pavement design

Test or Indicator	Material[1]	Material classification			
		NME1	NME2	NME3	NME4
Minimum material requirements before stabilisation and/or treatment (Natural materials)					
Material spec. (minimum) Unstabilised material: Soaked CBR[2] (% of MDD)	NG /(CS)	> 45[2] (95%) ACV < 30%	> 25[2] (95%)	> 10[2] (93%)	> 7[2] (93%)
Grading Modulus (GM)	NG	> 1.5	> 1.0	-	-
	GS	NA	> 1.0	-	-
Sieve analysis: % < 0.075 mm ($P_{0.075}$)	ALL	< 25 %	< 35 %	< 50 %	-
XRD scans: - Total sample - 0.075 mm fraction ($P_{0.075}$)	ALL ALL	Required Required	Required Required	Required Required	Required Required
% Material passing 2 µm ($P_{0.002}$) (e.g., Clay & Mica & Talc) as a % of the 0.075 mm fraction (with Talc <10%) (XRD-scans of the material passing the 0.075 mm sieve are used to determine the % clay, mica and talc in the material)	NME stabilisation with micro-meter (µm) emulsion particle sizes				
	ALL	< 15 %	< 15 %	< 15 %	< 15 %
	NME stabilisation with emulsion containing micro-scale as well as nano-scale particles (adjusted according to material grading)				
	ALL	NA	< 35 %	< 35 %	< 35 %
	NME stabilisation with emulsion containing nano-scale and pico-scale particles (grading adjustments) together with technologies addressing the workability of materials on site				
	ALL	NA	NA	> 35 %	> 35%

Table 1: Cont'd

Test or Indicator	Material[1]	Material classification			
		NME1	NME2	NME3	NME4
Material specifications after stabilisation and/or treatment					
In-situ density to be required after stabilisation and compaction (% of MDD)	Base	> 100 %	> 100 %	> 98 %	> 97 %
	Sub-base	NA	> 98 %	> 96 %	> 95 %
DCP(DN mm/blow)(Quality control) (stabilised and compacted)	DCP-DN	NA	NA	< 3.0	< 3.5
CBR as % of MDD (for laboratory testing)		> 100 %	> 100 %	> 100 %	> 100 %
*UCS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 2 500**	**> 1 500**	**> 1 000**	**> 750**
	Construction[4]	**> 2 200**	**> 1 200[5]**	**> 700[5]**	**> 450[5]**
Retained Compressive Strength (RCS): (UCS_{wet}/UCS_{dry}) (%)	RCS	> 85	> 75	> 70	> 65
RCS in relation to minimum $UCS_{wet(criteria)}$ = $RCS_{effective}$ = (RCS x ($UCS_{wet}/UCS_{wet(criteria)}$)) (%)	RCS-E	>100	> 90	>85	> 80
*ITS_{wet} (kPa) (150 mm Φ Sample)	**Design[3]**	**> 240**	**> 200**	**> 160**	**> 120**
	Construction[4]	**> 220**	**> 180[5]**	**> 140[5]**	**> 100[5]**
Retained Tensile strength (RTS): ITS_{wet}/ITS_{dry} (%)	RTS	> 85	> 75	> 70	> 65
RTS in relation to minimum $ITS_{wet(criteria)}$ = $RTS_{effective}$ = ((RTS x ($ITS_{wet}/ITS_{wet(criteria)}$)) (%)	RTS-E	>100	> 90	> 85	> 80

[1]CS – crushed stone; NG – natural gravel; GS – gravel soil; SSSC – sand, silty sand, silt, clay.
[2]CBR is only used as a reference to traditionally used test procedures as a broad first indicator and is normally unrelated to the engineering properties achievable using an MC-NME stabilising agent
*Definitions: UCS = Unconfined Compressive Strength; ITS = Indirect Tensile Strength);
UCS_{dry}; ITS_{dry} = testing after rapid curing; UCS_{wet}; ITS_{wet} = testing after rapid curing and 4 hours in water (as per test procedure specified for the testing of cementitious stabilising agents (SANS 3001-GR32:2010, 2010));
Design[3] = Minimum criteria to be met in the laboratory during the design phase
Construction[4] = Minimum criteria to be met during construction as part of quality control
[5]Criateria based on reference TG2 (Asphalt Academy, 2009)

