MATERIAL COMPATIBLE NANO MODIFIED EMULSION (MC-NME) TECHNOLOLOGIES IN SLURRY DESIGN AND APPLICATIONS FOR ROAD SURFACINGS

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ABSTRACT

The use of slurries as an alternative surfacing and maintenance option is well established within the South African roads industry. Following the successful use of anionic Material Compatible Nano Modified Emulsions (MC-NME) for the stabilisation of granular pavement layers, the question was raised whether the same technology could be used to improve the properties of cost-effective surfacings, with specific reference to cost-effective, labour-intensive slurries. The first test section using a slurry containing a modified binder without a cement filler comprising of an anionic Material-Compatible Nano Modified Emulsion (MC-NME) binder without any cement additive as part of a Cape seal, was done in 2018 This MC-NME slurry, based on normal slurry mix design principles, was done in order to test the viability of such an modified binder, while optimising the labour component for road surfacing using rudimentary concrete mixers next to the site of operation and minimum training to achieve the required mix. Subsequently, a laboratory investigation was done to compare test results using a single granular material source to quantify any potential benefits to be achieved using a MC-NME binder in a slurry mix. This paper gives the results of the first comparative tests done on a slurry mix, comparing a MC-NME binder slurry mix to a conventional slurry mix. The results from these initial tests show a considerable increase in several performance properties of a slurry prepared using a MC-NME binder as measured in a laboratory. (e.g. increase in tensile strength). These results give ample motivation for a more comprehensive investigation to fully comprehend and quantify the potential benefits from using a MC-NME binder in a slurry mix and to establish design criteria for MC-NME modified binder slurries.

1. INTRODUCTION

Slurries are used in South Africa as micro-surfacing, thin texture treatments, for rut filling and within the structure of Cape seals and slurry bound macadam seals (SABITA. Manuel 28, 2011). It is considered a low-risk application and ideal for labour intensive projects. However, low binder film thickness, resulting in a poor ability to retard crack reflection and, initial permeability often results in slurries not being selected as surface treatments. Traditional slurry mixes also contain about 1 percent cement that could lead to a relatively low flexibility, leading to early cracking on highly flexible rural roads. Slurry surfacings, with a high labour component could be ideal as a surfacing option on highly flexible rural roads and the periodic maintenance thereof, provided that a mix can be designed with improved characteristics in terms of flexibility and permeability.

Work done over the last decade in South Africa has led to the incorporation of Material Compatible Nano Modified Emulsions (MC-NME) technologies for the stabilisation of naturally available granular materials into official design documents (COTO TRH24, 2024). These technologies have been evaluated through numerous studies for lower order as well as higher order roads through laboratory testing (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., 2021) and in practice (Jordaan & Steyn, 2019a; 2022a; 2022b). The fundamental requirements for the successful application of NME products have been identified and discussed (Jordaan & Steyn, 2019a; 2021a) and scientifically based design concepts have been developed and published in international peer-reviewed reputable journals (Jordaan & Steyn, 2021b; Jordaan & Steyn, 2021c) and conferences (e.g. Jordaan et al., 2023). This work, already done, is to ensure that these technologies can be universally applied without risk to life and the environment, while meeting fundamental engineering requirements. Compared to tradition stabilisation technologies, the use of MC-NME technologies, inter alia, have shown that a considerable increase in tensile strengths (associated with high flexibility) and hydrophobicity (associated with permeability) can be achieved using the developed materials design methodology.

It follows that the use of MC-NME technologies in the design of slurry mixes (excluding the use of cement) could have the potential to increase the flexibility of slurry micro-surfacing while also resulting in a decrease in the permeability of the surfacings. During the testing of the MC-NME technologies, the opportunity also presented to construct and test, in practice, a test section containing a MC-NME binder slurry without any cement additive. This test section was constructed as part of a Cape seal on a newly constructed MC-NME base layer in 2018 (Steyn et al., 2019; Jordaan et al., 2021). The placing of the slurry was done using rudimentary equipment, mixed next to the road and placed using just labour-intensive practices. At the time of the placing of the MC-NME binder slurry in 2018, no comparative laboratory testing was done.

As a result of the successful placing of a MC-NME binder slurry as part of a 20 mm Cape seal, a study was undertaken to do a comparative set of standard tests on a conventional slurry mix consisting of a bitumen emulsion (SS60) with 1 percent cement and a MC-NME binder slurry with no addition of cement. This test aimed to assess the potential impact of the use of a MC-NME binder, especially with regard to its potential application as a maintenance option on highly flexible rural roads. This paper gives the comparative results of the laboratory test results between the conventional slurry mix and the slurry mix using a MC-NME binder without any cement. Considerable benefits in terms of an increase (for example) in tensile strength is shown, that is significant in addressing the low flexibility of traditional slurry mixes (mentioned before). This study gives ample positive data, warranting a more comprehensive study to quantify the potential benefits using a MC-MNE binder and the development of design guidelines for incorporation into official design documents.

It is noted that this paper does not address the use of slurry in practice and is purely aimed at determining the potential benefits of the use of a modified binder in the manufacturing of a surfacing slurry. The application of any warrants for the use of slurries are addressed in full in existing documents (SABITA Manuel 28, 2011).

2. MATERIALS AND SLURRY TESTING AND MIXING

2.1 Summary of Laboratory Testing

Table 1 gives a summary of all the tests done on the granular materials used to obtain a type 2 micro-texture slurry as well as the various tests done on the slurry mixes.

