Investigation into Effects of Construction Moisture Content on Inerted Manganese Product Stiffness in Road Pavement Layers

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Received: 10 December 2012 Accepted: 3 January 2013 Published: 15 January 2013

Abstract

The use of waste materials from various processes as pavement layers has long been an option for disposing of such materials. Huge volumes of material are typically required to construct pavement layers and this option provides the opportunity for disposing of large volumes of materials without requiring landfill areas. Electrolytic Manganese Dioxide (EMD) is produced in South Africa from manganese ore through the process of electrolysis. Belt filter residue from the EMD production residue is thixotropic, and is dried by adding lime. The dried product is known as Inerted Manganese Product (IMP). IMP has been used successfully in pavement layers in South Africa. Uncertainty regarding the optimal Construction Moisture Content (CMC) led to research where five sections with IMP base layers were constructed at different CMCs, followed by monitoring of both short-term and long-term stiffness development in the layer. Data analysis consisted of evaluation of changes in base layer stiffness, focusing on the effect of the differing CMC contents. The paper covers the experimental design, data collected and analyses, leading to conclusions regarding the optimal CMC required to obtain optimal short-term stiffness in the IMP-constructed base layer.

Index terms— stabilization, inerted manganese product, behaviour, stiffness.

1 Introduction

he use of waste materials and by-products from various processes and sources as road pavement layers has long been one of the options of disposing of such materials. As huge volumes of material are typically required to construct pavement layers, this option provides the opportunity for disposing of large volumes of materials without requiring landfill areas. It has always been important to ensure that such materials adhere to the minimum engineering specifications required for the specific layer in which it was to be used, that there are no health and safety issues that could lead to pollution of the environment and population and that it still provides a cost-effective option for the road construction.

Mining is another activity that contributes to the depletion of natural resources. Mined material is processed to produce useable products. Waste (which is often hazardous to the environment) is produced in the process. If no use is found for the waste it is disposed of at waste disposal facilities. However, when waste is used as road building materials, natural resources are saved and the waste piles at waste disposal sites become smaller and may ultimately disappear. It is clear that the responsible use of waste in road construction potentially has major environmental advantages [1].

Electrolytic Manganese Dioxide (EMD) (used in the production of batteries) is produced in South Africa from manganese ore through the process of electrolysis. Inerted Manganese Product (IMP) originates from EMD waste. When EMD is produced, "manganese containing belt filter residue" is also produced. The belt filter residue is thixotropic, meaning that when the residue is stirred, it becomes liquid. The residue is dried by adding lime to it. The dried product is known as IMP [2]. The pH of the IMP is in the order of 12 and it poses a chemical hazard. IMP delists to a general waste in South Africa and is typically disposed of at designated waste disposal facilities. The production of IMP in South Africa amounts to approximately 35 000 tons per year, and it is slowly increasing [3]. Due to the well-controlled industrial process that leads to the production of the IMP, the produced material is consistent in quality and properties. Use as selected, subbase and base layer (combined 450 mm thickness) in a normal single lane road translates this to construction of around 98 km of road per year.

Continued disposal to landfills requires expansion of existing waste disposal facilities. This is not preferable in terms of environmental considerations. In 2002 the Department of Water Affairs and Forestry (DWAF) approved the use of IMP as a road building material under the following conditions:

? The IMP layer must be sealed;

? The volume of IMP per area must be limited to 2 400 tons/hectare, and ? The use of the material must be controlled and monitored [4].

In 2007, Komatiland Forests (Pty) Ltd constructed the first road using IMP [3]. The road is located at the Brooklands plantation in Mpumalanga and is 7.9 km long. Three 150 mm layers of IMP were used as the base, subbase and selected layers with the in-situ material used as subgrade. Standard engineering properties of the IMP were evaluated prior to the construction of the road. The IMP layers were field compacted at the Optimum Moisture Content (OMC) of 26.4 per cent. Good compaction was attained but the IMP layer appeared brittle after a while. During further construction of the pavement it started to rain and the moisture content of the IMP layer increased to a value well above the OMC. The compaction results appeared much better at this increased moisture content. The IMP layer became harder, to such an extent that the grader was unable to finish the layer. The tracks of the roller were imprinted on the layer and the layer had to be smoothed by the addition of a thin IMP layer on top of the uneven, compacted layer. After completion of the base, the road was left to cure for approximately 90 days before it was sealed with a 6 mm bituminous slurry seal. It is suspected that the high dosage of lime added to the residue to dry it at source affected the moisture content of the material. The IMP layer gains strength and shows improved compactability, probably due to a pozzolanic reaction between the constituents of the IMP and the lime (CaO) used to dry the IMP.

