APPLICATION OF THE MMLS3 AS APT TOOL FOR EVALUATING ASPHALT PERFORMANCE ON A HIGHWAY IN NAMIBIA

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ABSTRACT

Since 1997, the MMLS3 has been used as an APT tool to evaluate asphalt performance. This paper discusses a case study in Namibia in which performance of newly constructed rehabilitation asphalt on Highway B1, south of Windhoek, was evaluated. Two aspects were investigated, namely use of lime to counteract stripping of binder under wet trafficking and evaluation of the effect of compaction density on performance of the mix. Wet, dry, laboratory and field tests were utilized. Laboratory tests were done on field cores and field tests were conducted on in-service highway sections. Performance was evaluated in terms of expected traffic and environmental conditions. This provided a sound basis for decisions on adjustments to mixes and adjudication of already paved asphalt.

Keywords: Rutting, moisture damage, semi-circular bending strength, lime treatment, construction

1. BACKGROUND

In June 2003, the Institute for Transport Technology (ITT) in Stellenbosch was commissioned to conduct a series of MMLS3 and related supplementary tests, to evaluate the performance of asphalt that had been laid as part of the rehabilitation of route B1, South of Windhoek in Namibia. The asphalt comprised surfacing mixes that had been prepared with and without lime additive. The binder was 60/70 pen grade bitumen in all cases.

MMLS3 trafficking was done in both wet and dry modes at 50C. Rutting performance was evaluated as trafficking progressed in order to estimate the performance life of the material. To evaluate the performance, one hundred millimeter cores were extracted from the trafficked wheel path to determine the residual *Semi Circular Bending* (SCB) tensile strength at 20C in comparison to the same asphalt untrafficked. The strength ratio is considered representative of the resistance of the mix to wet trafficking. It also served to indicate the effect of trafficking under dry high temperature conditions. Cores were also retained for determination of residual fatigue life later, if this were considered necessary. *Bulk Relative Densities* (BRD's) were determined at the various stages to take account of the volumetric and physical condition of the asphalt in the evaluation.

Initially two sets of one hundred and fifty millimeter cores from the field were tested in the laboratory of the ITT to explore the performance of asphalt that been constructed without lime additive. The first set had a density below the specified level, while the second set had been compacted according to the specified level. The performance of the mix was found satisfactory only when compacted according to specification.

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A further two laboratory tests were then conducted. The first had lime added, while the second did not. The performance of the mixes when compacted to specification was again found to be satisfactory with the lime mix slightly superior in terms of moisture damage. In the light of the results of the initial MMLS3 tests on properly compacted mixes with and without lime, a collective decision was taken to conduct wet and dry heated MMLS3 trafficking tests in-situ. This was approved by the Roads Authority of Namibia (RA). The goal of these tests was to determine whether field performance was similar to the laboratory performance before making a decision on the *fitness for purpose* of the material. Tests were scheduled to be conducted on mixes that had reached the required density specification as well as mixes that had not met the specification. The latter was subsequently found to be not feasible due to safety reasons and it was decided to complete the investigation by testing cores in the laboratory once the relations between field and lab tests had been established.

After completion of the field tests, a second series of laboratory tests were conducted by ITT on specimens extracted from completed sections of the highway. This paper sets out the procedures that were followed and the findings of the full investigation. These were initially reported to the *RA* in 2003.

2. TEST SET-UP

Field and laboratory test set-ups have been standardized. An overview is presented in this section. The same procedures were followed in the other South African case study presented at this conference (Molenaar et al. 2004). Tests are conducted either in wet heated or dry heated mode. The dry heated mode is conducted by setting up the MMLS3 with plenums on either side of the MMLS3 to circulate heated air across the tests section. The air is regulated to flow in one direction for a pre-selected period (7 minutes in this case) and then the flow is reversed. This is continued throughout the duration of the test. When the outside air temperature is cold the environment inside the MMLS3 is partially sealed by covering the device with a plastic sheet or environmental chamber. For heated wet testing in the field, a small square metal tube dam is built around the test section. The contact with the asphalt surface is sealed off. The hot water that is heated in a tank electrically, is then sprayed along the length of the test section on either side and re-circulated back into the heating tank by vacuum suction. Temperatures are controlled by inserting thermocouples into the pavement at a depth of 25 mm and deeper depending on the depth of the asphalt. The temperature at 25 mm is used as the control test temperature.

The initial test set-up in the laboratory allowed eight 150 mm cores to be placed adjacent to each other, fitted snugly into a polypropylene mould. In the latest design the number of cores has been increased to nine and the width of the cores changed to 105 mm. This was done to increase the width through which the asphalt has to flow when it is shoved transversely and extruded adjacent to the outer edge of the wheel path. The polypropylene mould has also been replaced by an aluminium test bed comprising three moulds each capable of holding three cores or briquettes.

Trafficking by the MMLS3 in the laboratory is done in the same way as in the field in both wet heated and dry heated modes. A water bath surrounds the test bed. Heated water is circulated in the water bath through a heating-suction unit during trafficking while the temperature is maintained at a predetermined temperature.

