LESSONS LEARNT FROM IMPLEMENTATION OF NANO MODIFIED EMULSION TECHNOLOGY ON STREET REHABILITATION ON A RECENT SANRAL FUNDED COMMUNITY DEVELOPMENT PROJECT

E HORAK[1]*, J KABALE[1], Z NDODANA[1], F Le ROUX[2], T MATHEBULA[3] and R OERLEMANS[3]

[1]Ndodana Consulting Engineers (Pty) Ltd; *E-mail: emileh@global.co.za
[2]Nyeleti Consulting Engineers (Pty) Ltd
[3]SANRAL Northern region, SANRAL (SoC)

ABSTRACT

The SANRAL funded research on unconventional soil stabilisers identified Nano Modified Emulsion (NME) as effective and viable natural soil and gravel stabilisation options. The inclusion of NME in the new Draft (2022/23) TRH 24 established NME technology as cost saving option to upgrade low traffic volume gravel roads to surfaced standards. NME treated material makes natural or marginal quality granular materials water proof and flexible versus the negatives of cracking and potential crushing of cement treated material. A Community Development Project (CDP), linked to the current SANRAL upgrade and special maintenance contracts on the R504 (Wolmaransstad to Leeudoringstad and to Bothaville) offered an opportunity to do upgrades to various streets. A budget of R30 million was set aside for such CDP street upgrade and rehabilitation of selected badly deteriorated streets in these towns. A variety of NME technologies were designed for implementation. The traditional single seal or Cape seal was used as surfacing on the surfaced streets. Cement treated base type construction was also done for comparative purposes as well as gravel preservation treatment of some lower traffic volume streets. There are various lessons learnt by the collective team involving client, consultant and contractor plus community based local contractors as sub-contractors.

Keywords: End use specification, Nano-silane, Nano Modified Emulsion (NME), Nano Polymer Nano Silane (NPNS), Clear seal, XRD, Community Development Project.

1. INTRODUCTION

1.1 Contextual Social-Political Background

Ndodana Consulting Engineers (Pty) Ltd (NCE) were appointed by South African National Roads Agency SOC Ltd (SANRAL) for the Consulting Engineering Services for the rehabilitation and strengthening of National Road R504 Section 3 from Wolmaransstad (km 0.0) to Leeudoringstad (km 28.9) with a total length of 28.9 km. The contractor appointed is Tau Pele Construction (Pty) Ltd. Nyeleti Consulting Engineers (Pty) Ltd was appointed on the special maintenance of R504-4 stretching from Leeudoringstad to Bothaville. The contractor appointed there is Actop-Phambile Surfacing-Mvule Joint Venture. The Community Development Project (CDP) funding provided by SANRAL was pooled for both SANRAL projects for CDP work in Wolmaransstad, Witpoort and

Leeudoringstad. All these towns fall in the Maquassi Hills local municipality as identified in the locality map in Figure 1. The implementation was designed and project managed by NCE and the managing contractor was Tau Pele.

Figure 1: Maquassi Hills Local Municipality location map

Road and street conditions in rural towns in South Africa lately show significant distress and deterioration due to longer term lack of maintenance and the correct technically qualified staff (Lawless, 2017). The N12 portion of the main street through Wolmaransstad previously deteriorated to a severe distressed condition with much negative social media coverage. In 2021/22 SANRAL used the R504-3 contract and contractor (Tau Pele) to execute an emergency project to restore and repair approximately 2km of the N12 portion that runs through Wolmaransstad. The funding came from the National Department of Transport (NDoT) with a contract value of R27 million. This emergency improvement had significant positive impact on the business community of Wolmaransstad. The N12 portion was subsequently transferred to SANRAL ownership in 2023.

Like various rural towns in South Africa, other bituminous surfaced streets in Wolmaransstad, as well as Leeudoringstad, fell into severe disrepair over time, became dysfunctional due to lack of basic maintenance and clearly are in need of urgent rehabilitation. Typical forms of distress observed were potholes, loss of bituminous surfacing and in some cases even washaways of the base and surfacing. The distress forms were mostly severe and extensive over the whole street length of these towns. The various forms of distress observed are portrayed by the collage of images in Figure 2 from Wolmaransstad streets directly after seasonal rains. It is clear an innovative solution to the restoration of the street network was needed.

Figure 2: Collage of typical worst case street condition illustration

1.2 The Community Development Project Context

SANRAL regularly sets aside an amount for community development linked to major rehabilitation and rural road upgrade projects. This is particularly applicable and aimed at rural areas and rural towns, such as Wolmaransstad, Witpoort and Leeudoringstad. The intent is to do community development with the purpose of improving life and living conditions in such rural settings with the added benefit of creating job opportunities for local small contractors. The rehabilitation of the streets in these three towns thus fit the ideal description and aim of a Community Development Project (CDP).

The CDPs are designed to be community and Small Medium and Micro Enterprise (SMME) contractor friendly. This CDP project was put together for various small sub-projects suiting a tender and construction methodology with low technical hurdles to maximise these SMMEs involvement. The projects in this case focused on road/street maintenance and rehabilitation actions that will improve a number of streets in the affected communities. The SANRAL CDP “implementation rules” evolved during design phase. The rule introduced late during the design phase was that streets or the street network must be linked to existing SANRAL assets/roads. In the targeted towns other streets with obvious need for rehabilitation or upgrade to surfaced standards could also not be linked to a SANRAL road and were not included on the list of identified projects. It was clear there remain a number of streets in these towns that could also have benefitted from the CDP intervention, but the small budget limited possible inclusion.