As the compaction results appeared better at a moisture content above OMC, it was decided to compact the IMP for the remainder of the projects at a moisture content of 30 per cent. Although this provided good compaction, it was unknown whether the 30 per cent moisture content was optimal. If it is still too low, the IMP layers will still not be at optimum strength. If it is too high, water may be wasted during construction. Research was conducted to evaluate the effect of a range of moisture contents on the properties of the IMP.

The objective of this paper (based on a phase of the research) is to determine the effect of the construction moisture content on the short-term stiffness of the IMP used as a base layer in a pavement.

The impact of IMP on the environment was excluded from this study, as it was done in a separate phase of the research and it was found that no negative environmental effects exist as long as the material is used under controlled conditions [2]. The effects of traffic loading on the IMP layers are also excluded from this paper, as the potential for carrying moderate amounts of traffic was already proven in the field, provided that it has been compacted sufficiently [3]. This research will contribute to the understanding of the behaviour of the IMP when it is used as a pavement material, ensuring that it can be used efficiently in this application, where no wastage of water will occur and optimal stiffness and strength will be achieved. It will also enable protection of natural resources that would have been used in the place of IMP and save the effort and costs of disposing of the material at designated waste disposal facilities.

Previous research has shown that the IMP is suitable for use as base and subbase material in a pavement **??**2; 4]. The amount of IMP must be limited to 2 400 tons per hectare. Assuming a 100 m long road section, 8 m wide, running through the length of a hectare, a pavement with three 150 mm thick layers of IMP with a density of 1 500 kg/m 3 will amount to 540 tons of IMP. This is less than a quarter of the allowable amount of IMP. The permeability and leachability of the IMP is very low due to the fact that the belt filter residue is treated with lime. The leachability is considerably lower than that of many other common construction materials such as ordinary Portland cement [2].

The paper covers the experimental design, the data collected and the analyses of these data, leading to conclusions regarding the optimal moisture content required to obtain optimal short-term stiffness in the IMP-constructed base layer. The long-term stiffness data will be collected in an extension of the project.

2 II.

3 Experimental Design

Five test sections were constructed at different moisture contents (OMC = 26.4 per cent) as indicated in Table 1. The moisture contents were selected based on field experience indicating viable moisture content values to enable adequate compaction. Test sections consisted of a 5 m long, 1 m wide and 150 mm thick IMP layer, on top of compacted in-situ material. In practice the IMP layers are sealed with a bituminous surfacing, however, the reported sections were constructed and evaluated without this surfacing, as a curing period of ninety days is typically allowed and the duration of this study was less than 90 days. The layout of the test sections is shown in Figure 1.

The in-situ material was compacted with a Bomag BW 70 tandem vibratory roller to ensure good support conditions. After compaction of the in-situ material, the IMP was imported and mixed with water using a Rotovator. The IMP was compacted using 17 roller passes on each test section with the Bomag BW 70 tandem vibratory roller. The test sections were covered with a plastic sheet for the first 7 days after construction, as there were still some rainy days (the experiment was conducted towards the end of the rainy season).

Decagon 5TE moisture and temperature sensors were installed horizontally at mid-depth (75 mm) in each of the sections together with i-buttons. These were continuously monitored at 15 minute intervals over a period of 84 days. Seismic layer stiffness was measured using a Portable Seismic Pavement Analyzer (PSPA) [5] while the elastic surface deflection was measured using a Dynatest Light Weight Deflectometer (LWD) twice a week (3 repeat measurements of each at each test point). In situ density of the IMP base layers was monitored twice a week using a CPN MC-3 Portaprobe strata gauge, while gravimetric moisture samples were taken at the start and end of the project. Weather data for the testing period was obtained from a nearby station of the South African Weather Services (SAWS). The measured layer stiffness and elastic deflection data were used as the main stiffness indicators for the test sections. The basic engineering properties of the IMP are shown in Table 2 and the grading curve in Figure **??**.

4 III.

5 Data Analysis

The data analysis conducted for this paper consisted of an evaluation of the changes in base layer stiffness over the duration of the project, focusing on the potential effect of the differing construction moisture contents on the short-term stiffness values and densities. In this section the changes in in situ moisture content, seismic stiffness and elastic surface deflectionbased stiffness over time for the five sections are discussed.