2.2 Granular Material Characteristics Used in the Slurry Mixes

Granular materials from the Rooikraal Crusher Plant, East Rand (Brakpan) was sampled and blended to meet the specification of a Type 2 micro surfacing slurry, consisting of:

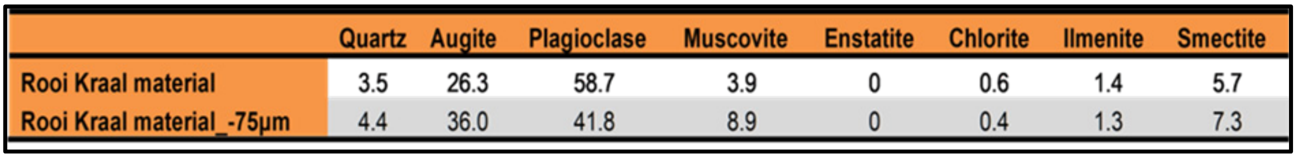
- 10.0 mm Aggregate.
- 7.1 mm Aggregate.
- Crusher dust.

SABITA Manual 28 (SABITA, 2011) was used to blend the granular material to obtain the final mix. In line with the basic recommendation for MC-NME designs (Jordaan and Steyn, 2019; 2021c), the mineralogy of the granular materials is crucial in the design of a MC-NME binder. The XRD scan and analyses of the granular mix is given in Table 2 with the grading of the blended granular material used in the slurry mixes shown in Figure 1. The grading of the materials is shown together with the recommended grading envelopes for a Type 2 micro surfacing slurry (SABITA Manuel 28, 2011).

Table 1: Summary of all laboratory tests done on the materials and slurry mixes

Material Source	Rooikraal Quary, East rand, Brakpan
Sample Description/ Condition:	Fine & Coarse aggregate samples and cement were received in sealed containers. Emulsion samples were received in 20L containers and potable water from the lab was used, thus material loss and contamination were unlikely.
Deviation/Irregularity from test method:	N/A
Total number of pages:	1
Tests carried out:	***Test Methods:***
Sample Riffling	TMH5 MD1
Sieve Analysis	SANS 3001-AG1
Sand Equivalent Test	SANS 3001-AG5
Sieve Analysis	SANS 3001-AG1
BD + MVD	SANS 3001: AS10 + ASH
Methylene Blue Test #	SANS 1243.
Loose Bulk Density of Aggregate #	TMH1 B9
BD, AD & Water Absorption	SANS 3001: AG 21
Wet track Abrasion Test	ISSA TB-100 (2017)
Load Wheel Test	ISSA-TB109 (2005)
X-Ray Diffraction	
Modified Marshall of Micro surfacing & Slurry Seals	ISSA TB-148 (2005)

Table 2: Mineralogy of the blended granular material used in the slurry mixes



	Quartz	Augite	Plagioclase	Muscovite	Enstatite	Chlorite	Ilmenite	Smectite
Rooi Kraal material	3.5	26.3	58.7	3.9	0	0.6	1.4	5.7
Rooi Kraal material_-75µm	4.4	36.0	41.8	8.9	0	0.4	1.3	7.3

The mineralogy scans contained in Table 2 shows that the material consist mainly of minerals that could be subjected to weathering over time. A very small percentage of the granular material consists of quarts, the only mineral not subjected to chemical weathering. Problematic minerals within the mix (i.e., Muscovite and clays) comprises between 15 and 20 percent of the fines passing through the 0.075 mm sieve. Thes problematic minerals need to be neutralised in the design of a MC-NME mix to ensure that the risk of using this blend of granular material will not result in future problems with regard to expected performance of the slurry mix. This approach is an obvious advantage using a MC-NME design approach versus a conventional design approach.