The Maquassi Hills local municipality political leadership, did play a significant role in identification and prioritising of streets as potential projects. Sensitivity had to be displayed as need for upgrade of streets in these townships far exceed what can be done with the limited budget, thus community preferences had the highest weight in the prioritisation of streets to be rehabilitated.

2. TECHNOLOGY ASSOCIATED WITH THE NANO MODIFIED EMULSION (NME)

2.1 Background

New research outcomes/output funded by SANRAL on Alternative Modifiers of Granular Materials have now reached the technology transfer and implementation phase. The use of nano-silanes originating from building rock facade protection against the environment had built up a remarkable track record (Jordaan & Steyn, 2022). This technology had recently been implemented in soil and gravel road stabilisation with clear evidence of construction efficiency and cost savings. The focal point is the Nano-silane technology which is fully described in various research papers and publications (Jordaan & Steyn, 2020). This new innovative application in Nano-Modified Emulsion (NME) as an alternative soil and gravel stabilisation treatment received a significant implementation boost with their inclusion in the new draft TRH 24 (November 2022) guideline design document. Even though such gravel roads relate mostly to very low to low structural traffic classes it has also been shown to provide low risk solutions for potential use of in situ recycled lower quality materials also traditionally described as marginal materials. Jordaan and Steyn (2020) in their handbook on NME design and utilisation indicate via catalogue of designs that NME treated base and subbases can accommodate up to ES30 traffic classes (up to 30 million equivalent standard 80kN axles (MESA)).

2.2 Material Requirements

Nano Modified Emulsion (NME) using the benefits of the nano-silane for chemical bonding and water proofing had been developed as a special type of a Bitumen Stabilised Materials (BSM) as described in TG 2 (2020). NME application had been well researched and reported in peer reviewed papers and lately been included in the afore mentioned TRH 24 (2023). NME treatment has no cement, has a lower bitumen content, but has strong chemical bond with the silica (Si) in typical soils and gravels. NME treated lower quality base materials (e.g. even a G8, with CBR between 10% and 15%at 93% Mod AASHTO density) had been tested with an accelerated pavement test (APT), the Heavy Vehicle Simulator (HVS) (Rust et al, 2019&2020), giving it very credible performance evaluations. Subsequently a number of provincial roads were designed and constructed successfully with quantified good performance and cost savings (Jordaan et al., 2023).

The NME achieves a strong durable bonded lower quality natural gravel and soil material. This enables significant cost reductions by the use of in situ marginal or lower quality granular materials with proven production rate improvements during construction. The fundamental aspect of minerals in the soil or gravel are determined by X-Ray Diffraction (XRD) testing and analysis (Jordaan & Steyn, 2017, 2020, 2021). XRDs are done to determine the quantum and presence of Si minerals as main chemical bonding mineral. It also determines secondary deleterious minerals present which normally would be problematic even with cement stabilisation. In this case though nano size (10^{-9} m) of the silane particles ensures a deep penetrating and homogenous mix in and encapsulation of the deleterious secondary minerals.

The very high specific area aspect of the nano silane particle size significantly contributes to natural granular materials (even clays) be made moisture resistant (water phobic). A strong chemical bond with Si in the soil and gravel ensures high structural strength with the modified emulsion. Bitumen emulsion droplets bond very effectively with the silane, thus strongly bonded to the soil or gravel particles. Strength is gauged via Unconfined Compressive Strength (UCS) tests as well as Indirect Tensile Strength (ITS) tests.

Therefore, standard soil laboratory testing for design and QA/QC purposes are used and no special testing, equipment or evaluation techniques are required.

The design criteria or specification per NME type (NME1 to NME4) are described in TRH 24 (2023). Wet strength UCS and ITS (in red) are the main criteria used during the design stage. Durability is monitored via the wet/dry ratios of the UCS and ITS expressed as Retained Compressive Strength (RCS) and the Retained Tensile Strength (RTS). Note NME treatment needs no special equipment or post treatment to construct.

Lower quality natural gravel materials, eg below G6 quality to typically G8 , as shown in green at the bottom of Figure 4, can be used to produce NME treated material typically on the same level as C4 and C3 cement stabilised materials. (Jordaan & Steyn, 2017, 2020; Jordaan et al., 2023) It is known C4 and C3 respectively requires better quality untreated granular materials with G6 or G5 minimum as quality. As stated before the comparative NME2, 3 and 4 quality materials are achieved via material with qualities as low as a G8 material (CBR between 10 and 15).

Lower quality natural gravel materials, eg below G6 quality to typically G8, can be used to produce NME treated material (Jordaan & Steyn, 2017, 2020; Jordaan et al., 2023). Their strength values are typically on the same level as C4 and C3 cement stabilised materials. It is known C4 and C3 respectively requires better quality untreated granular materials ith G6 or G5 minimum as quality. As stated before the comparative NME2, 3 and 4 quality materials are achieved via material with qualities as low as a G8 material (CBR between 10 and 15).

3. TREATMENT DESIGNS FOR STREETS

3.1 Street Categories

A variety of street classes identified for NME treatment were identified in Witpoort, Leeudoringsstad and Wolmaransstad. As previously described these streets met the SANRAL asset linkage requirement and the priorities set by the local political and society role players. The streets identified covered a range of traffic volumes. They were classified as follows (UTG 3, 1988; CSIR, 2007):

1. The very low volume access gravel streets on the **bottom of the traffic volumes or very low traffic volumes** centred around Witpoort streets. Traffic volumes on these streets are often even below 5 vehicles per day (vpd). These streets fulfil basic mobility and access needs with lots of cattle and foot traffic.
2. The vast majority of streets in Leeudoringstad and Wolmaransstad have a **closer fit to the basic access streets definition of below 75 vpd**.
3. At least three streets identified for rehabilitation in Leeudoringstad **classify as a classical collector street.** The traffic on these streets consists mostly of seasonal grain transport with big trucks going to the silos in Leeudoringstad. Their traffic can be defined as per the TRH4 classification (1996) as >700vpd (medium traffic volume with many heavy vehicles). Therefore their traffic class is in the order of up to 3 MESA or the ES3 traffic class.