Evaluation of the dry density values indicates that they ranged between 1 704 kg/m 3 and 1 988 kg/m 3 after construction with no clear correlation with the construction moisture contents. The range decreased towards the end of the experiment with the final dry density values ranging between 1 728 kg/m 3 and 1 876 kg/m 3 . The two sections with the lower construction moisture contents had Final Dry Density (FDD) to Maximum Dry Density (MDD) ratios of 1.10, while the two sections with the higher construction moisture contents had FDD to MDD ratios of 1.13 and 1.15.

In Figure **??** the relationship between the in situ moisture content at a depth of 75 mm (middle of base layer) over the duration of the experiment is shown for the five sections. These data indicate variations over the duration of the experiment. Based on the data trend, it appears as if the in situ moisture content is relatively stable. In Figure 4 the relationship between the final in situ moisture content and the construction moisture content as well as optimum moisture contents for the five sections are shown. The average final in situ moisture content was between 84.5 per cent and 89.7 per cent of construction moisture content (except for Section 5 which had the lowest construction moisture content of 22.7 per cent and a final to construction ratio of 108.8 per cent). The final in situ moisture contents were between 86.1 per cent and 94.5 per cent of the OMC. This compares with observations by Emery [6] for the equilibrium moisture content (after at least 2 years) of a base layer in the field under a bituminous surfacing of between 53 and 63 per cent. It can thus be expected that this base would dry out to about 60 per cent over time under a seal and to much lower moisture content in the dry season if unsealed.

The seismic PSPA-measured stiffness values (measured longitudinally) for the five sections are shown in Figure 5. Analysis of the data shows a significant increase in all the stiffness values (after the first approximately 10 days of relatively constant datasections closed with plastic). The measured stiffness values for Sections 1, 2 and 4 appear to stabilize towards the end of the monitoring. The Coefficient of Variation (CoV) of the data ranged between 0.0 per cent and 35.6 per cent, with the large variations in the initial data. The typical range of CoV data was between 0.6 per cent and 18.9 per cent.

Evaluation of the data in Figure 6 indicates that the seismic stiffness is not directly dependent on the changes in the in situ moisture content over time. While the in situ moisture contents remained relatively constant through the experiment (Figure **??**), the seismic stiffness values increased. Statistical analysis indicates that the initial seismic stiffness values had a correlation coefficient of 0.775 with the construction moisture contents, while the final seismic stiffness values only had a correlation coefficient of 0.011.

In Figure 6 the elastic stiffness values based on elastic deflections measured using the LWD are shown for the five test sections. Analysis indicates a general increase in the stiffness values for all sections over the 35 day period. The reason for the slight decrease in elastic stiffness values for Sections 1, 4 and 5 between 6 and 19 days is not clear. It may be related to rainfall that occurred between days 9 and 18, and resultant ponding (due to an uneven surface) of water that was observed on these test sections. The CoV of the data ranged between 0.5 per cent and 28.8 per cent, with the large variations in the initial data. The typical range of CoV data was between 0.6 per cent and 4.8 per cent.

When comparing the potential effect of construction moisture content on these stiffness values, it is observed that the construction moisture content for Sections 2 and 3 were the highest (with the highest stiffness moduli in Figure 6) while the construction moisture contents for Section 5 was the lowest (with the lowest stiffness modulus in Figure 6). The ratio between the final and the original elastic stiffness values for the five sections ranged between 1.1 (Section 5 -lowest construction moisture content) and 2.8 (Section 2second highest construction moisture content) with a correlation coefficient of 0.69. A correlation coefficient of 0.75 was calculated between the construction moisture contents and the final LWD-based stiffness values, with no correlation between the initial elastic stiffness values and the construction moisture content (correlation coefficient of -0.10).

6 Potential Applications of Imp

An overview of the stiffness, density and moisture data provided in this paper indicates that the construction moisture content of the IMP plays a significant role in the short-term stiffness values obtained by the IMP in the field. Although this was not clear from the seismic stiffness data, the elastic stiffness and density data indicated the trend.

IMP currently classifies as a G5 material [7] according to its engineering properties (Table 2). However, the measured short-term performance observed in this experiment with increases in stiffness values of between 6 and 185 per cent indicates that the material develops some cementitious bonds during curing. This would be similar to a lightly cemented (C4) material in the TRH14 classification.

The presence of lime in the IMP was verified using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray analysis (EDX) techniques. In Figure 7 a SEM image of a crack in the IMP (recovered from the test sections after 46 days) is shown with the EDX analysis in Figure 8. The presence of calcium is visible in both locations.

Observation of the elastic stiffness values obtained the short term (between 100 MPa and 250 MPa) indicates that the elastic stiffness values are still lower than that typically found for C4 layers (between 500 MPa and 2 000 MPa initially), the elastic stiffness values were still increasing when the final measurements were taken. It is expected that the in situ quality of the material is at least similar to a C4 material in the initial equivalent granular condition.