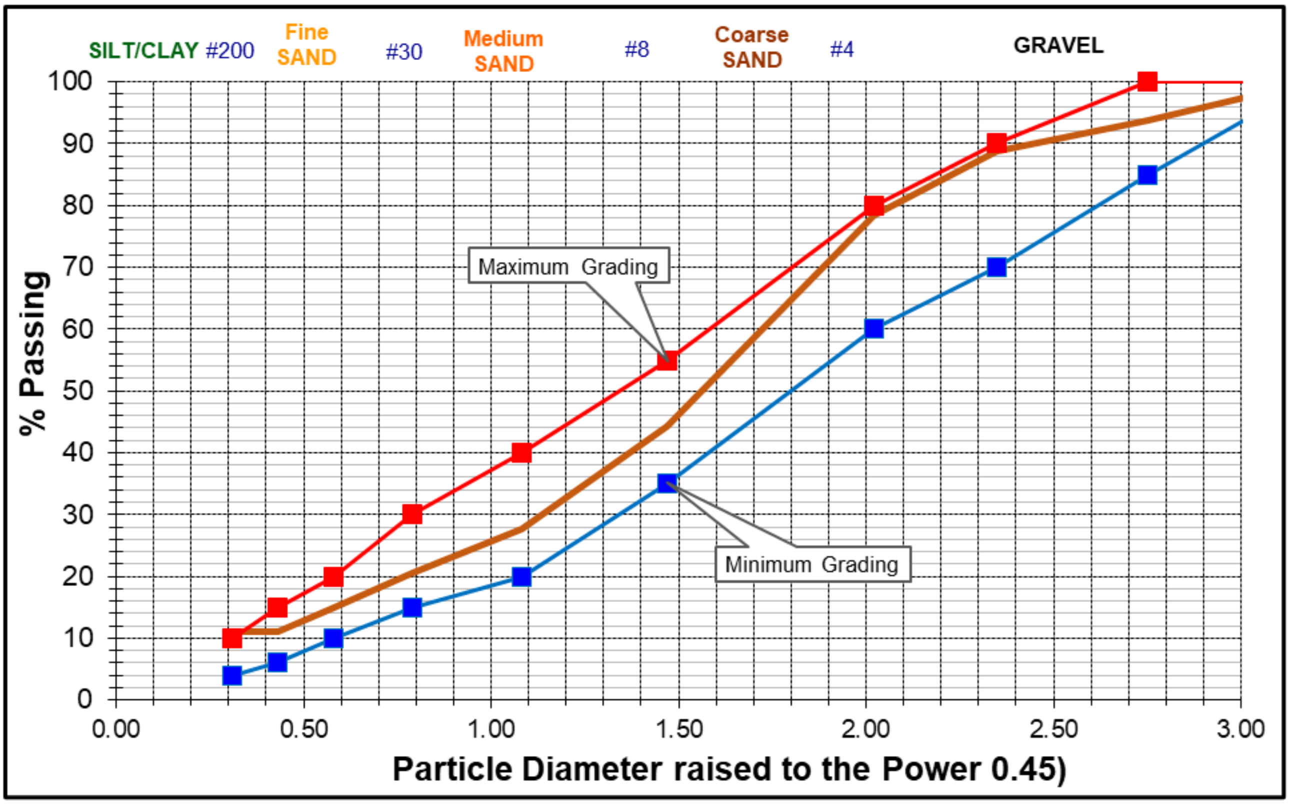


Figure 1: Grading of the blended granular materials used in the within the grading envelope for a Type 2 micro surfacing slurry (SABITA Manuel 28, 2011)

2.3 Binders Used in the Slurry Mixes

The binder used in the Conventional Slurry mix consisted of:

- SS60 bitumen emulsion and various percentages, and
- 1 per cent cement.

The binder used in the MC-NME slurry mix consisted of:

- SS60 bitumen emulsion modified with 1.5 per cent anionic nano-silane.

3. SLURRY MIX DESIGN

3.1 General Comments – MC-NME Slurry Mix Design

Similar to conventional slurry, the design of micro surfacing requires evaluation of the aggregate grading and properties as well as the minimum binder content to prevent raveling (SABITA Manual 28, 2011). However, in line with the design developed for the MC-NME stabilization of granular materials (COTO TRH24, 2024), additional testing was required to determine the quantity of the required nano-silane modifier.Multiple exercises of slump test were done to achieve a proper and suitable mix with the recommended quantity of the “break control” additive and visual observation would confirm if the designs were appropriate (refer Figures 2 and 3).

Note: Care needs to be taken when mixing the MC-NME binder with water. The nano-silane and bitumen emulsion must be blended with the water prior to mixing onto the sample. This will give a homogenous mix to ensure that no segregation of the aggregate fractions occur and that all aggregate particles are fully covered. The mixing time before breaking for a micro surfacing should be at least 90 seconds.

Note: No pre-wetting of the sample material should be done when mixing a MC-NME binder to obtain a slurry mix.

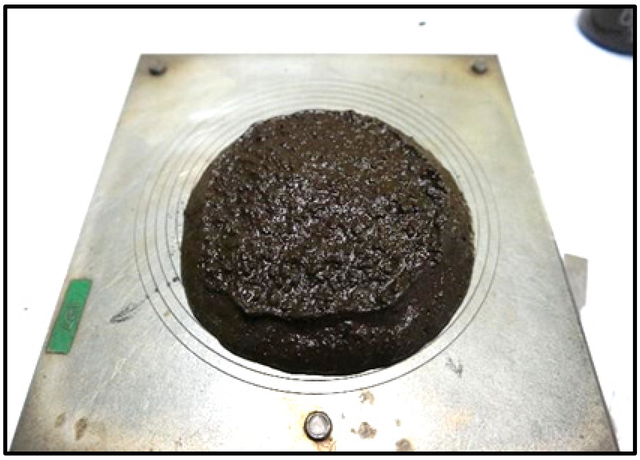


Figure 2: Slump of 35 – not suitable for design

Figure 3: Slump 20 – suitable for design

3.2 Methylene Blue Absorption Test

The purpose of the Methylene blue test is to verify the degree of electrostatic attraction between emulsion and the aggregate. With the testing of the conventional mix design a value of 6 was obtained. Values from 6 to 8 indicate a workable mix design.

4. MIX PROPERTIES OF THE CONVENTIONAL AND MC-NME SLURRIES

4.1 Mix Preparation of the Slurry Mixes

The water addition and the bitumen emulsion content for the conventional and the MC-NME slurry mixes are shown in Figures 3 and 4. These mixes are prepared for comparative testing.

From Figure 4, it is seen that considerably less water is required when mixing a MC-NME binder to obtain a slurry mix. This is to be expected due to the hydrophobicity achieved with the nano-silane modifier. Hence, water absorption into the aggregate is largely prevented through the coating of each granular particle with a 3-dimensional nano-silane shield that is hydrophobic in nature. Figure 5 shows that the residual bitumen content of the MC-NME binder is almost 10 percent higher than that of the conventional slurry. This can be explained due to the smaller bitumen particles created during the modification thereof during the introduction of the nano-silane. The smaller particles result in a slight increase in the bitumen content within the binder.