The NME type treatment of the three towns streets are summarised as shown in Table 1. The NME treatment was designed to cover surface protection only or just gravel preservation (Horak et al., 2023). The NME treatments were done for 50mm to 75mm deep NME treatment. Only in one case where structural strength was required a 150mm deep recycling and NME treatment with a bituminous surfacing was done. The lowest form of gravel preservation treatment was where gravel roads were recycled, compacted and (Horak et al., 2024) then received a Clearseal (basically a Nano-polymer Nano Silane (NPNS)) as surface protection. This transparent rejuvenator type spray application is normally applied as surface protection and or rejuvenator on asphalt surfaces. All the surfaced roads received a 10mm Cape seal treatment except on a single high traffic volume road where turning movements at intersections required an asphalt inlay.

Table 1: Summary of treatment types

Treatment Type	Treatment Classification	Length of Street (m)	Towns
Preparation with grader and compacted to 98% Mod AASHTO with Clearseal surface treatment	Gravel preservation	920	Witpoort
50mm to 75mm NME gravel streets with clearseal surface treatment	Gravel Preservation	1050 450	Witpoort Wolmaransstad
50mm to 75mm NME old surfaced streets with single seal/cape seal surface treatment	Surface rehabilitation	1015 2840	Leeudoringstad Wolmaransstad
C3/C4 base plus single seal/cape seal surface treatment	Base and surfacing rehabilitation	980 350	Wolmaransstad Witpoort
150mm NME treatment single seal/cape seal surface treatment	Base and surface rehabilitation	1585	Leeudoringstad
Pothole patching with NME treated G5 and Clearseal surface protection	Maintenance and preventative maintenance	4550 2840	Leeudoringstad Wolmaransstad

3.2 Pavement Structures and Materials Classification

Pavement material sampling on the candidate streets were taken and tested in the laboratory. The main classification of the pavement structures was based on a Dynamic Cone Penetrometer (DCP) survey. The DCP sounding expressed as penetration rate (mm/blow) was used to determine typical 150mm thick layers material classification. The base layer quality varied between the best as a G4 (CBR> 80) to the lowest a G7 (CBR between 15 and 25 at 93% Mod AASHTO Density). All of these base material qualities are ideal for NME treatment (Jordaan & Steyn, 2019, 2020, 2021, 2022, 2023 and 2024).

The outcome of this DCP survey is shown in Figure 3 representing the worst 10% example of typical street pavement structures in Wolmaransstad. The better-quality streets had a G4 as base material. Most pavement structures have the benefit of densification and strength in depth which developed over time. The total strength of the pavement structure can be inferred due to the fact that the majority of failures observed are on the surface and in the base. Such failures are mostly caused by environmental factors affecting the base and surfacing layers typically due to drainage, aged brittle asphalt, being cracked (crocodile) and potholed. This often leads to erosion of the cracked asphalt surfacing and potholes formation when seasonal rains occur as the street formation typically form part of the total stormwater system with limited sub-surface piped systems in place.

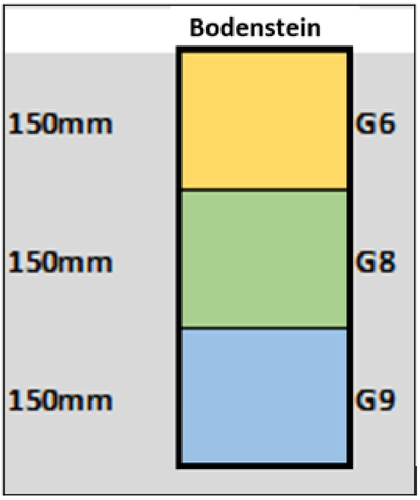

Figure 3: Representative worst 10% street pavement structure

In Table 2 the XRD analysis of a number of the streets are shown. The nano-silane forms a strong chemical bond with the Si (quartz) and is of specific interest. The lowest percentage quartz is 72% indicating al these materials are suitable for NME treatment. The XRD results also show significant mica in the form of Muscovite (up to nearly 20%) in some of the street base samples. Under normal circumstances this may be red flag, but one of the claimed or professed benefits of NME treatment is the encapsulation of such potentially deleterious secondary minerals. This is basically due to the specific area aspect of the nano-size silanes and nano silane in the modified emulsion allowing better penetration of finer graded soils and gravel and also making it water phobic.

The results from an example laboratory tests with NME treatments are shown as example in Table 3. It is clear the criteria or specification for the wet strength UCS and ITS are met as well as the desired RCS and RTS as per specification in TRH 24 (2023). The RAG benchmark criteria used for the colour superimposition is (Red-fail, Amber-warning and Green-sound). The materials clearly made the NME 3 class with some marginal values on the RCS. The low traffic volumes on most of the streets actually only require a NME4 quality material and that was what was aimed for to achieve in the construction.

