EFFECT OF NANO-MODIFIED EMULSIONS (NME) (NANO-SILANES) STABILIZERS ON THE PROPERTIES OF DOLOMITE

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ABSTRACT

While it is acknowledged that good transport infrastructure is a prerequisite to economic growth, the costs of providing, maintaining and rehabilitating road infrastructure over the last few decades, have soared, consuming scarce available funds. In view of increasing traffic volumes experienced worldwide as well as current economic realities, the investigation, testing and application of "alternative" new road building products, including the application of nano-technology, have become essential.

The study focused on the effect of a nano-salines stabilising agent on dolomite (a so-called "problem" soil due to its susceptibility to weathering in the presence of water), particularly with regards to water-repellence and moisture sensitivity. The results described the influence of a Nano-Modified Emulsions (NME)(Nano-Silanes) stabilising agent on the plasticity index (PI), Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) between the neat and stabilised dolomite material. This knowledge on the effect of nano-stabilisers on the moisture density relationship and index properties could be used to predict the behaviour of compacted soils encountered in pavement engineering practices and assessing the suitability of so-called "problem" soils, ultimately making the utilisation of naturally available materials such as dolomite possible and practical in pursuit of providing cost-effective, safe and sustainable road infrastructure.

The results showed that the addition of the nano-silanes stabiliser:

- Improved the properties of the dolomite;
- Reduced the plasticity of soils and thereby reduced the effect of moisture variations; and
- Acted as an adequate lubricant for re-compaction in the rehabilitation phase. The stabilised dolomite material was shown to be less moisture sensitive than the neat material, and
- Being less moisture sensitive, any changes in moisture content would have less effect on the Mod AASHTO criteria for compactibility of the stabilised material.

Keywords: Moisture sensitivity; Optimum Moisture Content; Plasticity Index; Water Repellence; Nano-technology; Dolomite.

1. INTRODUCTION

Numerous studies have shown that the provision good transport infrastructure, its preservation and timely rehabilitation are prerequisites to economic growth. For economies to remain competitive, any cost adding to production and delivery costs – and transportation costs are a major contributor -needs to be minimised. Yet, the costs of providing, maintaining and rehabilitating road infrastructure over the last few decades, have been increasing, consuming scarce available funds. In view of increasing traffic volumes experienced worldwide as well as current economic realities described above, the investigation, testing and application of “alternative” new road building products, including the application of nano-technology, are becoming essential (Chong, 2003; Jordaan et al., 2017a; Jordaan et al., 2017b).

In some regions in southern Africa, problems are experienced with natural soil for designing pavements where the need exists to stabilise the materials to improve load-bearing and plasticity characteristics for pavement design. These so-called “problem” soils typically include dolomite ($CaMg(CO_3)_2$) and clays. The problems associated with dolomite are related to its response to moisture and the effect thereof on its structure.

It is against this background that the effect of a nano-silanes stabilising agent on the properties of dolomite material was evaluated. The dolomite material contained dark grey gravel and a dark chocolate brown soil (weathered material), which suggested that it was chert-rich material forming part of the Eccles formation (Trollop, 2006). This type of dolomite material is mainly found in the Gauteng area (Wagener, 1985). In these areas seasonal rains are expected and therefore the dolomite has a high weathering probability (Weinert, 1980). Being a soluble salt, water penetrating dolomite poses a great threat to the dolomite.

The effect of climate on the weathering process (i.e. soil formation) is described by the climatic N-value defined by Weinert (1980). An N-value of less than 5 (which is applicable to the region from which samples used in the study were taken) is associated with humid warm areas and a surplus of water, where chemical decomposition is the predominant rock weathering mode (Weinert, 1980).

Due to the perceived issues with the aforementioned “problem” soils, engineers are reluctant to use these materials (Wagener, 1985; Faruqi et al., 2015). “More suitable” materials, according to their evaluation as per commonly used road pavement design manuals, are imported - despite good design documents and test protocols specifically for the analysis and interpretation of naturally available road building materials having been developed - increasing the costs of road construction and rehabilitation (Jordaan et al., 2017).

