SAVING OUR SURFACED ROAD NETWORK THROUGH LABOUR INTENSIVE WATER-PROOFING AND RESTORATION

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ABSTRACT

Similar to many developing countries, most of the surfaced road network in South Africa has received little in terms of preventative maintenance over a number of decades. The all too familiar consequences of this neglect is seen on many of the rural and urban road networks (especially during the wet season) with a general deterioration in surface condition and riding quality and the formation of numerous potholes. Consequently, road authorities are subjected to considerable community and hence, political pressure to urgently address the deterioration of the existing surfaced road networks. In addition, road authorities are also under considerable pressure to increase the amount of labour opportunities in the provision of road infrastructure. Road authorities are in a situation where both of these aspects can be addressed with immediate effect through the implementation of proven and tested New (Nano) Modified Emulsion (NME) technologies, incorporating Nano-Polymer Nano-Silane (NPNS) products. These technologies have been adapted and adjusted from the built environment for use in the roads industry in South Africa. Numerous laboratory investigations, Accelerated Pavement Tests (APT) and practical implementation on a number of roads since 2015 have proven the technology to be cost-effective. The same NME technologies, incorporating applicable NPNS products, can be used to protect the integrity of the existing surfaced road networks. These products diluted in water, and applied by hand sprayers, will water-proof existing surfacings and prevent future water damage and create numerous job opportunities with little training. In addition, the same NME technologies can be used to restore some severe distress already existing on many of the surfaced roads. This paper demonstrates the applicability and practicality of the NME incorporating NPNS technologies using available labour with little training for:

- Protection of the existing paved road network and the prevention of severe distress in the presence on water (e.g. pothole forming); and
- Restoring some of the existing surfacings already is severe distress, such a pothole repairs and surface deterioration.

1. INTRODUCTION

The developing world faces high unemployment statistics, exacerbated by an extended lockdown of economies enforced by the Covid-19 pandemic. Governments are under increasing pressure from the electorate to create job opportunities with increased expenditure on infrastructure projects and to create an environment for economic growth.

A prerequisite for economic growth is a transportation infrastructure supporting economic activities, giving access to markets, etc. Hence, road authorities are also under increasing pressure to increase the labour component of road infrastructure projects. The construction of high-order primary roads supporting economic growth requires a high degree of compliance with engineering specifications and increasing the labour content of these projects is often difficult.

An increase in the labour component of lower-order roads is more easily achieved, where the expected level of service, in line with the number of vehicles to accommodate, is of lesser importance as a component of economic growth. However, an often-overlooked component for increased labour-intensive operations on road networks is the periodic maintenance of the existing surfaced roads, especially on provincial and municipal road networks. Periodic maintenance (also known as preventative maintenance) is notoriously lacking in numerous countries (including South Africa), often leading to premature distress and the destruction of valuable road infrastructure assets (a true pandemic of potholes destroying a valuable national asset). In the absence of Maintenance Management Systems (MMSs), the integrity of road surfacings is relatively compromised (compared to the original road structure design period) due to the ageing effect (environmental impact) of the surfacing binder, leading to cracking and water ingress into the road pavement structure, which result in accelerated premature distress in the form of cracking, surface disintegration and potholes. In effect, the absence of MMSs can be directly associated with destroying valuable state assets (roads) that directly support economic growth.

Over the last decade, the use of Material-Compatible New (Nano) Modified Emulsion (MC-NME) technologies for the stabilisation of marginal granular materials for lower and higher-order roads has been proven through Accelerated Pavement Testing (APT) (Rust et al., 2019; Rust et al., 2020; Jordaan et al., 2021) and in practice (Jordaan et al., 2017b; Jordaan & Steyn, 2022a). Simultaneously, the fundamental requirements for NME products have been identified and discussed (Jordaan & Steyn, 2021a) and scientifically based design concepts have been developed and published in international peer-reviewed reputable journals (Jordaan & Steyn, 2021b; Jordaan & Steyn, 2021c) to ensure that these technologies can be universally applied without risk to life and the environment, while meeting fundamental engineering requirements. Risks to pavement design engineers are also minimised regarding future pavement materials' behaviour, i.e., durability (Jordaan 2011a), and cost implications using life-cycle cost analysis (Jordaan, 2011b). Adopting design concepts incorporating MC-NME nanotechnology solutions has been shown to reduce the provision of sustainable road transportation infrastructure by more than 50 per cent (Rust et al., 2019; Rust et al., 2020). The data also show reduced damage caused by overloading (of high importance in the absence of law enforcement in terms of heavy-vehicle overloading) compared to traditional pavement structural design approaches (Rust et al., 2019; Rust et al., 2020). The water-repellent nature and climate resiliency of materials treated with a MC-NME stabilising agent has been demonstrated during the APT and shown in practice (Jordaan & Steyn, 2022a) where unprotected pavement layers treated with a MC-NME stabilising agent withstood severe flooding without any damage to the layer-works.