The test temperature is normally determined by establishing the average maximum air temperature of the hottest seven day period in a year in accordance with the procedure set out in SHRP (1994). In this study, 50C was selected as the critical temperature in all cases. In comparison, the calculated critical temperature was 54C. The temperature was maintained at +/-2C. The wheel load was set at 2,7 kN and the tyre pressure at 25C at 690 kPa.

Profiles of the test section are measured prior to trafficking after the pavement surface reaches the test temperature. Before the initial measurement are taken in the laboratory, 20 load applications are applied to ensure complete seating of the cores. This is considered the zero measurement. In the field, transverse profiles are measured at four points along the length of the test section at pre-selected intervals until trafficking is terminated. In the laboratory, profiles are measured at right angles to the wheel path, at the center of each core. A longitudinal profile is also measured at the beginning and end of trafficking in the field as well as in the laboratory. It is noteworthy when there is a need to differentiate between surface deformation and deformation at the level between the surface and layer below, two pins are embedded along the wheel path. They are anchored at the bottom with epoxy. The length is such that the top of the pin is 5mm below the surface. An extension can then be screwed on top to stand proud of the surface for measurement by profilometer relative to the fixed bench marks that are used throughout the test. The plan layout of the test sections in the field is shown in Figure 1. A photographic view of the layout of the test bed in the laboratory is shown in Figure 2.

2.1 Namibia: Field Test

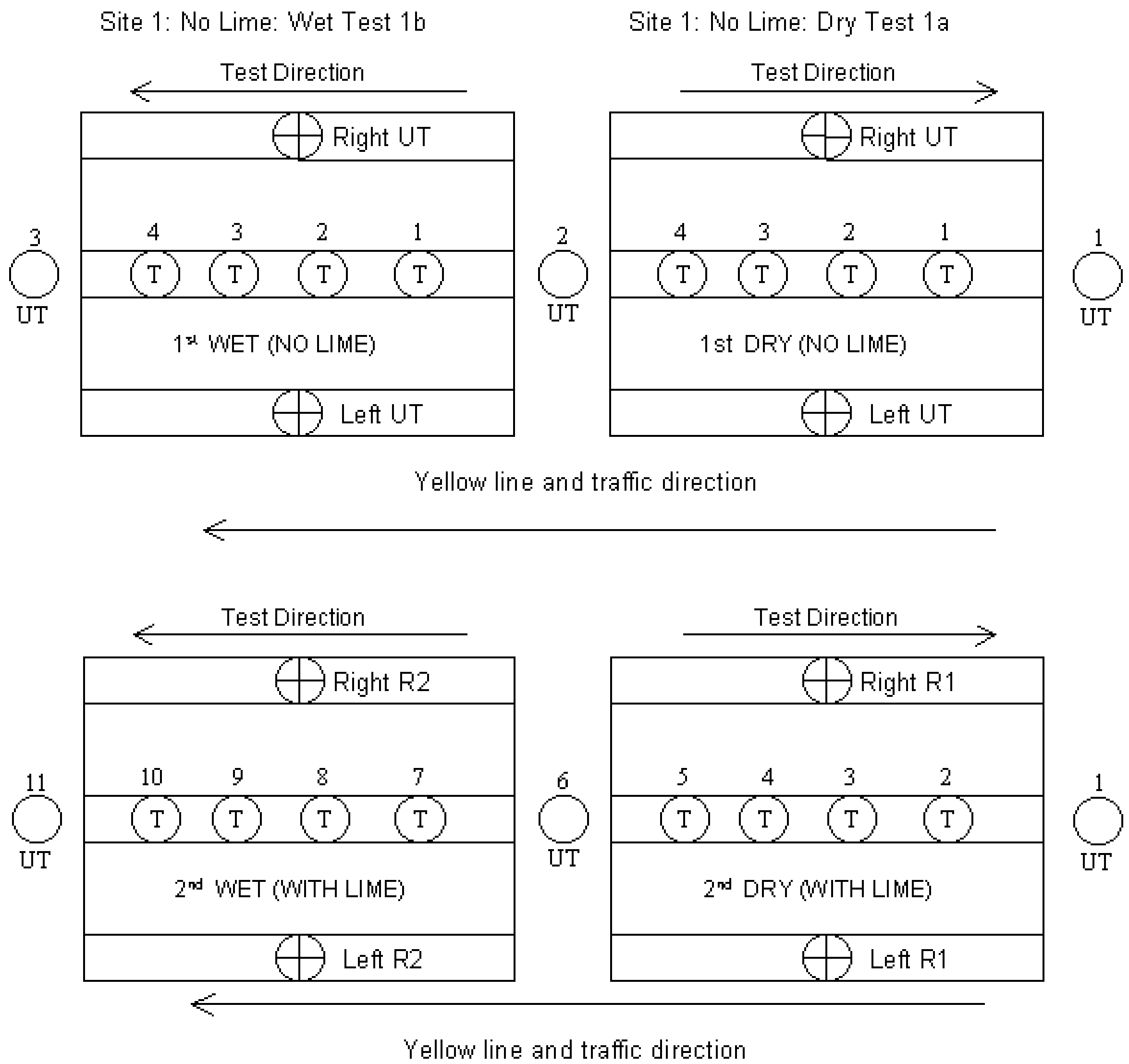

Figure 1. Layout of set up in the field sections.