Visual evaluation of the test sections approximately 85 days after construction indicated an extremely hard surface that developed transverse cracks at intervals of approximately 750 mm (Figure **??**). These cracks are most probably caused by hydration shrinkage of the base material (initial shrinkage of the original material was 0), as the material cured (and are probably similar in nature to that shown in Figure 7). This type of behaviour supports the motivation to view the material as being similar to a lightly cemented material (C4 according to [7]). It may thus be expected that the IMP will follow the typical behaviour pattern of C4 materials [8], reverting to an equivalent granular material with the on-going application of traffic. This needs to be confirmed through longer-term evaluations of the material performance.

V.

7 Long-Term Behaviour

Although a period of one year is relatively short, the behaviour of the material one year after construction has been evaluated to determine whether any major changes occurred. The test section was not covered during the period, and it thus received all environmental influences and very light traffic (mainly Light Delivery Vehicles at around 10 vehicles per day). In Figure 10 the behaviour of the five sections in terms of elastic modulus after one year is shown. The data indicate that the stiffness values all dropped during this period, and this is most probably due to the stabilization cracks that formed in the layer. The in situ stiffness values are still relatively high, indicating that, despite the stabilization cracking, the material still classifies as a stabilized material [7], and thus should perform well if used in a normal road layer.

8 VI.

9 CONCLUSIONS

The objective of this project was to determine the effect of the construction moisture content on the short-term stiffness of the IMP used as a base layer in a pavement. Based on the information provided in this paper the following conclusions are drawn:

Seismic stiffness values for IMP are initially affected by construction moisture content, although it does not appear to be the case when curing of the material occurs;

? Elastic stiffness values for IMP are affected directly (at least over the short-term) by construction moisture content; ? Elastic stiffness values of the IMP are expected to increase to levels close to those expected from C4 materials. The longer term behaviour of the IMP is expected to be similar to that of C4 materials; ? Higher construction moisture contents appear to lead to increased dry density values, although the differences are not necessarily significant; ? Chemical analysis of the material indicated the presence of calcium compounds (probably linked to the lime added during processing), specifically around internal cracks; ? Final in situ moisture content of the IMP base layer is between 86.1and 94.5 per cent of OMC; ? The long-term behaviourof the material appears to indicate relatively good life to be expected, similar to a normal lightly stabilized layer, and ? The use of waste materials in road construction potentially has major benefits in negating the use of landfills and reducing the requirement for new borrow-pits when constructing roads -leading to the conservation of non-renewable resources.

VII.

10 Recommen dations

Based on the discussion and analyses contained in this paper it is recommended that:

The moisture content at which IMP should be compacted during construction is 28 per cent, which is 1.6 per cent higher than OMC, as the section constructed at this moisture content showed the best performance results, and Figure **??** : Grading curve for IMP [7] Figure **??** : Relationship between in situ moisture content and duration of experiment for 5 test sections [1] [2] [3]

1

Figure 1: Figure 1 :

4 

Figure 2: Figure 4 :

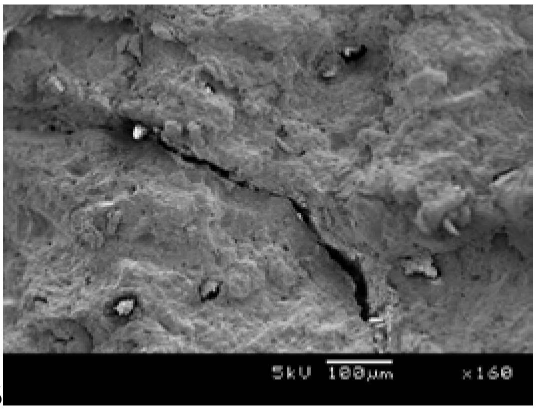
5 

Figure 3: Figure 5 :

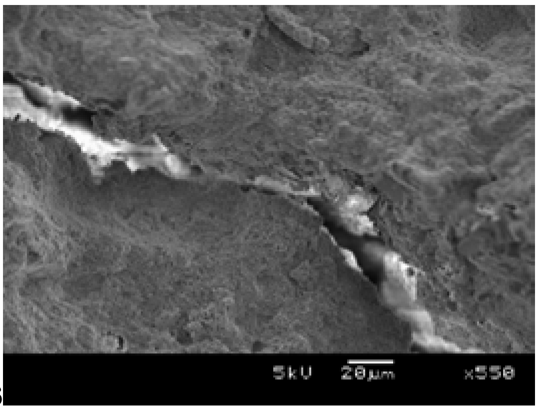
6 

Figure 4: Figure 6 :