Table 2: Typical XRD results of a selection of streets

XRD element analysis								
Source	**Quartz,**	**Musco-vite,**	**Micro-line,**	**Kao-linite,**	**Plagio-clase**	**Chlorite**	**Epi-dote**	**Geothite**
Witpoort Smit street	71.8	18.2	6.3	3.8	0	0	0	0
Witpoort Rissik/ Voortrekker streets	73.7	19.2	4.9	2.2	0	0	0	0
Makwasie McMillan street	82.4	3.6	5.1	1.7	5.3	0	0	1.8
Wolmaransstad hole 1	85.6	6.8	2.6	1.5	3.6	0	0	0
Wolmaransstad hole 2	81.5	6.9	10.4	0	0	0.70	0.5	0
Wolmaransstad hole 3	68.2	2.2	14.7	14.9	0	0	0	0

Table 3: NME treatment end specification results

Treatment	ITS dry (kPa)	ITS wet (kPa)	UCS dry (MPa)	UCS wet (MPa)	RTS (%)	RCS (%)	NME class
1% NME	270	170	4.11	3.10	75%	63%	NME 3/4
1.2% NPNS	335	260	5.09	2.9	78%	57%	NME 3/4

4. CONSTRUCTION AND PROCESS CONTROL

4.1 Overview on Construction Process

The construction of the NME treated streets was preceded by initial trails on the Witpoort streets. These streets are close to the construction site offices. This close proximity made communication, sample moisture contents, NME mix preparation, and equipment adjustment easier. The streets in Witpoort are all gravel streets and as previously reported only gravel preservation measures were implemented on these streets (Horak et al., 2024). In Figure 4 a collage of images illustrates aspects of the construction on such streets in Witpoort. Preparation work was done with a grader by ripping and blading of 150mm thickness of base material, compaction. The lowest form of gravel preservation was to then spray with Clearseal as the most basic treatment for the very low traffic volume streets (eg <5vpd). Figure 4 also shows some streets in Witpooort where after the top 150mm being ripped and recompacted the NME was mixed into the top 75mm, compacted and afterwards also receiving Clearseal surface application via a converted watercart. These are all defined as low cost gravel preservation and mobility measures for gravel streets (Horak et al., 2024)

Figure 4: Witpoort gravel preserved street: Grader preparation before hand, compaction before recycling, recycler trainn mixing in 75mm thickness NME, compaction with heavy vibratory roller and pneumatic, Clearspray with water cart

The logistics associated with the watercart and spray applications are illustrated in Figure 5. Rapid moisture determination in the laboratory of the street project base material had to be done, providing the calculation for the correct volume of mix water addition to the NME solution to get compaction moisture to just below Optimum Moisture Content (OMC) for the specific length of street to be treated. The correct NME for the layer thickness was added from Flowbins, enough for the specific volume of water for that street length project. An initial use of a water cart did not have the required uniformity and distribution on the road of the final surface spray of Clearseal. Final surface spray of the Clearseal was thus changed and done by hand on the Witpoort streets. It also helped to increase local labour involvement opportunities. On streets in Leeudoringstad and Wolmaransstad, where scale of economies dictated, a spray tanker/distributor was used to ensure uniform spray application was achieved.

Figure 5: Precise water volume measurement in water cart, NME addition from Flowbins, Clearseal application by hand spray, Clearseal accurate spray by spreader and tack coat on prepared surface

Pothole patching was the most labour friendly utilisation of local unskilled labour. Unskilled labour could also be used with the required traffic accommodation. A natural gravel G5 was used to mix with the NME on site (literally on the street surface) and mixed in by hand to form the pothole premix used with the pothole filling. This on site mixing process is demonstrated in Figure 6.

The pothole is cleared of loose material, painted with tack coat on the sides, bottom and rim with NME as demonstrated in Figure 6. Hereafter the G5 and NME pothole fixing pre-mixture is placed in the prepared pothole, compacted to refusal density with a hand tamper and the top painted with NME to ensure a black surface matching surrounding asphalt is provided.

Figure 6: Clockwise, Ease of hand mixing G5 and NME demonstrated, pothole cleared of all loose material, sides and bottom painted with NME, mixed G5 with NME placed in pothole with lips also painted with NME, compacted with tamper, NME painting on top after compaction and large scale production with local labour on Smit Street, Wolmaransstad

Where deeper recycling treatment depth (150mm) was required, such as South and West streets in Leeudoringstad, the recycler preprepared the street by ripping, grading and compacting to correct level. This was then followed by the recycler train with correct water quantity and NME dosage mixed in. This is directly followed with a smooth wheel heavy vibratory roller and finished off with a pneumatic roller. It was noted on other projects a grid-roller was also applied (Jordaan et al., 2023), but it was not deemed necessary on this project. The process on West and South streets where 150mm deep NME was mixed in the existing base and surfacing are illustrated in Figure 7.

Figure 7: Images Clockwise. West street linking to silos Leeudoringstad, compaction behind recycler, completed Botha street with slurry finish

The tack coat applications varied from straight SS60 anionic emulsion and various percentages of NME dilution. In the end the 50% NME dilution gave the best penetration. The original design was a standard tack coat, but this did not work as well as the NME tack coat. In Figure 8 the typical surfacing application of the 10mm seal application is shown in Botha street (Leeudoringstad) and after the slurry application and on the right hand side also West linking to the Silos are shown with a smooth new 10mm Cape-seal application.

Figure 8: Botha street in Leeudoringstad chip spreading and final surface with slurry show good surface on Botha as well as for West street (link to silos)

The same construction processes described above was followed in Wolmaransstad. In Figure 9 various stages of the seal and cape seal application for various streets are illustrated.

Figure 9(a) Borman street chip and spray operation

Figure 9(b) Vrede street chip and spray followed by slurry application in process

Figure 9(c) Bodenstein Street completed with new slurry seal

4.2 Quality Control

The normal QA/QC laboratory testing was done as to be reported in summary later. In Figure 10 it is illustrated after at least one day curing strength gain testing was done in some cases with a Rapid Compaction Control Device (RCCD) (De Beer et al, 1991), but in all cases the Dynamic Cone Penetrometer (DCP) (1998) was used for in situ strength evaluation. Illustration of the DCP testing to determine the average penetration through the top 75mm to 100mm is shown in Figure 10. The visual test of the obligatory water pouring flow test to demonstrate the water phobic characteristic is shown as well as drive by with a fast moving vehicle demonstrating initial dust suppression.