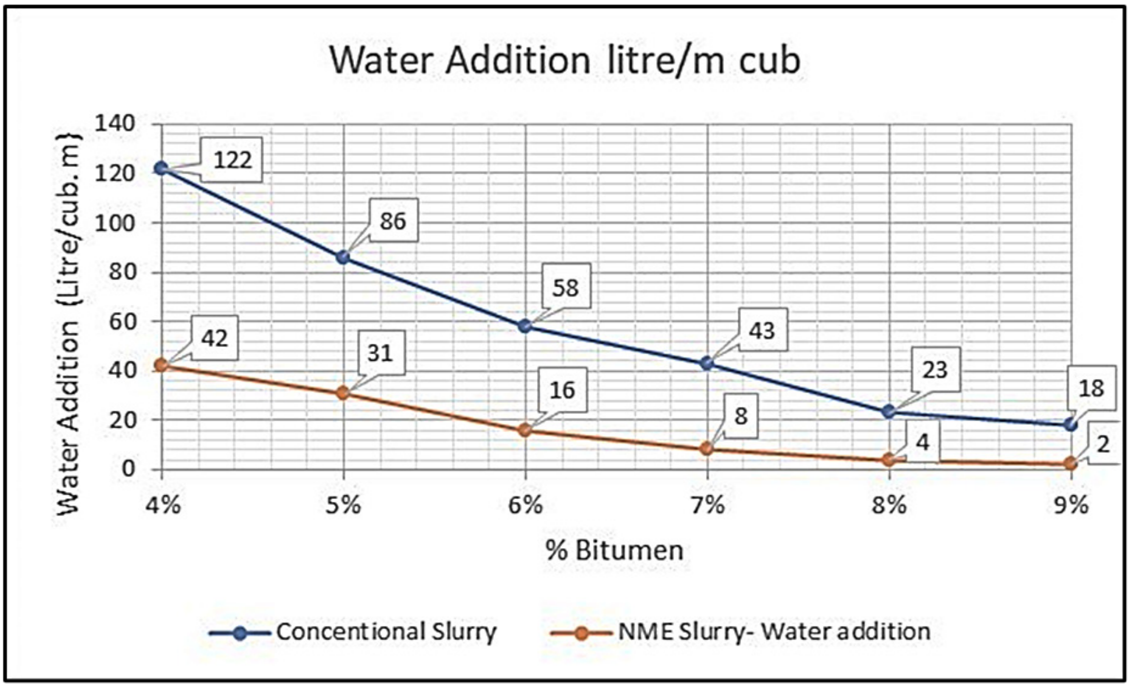
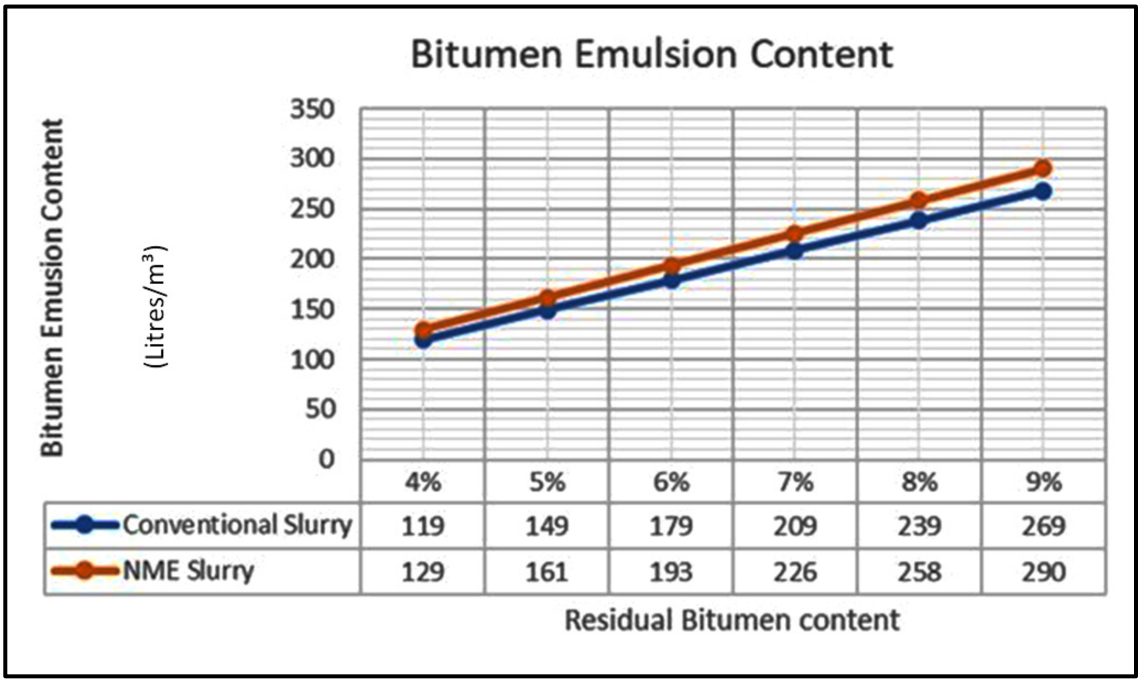


Figure 4: The Water addition in litres/m^3 for the conventional versus the MC-NME slurry mixes