5.2 Rationale Behind the Material Specifications in an EPS

The potential engineering strength criteria achieved with the MC-NME stabilisation of a NAGM are mainly independent of traditional granular material classification systems (e.g., COLTO, 1985; AASHTO, 1995). The potential bearing capacity of an MC-NME stabilisation is, to a large extent, a function of the (Jordaan, 2019, 2021a):

- Mineralogy of the NAGM in line with the findings of the built environment (Weeler, 2005) dating back to the early 1800s (± two hundred years age), i.e. the:
  - primary minerals comprising the formation of the ANGM (type of stone) and
  - secondary minerals within the NAGM formed over the years due to weathering due to chemical decomposition.

The specification of and emphasis on, the wet test results is not related to any climatic design conditions (these are dealt with during the application of a detailed design process) but is directly related to the durability of the materials in terms of hydrophobicity achieved during the stabilisation of the NAGM using an MC-NME stabilising agent. By implication, it will also be related to the climate resiliency of the MC-NME stabilised NAGM, even under loading conditions during wet conditions without any protective surfacing ($RCS_{effective}$). In-situ weathering through the chemical decomposition of granular material within road structures is not a new concept, even in relatively dry climatic zones, for all material classes, including high-quality crushed stone materials.

It has recently been shown during a rehabilitation design that a G1 (COLTO, 1985) quality base layer material decomposed within 22 years to an equivalent G4 – G6 (COLTO, 1985) material in the Gauteng area of South Africa (personal experience). Similarly, over 25 years, a C4 (COLTO, 1985) cement-stabilised layer deteriorated in situ to an equivalent G8 (COLTO, 1985) quality material in the same province (personal experience). Any granular material which still has access to moisture in an equilibrium moisture condition (including in layers stabilised using traditional stabilising agents such as cement, lime, unmodified bitumen emulsion and foam bitumen) can be subjected to chemical weathering, even over a relatively short period such as the normal design periods of a road pavement structure. It follows that a high percentage of hydrophobicity will give a high level of resistance to water access to the granular particles in the material and, hence, a high level of protection against weathering due to chemical decomposition as well as a high level of protection against excess water under flash flood conditions.

The recommended criteria in Table 1 are conservative, given the proven potential of MC-NME stabilising agents (Jordaan et al., 2017; Akhalwaya & Rust, 2018; Jordaan & Steyn, 2019). However, these criteria allow for inclusivity and generally applicable guidelines of NME stabilising agents as per the broader definition to be evaluated on an equal basis, incorporating criteria applicable to unmodified bitumen emulsion stabilisation (Asphalt Academy, 2009; Jordaan 2011) with stricter requirements in terms of required hydrophobicity as a function of long-term durability. In addition, provision is made to consider laboratory conditions versus field conditions, where higher criteria must be met under controlled conditions in a laboratory. These additional provisions incorporated into the recommendations ensure minimising the risk of implementing agencies introducing new technologies under NME stabilising agents. When the technology has been successfully introduced into the industry, these "strength" criteria may be revisited to (in future) further optimise the use of NAGM.

5.3 Test Protocols

The recommended test procedures must be clearly defined within the EPS, with no exceptions allowed, to enable fair and meaningful comparisons between various products available on the market. The recommended test procedures are as close as possible to those already specified in existing specifications to enable ease of comparison between different products. The test protocol requires oven temperatures not exceeding 50º C. The following recommended material test procedures should be included in any EPS (Jordaan & Steyn, 2019, 2020):

The following material test methods shall be used for the testing of NME stabilising agents or equivalent (engineering properties in terms of UCS and ITS values):

- As an input into the testing of the UCS and ITS of the material, the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) are to be determined using routine prescribed test procedures contained in existing specifications (SANS, 2015); and
- The testing of the Unconfined Compression Strength (UCS) (SANS, 2010a) and the Indirect Tensile Strength (ITS) (SANS, 2010b) of the stabilised materials shall be done according to existing specifications with some minor alterations. The entire protocols are detailed as follows.

In all prescribed specifications (SANS, 2015), the +37.5 mm material must be screened off and discarded. The aggregate passing the 37.5 mm sieve and retained on the 20.0 mm sieve must not be crushed and must be used in the testing process. A pH test must be performed to determine the acidity/alkalinity levels of the material.