These same applicable nanotechnologies proven for constructing road pavement layers are just as suitable for periodic preventative maintenance and protection of existing roads and local repairs. Road surface maintenance is a well-documented problem, especially in the developing world, where there needs to be more capacity for sustainable periodic preventative maintenance programmes. The expected distress-free durability of bituminous surfacing materials on roads under harsh environmental conditions (exposure to high ultra-violet radiation and high-temperature variations usually experienced between the tropics and in the desert areas of the world), usually is much less than the design period of road pavement structures of 20 years or more. If left unattended, in the absence of good MMSs, these road surfaces will develop environmental-related cracking that will soon deteriorate into surface disintegration and roads inundated with potholes in the presence of water and vehicle loading. It follows that any breach in the integrity of the road surface will result in considerable premature structural damage and the effective destruction of significant investments in road infrastructure. This scenario is all too familiar and shared in many parts of the world in dire need of economic development and associated employment opportunities.

Traditionally used preventative maintenance actions are usually associated with placing new surfacings (e.g., chip-seals) and applying high-temperature bituminous products. Similarly, traditionally used mixes for pothole repairs or the reinstatement of surface damage comes at a considerable cost. These “cold-mix” products are notoriously expensive and difficult to use under low-temperature conditions (below 20°C), resulting in relatively low compacted densities and highly porous surfacings. Hence, water penetration into these reinstated surfacings is relatively easy, resulting in quick deterioration in condition and the re-appearance of potholes, usually with increased extent and dimensions.

Adopting proven nanotechnologies for stabilising granular pavement layers (Jordaan & Steyn, 2021c), also applicable to road surface maintenance, could be vital to reversing the scenario of premature road pavement distress due to compromised road surfaces. The objectives of this paper are to:

- Demonstrate the advantages that can be achieved using applicable, safe nanotechnology solutions for periodic/preventative maintenance, specifically regarding the quantification of the water-repellent (hydrophobic) ability of these technologies;
- Recommend applicable modified binder applications suitable to address road surface distress when the integrity of the road surface has already been compromised where water ingress into the pavement structure is already occurring with associated development of distress; and
- Demonstrate the suitability of nanotechnology solutions to road preventative and routine road surface restoration activities for labour-intensive applications, creating rapid employment opportunities.

The considerable benefits in terms of depth of penetration (due to small particle sizes) of nano-based products, ease of application (little training required) and the proven high degree of hydrophobicity (water-repellent characteristics) (Jordaan & Steyn, 2021a) are ideally suited to cost-effective labour-intensive maintenance actions, exceeding the performance of traditionally used preventative maintenance products. The nanotechnology solutions are also used to present the ability to restore roads partially (primarily applicable to secondary, tertiary and urban roads) where the surface integrity has already been compromised, exhibiting continuously increasing surface cracking, disintegration and pothole formation at a fraction of the costs of the partial reconstruction as often required.

2. APPLIABLE NANOTECHNOLOGY SOLUTIONS FOR ROAD MAINTENANCE

The appropriate use of safe nanotechnology solutions for the labour-intensive maintenance of existing roads is shown in terms of the protection of and restoration of the surface integrity of existing road surfaces through the application of applicable hydrophobic NME products incorporating Nano-Polymer Nano-Silane (NPNS) “clear seal” nanotechnology solutions, the effect of which is demonstrated (under extreme conditions) on an:

- existing surfaced roads with the integrity of the road surface already severely compromised, exhibiting severe crocodile cracking (also known in some parts of the world as alligator cracking);
- effective repair of roads containing multiple potholes using pre-packed anionic NME repair pothole kits (or alternatively, the local mixing of the MC-NME liquid with Naturally Available Granular Materials (NAGM)) to create a hydrophobic restored road surface, which is easy to use, requiring a minimum of effort and training; and
- road resealing using a hydrophobic anionic MC-NME-modified binder slurry seal (without cement) to restore some deformities in the wheel tracks and produce labour-intensive, hydrophobic, cost-effective, water-resistant and durable surfacings.

These road surface periodic maintenance and restoration actions can easily be performed using labour-intensive operations, requiring minimum training. In light of high unemployment rates in many parts of the world, there is a heightened need to create employment through infrastructure investments. The introduction of nanotechnology solutions for the effective maintenance and restoration of road networks can result in the creation of rapid employment opportunities with considerable advantages in terms of road asset protection.