Figure 10: Illustration of alternative testing. RCCD testing, DCP testing, water resistance testing bottom with top dust absence behind travelling car and experimentation with tack coat types and application

5. SUMMARY OF QUALITY CONTROL TESTING

The site laboratory took samples behind the recycler and various Atterberg tests were done on these samples. The typical density measurements, moisture content and record of the actual NME application rates were measured and reported for each length or section constructed daily. The UCS, ITS values were determined for the wet and dry states with the accelerated test procedure described in TRH 24 (2023). The 28 day strengths were also determined to monitor strength gain. At the time of writing this report the latter may not have been available yet.

DCP strength evaluations for the NME treated depths of 50mm, 75mm and 150mm were done. The DN value of penetration rates averages (mm/blow) for such NME layers were determined as required in TRH 24 (2023). DCPs were also taken after 4 days to also monitor the strength gain since actual treatment.

RAG benchmark criteria (as per TRH 24 ranges) were superimposed on the results shown in Table 4 where Wolmaransstad and Leeudoringstad results are shown. Witpoort was used as trail section and processes and procedures for laboratory testing were still sorted out during this trail sections period. Testing protocol of sampling and actual testing improved from Witpoort to Leeudoringstad and eventually running like a well oiled machine when Wolmaransstad was done last. More detail reporting in the official completion report will be available soon to update this initial set of control information.

Table 4: Summary results of NME treatments on Wolmaransstad and Leeudoringstad

		Density	DCP pen rate (mm/blow)		UCS (rapid cure)		RCS	RCS	ITS		RTS	RTS in
		Mod AASHTO	Rapid	4 days	MPa	MPa	wet/dry	In relation	kPa	kPa	(wet/dry)	relation
		97%	<3.5	<3.5	dry	wet		to min	wet	Dry		to ITS
Township	Street				NME3>750	NME 3>450	>65	>100%	>100	NME3>120	>65	>100
	South	90%	3.84	3.5	1995	1207	43.7	120	105	197.5	54.9	80.2
	George (1)	98	4.4	2.69	955	956	45	92.63	127.5	240	53	67.82
	West	97.5	4.43	2.25	2940	1935	67.6	285.77	197.5	265	72.9	105.66
	Botha 1	97.2	4.42	3.18	550	2205	24.7	31	92.5	255	35.9	34.7
	Botha 2	94.8	4.81	3.56	3970	ND	ND	ND	ND	171.48	ND	ND
Leeudoringstad	Neser	93	3.69	2.21	2020	770	38.4	66.04	112.5	222.5	50.53	57.1
	Bodenstein (Potgieter to Kemp)	96.4	5.46	3.07	1875	690	36.9	55.4	95	181.67	52.2	50.27
	Bodenstein (Van Wyk to Kemp)	101.53	6.04	2.33	2195	930	41.3	82.8	98.3	196.67	50	49.2
	Bodenstein (Van Wyk to Van Riebeek	101.04	5.98	1.82	3540	1350	37.3	107.1	193	280	69	133.6
	Bodenstein (Smit to Van Riebeek	98.2	5.25	0.99	2625	1305	51	148.6	175	261.67	67.2	118.2
Wolmaransstad	Bodenstein (Smit to Piet Retief	99.36	5.76	ND	1083.33	2916.67	37.3	89.7	185	313.33	58.2	111.2
	Vrede (Smuts & Potgieter)	93.68	4.75	ND	2630	1200	45.8	121.9	220	305	81.4	158.7
	Vrede (Smits & van Riebeek)	89	14.25	ND	655	1945	31.6	45	76.67	243.33	31.5	24.5
	Vrede (Kemp 7 Potgieter)	91	4.91	ND	1150	2503	217	ND	263	245	115.2	314.1
	Potgieter ((Vrede & van Rensburg)	97.3	5.9		996.7	2086.7	45.5	101	190	285	66.5	127.6
	Piet Retief (Vrede & Bodenstein)	97.4	7.49	3.26	2200	1345	65.2	190.3	175	227.5	75.7	105.9
	Union (Kok&Liejds)	93.4	8.94	4.59	3355	1700	50	193.8	277.5	327.5	84.9	235.2
	Van Riebeek (Kruger & Kok)	97.9	9.32	3.44	2260	1983.3	129.0	603.3	185	200	120.2	215.4
	Borman (Smit & Piet Retief)	98.98	6.12	1.9	3366.7	1310	38.9	114.2	226.7	333.3	68.4	157.5

If Table 4 is viewed it is clear density was a problem to achieve on such short sections. The reason was the conversion from laboratory determined in situ moisture contents to adjusted NME application rates to aim at in situ moisture contents at or just below OMC. Seasonal rains played havoc, burst water pipes, etc caused fluctuations in moisture contents. The measurement technology of the moisture content of the recycler initially did not correspond well with the desired field moisture contents during actual construction. This anomaly was only sorted out towards the end of the fast moving CDP on the Wolmaransstad short street sections. Invariably compaction tended to be on the wet side of OMC . This implied lower density could be achieved as observed in the results.

The recorded values for the TRH 24 end use specifications also show the RCS values generally below specification. This is clearly a direct impact of the lower density. The wet and dry UCS values though tended to meet the designed for NME4 material type in most cases. Therefore the layers showed strength, but the possible durability may still be questioned. The RCS in relation to the wet designed values show a positive Green highlight in general indicating there was strength achieved in the NME treated layer. This value is seen as a better reflection of initial strength and verified with the discussed DCP results discussed before. This strength gain in the NME treated layers was confirmed by the RTS values compared the design wet values also indicating retained strength even when wet. It also confirmed the results for Leeudoringstad still showed the “learning process” while in Wolmaransstad results picked up.