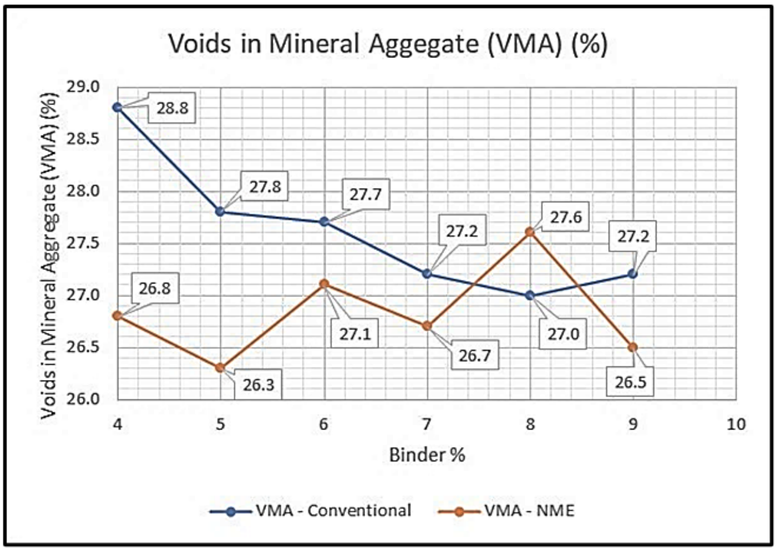


	4%	5%	6%	7%	8%	9%
Conventional Slurry	119	149	179	209	239	269
NME Slurry	129	161	193	226	258	290

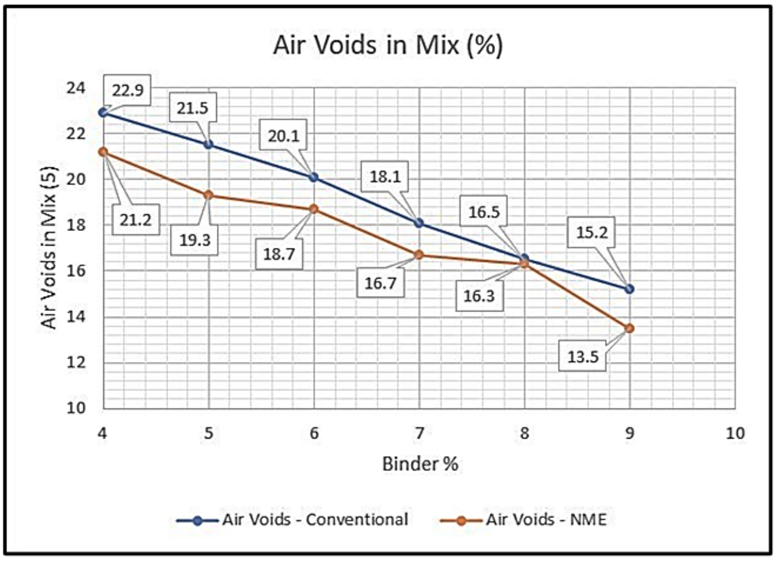
Figure 5: Bitumen emulsion content for the conventional and MC-NME slurry mixes

4.2 Basic Void Content Comparison Between the Slurry Mixes

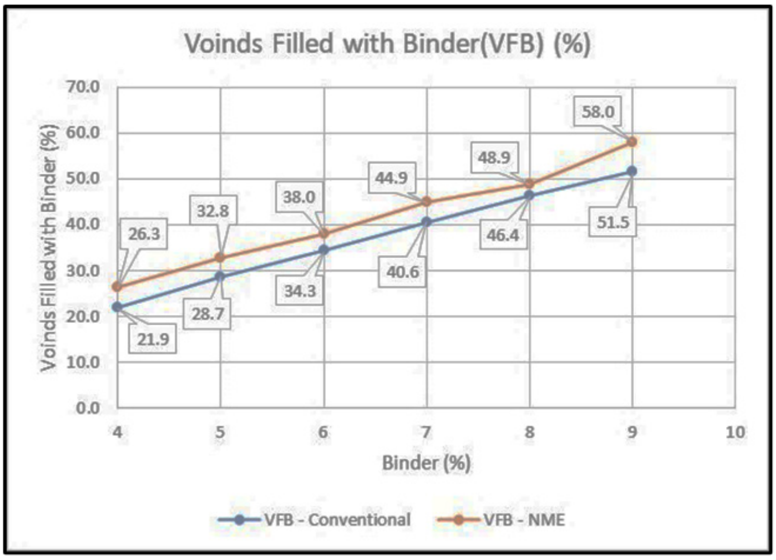
The comparative voids and filled voids in the conventional and the MC-NME mixes are show in Figures 6 (a), 6(b) and 6(c).



(a) Voids in Mineral Aggregate



(b) Air Voids in Mix



(c) Voids filled with binder

Figure 6: Comparative voids in the conventional and MC-NME slurry mixes

Figure 6 shows that more a MC-NME binder results in less voids within_the slurry mix. Less voids will contribute to a decrease in the permeability of the slurry mix (over and above the hydrophobicity that are being introduced through the addition of an anionic nano-silane).

4.3 Density of the Slurry Mixes

The comparative densities of the conventional and the MC-NME slurry mixes are shown in Figures 7 and 8. It is seen that the densities of the MC-NME slurries exceed that of the conventional slurry mix designs. These results are in line with the results shown in Figure 6.