3. PARTICLE SIZE AND THE EFFECT ON ROAD SURFACE MAINTENANCE

The main objective of road periodic (preventative) surface maintenance is to protect and restore the integrity of the surfacing to prevent secondary distress. The larger the particle sizes of the products used for road surface maintenance, the less the depth of influence on the road surface will be. This aspect is visually demonstrated in Figure 1.

Figure 1 shows that surface rejuvenators (e.g., diluted bitumen emulsions), comprising bitumen particle sizes between 2 and 5 µm (similar to most of the available polymers), will seal some micro-cracking with little in-depth penetration and protection of the surfacing. It follows that particle sizes of micro dimensions will have a limited impact on restoring the integrity of the road surface. It is well-known that using rejuvenators as a road surface maintenance action will increase the durability of the road surfacing for only a year or two. In the case of using a diluted bitumen emulsion, road markings will be affected and have to be re-instated as a road-safety measure. In contrast, a clear seal (diluted NPNS) will show much deeper penetration with a longer-lasting effect.

The practical effect of treating a material with a material-compatible nano-silane is shown in Figure 2, with (a) the treatment of black-cotton soil (clay) material. The treated material has been broken into small pieces. Although gaps exist between the separate material (treated black-cotton clay) pieces, the water drops do not penetrate the material or gaps and form water drops (beading) (Jordaan & Steyn, 2022c) on the top of the nano-silane-treated material.

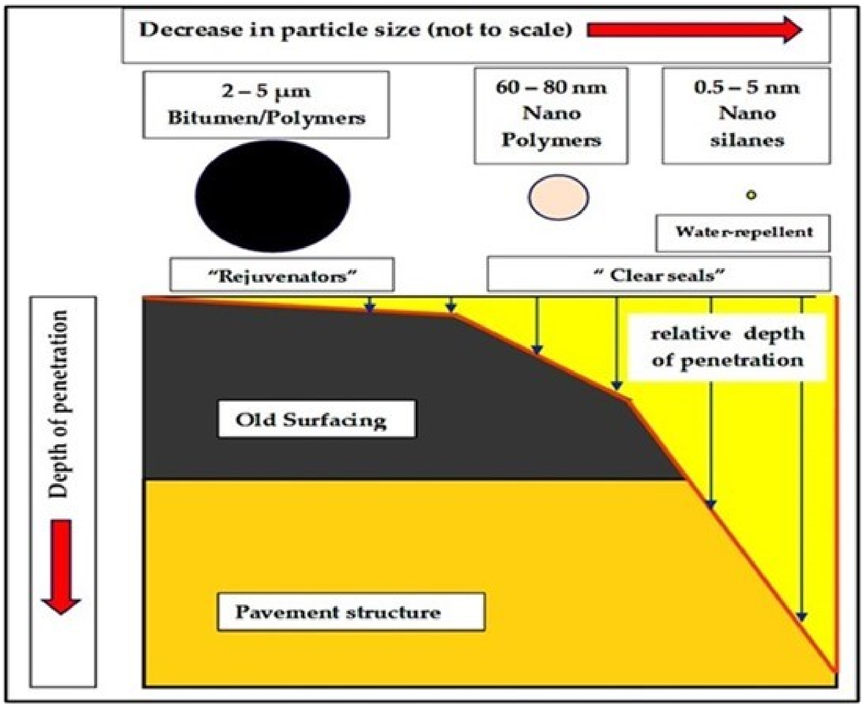

Figure 1: Demonstration of the effective penetration into a road surfacing using rejuvenators (diluted bitumen emulsions) in comparison to Nano-Polymer Nano-Silanes (NPNS) applications