The curing and testing process of the 152 mm diameter samples (127 mm high) shall be as follows:

The NME stabilising agent is mixed in with the construction water, and the sample is prepared at Optimum Moisture Content (OMC), considering the full fluid content of the NME stabilising agent. For example, suppose the OMC of the material is 8 per cent, and 1 per cent of the material-compatible NME stabilising agent is added and the in-situ moisture content is 3 per cent. In that case, adding (8-3) 5 per cent moisture should be added to the material to achieve OMC. The 5 per cent to be added will consist of a mixture of 4 per cent construction water and 1 per cent NME per total requirement.

No cement or lime is added to an MC-NME stabilised material (unless specified by the supplier). Hence, the samples are not placed in plastic bags to assist with the hydration of the cement (as per usual, Bituminous Stabilised Materials (BSM) designs which contain cement as an additive and hence, the samples need to be placed in plastic bags in the oven during the rapid curing process to assist in the hydration of the cement in the mix):

- The 152 mm diameter by 127 mm height samples are to be prepared as per specification (SANS, 2010a) to determine the UCS of Compacted and Cured Specimens of the MC-NME mix, and
- The 152 mm diameter by 127 mm height samples are to be prepared as per specification (SANS, 2010b) to determine the ITS of the compacted and Cured Specimens of the MC-NME mix.

The following procedure is followed during the rapid curing of an MC-NME mix:

1. Preparation and curing with the following changes:
   - When no cement is used as part of the MC-NME stabilising agent, the samples will not be enclosed in a plastic bag. (Plastic covering is required when cement is included in the mix to assist in the hydration of the cement), and
   - Samples are cured for 24 hours in an oven at 22 - 25°C before being subjected to a "rapid curing" process in an oven for 48 hours at 40 - 45°C (temperatures in the oven must NOT exceed 50°C).
2. After 48 hours, the samples must be allowed to "cool off" for twenty-four (24) hours. This is preferably done in the oven at 22 - 25°C for 24 hours.
3. Directly after the "cooling off" period, three (3) samples each must be crushed to determine the ITS and UCS values. The values obtained are called the ITS_{dry} and the UCS_{dry} values.
4. Six (6) samples must be placed in a bath of water at a temperature of 22 to 25°C for four (4) hours (as per the test procedure specified for the testing of cementitious stabilising agents (SANS, 2010) and after that removed from the bath and allowed to drain off excess water before determining the ITS_{wet} and UCS_{wet} values. The values obtained are called the ITS_{wet} and the UCS_{wet} values.

5. If approved by the Engineer, the “wet” tests (UCS and ITS) may suffice during the quality control during construction. For the lower-order roads (Category D and E), DCP tests (< 3.5 mm/blow for the base layer and < 5.5 mm/blow for the sub-base for an NME 4 (Table 1) material specification) at randomly selected spots, may be approved for quality control as approved by the Engineer.

6. During the design stage, three samples each (twelve (12) in total) must be preserved outside the moulds at an ambient temperature (22 -25ºC) for 28 days. After 28 days, the UCS (wet and dry) and the ITS (wet and dry) should be tested as described above. The results of the 28-day tests should not show a decrease in the tested values of the respective UCS and ITS tests (dry and wet) compared with results obtained after the rapid curing process (an increase in tested UCS and ITS values is usually expected with the use of an MC-NME stabilising agent).

7. It is important to note that sample preparation must be done in strict compliance with the prescribed procedures, and NO deviation will be allowed, including:
   - The moulds in which the samples are prepared are not to be treated with grease or any other lubricant to facilitate easy removal of the sample as this could influence the loss of moisture or seal the sample and hence, the measurements of UCS and ITS;
   - No additional soaking of samples in any “covering” liquid or any other material will be allowed as this will make any comparison and application of test requirements invalid and not comparable with what is practically achievable during construction, and
   - The compaction process, as detailed in the SANS specification (SANS, 2010a; SANS, 2010b), shall strictly be adhered to.