The DCP taken directly after construction invariably reflected a highly lubricated penetration rate (high values). Invariably after 4 days there was significant strength gain meeting the 3.5mm/blow TRH 24 criteria. The latter criteria was thus used as decision tool to guide the fast moving project to limit reworking of streets where density was coupled with low retained (RTS and RCS) values. It became clear NME treatment was more forgiving regarding density achievement by showing good strength gain via the in situ measured DCP penetration rates.

The sampling of a relatively thin 75mm (some times only 50mm) NME treated layer proved to be problematic in terms of representative sampling and may have contributed to often lower than expected UCS and ITS wet values.

6. LESSONS LEARNT

6.1 Cost and Logistics

NME as soil stabiliser product is still new on the market. Currently only a few suppliers could offer the product at short notice in sufficient quantities. It appears due to lack of market competition unit prices may also be on the high when compared with the standard cement stabilization alternative. Typically cement treatment at 3% can be used as reference to attest to this perception. Further to that it was experienced smaller or upstart company suppliers tend to have less of a credit facility with contractors and significant upfront payment were required for mixing the nano-silane and modified binder. This created a situation of limited security for goods (material) actually delivered on site. It is literally a case of the normal Materials on Site (MoS) is preceded by the payment for “materials not yet on site, but in manufacturing”. This is perceived to be risk going forward and more elegant payment with associated up-front payments will need to be developed for such smaller suppliers.

There are no site laboratory tests available for any of the delivered NME type products on site to verify product quality. This aspect is probably not needed as end-use specification aspects are used as per the TRH 24 specifications. It does not mean all products arriving on site will be problem free. It has become clear the mixing of the nano-silane and proprietary modified emulsions are highly dependent of the correct bitumen source, their compatibility and quality. A batch of NME was delivered on site during the first trial sections construction on Witpoort which segregated in the tanker due to this aspect. This links in with the point made above regarding upfront payment and payment for potentially defective MoS. Delivery and product quality aspects may need clearer guidance or specification even if the end specification aspect is the ultimate test of quality. Typically it would require a fast track test in the laboratory to monitor either wet strength only (eg ITS and or UCS). One future supplier, use a ‘Heath Robinson’ test where a sample prepared with the soil and prescribed or designed NME dosage is put in a water bath with a light circular weight on top of it and monitoring the time it takes for the edges break up in the water or not. There may be other fast track type tests that may need to be utilised in similar fashion.

6.2 Construction Process

The construction process followed in most cases required a preparation activity done with the grader via ripping, blading, and compaction as per normal gravel road preparation. In many cases the desperate local residents in the past resorted do pothole filling with concrete. Such concrete lumps had to be removed first to protect the recycler milling drum. In other cases builders rubble, also often with large pieces of concrete, filled up totally eroded base sections. Bodenstein street and Vrede streets are typical examples of washed away sections of the streets in Wolmaransstad. Considerable material quantities had to be brought in as make up material. Discard G2 material from the R504-3 contract could be used and in other cases good quality G5 make up material could be used.

One of the characteristics of such smaller rural municipalities is the total lack of actual qualified technical persons. This is in line with the Lawless (2015) description of local authorities showing significant loss of technical staff components, thus capability to identify, cost and put out maintenance tenders. The result is demonstrated by the simple issue of fixing a water leak prior to actual road work could be done. The contractor, Tau Pele often had to intervene and do such repair work self just to get the actual road preparation work done. Wolmaransstad was also prone to water pipe bursts. Such water pipes were often unknown to the council officials at very shallow depths. Thus they were discovered due to bursts or decoupled, due to the roller actions when already being compacted.

6.3 Ancillary Infrastructure and Drainage

The ancillary street infrastructure is also in a state of neglect and disrepair. Typically kerb stones are missing or broken. Unfortunately, such expensive replacement or repairs could not be included in the current NME rehabilitation interventions. In some cases, eg Wolmaransstad, street lengths were also deliberately only treated like a gravel preservation project. That implies the potholes on such a street section was so numerous in extent that pothole patching could not have any benefit. Therefore former surfaced streets were basically recycled and gravel preserved. This can be seen as a phased approach to allow the municipality to provide a bituminous surface to such streets during a next budget cycle. They will thus have some time to include such upgrade works on their budgets.

No actual stormwater maintenance or repairs could be done and as for the above the same approach was to urge the municipality to prioritise such basic stormwater system repair and maintenance actions. This is a concern as it is clear water that eroded and washed Vrede and Bodenstein streets in Wolmaransstad was caused by dysfunctional stormwater system further up in the town which is accumulated and dumped onto these two streets lower down in the town, leading to the Makwassie spruit.

6.4. Cost Comparisons

This CDP street repairs was always going to have higher cost/m^2 than a rural road. The two main aspects that increase the cost is the short length of streets that increase preparation work, traffic accommodation and general lack of space for storage and mobilising. The prescribe to use large mechanical equipment such as recycler production and associated costs are not favourable for short stop start type links. The fact that the main contractor act as managing contractor helps, but the prescribed involvement of small local contractors is known to have high costs associated with facilitating equipment, training, and fruitful involvement with the projects.