Figure 2. View of test bed showing specimens and clamps in the water tank.

Generally, rutting is determined after the following load applications:

20, 2 500, 5 000, 10 000, 25 000, 50 000, and 100 000

In accordance with the test plan, one hundred millimeter cores were extracted from the trafficked wheel path and, the residual *Semi Circular Bending* (SCB) tensile strength at 20C was determined. The same was done for the untrafficked cores. The strength ratios and the *Bulk Relative Densities* (BRD's) at the various stages of the investigation, are shown in Tables 1, 2 and 3.

3. DISCUSSION OF TEST RESULTS

3.1 Results from the Following Tests Will be Discussed

3.1.1 Initial laboratory tests on field cores

1. Wet trafficking at 50 C – without lime and with densities below specification
2. Wet trafficking at 50 C – without lime and densities according to specification
3. Wet trafficking at 50 C – with lime and densities according to specification
4. Dry trafficking at 50 C – without lime and densities according to specification

3.1.2 Field tests in-situ on the highway

Site 1: Route B1 – chainage 78100

1a Heated dry test - without lime and densities according to specification
1b Heated wet test - without lime and densities according to specification

Site 2: Route B1 – chainage 71100

2a Heated dry test - with lime and densities according to specification
2b Heated wet test - with lime and densities according to specification

3.2 Second Laboratory Tests

- One heated wet test - six cores with densities below specification jointly with 2 cores extracted from site 1 of the field tests (with tack coat)
- One heated dry test - a selection of cores (with and without lime) from sections meeting density specifications.

Profile levels were measured every 3 mm after each of the respective number of axle load applications. The rut depth was determined as the maximum value over a running average of five measured points (15 mm) in the central 100 mm of the wheel path. The maximum average rut depth for the profiles of all cores was then determined from these data, for the respective number of axle loads.

Power function curves were fitted to the data of all tests to estimate the rutting for axle load applications up to two million axle load applications. This approach was validated as reasonable during MMLS3 tests that were conducted at the test track of the National Center for Asphalt Technology (NCAT) at Auburn, USA (Smit et al, 2003 and Westrack by Martin Epps et al, 2002).

Typical rutting profiles from field tests and cores tested in the laboratory are shown in Figures 3, 4, and 5. These include both wet and dry heated tests. In the same vein, the cumulative rutting that occurred during these tests is shown in Figures 6, 7, 8 and 9. It should be noted that these results reflect the downward deformation only.

Figure 10 shows all the results of the cumulative rutting that were determined in the respective tests with extrapolation to 2 million load applications. From the results of the pins that were used to measure the deformation in the pavement below the asphalt surfacing, it was possible to determine the amount of deformation that occurred in the surfacing alone. On average 0,5 – 1mm of the field rutting was due to settlement below the surface layer. This was taken into account in determining the rutting performance in the field. In the laboratory tests the specimens were trimmed to test only the surfacing layer.

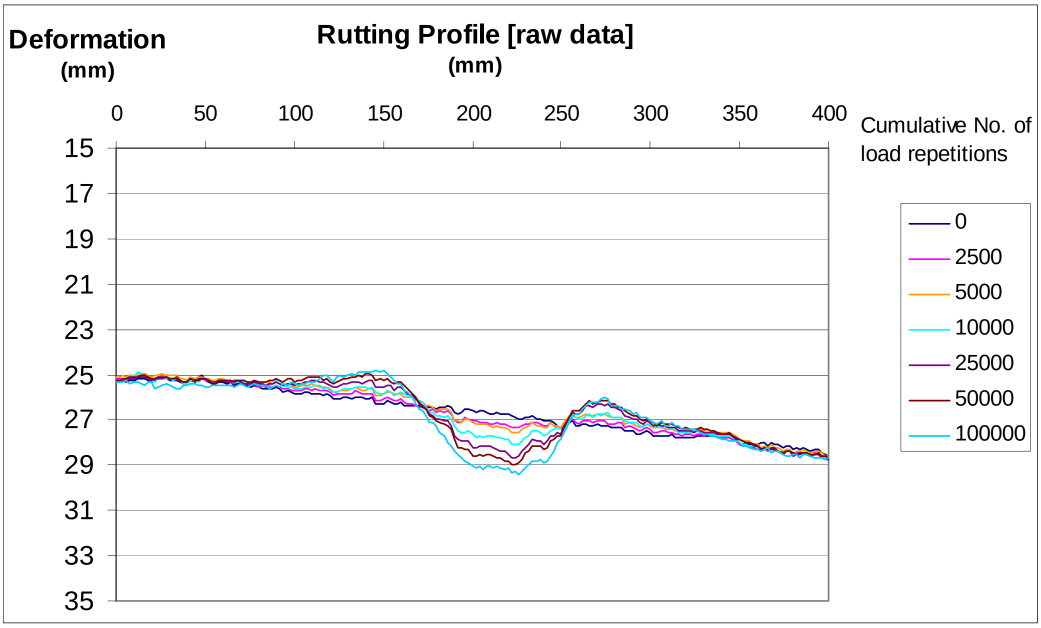

Figure 3. Typical uncorrected rutting profile of the road surface in the field during a heated dry trafficking test (Test 1a).