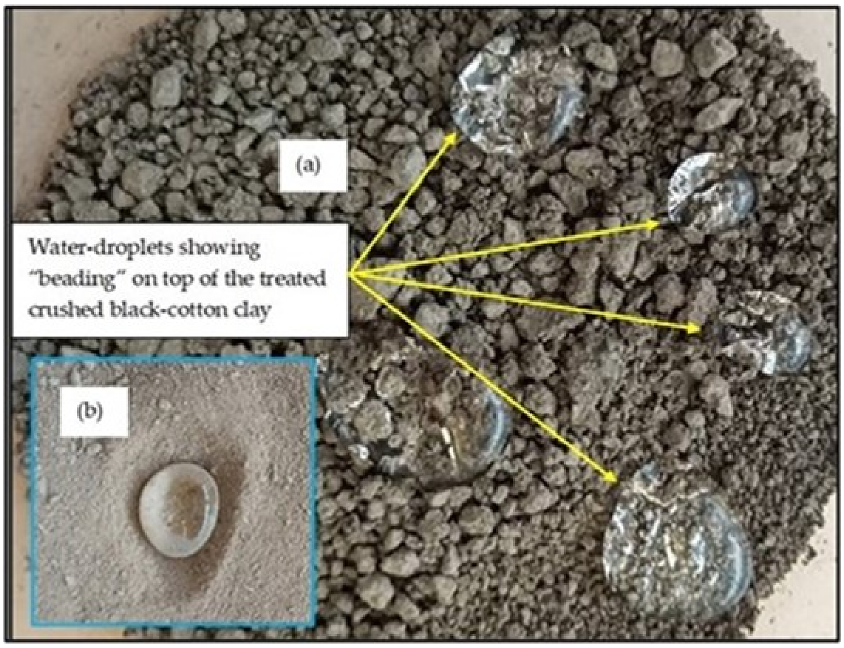

Figure 2: Practical demonstration of the hydrophobic (water-repellent) surfacing created on (a) black-cotton soil (clay) and (b) fine-grained sand treated with a MC Nano-Silane (refer Acknowledgements)

The same effect is achieved with the treatment of other materials, such as fine-grained sands, where water drops will remain suspended on top of the sand, as shown in Figure 2(b). In this case, the "glue" in the NPNS, i.e., the Nano-Polymer, is not present to bind the particles together and create the strength as part of a MC-NPNS treatment.

4. EASE OF USE – LABOUR-INTENSIVE FRIENDLY APPLICATION OF NPNS

The NPNS is diluted into water to contain about 5 per cent NPNS as a "clear seal" to be applied to road surfaces. The application can be performed by water truck (at a uniform rate) but is user-friendly for easy application by hand sprayer, as demonstrated in Figure 3(a). Due to the small particles of the clear seal, the particles penetrate the surface quickly. They are dry within a maximum of 30 min, as shown on the right, with a Marvil apparatus to measure the water penetration rate into the surfacing. The clear seal (NPNS diluted in water (5 per cent concentration)) is normally applied at about 1 to 2 L/m^2 – the application rate depends on the condition of the road surface and is applied at a rate that will not result in run-off from the road surface. In cases like that shown in Figure 3b, where the clear seal is applied as a preventative measure, no water penetration was measured over set intervals lasting over 3 hours. Clear seals applied as a preventative measure will require no new road markings and will not result in any pick-up and contamination of vehicles.

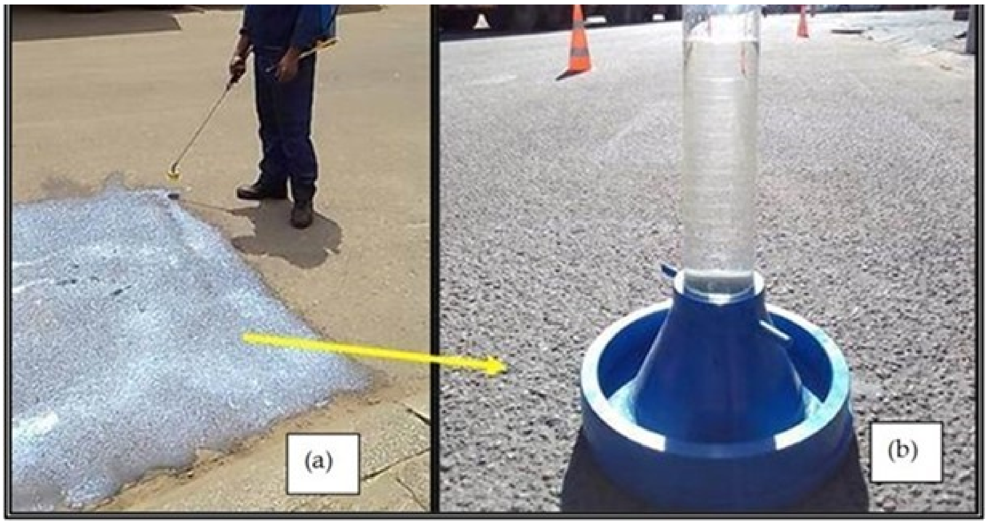

Figure 3: (a) Application of a clear seal by hand sprayer and, (b) Testing of the dried surfacing 30 min after application of the clear seal with a Marvil apparatus to measure the rate of water penetration into the treated surface

The fact that the rate of application of the clear seal should be a function of the condition of the road surface makes application by hand sprayer the preferred method. With hand application, the application rate can be adjusted based on visual observations. With more distress in certain areas of the road surface (e.g., the wheel tracks), the rate can be controlled to prevent run-off and wastage. In the case of a varying surface condition, application by water bowser will result in over- or under-application along a length of road.