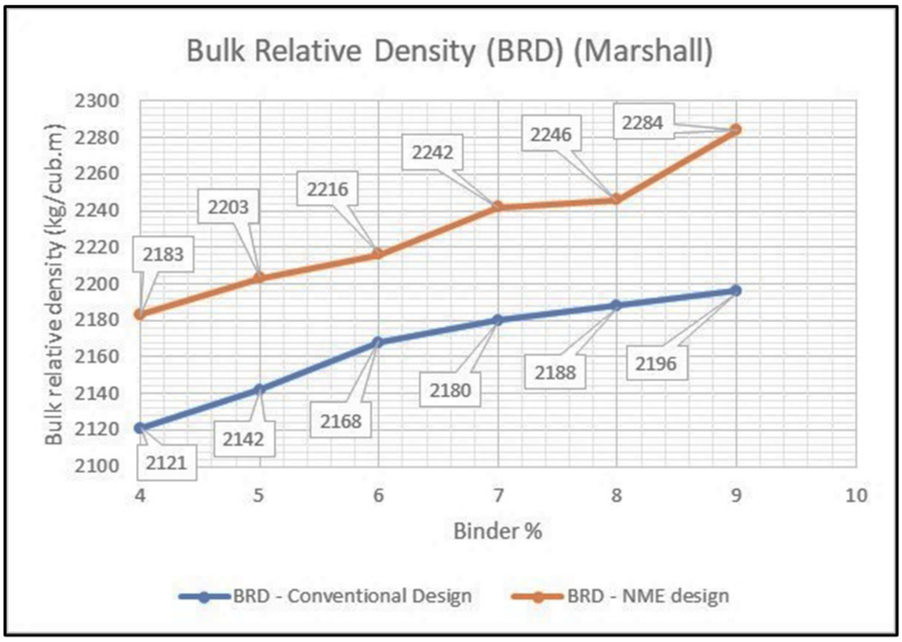


Figure 7: Bulk Relative Density (BRD) (Marshall) of the conventional and the MC-NME slurries

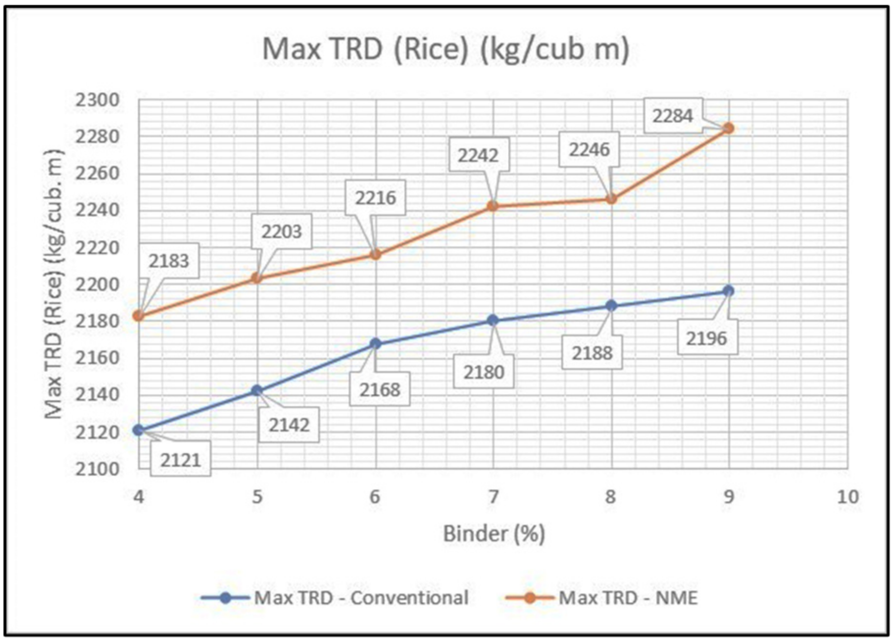


Figure 8: Maximum TRD (Rice) of the conventional and the MC-NME slurry mixes

Figures 6 and 7 clearly indicates that a denser mix is obtained with the introduction of the MC-NME binder in the slurry mix. In line with the previous results, this will in practice result in a less permeable surfacing.

5. PERFORMANCE TESTS DONE ON THE SLURRY MIXES

5.1 General

The following tests were performed on both the conventional slurry mix and the MC-NME slurry mix:

- Wet track abrasion test.
- Wheel load test.
- Modified Marshall tests of the slurry seal specimens.

5.2 Wet Track Abrasion Test to Assess the Resistance to Loss in Aggregate)

The Wet track abrasion test (ISSA TB-100, 2017) measures the wearing quality of the slurry surfacings under wet abrasion conditions. This test is of specific value for micro-surfacing, but not the slurry as part of a Cape seal. In the case of a Cape seal the slurry is a filler between the single seal and hence, the slurry may not be subjected to the abrasion actions of wheels.

Three samples of each percentage of binder were prepared for each of the designs and tested. The average of the test results for both the conventional and the NME slurries are shown in Figure 9.

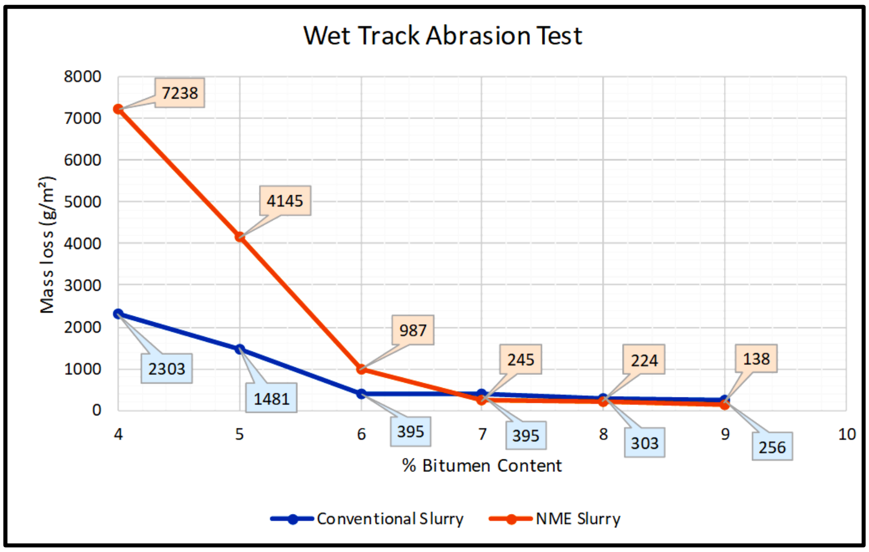


Figure 9: Comparative results for the Wet Track abrasion tests

From Figure 9 it is seen that at lower percentages binder (>7 per cent) the NME slurry is gives worse results than a conventional slurry. The NME Slurry at 7 per cent (38 per cent less loss in mass) and more outperformed the conventional slurry. This can be explained by the smaller bitumen particles (as previously discussed), resulting in shear between the bitumen particles and lower binder content. These results should be verified.