2. METHODOLOGY

A study was undertaken to determine whether a Nano Modified Emulsions (NME) (Nano-Silanes) stabilising agent would enhance the properties of dolomite material. In pursuit of the aim, the main objectives were to determine whether the stabilising agent would (i) make the dolomite water-repellent, and (ii) reduce the moisture sensitivity of the dolomite material. The improved understanding of the material and its bonds to water molecules would improve the understanding of the behaviour of these materials when applied in pavement layers, and therefore, expected changes that the material might undergo when moisture contents changed in pavement structures (Steyn, 2011).

In total, twenty-two samples (hereafter referred to as S1 to S22) were used in the study. Grading tests and Atterberg Limits tests (SANS 3001-GR1:2013) were performed on Samples 1 to 6 (neat material) and Samples 7 to 12 (stabilised material) to investigate the effect of the Nano-Modified (NME) (Nano-Silanes) stabilising agent on the dolomite in terms of classification. Optimum moisture content of the neat (S13 to S17) and stabilised (S18 to S22) material was determined, using the SANS 3001GR20 and SANS3001/GR30/31 (SAPEM, 2013).

X-Ray Diffraction (XRD) and X-Ray Fluorescent (XRF) scans were performed on the 0.075 mm and the 0.425 mm fractions of Sample 3 (neat material) and Sample 11 (stabilised material) to provide better insight into the chemical composition of the same material.

3. RESULTS AND ANALYSIS

3.1 Classification

XRD scans indicated (Figure 1) that besides Ankerite (substituted for dolomite since both minerals belong to the same crystal system and space group and have the same peak positions), the material contained mainly Quartz (SiO_2)(>20 per cent) with small percentages of clayey fines such as Illite (2 to 3 per cent) and Kaolinite (<2 per cent).