Table 1. Summary of test results obtained during the first laboratory test series.

Test no.	Test details	Asphalt characteristics	Predicted Rutting Performance in terms of Rutting @ 1 & 2 Million axles	Core Ref	Performance in terms of BRD				Performance in terms of SCB		
		Note: Untrafficked cores used for comparison			**Rice density**	**Untrafficked**	**Trafficked**	**Change due to Traffic**	**Untrafficked**	**Trafficked**	**Change due to Trafficking (T / UT)**
1.1	Wet - Abandoned after 2 500 axles	No lime and density below specification		1-8			NA	NA			
1.2	Wet - Trafficked to 35k load applications	No lime and density according to specification	5,6 and 6,5 mm	A-H	2,334	2177,4 (93,2 %)	2231 (95,6%)	102,5%	Ave 1780 (4 tests)	1418	80,5 %
1.3	Wet - Trafficked to 35k load applications	Lime added and density according to specification	10 mm and 11,5 mm	I-P		2189,3 (93,9%)			2014	2615	130 %
1.4	Dry - Trafficked to 100k load applications	No lime and density according to specifications	2,75 and 3 mm	A-H	2195,6	(94%)			2112	2620	124 %

Table 2 Summary of test results obtained during the field test series.

Test no.	**Test details**	**Asphalt characteristics**	**Predicted Rutting Performance in terms of Rutting @ 1 & 2 Million axles**	**Core Ref**	**Performance in terms of BRD**				**Performance in terms of SCB**		
		Note: Untrafficked cores used for comparison			**Rice density**	**Untrafficked**	**Trafficked**	**Change due to Traffic**	**Untrafficked**	**Trafficked**	**Change due to Trafficking (T / UT)**
1a	Dry – Trafficked to 100k applications	No lime and density according to specification Thickness = 40mm (nom)	Total = 6,4 and 8 mm Minus deformation of lower layer Net value est. @ 80%) = 5,1 and 6,4 mm	1-8	2,328	2204 (94,7%)	2225 (95,6%)	101%	2233	2349	105,2%
1b	Wet - Trafficked to 50k load applications	No lime and density according to specification Thickness = 40mm (nom)	7,4 and 8 mm Minus deformation of lower layer. Net value est. @ 80% = 6mm	A-H	2,328	2,177,4 (93,2 %)	2231 (95,8%)	102,5%	2233	2094	93,8 %
2a	Dry – Trafficked to 100k applications	Lime added and density according to specification Thickness =28 mm (nom)	7,4 and 9 mm Minus deformation of lower layer. Net value est. @ 67% = 5 & 6mm	I-P	2,331	2,180 (93,9%)	2154 (92%)	98.8%	1318	1850	140,4 %
2b	Wet - Trafficked to 50k load applications	Lime added and density according to specification Thickness = 28 mm (nom)	10 and 13 mm Minus deformation of lower layer. Net value est. @ 67% = 7 mm	A-H	2,331	2.191 (94%)	2171 (93%)	99.0%	1318	1490	113,1 %

Table 3. Summary of test results obtained during the second laboratory test series.

Test no.	**Test details**	**Asphalt characteristics**	**Predicted Rutting Performance in terms of Rutting @ 1 & 2 Million axles**	**Core Ref**	**Performance in terms of BRD**				**Performance in terms of SCB**		
		Note: Untrafficked cores used for comparison			**Rice density**	**Untraffic ked**	**Traffic ked**	**Change due to Traffic**	**Untrafficked**	**Trafficked**	**Change due to Trafficking (T / UT)**
2.0	Wet – Trafficked to 50k load applications but abandoned due to slippage of cores on the base	Selection of 6 cores with density below specification plus 2 cores from roximity of field trial with density according to specification	25,6 mm/-								
2.1	Wet – Trafficked to 50k load applications	Selection of 6 cores with density below specification plus 2 cores from proximity of field trial with density according to specification	15,8 mm/ 21 mm	1-8	2,334	2112 (90,5%) 2,188 (93,7%)	2080 (89%) 2,146 (92%)	98,5% 98%	1808	827 740	46%
2.2	Dry - Trafficked to 100k load applications	No lime and density according to specification Thickness = 40mm (nom)	4,4 mm/ 5,6 mm	A-H	2,328	2,176 (93,5 %)	2230 (95,7%)	102,4%	1880	1763	93,8 %

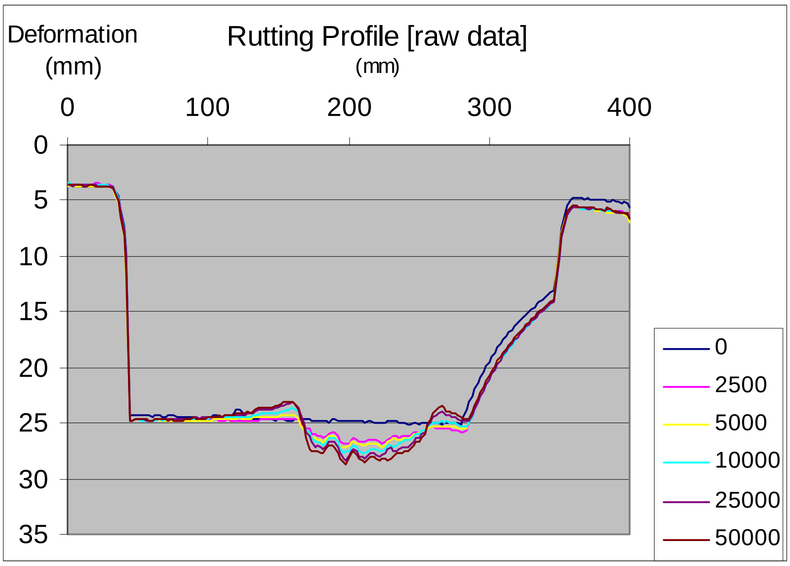

Figure 4. Typical uncorrected rutting profile of the road surface in the field during a heated wet trafficking test (Test 1b).