Optimum emulsion and water content for different type of slurry applications should be finalised based on a combination of all the test results including the wheel load and Indirect Tensile Strength (ITS) results.

5.3 Load Wheel Test

In the Wheel load test slurry samples are subjected to a loaded rubber-tyre reciprocating wheel. The aim of this test is to determine the shear (deformation or rutting) behaviour of the slurry mix at different percentages of binder. Both cracking and deformation characteristics of the slurry samples at different binder contents are determined.

The result of this test is compared in Table 3. Figure 10 gives a visual indication of the comparative condition after wheel loading of the slurry samples with binder contents from 5 to 8 per cent.

Table 3: Results of the Wheel load test

Loaded Wheel Test	4%		5%		6%		7%		8%		9%	
No. of Runs r/Sec (25min)	1200		1200		1200		1200		1200		1200	
Load applied (Kg)	56.7		56.7		56.7		56.7		56.7		56.7	
	NME	Con	NME	Con	NME	Con	NME	Con	NME	Con	NME	Con
Depth occurred (mm	6.7	Broken	4.2	6.10	3.4	6.30	3.1	4.40	2.8	5.20	2.7	4.90
Crack/No Crack (Visual)	No	Broken	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No
Bleed/No bleed (Visual)	No	No	No	No	No	No	No	No	No	No	Yes	No
The LWT is a traffic simulating device which produces the approximate compaction effort of one million vehicle passes in less than 25 minutes when loaded with 125 pounds (56.7kg) of lead shot weight												
Con = Convectional slurry mix NME = MC-NME slurry mix												

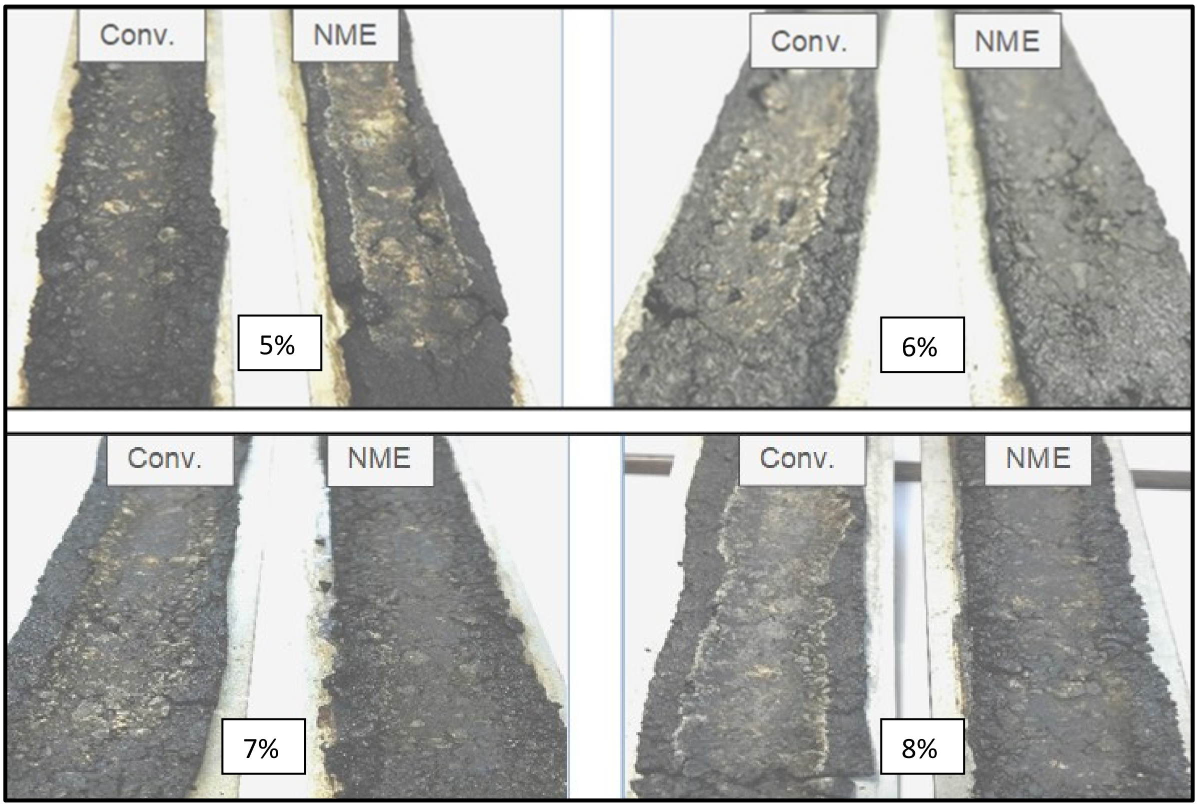


Figure 10: Visual condition of the comparative slurry samples after wheel loading at binder contents from 5 to 8 per cent

Table 3 shows that the MC-NME slurry (even under relatively low binder contents) give superior results than that of the conventional slurry mix. This is expected due to the chemical bonds created between the binder and the aggregate through the addition of the nano-silane modification. The cracking noticed at higher percentages of binder will be due to a shear between binder particles.