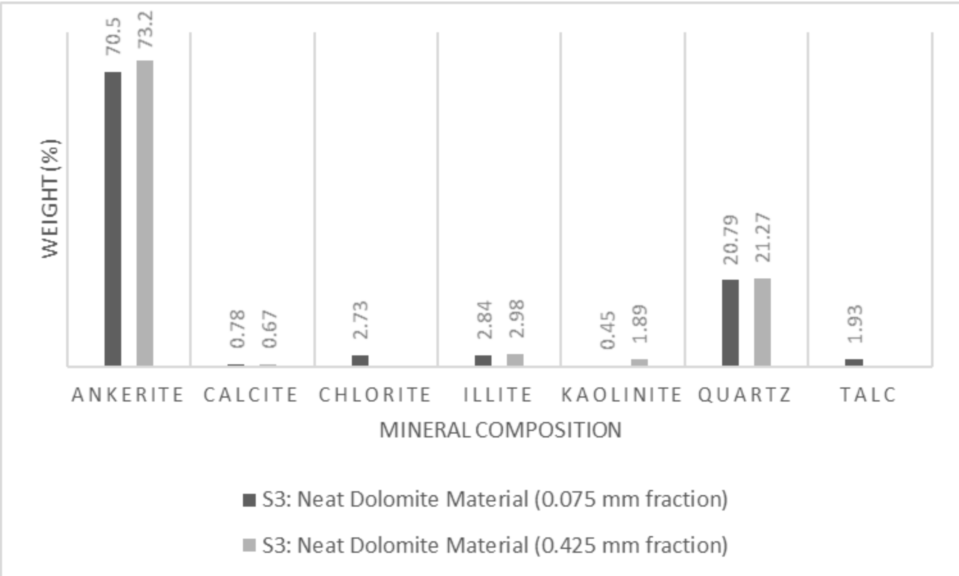


Figure 1: XRD Results of Neat Dolomite Material

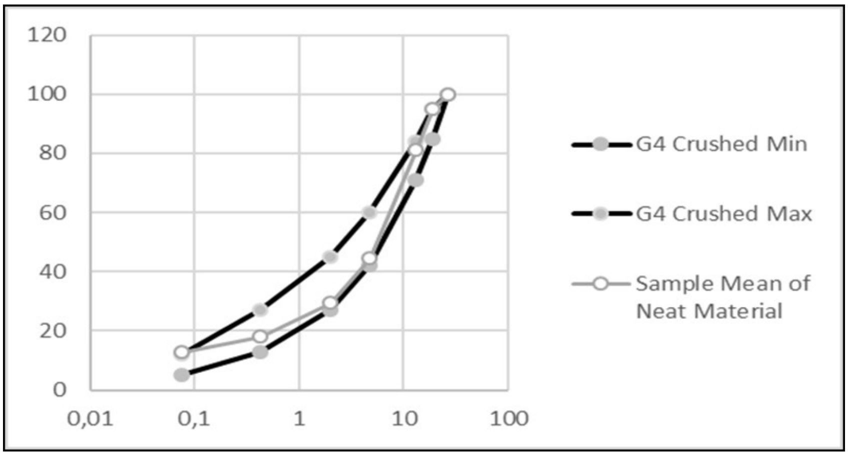
Jordaan et al. (2017a) and Achampong et al. (2013) emphasised the importance of identifying the presence and type of these clays with regards to the significant potential effect on compactibility of the soil. In the context of this study it was critical as, in the presence of water, they would cause degradation of the dolomite.

The neat material had an average grading modulus of 2.36 which, is an indication that it was coarsely graded, contained a low fine fraction and was of relatively good quality (SAPEM, 2013). COLTO (1998) was used for the classification of the neat material, according to which the neat dolomite material was classified as a G4 material. Given that the percentage fines passing the 0.075 mm sieve ranged from 10 to 16 per cent, the material, in terms of the AASHTO classification system, was classified as a gravel sand, a material which, by definition, does not contain a high percentage of silts and clays (Table 1).

The stabilised material was classified as an NME1 material according to the recommended material classification system for Nano-Modified Emulsions (Jordaan et al., 2017a) and TG2 (Asphalt Academy, 2009) (Table 2).

Table 1: Analysis of Neat Dolomite Material

DOLOMITE NEAT MATERIAL ANALYSIS			
Sample Information and Properties			
Material Description	Course Material = Dark Grey Dolomite		
	Fine Material = Chocolate Brown Soil		
Grading Analyses			
Method Used (TMH 1, 1986)	A1 (a)		
Sieve Size (mm)	Min (%)	Max (%)	Sample Mean Passing (%)
26.5	100	100	100
19	85	95	95
13.2	71	84	81
4.75	42	60	44
2	27	45	29
0.425	13	27	18
0.075	5	12	13



Atterberg Limits Analysis		
Method Used (TMH 1, 1986)	A2, A3 and A4	
	0.425 mm	0.075 mm
Plasticity Index (P.I.)	1.8	2.2
Linear shrinkage (L.S.) %	0.74	1.01
GM	2.4	
Classification of AASHTO	A-1-a	gravel and sand
Classification of TRH14	**G4**	
Classification of COLTO (1998)	**G4**	
MOD AASHTO		
Method Used	SANS 3001-GR30/31/20	
Optimum Moisture Content (OMC)%	5%	
Maximum Dry Density (kg/m^3)	2327	