5. TREATMENT OF A ROAD SECTION WITH SEVERE CROCODILE CRACKING

A worst-case scenario was selected to demonstrate the water-repellent nature of only a clear seal application and the effect thereof. A diluted NPNS was applied to a severely compromised surfacing exhibiting severe crocodile cracking, as shown in Figure 4(a) before treatment, with a Marvil apparatus to measure the water penetration into the cracked surfacing. Water is seen seeping out underneath the Marvil apparatus through the extensive network of crocodile cracking. After applying the NPNS clear seal to a rate of saturation and the drying thereof (30 minutes) as shown in Figure 4(b), another Marvil test was performed close to the original test site. After the NPNS clear seal application, no visual seepage of water could be observed in the cracks surrounding the Marvil apparatus.

Water penetration using the Marvil apparatus was measured before and after the application as recorded at different time intervals, as shown in Table 1. Table 1 also contains comparative measurements taken 14 days after the application of the NPNS clear seal, during which time the road was opened to normal traffic. The reduction in water penetration into the severely cracked surface is evident. After applying the clear seal, the water ingress into the pavement structure was reduced by 97 per cent. After 14 days of the road being opened to traffic, the water ingress was still reduced by 81 per cent. These results are significant and, combined with a hydrophobic cost-effective slurry mix, could restore the integrity of the surfacing for several years. (Normally, in such severe cases not only treatment with a NPNS NME application is recommended as will be discussed.)

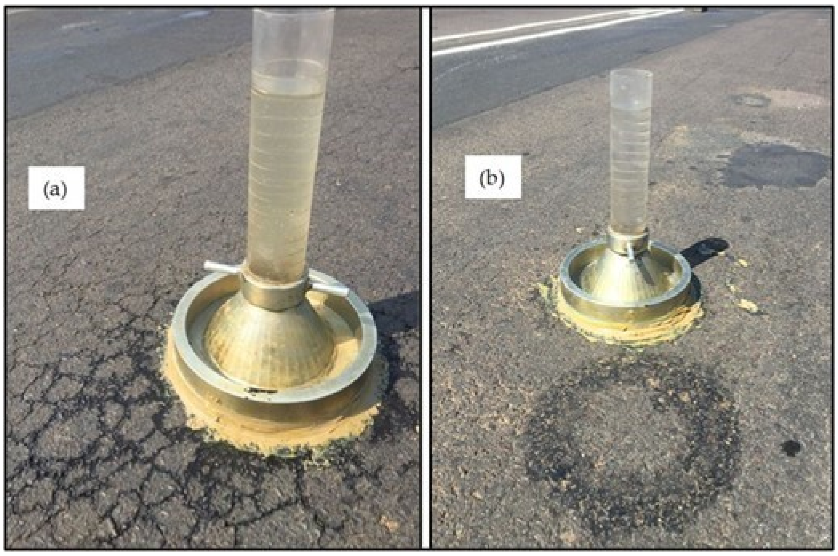

Figure 4: Marvil test on severely cracked road, (a) before application of a NPNS clear seal, showing water seeping out along the extensive network of cracks and, (b) after application of a clear seal

Table 1: Penetration rates tested using the Marvil apparatus on a severely cracked surfacing exhibiting closely spaced crocodile cracking before and after the application of a NPNS clear seal

Permeability at different intervals	**Pre-Treated (Figure 4a)**	**After the Application of a Clear seal (Figure 4b)**	**14 Days after the Application of Clear seal and Opened to Traffic**
7 min	0.214 L/h	0.000 L/h	0.017 L/h
15 min	0.200 L/h	0.008 L/h	0.020 L/h
20 min	0.150 L/h	0.009 L/h	0.018 L/h
Average Permeability	**0.188 L/h**	**0.006 L/h**	**0.036 L/h**

The nano-size particles are too small to affect micro-texture of the surfacing that influences the skid resistance of the surfacing at speeds below 60 km/hour. However, to address any concerns about a possible decrease in the micro texture of the surfacing caused by the application of the clear seal, micro-texture testing was performed using the British Pendulum Tester (Figure 5), both before and after the application of the clear seal. The results of the micro-texture tests are given in Table 2 (these tests were done for comparative reasons only – actual skid resistant tests is done under wet conditions). No statistical difference between the tests performed before and after the application of the clear seal was measured.