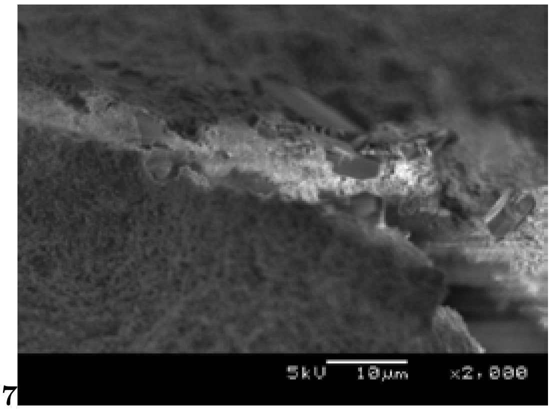
7 

Figure 5: Figure 7 :

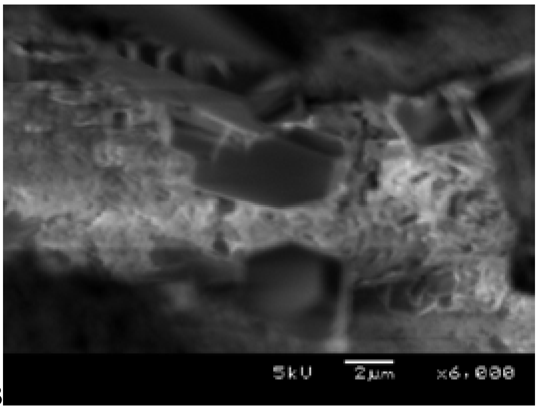
8 

Figure 6: Figure 8 :

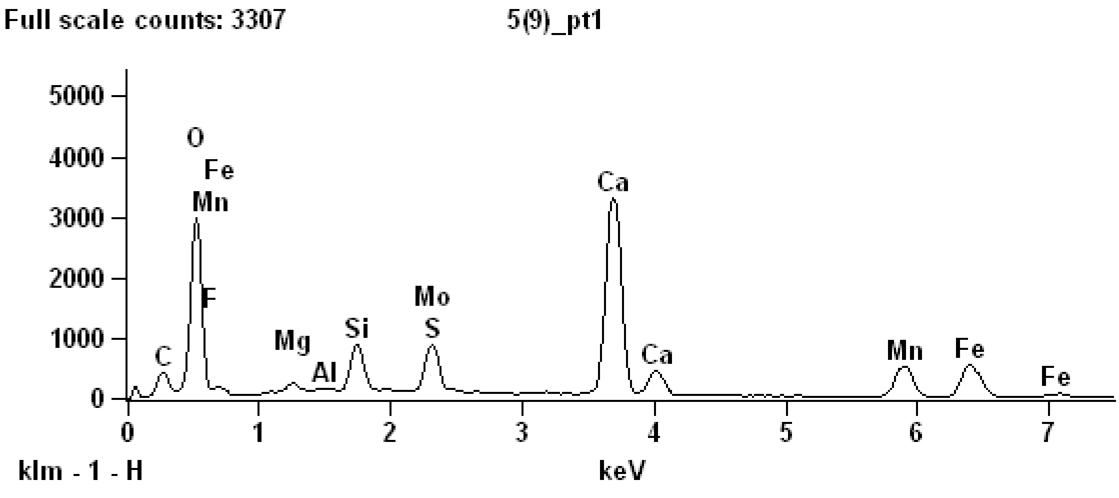


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Figure 7: Figure 9 : 2 GlobalFigure 10 :

especially as affected by different construction moisture contents, should be continued to ensure that the long-term performance of this material can be adequately described.

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Figure 8: ?

1

Densities for Five Test Sections

SECTION NUMBER	CONSTRUCTION MOISTURE CONTENT [%]
1	27.3
2	28.1
3	29.5
4	26.8
5	22.7

Figure 9: Table 1 :

2

ENGINEERING PROPERTY	VALUE
Plasticity Index	NP
Grading Modulus	2.46
Maximum Dry Density [kg/m 3]	1 623
Optimum Moisture Content [%]	26.4
CBR @ 100% Mod AASHTO	117
AASHTO classification	A-1-a
TRH14 classification (TRH14, 1985)	G5

Figure 10: Table 2 :

.1 Acknowledgements

The support of Delta EMD in supporting this research and providing permission to publish the results of this research is gratefully acknowledged. The assistance of the CSIR in data collection is acknowledged.

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