Table 2: Analysis of Stabilised Dolomite Material

DOLOMITE STABILISED WITH NANO-MODIFIED EMULSION (NANO-SILANES)				
Sample Information and Properties				
Stabiliser Percentage added	0.7% and 1.2% G.E. NME (Nano-Silanes)			
Method Used	TMH 1 A12-A14			
Plasticity Index (Untreated)	1,8			
Optimum Moisture Content (OMC) % Untreated	5			
Maximum Dry Density (MDD) Untreated	2327			
GM (Untreated)	2,4			
UCS and ITS Test Results				
Size of Specimen (diameter)	150mm			
Compaction Effort	100%			
Binding Agent Content	0.7%-G.E-Nano		1.2% G.E-Nano	
Curing Time	4 Days	4 Months	4 Days	4 Months
UCS (Wet)*** (kPa) *	3120	5510	4080	5140
UCS (Dry) (kPa) *	3730	4690	4680	6380
ITS (Wet)*** (kPa) **	263	298	315	536
ITS (Dry) (kPa) **	301	390,4	356	462
Retained Cohesion (ITSwet / ITSdry) (%)	87%	76%	88%	116%
Classification of Jordaan (et al 2017)	**NME1**	**NME1**	**NME1**	**NME1**
Classification of TG2 (2009)	**BSM1**	**BSM1**	**BSM1**	**BSM1**

* Unconfined Compressive Strength - THM1 Method A14 COLTO (1986)

** Indirect Tensile Strength - TG2 - Asphalt Academy (2009)

*** Specimens were under water in the soaking bath for 4 hours at 25°C (± 2°C)

3.2 Plasticity Index (PI)

The Plasticity Index (PI) and to a lesser extent Linear Shrinkage (LS), gives a strong indication of the sensitivity of the material to water (Department of Public Works, 2007). Materials with low PI values can be expected to perform better than materials with high PI values (SAPEM, 2013, Chapter 3).

An average PI of 1.8 for the 0.425 mm fraction and 2.2 for the 0.075 mm fraction was recorded for the neat material and thus the neat material was therefore classified as slightly plastic (P< 7) (Knappet and Craig, 2012). Although the initial PI was less than 7, after stabilisation, the consistency changed to non-plastic (PI of approximately zero).

In this study a nano-silanes stabilising agent was used. The effect of nano-silanes can be described as follows: Deep penetration into substrates is achieved due to the small molecular size of new generation nano-silanes (<5 nm in size). As a result of the interaction of these nano-silanes with the free energy surrounding the molecules of natural materials, the surface atom arrangements of aggregates are changed drastically. The nano-silanes react with themselves and any hydroxy (OH) groups within the substrate when moisture is present, forming a silicone resin network (Jordaan et al., 2017a; Dow Corning, 2004).

Comparing the neat and stabilised material, it could be seen that a chemical reaction had taken place as indicated by the change in the PI value. The smaller particles of the nano-silanes stabiliser had formed a protective layer (Figure 3), reducing the susceptibility of the dolomite to water and making the dolomite effectively water-repellent, thus preventing water from reacting with problem minerals in the dolomite and causing weathering. The results in Figure 2 show that the dolomite material became water repellent with the addition of nano-silanes as the PI dropped to nearly zero (Jordaan et al., 2017).