Figure 5: Skid resistance testing was performed before and after applying an NPNS clear seal (refer to Acknowledgements)

Table 2: Comparative dry micro-texture measurements using the British Pendulum testing device before and after the application of the clear seal (skid-resistant measurements is done under wet conditions)

Pendulum Test Results	Control (No Seal)	With Clear seal Application
Test Point 1	100	110
Test Point 2	110	100
Test Point 3	110	95
Test Point 4	90	100
Test Point 5	95	90
Total (Average)	**101**	**99**

6. REPAIR OF POTHOLES USING ON-SITE MIXED OR PRE-PREPARED NME POTHOLE REPAIR KITS

In cases where damage in terms of potholes has already occurred, the surfacing can quickly be fixed with an anionic MC-NME gravel mix pothole repair kit (Figure 6 (Jordaan & Steyn, 2022c). Due to the organofunctional modification of the anionic MC-NME mix, the pothole mix will dry within an hour. The use of an anionic NME pothole mix is performed at a fraction of the costs of a traditional cold mix, providing a hydrophobic (water-repellent) restored surfacing not allowing for any future penetration of water. The tested Unconfined Compressive Strengths (UCS) and the Indirect Tensile Strengths (ITS) performed according to the recommended rapid curing process in a dry and wet state (Jordaan & Steyn, 2019; 2021c) using an anionic MC-MNE mixed with relatively inexpensive dolomite NAGM are shown in Table 3. Before repairing potholes, the pothole should be cleaned of any loose material per normal procedure. The pothole must be dry, and for potholes requiring more than one bag to fill, the exposed material within the pothole should be treated “painted” with an anionic NME liquid (as used for the preparation of the pothole repair kit).

Figure 6: Pothole repair using a MC-NME mix, (a) Cleaning of the pothole and "painting" of pothole with anionic NME liquid, (b) filling pothole with a water-resistant anionic NME mix, (c) pothole filled and partially compacted by hand, and (d) vehicles driving over filled pothole

Table 3: Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) tests performed on an anionic MC-NME binder (refer to Acknowledgements) Pothole Repair Kit (using a dolomite NAGM)

UCS (MPa)		Material Classification*	ITS (kPa)		Material Classification*
UCS (dry)	4.4	NME1	ITS (dry)	350	NME1
UCS (wet)	4.3	NME1	ITS (wet)	320	NME1
RCS **	98%	NME1	RTS ***	91%	NME1

*Material Classification; **RCS = Retained Compressive Strength; ***RTS = Retained Tensile Strength (Jordaan and Steyn, 2019; Jordaan and Steyn, 2021c).

The formation of potholes usually indicates a severely compromised surfacing in terms of its ability to prevent water from entering the pavement structure. It follows that fixing individual potholes will not be a solution to restore the integrity of the surfacing, and potholes will continue to develop along the length and width of the road. To restore the integrity of a road surface, the filling of potholes should be performed as one element to repair and restore the integrity of the surfacing and prevent water ingress into the base layer and the continued formation of potholes.

As per the standard in the industry, anionic MC-NME binder pothole kits used in this demonstration and tests are prepared in 25 kg bags for ease of use on site. Due to the binder's low viscosity, no application problems at temperatures above freezing are experienced. These anionic NME binder pothole kits can be produced at about R45/25 kg (including packaging) at an established manufacturing place. For pre-prepared NME pothole mixes a shelf-life of 3 months can be expected. However, the MC-NME liquid can be transported to site and mixed with local NAGM to create a mix on site at considerable savings in transportation costs.

The material must be compacted using normal hand compactors, or vehicles can be used to effectively compact the material and fill the pothole to the level of the original surface. The road can be opened to traffic immediately following the filling and compaction of the pothole, as shown in Figure 6d. The anionic NME pothole binders are designed to bind firmly with the exposed granular materials. Handling by hand will cause minimum contamination, with little or no bitumen sticking to exposed skin (bitumen modified to chemically bind with the minerals in the NAGM).

7. RESTORING DAMAGED SURFACINGS USING A LABOUR-INTENSIVE SLURRY SEAL PREPARED USING A HYDROPHOBIC ANIONIC MC-NME BINDER

It is, unfortunately, the experience that numerous roads in various municipalities and regions all over the world have deteriorated due to a lack of maintenance to a condition requiring at least some improvement within the wheel tracks. A cracked surface, similar to that shown in Figure 5, is at a point where severe pumping of fines under the action of water and traffic will develop, with an associated increase in deformation, reduced riding quality and the development of potholes. In the presence of extensive existing crocodile cracking and pothole filling, applying a diluted NPNS clear seal and anionic MC-NME binder pothole filling should be followed by a labour-intensive anionic medium MC-NME modified slurry with no cement in the mix. Such a reseal can restore some riding quality, providing a hydrophobic, maintenance-free, flexible surfacing with increased resistance to ultra-violet (UV) radiation-resistant new surfacing (with smaller particles chemically attached to the NSGM) and an expected surfacing life of at least 5 to 10 years (or longer), depending on traffic and climatic conditions.