In all cases a grader was needed with the actual preparation work. Considerable hand work was also needed with rubble removal and ill advised community desperation measures of concrete pothole filling removal. The latter is not good for recycler health. Such work as well as general cleaning could be done very well with local contractor labour. Compaction can not be compromised and heavy vibratory rollers plus pneumatic rollers were found to be necessary. In some cases spraying of the Clearseal was experimented with a Flowbin on top of a trailed, with a generator and pump for hand spray of Clearseal but uniformity of application is needed with practice and tempo of spray movement. Water carts, flat bed trucks and or bakkies with trailers were also found to be needed. Typically the correct type of pump for the NME or Clearseal spray had to be sourced to prevent "balling up" and blockages.

6.5 Construction Process Issues

The nozzles, filters, etc of all equipment using NME solutions to pump or spray needs daily cleaning. Typically the coupling between the watercart and the recycler clogged up and resulted in wrong NME application rates.

The spray rates used with the recycler also had to be tweaked to ensure all the NME water is in fact applied and not just partial with solution left in the spray tanker after completion. After some experimentation the ideal setting on the recycler was found to ensure all NME treated water is applied in a single run.

It appears there is a "compaction window" like HMA and the rollers should be following the recycler closely to give a first settling in compaction. The use of pneumatic rollers also proved to be beneficial. The contractor preferred to treat the NME application process similar to what is done with BSM treatment. According to the contractor they also found that once NME treatment was done the compaction must follow as soon as possible and no reworking afterwards should be done.

It is unknown to what extent the presence ofMica int eh soil may have contributed to the reported compaction issues. This relates to the percentage actual nano-silane in the NME "premix". In the ideal situation it now appears in hind sight that the Nano-silane application could be varied to meet the secondary mineral (Mica included) demands to make it water proof and 'encapsulated" from further water effects. It is speculated that the fixed or rather unknown nano-silane proportion in the premixed NME may therefore also have contributed to the density issues reported before. Other product suppliers on the next project (Leeudoringstad to Bothaville) are involving other suppliers with other mix in procedures, using cationic NME mixes and with much higher Mica mineral contents (up to 40%). Therefore mush is still to be learnt in this regard on a practical level.

6.6 Intersection and Turning Movements

It is always difficult to construct streets in an urban environment. Access to residents must be allowed. In some cases destruction of the surface seals were caused by truck movement in and out of stands before the Cape Seal properly set. South street and West streets in Leeudoringstad are actually high volume heavy vehicle streets. Seasonal transport of maize and other agricultural products are stored in the silos linking via these two streets. Since Spoornet is not serving the rail side line anymore all the stored maize and other agricultural products are then again redistributed from this regional storage hub via road transport to other processing plants elsewhere.

T junctions and intersections associated with South and West streets had to receive an asphalt premix surfacing to prevent destruction due to the torsion shear movements on the curves with turning movements. The intersection in George street, just off South street also received an asphalt overlay as it was badly deformed and destructed by the heavy trucks coming from the silos to Tau Mills. Tau Mills was identified as one of the main destinations of the stored maize and thus puts additional stress on South, West and the short section of George street in Leeudoringstad. Further to this the large trucks and trailers also had an ongoing issue with the sharp turning circles at intersections coming into town as well as in town. The trailers tend to take short cut over the concrete kerbs and corners. Adjustments had to be made to provide for better turning circles by moving kerbing back with longer turning circles.

Drainage on these streets had to be attended to and was improved. South street in particular in the past deformed badly due to very flat terrain and lack of drainage from the street. Make up material from recycled G2 waste material could be used in taking out the undulations and low points on South street. The pre-cast kerb stones on the lower side of the street had to be taken out in various places and daylighted channels provided away from the road in an open road reserve next to it. An additional cut off drain or channel had also to be cut by a grader to enable water to flow away from this low laying area.

7. CONCLUSIONS

The new TRH 24 (2022) on low traffic volume gravel road upgrades promotes the use of technology disruptor Nano Modified Emulsions (NME). End use specification based on the Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) and ratios of wet over dry values provides for durable strong treated materials.

The CDP in Wolmaransstad, Witpoort and Leeudoringstad provided a good early adopter or implementation opportunity of the use of NME. NME application could be done to streets which ranged from very low traffic volumes (less than 5 vpd) to the average street fitting the description of basic access streets (les than 75 vpd) to medium to high traffic volume streets.

The CDP allowed for classic gravel preservation on streets like in Witpoort where the in situ gravel was treated with NME and treated with a surfacing of Nano- Polymer Nano-Silane (NPNS) branded as Clearseal. In some cases streets were just regraded, compacted and Clearseal surface protected. Other streets, e.g. Wolmaransstad could benefit from the water resistance characteristic of NME with a 75mm thick treatment and a Cape seal surfacing.

Lessons were learned regarding handling the NME with highly mechanised recycler technology, grader only and water cart and compactors. The quick daily determination of in situ moisture in the road clearly needed to be improved. This placed significant pressure on the laboratory staff and their capacity.

Issues with payment of the NME product supplier surfaced with larger implications for small product suppliers in terms of funding and linked to the traditional concept of materials on Site (MoS). It is believed this issue should be addressed on larger scale projects, like the next door project under Nyeleti Consulting and with a more competitive supplied or specified product variations.

Early performance observations show basic access streets were in fact adequately rehabilitated with good riding quality and are now clearly water resistance where NME treatment could be done. Problem streets like Vrede and Bodenstein in Wolmaransstad proved to be now water proof, but they still function as main surface stormwater collectors. Intersections where heavy trucks turn on basic collector type streets with higher traffic volumes needed extra protection with premix asphalt surfacings. Without the asphalt premix the Cape seal tended to be sheared off the base and be destructed by the turning trucks. Adjustments also had to be made to intersection turning circle curves to prevent trailers from taking short cut over the precast kerbs.