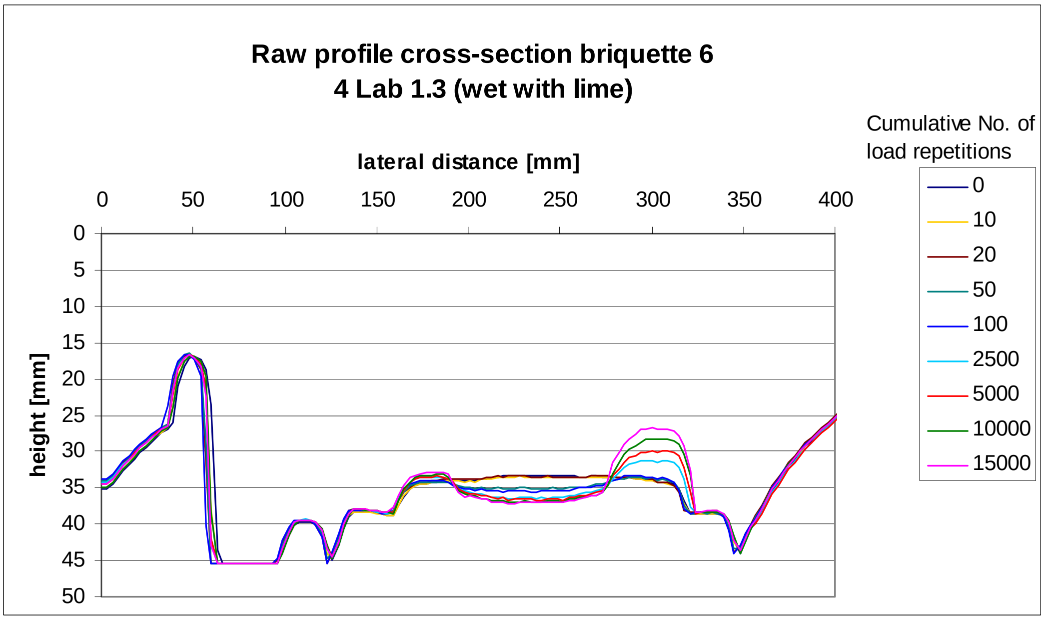

Figure 5. Typical uncorrected rutting profile of cores trafficked in the laboratory during a heated wet test (Test 1.3).

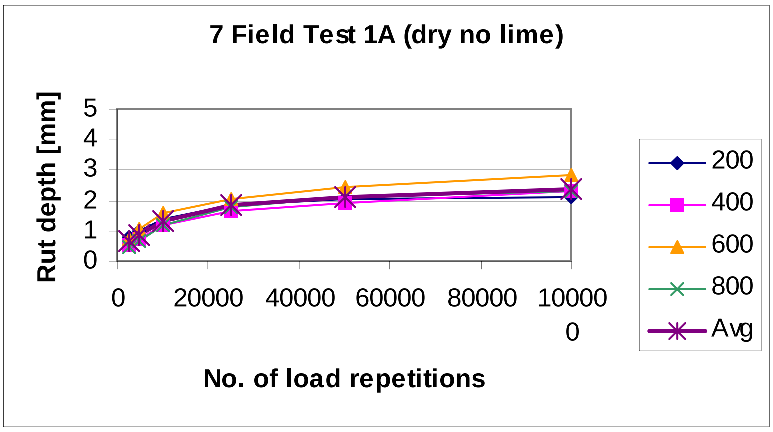

Figure 6. Cumulative rut development in the field during a heated dry trafficking test (Test 1a).