Slurry resealing using anionic NME binders can be performed entirely through labour-intensive methods, as shown in Figure 7. The anionic MC-NME slurry mix can be prepared at a central plant near the site in a large concrete mixer and delivered to the site. Alternatively, the anionic MC-NME slurry can be prepared using labour-intensive methods, with small concrete mixers next to the road, as shown in Figure 8. In all cases, the final spreading and completion of the anionic MC-NME slurry are performed by hand using squeegees for dissipating the slurry and a hessian drag mat for the final texture, as shown in Figure 7(b). In cases where some substantial repairs are required in the wheel tracks, the final seal can be preceded by rut-depth deformation filling, as shown in Figure 9.

With little layout, numerous employment and SSME development opportunities can be created, effectively protecting existing surfaced roads from the detrimental effect of water ingress and the resultant formation of potholes. These activities can effectively protect surfaced roads and positively address well-documented existing backlogs in maintaining surfaced road networks.

Figure 7: (a) Application of a labour-intensive anionic NME slurry seal to effectively provide a water-repellent new surfacing, preventing water ingress into the pavement structure on a severely cracked surfacing-restoring some riding quality; (b) A hessian drag-net is pulled over the slurry seal to provide even distribution and even texture to the slurry seal

Figure 8: Labour-intensive roadside manufacturing of the slurry mix for an anionic NME binder slurry seal or a modified Cape seal using an anionic NME binder

Figure 9: Filling of deformed areas on the road surface using a medium MC-NME slurry mix as a pre-treatment to address severe deformation before applying an anionic MC-NME slurry across the whole width of the lane and road

8. RECOMMENDED LABOUR-INTENSIVE RESTORATION OF COMPROMISED EXISTING SURFACED ROADS

The preceding sections demonstrate the labour-intensive preventative and surface restoration practice that road authorities can implement immediately using applicable and proven nanotechnology solutions with enhanced performance characteristics on existing surfaced road networks. Without well-managed MMSs, road networks worldwide have deteriorated to a state where preventative maintenance is no longer viable. Many roads have deteriorated to a stage where potholes are a common phenomenon, requiring a combination of the actions as discussed to restore the integrity of the pavement surfacing in a cost-effective alternative to partial reconstruction.

A combination of the labour-intensive options may be viable to safeguard and restore numerous roads while presenting opportunities for rapid employment as a relief to social problems (e.g., poverty alleviation) experienced worldwide. To restore the integrity of damaged roads, the process as illustrated in Figure 10 is recommended, as per following:

- Step 1: Restore the hydrophobicity of the road surface through the application of an anionic clear seal (NME consisting of a diluted NPNS) by hand application to the point of saturation;
- Step 2: Clean and repair existing potholes using an anionic MC-NME Pothole kit to provide a hydrophobic fill (or mixing the MC-NME on site with a NAGM), and
- Step 3: Fill all cracked areas and restore some localised deformation by applying an anionic MC-NME slurry mix before restoring the surfacing with an anionic MC-NME slurry mix (it should be noted that curing of an MC-MNE slurry occurs relatively quickly due to the water-repellent organofunctional-silane in the mix).