5.4 Stability of an NME Stabilising Agent on Site

The EPS must contain guarantees as to the on-site stability of any proposed NME stabilising agent. Conditions in practice in remote areas are often unpredictable, with numerous aspects that could result in delays during construction. Hence, guarantees as to the stability of the NME material for at least four months should be written into an EPS. These guarantees will be required as a pre-requisite for any proposed NME stabilising agent under often harsh environmental conditions in the middle of the summer and/or winter. The NME stabilising agent should show no visible sign of separation (no discolouring or particles floating on top or settling on the bottom) of the various components, with no increase in viscosity during storage on site before use. It has been demonstrated that high-quality MC-NME stabilising agents could meet this requirement with once-a-week maintenance by the supplier (circulation within ample storage facilities for up to a year has remained stable with no marked increase in viscosity). The required stability is of particular importance when using NME stabilising agents consisting of Nano-Polymer Nano-Silane (NPNS) components where the undiluted product (before addition to the construction water) can show signs of conglomeration of the different components in the mix when the preparation is not done with the required knowledge and quality control. In such cases, in-situ stabilisation will become difficult, and the engineering properties specified in the ESP for the layer works of the required material class, as contained in Table 1, will not be met.

6. ADDITIONAL PRACTICAL REQUIREMENTS FOR NME STABILISATION

6.1 Clean Equipment

Any NS modifying agent is a reactive agent (like cement and lime). Hence, any residue from previous works left in water tankers and other equipment will be activated in the presence of an MC-NME stabilising agent. Water tanks and other equipment must be thoroughly cleaned before use with an MC-NME stabilising agent containing a reactive agent that can chemically react with old residue. Practical experience has shown that most problems on site at the start of any project can normally be associated with equipment containing some residue from previous works (Jordaan & Steyn, 2019; Jordaan & Steyn, 2022b).

6.2 Reworking of Layers That Did Not Meet the Engineering Requirements

Reworking of layers (Jordaan & Steyn, 2019, 2022b) due to MC-NME stabilised NAGM sections not meeting the specified criteria contained in Table 1 for a specific material class presents no problem. The layer is reworked in a way similar to any emulsion-stabilised layer. The nano-silane modification reduces the Optimum Moisture Content (OMC) by about 10 per cent (depending on the percentage of problematic minerals within the material). The layer is reworked, adding half of the original MC-NME content into the construction water while re-working a specific road section. Experience has shown that optimum compaction is usually achieved at 0.5 to 1 per cent below OMC. Due to the initial treatment, the construction water mix is now mainly used as a lubricant during compaction with minimum water absorption in the NAGM due to the initial stabilising process.

7. CONCLUSIONS

The potential benefits in terms of bearing capacity, durability and cost of the use of naturally available Granular Materials (NAGM) stabilised with a Material Compatible New (Nano) Modified Emulsion (MC-NME) have been proven over the last decade in laboratories through Accelerated Pavement Tests (APT) and in practice. However, several products are on the market, not all of which have the same quality and material compatibility. In addition, introducing new technologies could also lead to the re-emerging of old “snake oils” under the broad definition of MC-NME stabilising agents. The potential introduction of sub-standard stabilising agents could harm the road industry and deter agencies from using new technologies.

To prevent the introduction of substandard products under the auspices of MC-NME stabilising agents, it is recommended that the industry introduces an “End Product Specification” (EPS) where the contractor and supplier will guarantee that the use of their product will meet the necessary specifications as contained in the EPS.

This paper discusses the main aspects to be contained within such an EPS and specifically addresses the rationale behind these specifications. Special attention is given to the recommended material specifications for the recommended different NME material classes to be specified within a pavement structure as a function of the design traffic loading. The specifications of these material classes are independent of traditionally used material classification systems and depend mainly on the mineralogy of the NAGM, the particle sizes of the various components of the stabilised mix, the quality of the modifying agent, and the binder used.

8. REFERENCES

Akhalwaya, I & Rust, FC. 2018. Laboratory evaluation of road construction materials enhanced with nano-modified emulsions (NME). Proceedings of the Southern African Transportation Conference (SATC2018), Pretoria, South Africa.

American Association of State and Highway Transportation Officials (AASHTO). 1995. M145-91: Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes, Published by the American Association of State Highway and Transportation Officials (AASHTO), Washington DC, USA.

Asphalt Academy. 2009. Technical Guideline (TG2), South Africa.

Baumgardner, GL. 2006. Asphalt Emulsion Manufacturing Today and Tomorrow, Transportation Research Board, Transportation Research Circular, Number E-C102, Washington, DC., USA.

