Properties controlling the resistance to abrasion and erosion of stabilized sandy soils using non-traditional additives

Les propriétés contrôlant la résistance à l'abrasion et à l'érosion de sols sablonneux stabilisés en utilisant des additifs non-traditionnels

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ABSTRACT

Sands are generally loose with very little natural binding capacity to resist wheel traction forces and therefore do not generally meet the traditional requirements of wearing course materials for unpaved roads unless they are subjected to some form of treatment. On the basis of the sand properties and performance before and after treatment, measured by the abrasion and erosion tests, the factors that controlled the effectiveness of the stabilization were established. It was found that particle size distribution, Atterberg limit values as determined on material passing the 0.075 mm sieve, particle characteristics such as grain structure morphology determined by SEM are the contributing factors to the difference in performance exhibited by the sand samples.

RÉSUMÉ

Les sables sont généralement desserrés avec très peu de capacité de liant naturelle pour s'opposer aux forces de traction de roue. De ce fait, ils ne satisfont donc pas généralement les conditions traditionnelles leur permettant de porter une grosse charge pour les routes non pavées à moins qu'ils ne soient soumis à une forme de traitement. Sur la base des propriétés de sable et de la performance mis en œuvre après traitement, mesuré par l'abrasion et les épreuves d'érosion, les facteurs qui ont contrôlé l'efficacité de la stabilisation ont été établis. Il a été constaté que la distribution de grandeur de particule, les valeurs de limite d'Atterberg, comme déterminé sur la matière passant le tamis de 0.075 millimètres, les caractéristiques de particule comme la morphologie de structure de grain déterminée par SEM, sont les facteurs de contribution aux différences en performance des différents échantillons de sable.

Keywords : abrasion, erosion, non-traditional additives, soil stabilization

1 INTRODUCTION

Sands are generally loose with very little natural binding capacity to resist wheel traction forces. The movement of loose material under traffic action results into corrugations and ravelling of the road surface due to insufficient binding ability of the material to keep the surface intact (Visser & Hudson 1983) In addition to the deterioration caused by traffic, the flow of water over the road will cause loss of surface material, particularly in finer grained material with minimal coarse aggregate, creating run-off channels which, when they occur perpendicular to the direction of travel result in extreme roughness (TRH20). According to Netterberg & Paige-Green (1988) good wearing course on unpaved roads should have; the ability to provide smooth and safe vehicle ride without excessive maintenance, an ability to resist deformation under both wet and dry conditions, the ability to shed water without excessive erosion, resistance to the abrasive action of traffic and erosion by water and wind, freedom from excessive dust during dry weather and freedom from excessive slipperiness during wet weather

The requirements of good wearing courses in unpaved roads show that in areas dominated by sandy soils, the material will be more susceptible to the identified forms of deterioration and it will be difficult to find material that will conform to the requirements unless some form of treatment is done. This can take the form of mechanical (blending of materials) or chemical stabilization. Potential chemical stabilizers for sands include both natural and synthetic polymers, and bitumen (Kėzdi 1979). This study focuses on the use of synthetic polymer emulsions as stabilizers for sands. Synthetic polymer emulsions are categorized as non-traditional additives in soil improvement methods (Jones and Ventura, 2004).

Numerous formulations of synthetic polymer emulsions have been developed and introduced in the road industry. Laboratory and field studies on the use of synthetic polymer emulsions have shown that these products have potential for use as stabilizers (Al-Khanbash & Abdalla 2006, Rauch et al. 2002, Tingle et al. 2007 Viljoen, 2004). Studies on other types of non-traditional additives such as Sulfonated Petroleum Products (SPPs) have shown that the effectiveness of these products is dependent on material characteristics Paige-Green 1999a). The objective of the study was to identify specific properties of sand samples that would be considered as indicators for potential reactivity of the sand with the synthetic polymers. In order to achieve this objective, laboratory tests were undertaken using special testing techniques developed by Jones and Ventura (2004) for the assessment of non-traditional additives.

2 MATERIAL CHARACTERISTICS

Four sand samples are considered for discussion in this paper. The choice was based on their inservice performance on unpaved roads. Two of the samples were from poor performing roads and the other two from good performing roads. The rate of surface deterioration was the criterion used for performance categorization. Thus a poor performing road is one that exhibited faster surface deterioration such as corrugation development than would generally be considered under similar conditions. For the purpose of characterising the sand, samples were subjected to basic indicator tests which included grading analysis, Atterberg limits, but on the material passing the 0.075

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mm sieve, maximum dry density and optimum moisture content relationships. The results are given in Table 1.