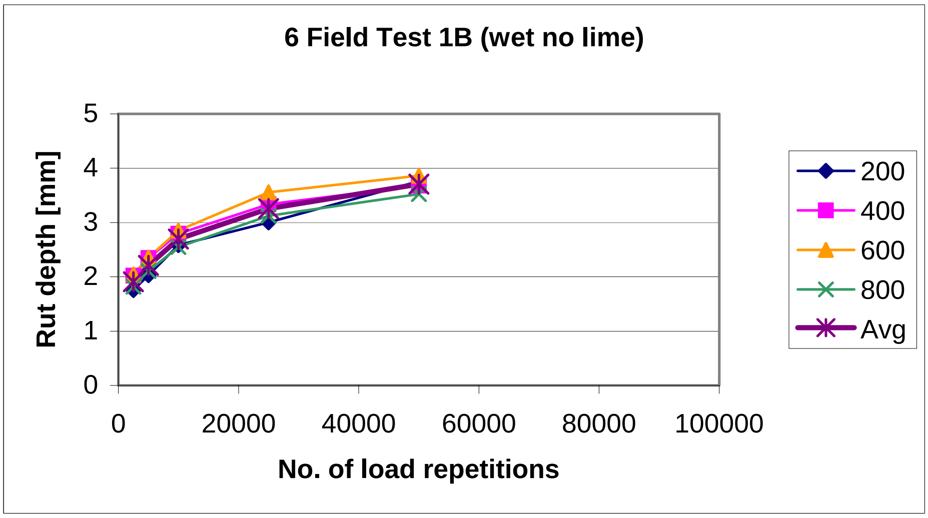

Figure 7. Cumulative rut development in the field during a heated wet trafficking test (Test 1b).

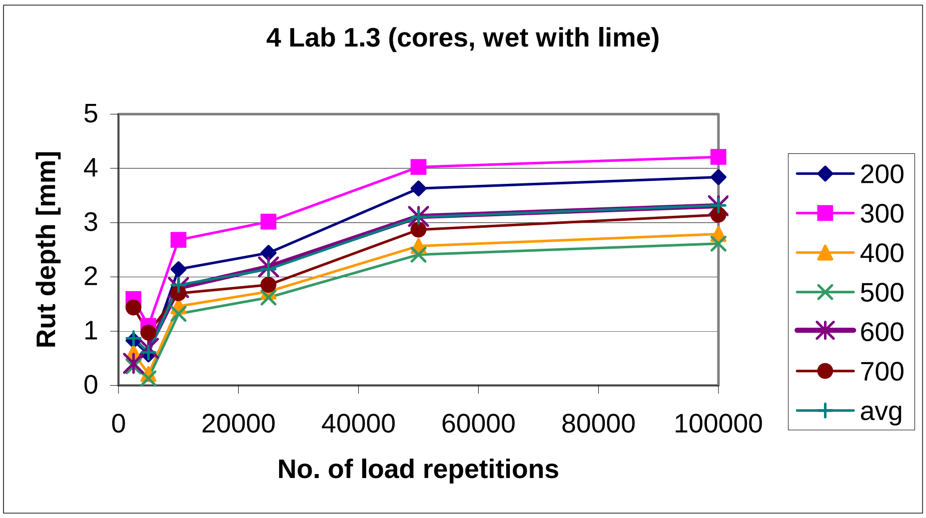

Figure 8. Cumulative rut development in the laboratory during a heated wet trafficking test (Test 1.3).

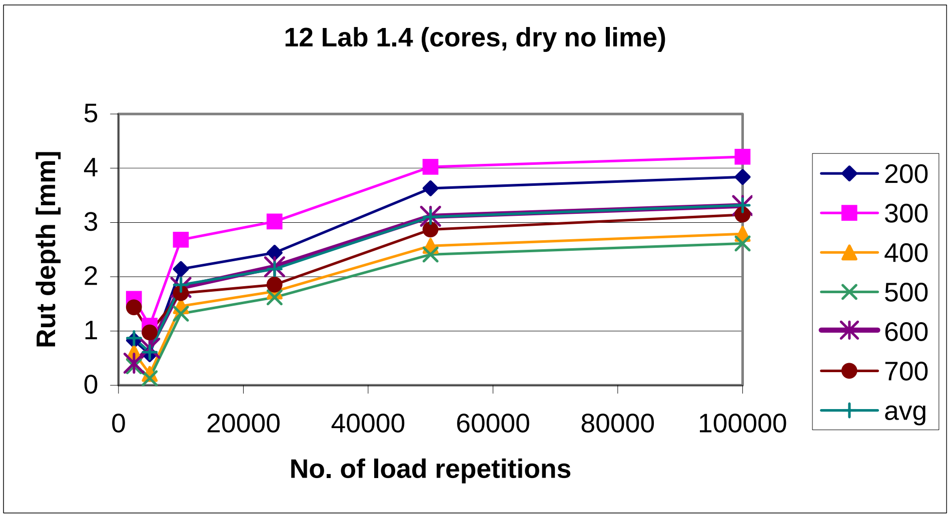

Figure 9. Cumulative rut development in the laboratory during a heated dry trafficking test (Test 1.4).

4. INTERIM PROTOCOLS FOR EVALUATING RUTTING AND MOISTURE DAMAGE

The comparative results from MMLS3 and full-scale trafficking at the test track of the National Center for Asphalt Technology (NCAT) (Smit et al 2003, Smit et al 2004) and WesTrack (Epps et al 2003) were used as benchmarks for establishing criteria for acceptable rutting performance. The results of tests in Texas (Walubita et al 2002) were used as guidelines for establishing criteria for moisture damage.

Details are set out below.