British Standards Institution. 1954. Selection of road aggregates in the field, In British Standard BS 882; British Standards Institution: London, UK.

Committee of Land Transport Officials (COLTO). 1985. Draft TRH14: Guidelines for Road Construction Materials, National Institute for Transport and Road Research (NITRR), CSIR: Pretoria, South Africa.

James, A. 2006. Overview of Asphalt Emulsion. Transportation Research Board, Transportation Research Circular, Number E-C102, Washington, DC, USA.

Jordaan, GJ. 2011. Behaviour of an Emulsion Treated Base (ETB) layer as determined from Heavy Vehicle Simulator (HVS) Testing, Proceedings of the 10th Conference on Asphalt Pavements for Southern Africa (CAPSA 2011), Drakensberg, South Africa.

Jordaan, GJ & Kilian, A. 2016. The cost-effective upgrading, preservation and rehabilitation of roads – optimising the use of available technologies, Proceedings of the Southern African Transport Conference (SATC 2016), Pretoria, South Africa.

Jordaan, GJ, Kilian, A, Du Plessis, L & Murphy, M. 2017a. The Development of Cost-effective Pavement Design Approaches using Mineralogy Tests with New Nano-Technology Modifications of Materials, Proceedings of the Southern African Transport Conference (SATC 2017), Pretoria, South Africa.

Jordaan, GJ, Kilian, A, Muthivelli, N & Dlamini, D. 2017b. Practical Application of Nano-Technology in Roads in southern Africa. Proceedings of the 8th Transportation Technology Transfer (T2) Conference, Lusaka, Zambia.

Jordaan, GJ & Steyn, WJ vdM. 2019a. A Comprehensive Guide to the Use of Applicable and Proven Nano-Technologies in the Field of Road Pavement Engineering Design and Construction, Department of Civil Engineering, University of Pretoria: Pretoria, South Africa, 2019; ISBN 978-0-620-83022-5.

Jordaan, GJ & Steyn, WJ vdM. 2019b. Testing of granular/soil characteristics for the optimisation of pavement designs using reactive stabilising agents, including “new-age” nano-technologies, Proceedings of the Conference of Asphalt Pavements for Southern Africa, CAPSA19, Sun City.

Jordaan, GJ & Steyn, WJ vdM. 2020. Cost-effective Upgrading of Gravel Roads using Naturally Available Materials with Anionic New-Age Modified Emulsion (NME) Stabilisation," published through the University of Pretoria, Department of Civil Engineering, distributed through www.lulu.com, ISBN 978-0-620-91415-4.

Jordaan, GJ, Steyn, WJ vdM & Broekman, A. 2021a. Evaluate cost-effective modified binder thin chip and cape seal surfacings on an anionic nano-modified emulsion (NME)-stabilised base layer using accelerated pavement testing (APT), *Appl. Sci.,* 11:2514. 2021. Doi: 10.3390/app11062514.

Jordaan, GJ & Steyn, WJ vdM. 2021b. Nanotechnology Incorporation into Road Pavement Design Based on Scientific Principles of Materials Chemistry and Engineering Physics Using New-Age (Nano) Modified Emulsion (NME) Stabilisation/Enhancement of Granular Materials, *Appl. Sci.,* 11:8525. 2021. Available at: https://doi.org/10.3390/app11188525.

Jordaan, GJ & Steyn, WJ vdM. 2021c. Fundamental principles ensuring successful implementation of new-age (nano) modified emulsions (NME) for stabilising naturally available materials in pavement engineering, *Appl. Sci.,* 11:1745. 2021. Available at: https://doi:10.3390/app11041745.

Jordaan, GJ & Steyn, WJ vdM. 2021d. Engineering Properties of New-age (Nano) Modified Emulsion (NME) Stabilised Naturally Available Granular Road Pavement Materials Explained using Basic Chemistry, *Applied Sciences,* 11(20):9699. 2021. Available at: https://doi.org/10.3390/app11209699 .

Jordaan, GJ & Steyn, WJ vdM. 2021e. Nanotechnology in road pavement engineering: Introduction, Webinar Workshop on Application of Non-conventional pavement materials and NDT in road infrastructure - Current practice and Future trends, Kolkata, India.