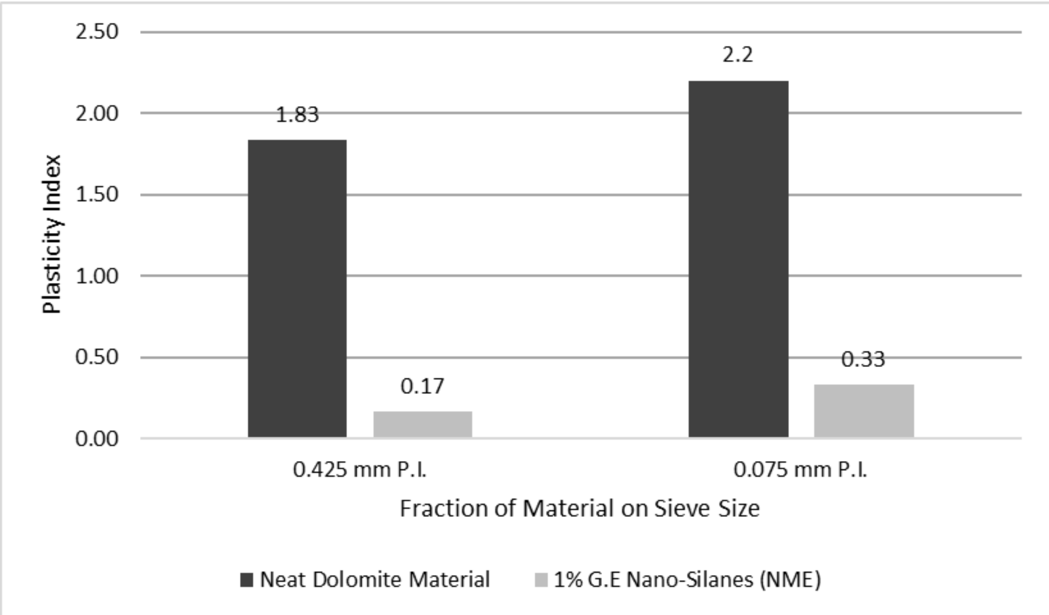


Figure 2: Comparison of Atterberg Limits for Neat and Stabilised Material

Figure 3 is a visual presentation of water-repelling effect of the nano-silanes: Water was unable to penetrate the Nano-Modified Emulsion (Nano-silanes) material shortly after nano-silanes had been added.

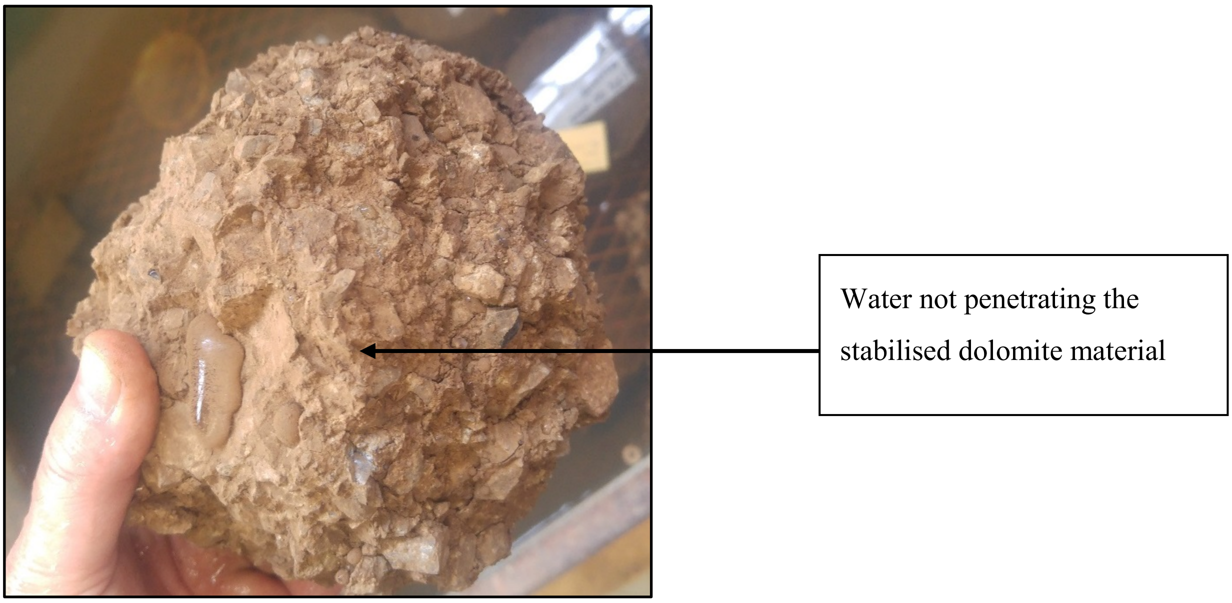


Figure 3: Water-Repelling Effect of Nano-Silanes

3.3 Compactibility

In engineering projects such as the construction of highways, loose soils must be compacted to increase their unit weight. By means of compaction the characteristics of soils are improved by increasing strength, decreasing permeability and reducing settlement of foundation (Wagener, 1985).