- When considering the rutting performance fundamentally, vertical stress profiles under the respective wheels are used for purpose of comparison. The limiting rut depth has to be determined in terms of *expected traffic, lateral wander, climatic conditions during life cycle, tyre pressure and layer thickness*

- General rutting performance guidelines at critical temperature (generally 50C or more*) and 7200 load applications per hour are:
  - < 3mm after 100k MMLS3 load applications on highways

  Note that values have to be adapted to suit less critical trafficking conditions

- For determining moisture susceptibility of asphalt pavements using wet trafficking after 100k applications at 50C heated wet MMLS3 axles:
  - SCB residual strength of hot mix asphalt 80%
  - SASW residual stiffness 80% and
  - SCB fatigue ratio 50% for hot mix asphalt

- Composite pavements require special consideration to evaluate entrapment of water

- Critical temperature conditions are determined from the hottest seven (7) year period in a selected number of years according to SHRP Manual 648A (Huber,1994)

5. SYNTHESIS OF FINDINGS

From a synthesis of the findings of field and laboratory MMLS3 trafficking it was concluded that:

1. Sections with lime added performed better in terms of resistance to water damage. Rutting performance was also satisfactory.
2. Sections without lime performed well when the specified density was achieved.
3. Dry heated trafficking increased the service life of the layer as measured by SCB
4. Increase in the post construction density increased the SCB tensile strength.
5. Under heated, wet and dry trafficking conditions, rutting due to laboratory trafficking was generally less severe than due to field trafficking (possibly due to mould constraint). The laboratory rutting varied between 50 percent and 80 percent of the field rutting. Similar results were found by Molenaar et al., 2004 with the MMLS3 study of asphalt performance at Johannesburg International Airport.
6. The variation in deformation along the trafficked road sections was less than that found in the laboratory on the core tests. The reason for this is not clear and the phenomenon is being investigated further. It could be related to longitudinal shoving of the asphalt under the rolling wheel loads and variation in the shear resistance at the underside of the lab specimens and the base of the test mould.

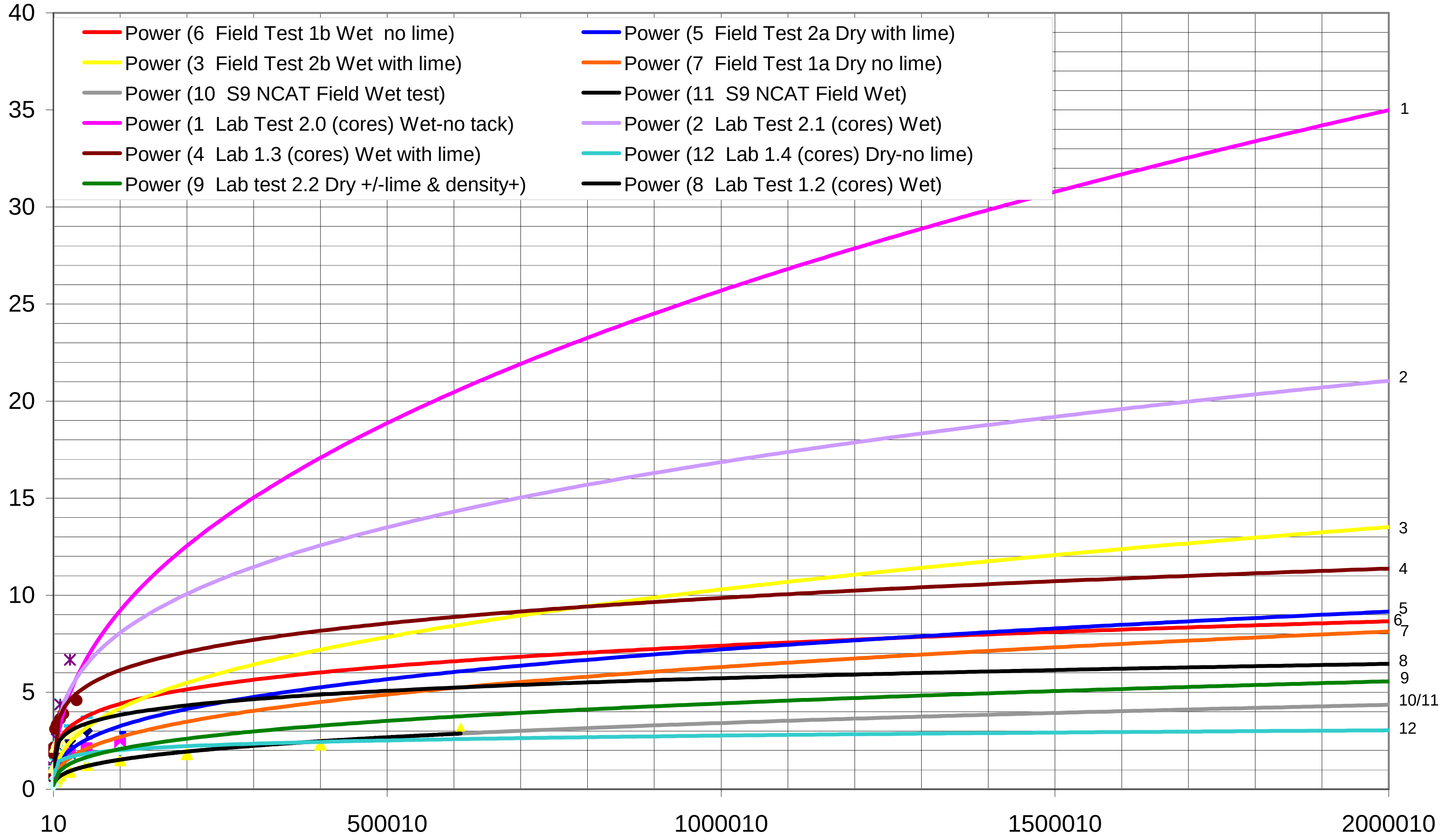

Figure10. Comparative summary of results.