Table 1. Material properties

Sample	LL on <0.075 mm material %	PI on <0.075 mm material %	Max. dry density Kg/m^3	OMC %	Grading modulus
Sample 1	27.3	9.8	2140	7.8	1.2
Sample 2	23.4	6.95	2110	5.7	1.16
Sample 3	NP	NP	1710	4.0	1.01
Sample 4	NP	NP	1820	4.8	1.12

The samples are categorised as materials that are highly susceptible to ravelling and corrugation, based on TRH20 and Paige-Green (1999b). Thus the sands do not meet the requirements of materials for unpaved roads,

2.1 *Particle size distribution*

The respective particle size distributions of the samples are shown in Figures 1 to 4. The results are presented in terms of volume proportion to particle size. Distinct characteristics of the particle size distribution curves can easily be distinguished. Samples 1 and 2 show a bi-modal distribution and slightly for sample 4 but not sample 3.

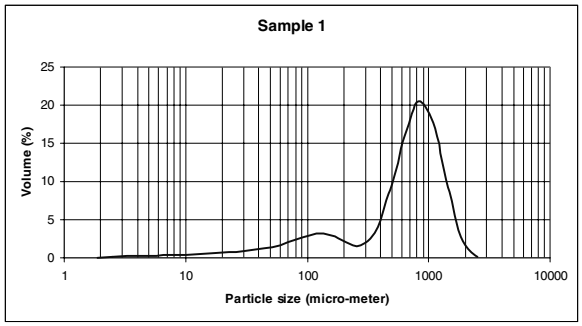

Figure 1. Particle size distribution for sample 1

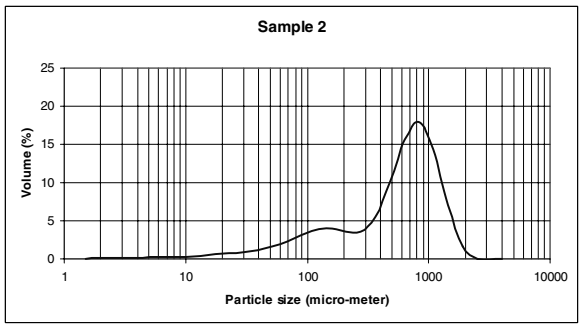

Figure 2. Particle size distribution for sample 2

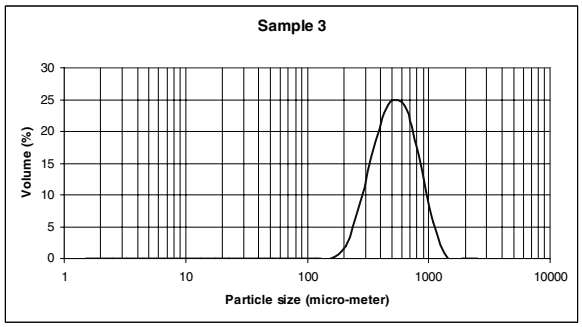

Figure 3. Particle size distribution for sample 3

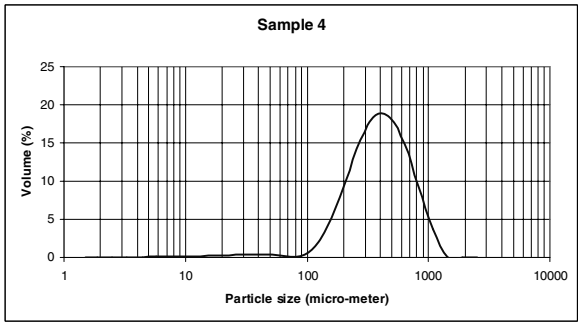

Figure 4. Particle size distribution for sample 4

2.2 *Particle characteristics*

A Scanning electron microscope (SEM) was used to quantify the particle characteristics of the samples. The results are shown in Figures 5 to 8. The images are at a magnification of 1000x. They reveal that the samples have a wide range in particle shape and the difference in the grain texture and structure between the samples can be observed from the images. The images show that the grain surfaces for Sample 1 and Sample 2 are covered with a pellicle of fine material compared to Samples 3 and 4 whose grains are generally clean, only traces of the much smaller particles can be seen on the surfaces of these grains. There are fine material micro-aggregates between the grains of samples 1 and 2.

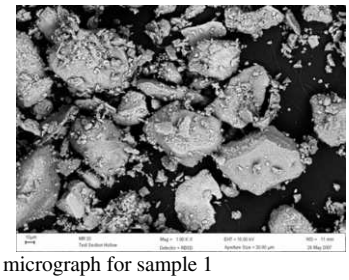

Figure 5. SEM micrograph for sample 1

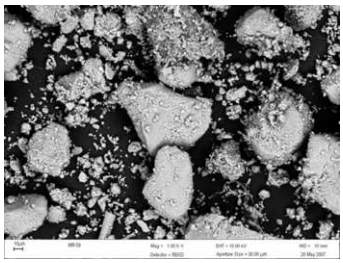

Figure 6. SEM micrograph for sample 2

Images in Figure 7 and Figure 8 show the difference in surface texture between sample 3 and Sample 4. Sample 3 has a smoother surface texture than sample 4. On the other hand, the dominant difference between sample 2 and Sample 3 is the presence of the much smaller particles on the surface of the grains for sample 2.