Moisture content of the soil is vital to proper compaction. Moisture acts as a lubricant within soil, sliding the particles together. Too little moisture means inadequate compaction - the particles cannot move past each other to achieve density. Too much moisture leaves water-filled voids and subsequently weakens the load-bearing ability (VDOT, 2016).

Figure 4 shows the OMC Curve for the neat and the 1% GE-Y1 NME (Nano-Silanes) stabilised material. The moisture density curve for the neat material was relatively steep on both sides of OMC. On the left side of the graph, water content was too low, preventing soil particles to slide past each other with ease, therefore compaction would be inefficient. As water was added, due to its lubrication effect, the soil particles were able to slide past each with greater ease. MDD was reached at 2327 kg/m^3 after which the curve declined steeply due to the density decreasing, as water, being lighter, replaced soil.

As can be seen, the addition of the nano-silanes stabiliser had no major effect on OMC and MDD values. There was, however, a marked difference in moisture sensitivity, as was indicated by the curve being much flatter. A comparison of the MDD percentage change over a wider OMC range, as illustrated in Table 3 and Figure 5, shows the real benefit the addition of the stabiliser had.

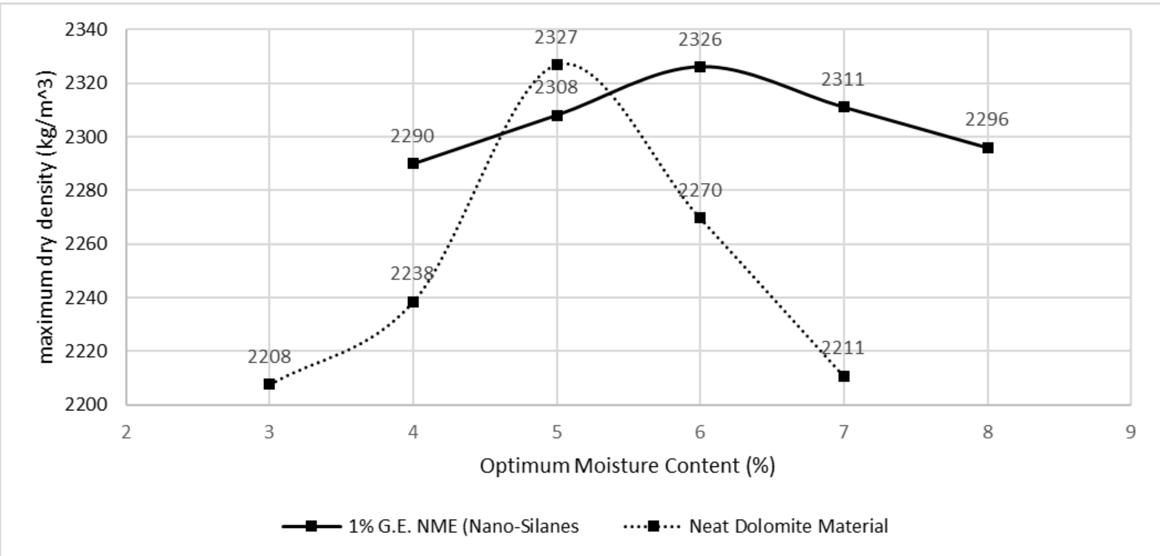


Figure 4: OMC Curve for Neat and Stabilised Material

Table 3: Comparison of OMC Range and MDD Percentage Change

Optimum Moisture Content Range	-2	-1	0	1	2
Neat Dolomite Material MDD % Change	90.14%	91.39%	95.00%	92.67%	90.27%
1% G.E. NME (Nano-Silanes) MDD % Change	92.55%	93.27%	94.00%	93.39%	92.79%
Difference	2.41%	1.88%	-1.00%	0.73%	2.52%