Jordaan, GJ & Steyn, WJ vdM. 2022a. Practical Application of Nanotechnology Solutions in Pavement Engineering: Construction Practices Successfully Implemented on Roads (Highways to Local Access Roads) Using Marginal Granular Materials Stabilised with New-Age (Nano) Modified Emulsions (NME), *Applied Sciences* 12(3):1332. 2022. Available at: https://doi.org/10.3390/app12031332.

Jordaan, GJ & Steyn, WJ vdM. 2022b. Practical Application of Nanotechnology Solutions in Pavement Engineering: Identifying, Resolving and Preventing the Cause and Mechanism of Observed Distress Encountered in Practice during Construction Using Marginal Materials Stabilised with New-Age (Nano) Modified Emulsions (NME), *Appl. Sci.,* 12:2573. 2022. Available at: https://doi.org/10.3390/12052573.

Jordaan, GJ. Steyn, WJ vdM & Horak, E. 2023. Pavement design concepts based on the principles of flexible pavements design incorporating New (Nano) Modified Emulsion (NME) technologies for the stabilisation and optimisation of the use of naturally available granular materials, Proceedings of the Conference for Asphalt Pavements for Southern Africa (CAPSA 2023), Drakensberg, South Africa.

Kidgell, MM, Steyn WJ vdM & Jordaan, GJ. 2019. Effect of Nano-Modified Emulsions (NME) (nano-silanes) stabilisers on the properties of Dolomite, Proceedings of the Southern African Transportation Conference (SATC 2019), Pretoria, South Africa.

Rust, FC, Akhalwaya, I, Jordaan, GJ & Du Plessis, L. 2019. Evaluation of a nano-silane-modified emulsion stabilised base and subbase under HVS traffic, Proceedings of the 12th Conference on Asphalt Pavements for Southern Africa (CAPSA 2019), Sun City, South Africa.

Rust, FC, Mahoney, JP & Sorenson, J. 1998. An International View of Pavement Engineering. Paper presented at the 1998 Bearing Capacity of Roads and Airfields Conference meeting in Trondheim, Norway.

Rust, FC, Smit, MA, Akhalwaya, I, Jordaan, GJ & Du Plessis, L. 2020. Evaluation of two nano-silane-modified emulsion stabilised pavements using accelerated pavement testing, *Int. J. Pavement Eng*., 2020. Doi: 10.1080/10298436.2020.1799210.

South African Bureau of Standards. 1976. Aggregate from natural sources, In *SABS Specifications* 1083-1976 (as Amended 1979), South African Bureau of Standards: Pretoria, South Africa.

South African National Standards. 2010a. SANS 3001-GR53, Civil Engineering Test Methods: Determination of the Unconfined Compressive Strength of Compacted and Cured Specimens of Cementitiously Stabilised, SABS Standards Division: Pretoria, South Africa.

South African National Standard. 2010b. SANS 3001-GR54, Civil Engineering Test Methods – GR54: Determination of the Indirect Tensile Strength of Compacted and Cured Specimens of Cementitiously Stabilised Materials, SABS Standards Division: Pretoria, South Africa.

South African National Standards. 2014. SANS 4001-BT3, 2014. Civil Engineering Specifications Part BT3: Anionic bitumen road emulsion, SABS Standards Division: Pretoria, South Africa.

South African National Standard. 2015. SANS 3001-GR51, Civil Engineering Test Methods: Sampling, preparation, compaction and curing of field mixed freshly cementitiously stabilized materials including the determination of the maximum dry density and optimum moisture content, SABS Standards Division: Pretoria, South Africa.

Steyn, WJ vdM. 2021. The upside of disruptive 4IR technology and innovation, University World News – Africa Edition.

Von Ebelman, JJ. 1846. Untersuchungen über die Verbinddungender Borsäure mit Aetther, Ann. Chem. Pharm. 1846, 57:319-353.

Von Hoffman, W. 1961. Stone-preserving processes, Royal Institute of British Architects. Build, 1861, 19:103-105.

Weinert, HH. 1980. The Natural Road Construction Materials of Southern Africa," National Book Printers: Cape Town, South Africa.

Wheeler, G. 2005. Alkoxysilanes and the Consolidation of Stone, The Getty Conservation Institute: Los Angeles, CA, USA.