6. INDIRECT TENSILE STRENGTH (ITS) RESULTS

The results of the ITS measurement of the conventional and the MC-NME slurry mixes are shown in Figure 11. It is shown that at 5 percent binder content the MC-NME slurry mix already exceeds by some margin, the maximum ITS results obtained with the conventional mix at a binder content of 7 percent. At 7 percent binder content, the ITS of the MC NME slurry mix is more than double of the conventional mix.

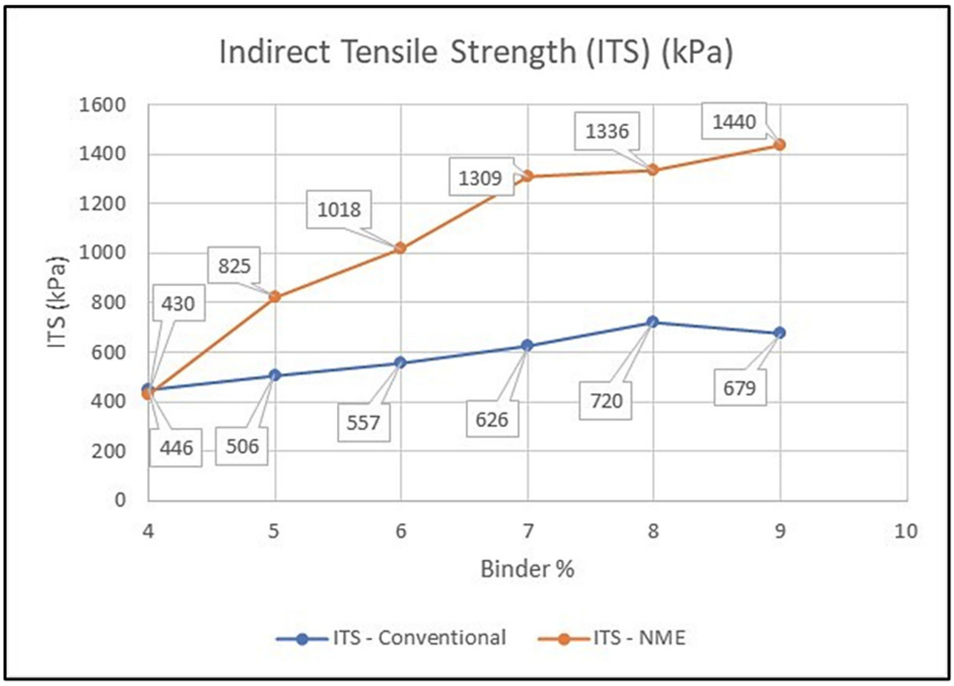


Figure 11: Indirect Tensile Strength (ITS) results of the conventional and MC-NME slurry mixes

7. DISCUSSIONS

The comparison between the conventional slurry mix and the alternative using a Material Compatible Nano Modified Emulsion (MC-NME) binder with no cement shows promise in terms of the various comparative laboratory tests performed. The laboratory tests can be summarised as follows:

- Considerably less water needs to be added to the MC-NME slurry mix to obtain a workable mix (Figure 3).
- More voids are filled with the binder in the MC-NME slurry mix (Figure 6c) resulting in less remaining air voids in the slurry mix (Figure 6b) – less voids should, in practice result in a less permeable surfacing.
- The MC-NME slurry mix constantly shows higher densities than the conventional mix at all binder percentages (Figures 7 and 8). A denser mix should similarly, in practice result in a less permeable surfacing.

- The Wet abrasion tests only show improved performance of the MC-NME at a binder content between 6 and 7 percent upwards.
- The load wheel test shows better deformation and cracking results by the MC-NME slurry at binder contents from 4 to 9 percent (Table 3).
- The ITS results of the MC-NME slurry exceed, the results from the conventional mix by some considerable margin (Figure 11). Hence, in practice, the MC-NME slurry results should provide a much higher tolerance against the formation of cracking on highly flexible pavements.

8. CONCLUSIONS

The use of an anionic Material Compatible Nano Modified Emulsion (MC-NME) binder in the design of a road surfacing slurry shows improved mix design and performance characteristics compared to that of a conventional slurry mix. The anionic MC-NME binder consisted of a bitumen emulsion (SS60) modified with a anionic nano-silane that is adjusted to be compatible with the granular material in the mix. It is of note that no cement is used in the anionic MC-NME slurry mix. The laboratory tests indicates that the anionic MC-NME slurry should, in practice be less permeable than a conventional mix with a higher percentage of voids filled with the binder and less air voids present in the mix. Due to the introduction of the nano silane modifier, creating a 3-dimensional hydrophobicity to the slurry mix, the end should result in a less permeable surfacing.

Of particular interest from a performance point of view is that the anionic MC-NME slurry has been tested to have a considerable higher Indirect Tensile Strength (ITS) compared to that of the conventional mix (more than double at a binder content of 7 percent). These results is similar in line with results found with the stabilisation of naturally available granular materials for use in the upper layers of a pavement structure. The higher ITS results should be indicative of a higher resistance to the formation of cracking.

The results contained in this paper is based on the testing of one material (an anionic MC-NME) in a laboratory. However, the results clearly lay the foundation and warrants for a more comprehensive study to determine the probable benefits to the introduction of a MC-NME binder in the preparation of surfacing slurries. This work needs to be verified in the field and duplicated in laboratories to verify the results for incorporation in guideline documents for general implementation.

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