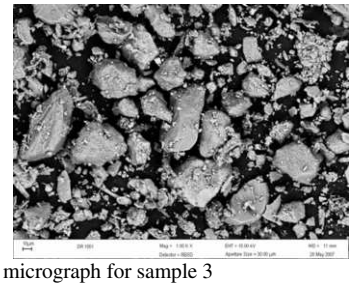

Figure 7. SEM micrograph for sample 3

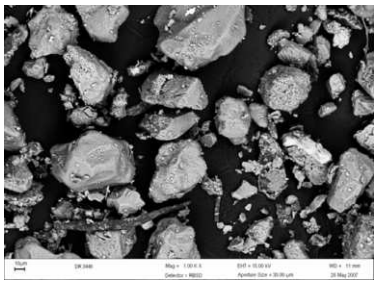

Figure 8. SEM micrograph for sample 4

2.3 *Mineralogy*

X-Ray diffraction analyses were carried out on the samples to ascertain the general mineralogical composition of the materials. The results are shown in Table 2. The results show that quartz dominates, but for samples 1 and 2 the grains were coated by secondary iron compounds such as goethite and hematite, with a presence of plagioclase and K-feldspar in varying quantities. For sample 1 more minerals are detected compared to the other samples.

Table 2. Mineralogy of samples

Mineral	Mineral content in samples %			
	Sample 1	Sample 2	Sample 3	Sample 4
Hermatite/Geothite	2	-	-	-
K-Feldspar	3	4	-	-
Plagioclasse	6	3	-	-
Quartz	83	92	100	100
Amphibole	2	-	-	-
Mica	4	-	-	-
Illite/Smetite/	-	1	-	-

3 PERFORMANCE-BASED TEST METHODS

Tests were undertaken on both treated and untreated materials to assess the performance of selected synthetic polymers. The abrasion and erosion resistance tests were considered to be the most appropriate methods of evaluating the performance of the different synthetic polymers on the different sands. Although the tests are not yet standardised, they have specifically been developed and validated for the assessment of the effectiveness of non-traditional road additives. The details to the development of the tests are discussed in Jones and Ventura (2004) and in Jones (2007).

3.1 *Abrasion*

Three replicate specimens were prepared by compaction in a mould and then dry cured to constant mass at 50˚C. After curing, the treated and untreated specimens were weighed, mounted in a brushing apparatus as shown in Figure 9 and then subjected to 250 revolutions with a brush loading of 2.0 kg. The brushed specimens were then weighed and the mass loss recorded as a percentage of the original mass. Treated specimens were then subjected to a further 250 revolutions before final weighing and determination of percentage mass loss. The average loss for the three specimens after 250 and 500 revolutions is what is reported. If the loss from any one specimen differed from the other two by more than five per cent, the test was repeated.

Figure 9. Abrasion test apparatus

3.2 *Erosion*

Specimens were prepared in the same way as for the abrasion resistance test. After curing, the treated and untreated specimens were weighed, positioned in the test apparatus and then subjected to five minutes of water flow at a constant water head of 1.0 m as illustrated in Figure 10. Excess water was allowed to drain for a further five minutes after which the specimens were removed from the apparatus and dried at 105°C for 24 hours. The specimens were then weighed and the percentage mass loss recorded. The average loss for each set of three specimens is what is reported. Similarly as in the case of abrasion test, if the loss from any one specimen differed from the other two by more than five per cent, the test was repeated.

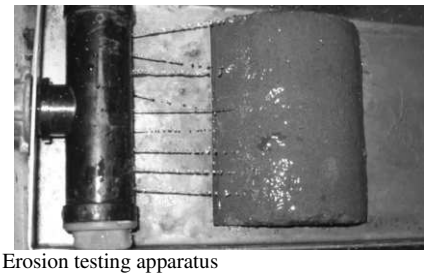

Figure 10. Erosion testing apparatus

4 RESULTS OF PERFORMANCE-BASED TESTS

Tables 3 and 4 list the results of the abrasion and erosion resistance tests respectively.