Labour friendly NME mix with G5 natural gravel was proven to be effective in doing pothole patching. This is done by hand mixing on the road, filling the cleaned out pothole, and use a hand held tamper for compaction. Pothole patching appeared to perform well, but the street surfacing is in most cases already in such an aged and deteriorated state that potholes appeared right next to previously repaired potholes. The person friendliness and low technology barrier with mixing the natural gravel with NME on the road and filling the pothole by hand and hand tamper compaction had been proved though for future use and application by the local municipality.

Considerable confidence had been built up by the consulting team, the laboratory and the contractor in the use and application of NME and NPNS with natural gravels.

8. REFERENCES

American Society for Testing Materials (ASTM). 2009. "D3282-09: Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," ASTM: Pennsylvania, PA, USA, 2009.

American Society for Testing Materials (ASTM). 2009. "D3282-09: Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," ASTM: Pennsylvania, PA, USA, 2009.

Committee of Land Transport Officials (COLTO). 1996. "Draft TRH4: Structural Design of Flexible Pavements for Interurban and Rural Roads, National Institute for Transport and Road Research (NITRR), CSIR: Pretoria, South Africa, 1996.

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, 1985.

CSIR. 2007. Guidelines for Human Settlement, Volume 2. Compiled by CSIR under patronage of the Department of Housing, Pretoria, SA.

Horak E, du Plessis L, Jordaan GJ & Murphy M. 2024. Preservation of gravel roads to make them durable and erosion resistant using technology disruptor nano-silanes. Paper accepted for SATC 2024, CSIR Conference Centre, CSIR, Pretoria, RSA.

Jordaan GJ, Steyn WJ vdM & Horak E. 2023. Principles of Flexible Pavement Design Incorporating Nano Modified Emulsion. Proceedings of the 13th Conference on Asphalt Pavements for Southern Africa (CAPSA), 15-18 October 2023, Champagne Sports Resort, Drakensberg, South Africa.

Jordaan GJ, Kilian A, du Plessis L & Murphy M. 2017. The Development of Cost-Effective Pavement Design Approaches Using Mineralogy Tests with New Nano-Technology Modifications of Materials. Proceedings of the 2017 Southern Africa Transportation Conference (SATC 2017), Pretoria, South Africa, 2017.

Jordaan GJ & Steyn, WJ vdM. 2022. 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 Nano Modified Emulsions (NME). *Appl. Sci*., 12(5):2573. 2022 Available at: https://doi.org/10.3390/app12052573.

Jordaan GJ, Steyn, WJ vdM, van Niekerk P, Swart H & de Villiers L. 2023. Addressing Constructability Fears with the Introduction of Material MC-NME Technologies in Practice-Contractor Perspective. Proceedings of the 13th Conference on Asphalt Pavements for Southern Africa (CAPSA), 15-18 October 2023, Champagne Sports Resort, Drakensberg, South Africa.

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

Jordaan GJ & Steyn, WJ vdM. 2020. Cost-Effective Upgrading of Gravel Roads Using Naturally Available Materials with Modified Emulsion (NME) Stabilisation," Department of Civil Engineering, University of Pretoria: Pretoria, South Africa, 2020. ISBN 978-0-620-91415-4.

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

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

Lawless A. 2017. Numbers and Needs in Local Government-Where are we now?: numbers and needs. Available at: https://journals.co.za/doi/10.10520/EJC-5f26e7380#:~:text=Published%20Online%3A24%20Feb%202017https%3A//hdl.handle.net/10520/EJC%2D5f26e7380

Le Roux F, Horak E, van Niekerk W & Tulsi K. 2023. Rehabilitation of Highly Flexible Pavement with Innovative use of Nano-Technology and a Waterproof Flexible Surfacing. Proceedings of the 13th Conference on Asphalt Pavements for Southern Africa (CAPSA), 15 to 18 October 2023, Champagne Sports Resort, Drakensberg, South Africa.

Leyland R, Paige-Green, P, Momayez, M. 2013. Development of road aggregate test specifications for the modified ethylene glycol durability index for basic crystalline materials. *J. Mater. Civ. Eng.,* 10.1061/(ASCE)MT.1943-5533.0000946 (20 Sep 2013).

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. Available at: https://doi.org/10.1080/10298436.2020.1799210.

Rust FC, Smit MA, Akhalwaya I, Jordaan GJ & du Plessis. 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, 2019.

SABITA. 2020. Technical Guideline: Bitumen Stabilised Materials A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials TG2 Third Edition August 2020, First published in 2002, ISBN 978-1-874968-77-1.

Southern Africa Transport and Communications Commission (SATCC). 2003. Guideline: Low-Volume Sealed Roads. The Southern Africa Development Community (SADC), SADC House: Gaborone, Botswana, 2003. ISBN 99912-0-456-5.

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

SANRAL. 2022. Draft TRH 24 UPGRADING OF UNPAVED ROADS. Draft Technical Recommendations for Highways. Compiled under auspices of Roads Coordinating Body (RCB), Committee of Transport Officials (COTO), Road Asset management Subcommittee. Published by the South African Roads Agency SOC Ltd (SANRAL).

SANRA. 2014. South African Pavement Engineering Manual. Published by the South African Roads Agency SOC Ltd (SANRAL).

SANS 3001-GR54. 2010. “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, 2010.

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

TRH14. 1985. (reprinted 1989) Guidelines for Road Construction Materials. Technical Recommendations for Highways, ISBN 0 7988 3311 4, CSRA, Pretoria. Available at: www.nra.co.za

UTG 3. 1988. Urban Transport Guidelines, Structural Design of urban Streets. ISBN 079884465-5 Previously published by the National Department of Transport, Pretoria, SA

Weinert, HH. 1980. The natural road construction materials of Southern Africa. PPublished by Academina, Pretoria.