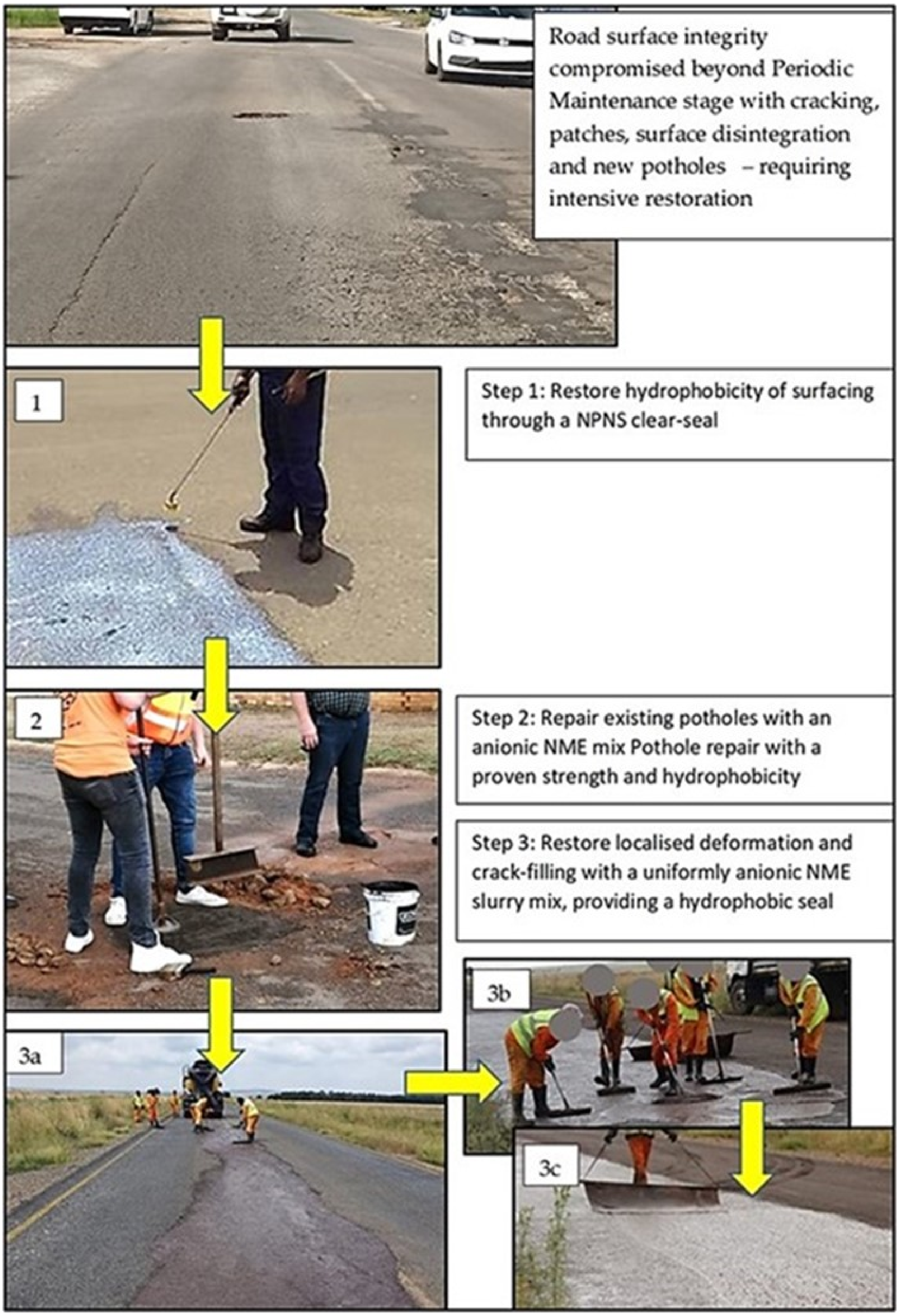

Figure 10: Recommended restoration of compromised surfaced roads using proven nanotechnology solutions suitable for labour-intensive applications providing valuable asset protection

9. CONCLUSIONS

Road authorities are under considerable pressure to address decades of inadequate preventative maintenance, resulting in severe distress on the paved road networks (especially during the wet season). In addition, the same authorities are expected to increase labour opportunities with the provision of road infrastructure projects. Both these aspects can effectively be addressed with immediate effect through the introduction of proven and applicable nanotechnology solutions to render existing surface roads to be water-repellent and restore some integrity to surfacings that has already been damaged. Preventing water ingress through the surfacing, damage to the underlying layers and pothole formation can be prevented on roads. These technologies have been adapted from the built environment to the road industry in South Africa. The materials design method developed is based on fundamental scientific principles, universally appliable. The water-proofing, climate resilient characteristics of the MC-NME products have been verified in practice during APT and during construction under conditions of severe flooding with no resultant damage.

The same nanotechnology solutions to design MC-NME stabilising agents using naturally available materials, incorporating NPNS materials, have been shown to be effective to restore the integrity of the surfacings of existing paved roads. The treatment of severely cracked roads have shown a remarkable reduction in water penetration after treatment. This treatment is ideally suitable for hand application where the condition between and in the wheel-tracks may differ considerably, requiring a change in application rates. In addition, the MC-NME treatments have been demonstrated to be effective for the restoration of roads already subjected to severe distress. MC-NME mixes can be prepared for pothole repairs of site, using NAGM at a fraction of the cost of traditional cold-mix solutions at ambient temperatures, providing a surfacing resistance to future water penetration. Similarly, it is shown that in combination, a number of proven MC-NME technologies incorporating also NPNS, can effectively be applied to restore some distress and provide a water-repellent surfacing. All these actions can be performed with local labour with little training required, creating numerous immediate employment opportunities, and in the medium term provide similar opportunities for Small, Micro and Medium Enterprise (SMME) development.

10. ACKNOWLEDGEMENTS

The support of GeoNANO Technologies (Pty) Ltd., www.geonano.co.za, in support of students in the Department of Civil Engineering, University of Pretoria, Pretoria, South Africa, to test a wide variety of materials as part of final year projects and post-graduate theses, testing the various principles identified in this paper, is acknowledged.

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