4.1 *Abrasion*

Table 3. Abrasion test results

Additive	Rate	250 Revs	500 Revs	250 Revs	500 Revs	250 Revs	500 Revs
	%	Sample 1		Sample 2		Sample 4	
None	0.0	7.1	21.1	13.3	35.7	NR	NR
Polymer	1.0	0.9	1.6	2.8	5.6	30.5	NR
A	2.5	0.3	0.5	0.5	0.9	1.6	2.6
	5.0	0.1	0.1	0.1	0.1	0.5	0.7
Polymer	1.0	2.6	6.2	9.0	23.0	NR	NR
B	2.5	1.5	2.6	2.0	4.3	18.2	34.6
	5.0	0.4	0.6	0.4	0.6	3.6	6.4
Polymer	1.0	1.1	2.2	4.3	10.0	NR	NR
C	2.5	0.4	0.7	1.2	2.2	3.1	6.9
	5.0	0.2	0.3	0.2	0.2	1.0	1.4
Bitumen	1.0	4.2	10.5	3.9	7.0	NR	NR
Emulsion	2.5	0.7	1.0	2.7	4.0	NR	NR
	5.0	0.6	0.9	1.2	2.0	NR	NR

Note: Results for Sample 3 are not shown as specimens collapsed after compaction

4.2 *Erosion*

Table 4. Erosion test results

Additive	Rate %	Sample 1	Sample 2	Sample 3	Sample 4
None	0.0	73.0	40	NR	NR
Polymer	1.0	0.9	0.6	NR	0.3
A	2.5	1.0	0.6	NR	0.3
	5.0	1.8	1.5	NR	0.1
Polymer	1.0	0.7	0.7	NR	1.3
B	2.5	0.8	0.7	NR	0.4
	5.0	1.0	0.9	NR	0.2
Polymer	1.0	0.8	0.6	NR	0.8
C	2.5	0.5	0.6	NR	0.4
	5.0	1.5	0.9	NR	0.1
Bitumen	1.0	3.4	3.8	NR	0.6
Emulsion	2.5	0.9	1.6	NR	0.3
	5.0	0.4	0.6	NR	0.2

Note: NR = No result as the specimens collapsed after compaction

In assessing the effectiveness of non-traditional additives as stabilisers for sandy soils, Jones and Ventura (2004) recommend that the material loss should be less than 10 percent after 500 brushing revolutions and 8 percent after being subjected to 5 minutes of water flow in an erosion test. Both criteria are used in analysing the results.

The resistance to both erosion and abrasion was improved for specimens of samples 1, sample 2 and sample 4. None of the polymers had an effect on sample 3 specimens, which collapsed after compaction. Even at five percent application rate of the polymers, handling after compaction was impossible. Abrasion resistance results indicate that the polymers performed differently on the four sands. However all additives significantly improved the erosion resistance of the different sands as measured by the loss of material in the erosion test. While the abrasion resistance of sample 1 was improved by all the polymers, improved abrasion resistance to levels of less than 10 percent of material loss after 500 revolutions, polymers A and C provided the most significant improvement in abrasion resistance for sample 1 at the different concentration levels. The Bitumen Emulsion performed well at application rates of 2.5 and 5.0 percent, but did not meet abrasion resistance limits at a rate of 1.0 percent .A general improvement was also obtained for Sample 2. Polymer A provided the highest level of abrasion resistance at all application rates for this sample. The other polymers performed relatively poorly at 1.0 percent. At 2.5 and 5.0 percent Polymer C provided the next best performance, followed by Polymer B and Bitumen Emulsion. On the other hand, limited improvement was recorded on sample. Polymer A provided the best abrasion resistance for sample 4. Sample 4 was able to withstand 355 revolutions with Polymer A treatment at 1.0 percent application rate, while all other specimens collapsed at this low application rate. The Bitumen Emulsion treated specimens at all application rates collapsed well before the required number of revolutions.

The presence and extent of the pellicle of fine material covering the grains of the samples can be related to the mineralogical composition of the samples as determined by the XRD test and the plasticity characteristics of the sands as determined on the material passing the 0,075 mm sieve which played a role in the performance of the sands after treatment. The SEM analysis images of the samples show that particle characteristics such as grain structure morphology are other contributing factors to the difference in performance exhibited by the sand samples. The poor performance of sample 3 can be attributed to the absence of the pellicle of fine material covering the grains, the smoothness and roundedness of the grains as well as a uniform grain size distribution, depicted by a single peak in Figure 3.

5 CONCLUSIONS

The effectiveness of the synthetic polymers with respect to abrasion resistance was dependent on the sand properties, defined by the particle size distribution, particle structure texture and on the plasticity characteristics measured on the material fraction passing the 0.075 mm sieve and the amount of material finer than 0.075 mm. The type of polymer as well as the application rate also played a role. The results of the tests in this study indicate that application rates of between 1.5 and 2.5 percent by mass appear to be the range in which synthetic polymers will provide the best performance, reduce abrasion loss to levels below the recommended limit of 10 percent for the sands. The results of the study also reveal that properties of sand should include characteristics measured on the material finer than 0.075 mm and mineralogy when considering sand stabilisation using synthetic polymers. Using the SEM analysis images of the samples it was possible to determine that particle characteristics such as grain structure morphology are other contributing factors to the difference in performance exhibited by the sand samples

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