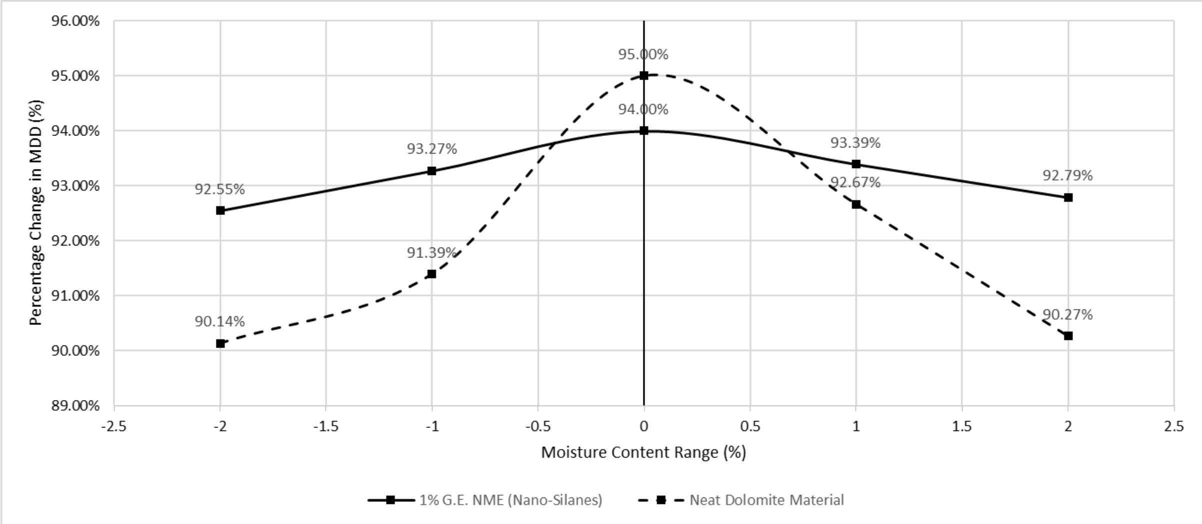


Figure 5: Comparison of OMC Range and MDD Percentage Change

The Mod AASHTO criteria applicable to the neat material (G4) ranged from 90 per cent (for subgrade layer) to 95 per cent (for subbase layer). Any change in moisture content of the neat material, would therefore have a major impact on its compactibility, as can be seen from the graph. Moisture control during compaction would therefore require much stricter control than in the case of the stabilised material. The Mod AASHTO criteria range for the stabilised material was much narrower (between 93 and 94 per cent) since it was less moisture-sensitive, therefore allowing for a greater margin of compactibility.

4. CONCLUSIONS

Dolomite contains soluble salts and is known to weather in the presence of moisture. The study set out to determine the effect of a nano-silanes stabiliser on dolomite, particularly with regards to its moisture sensitivity and ability to repel water. This specific paper excludes the detailed comparison of XRD data before and after stabilisation, as well as cost-effectiveness. These aspects are dealt with in follow-up studies.

The results showed that the addition of the nano-silanes stabiliser improved the properties of the dolomite:

- It reduced the plasticity of soils thereby reducing the effect of moisture variations;
- It also acted as an adequate lubricant for re-compaction in the rehabilitation phase. The stabilised dolomite material was shown to be less moisture sensitive than the neat material, and
- Being less moisture sensitive, any changes in moisture content would have less effect on the Mod AASHTO criteria for compactibility of the stabilised material.

The addition of the stabiliser should prevent decomposition over time due to its water-repellent nature.

Furthermore, based on the results of this study and the literature, in particular the work of Jordaan et al. (2017a; 2017b), the following was concluded:

- Using a classification system and materials criteria, based on the principles of traditionally used and tested systems but providing for new nano-materials, new nano-testing technologies to identify problem materials, and carefully selected nano-products which will counter the specific problems associated with those materials at a specific location, will make the utilisation of naturally available materials such as dolomite possible and practical. In this way cost-effective, safe and sustainable road infrastructure could be pursued.

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