6. APPLICATION OF FINDINGS

The design traffic on the highway was set at 5,6 million standard axles over the next twenty years. Based on the weather statistics of the past ten years and the related pavement temperature, it was concluded that 30 percent or ~1,7 million high temperature load applications should be used for performance purposes. In the same vein, 50k heated, wet load applications were considered appropriate for performance purposes.

In terms of stripping and related distress, it was concluded that the asphalt that had not had lime added suffered unacceptable distress when the density was below the specified value. The material also deformed longitudinally under trafficking and binder/aggregate separation manifested. However, when the density specification was achieved and a tack coat of emulsion was applied at the underside of the specimens, the performance was acceptable. The asphalt with lime added performed better than without.

From the rutting results, it was concluded that it was unlikely that a downward rut depth of >10 mm would occur under traffic loading of 1,7 million load applications at high temperature. From the amount of extrusion from under the load wheel, due to shear, it was also estimated that the total rut depth would not exceed 15 mm.

The difference between performance of sections 1a and b and 2a and b and their respective times of construction appears to have caused the latter to manifest more rutting. This is probably because of vulnerability of the fresh asphalt, which settles as time lapses after construction. This phenomenon was subsequently investigated further by conducting additional field and laboratory tests after the asphalt has been in service for approximately twelve months (ITT report 2004). The results confirmed the earlier observation. Figures 11 and 12 below show the processed results that were obtained in the latest tests.

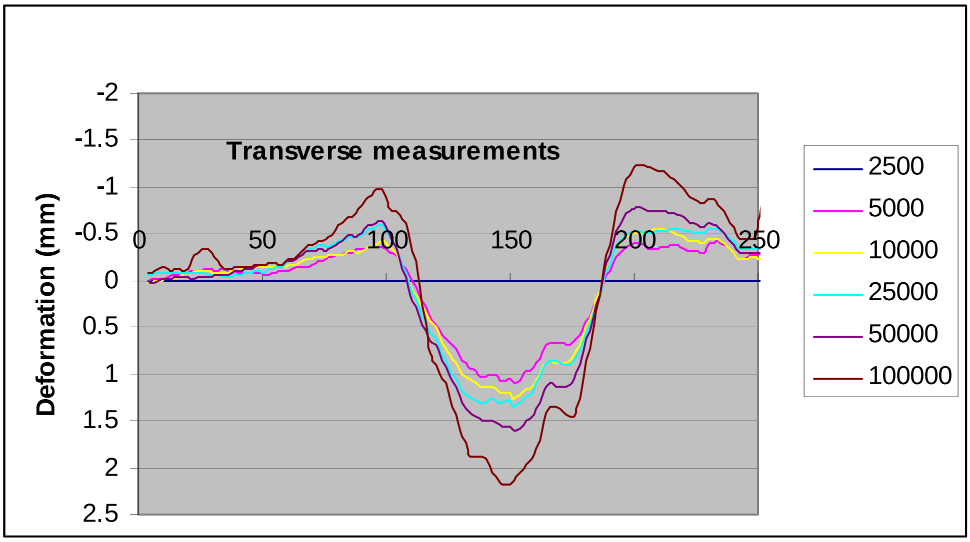

Figure 11. Dry heated field MMLS3 rutting performance approximately twelve months after paving. (Test 3a).

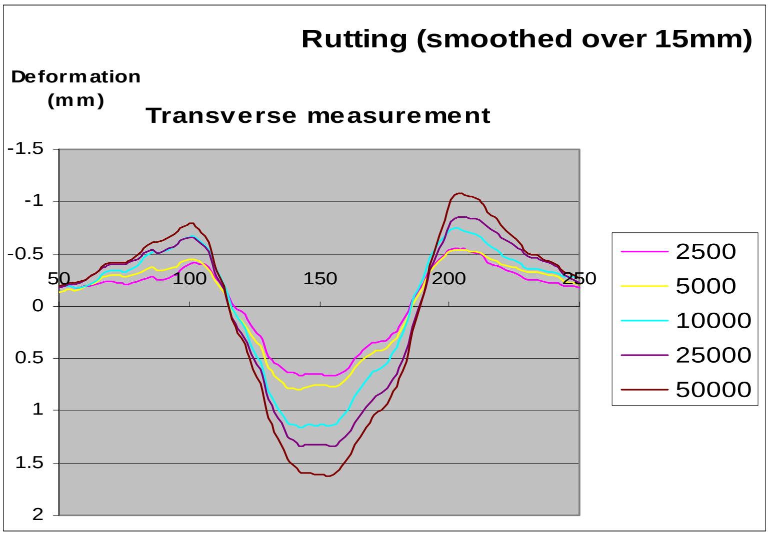

Figure 12. Wet heated field MMLS3 rutting performance approximately twelve months after paving. (Test 3b).

7. CONCLUSIONS

From the results of the limited MMLS3 tests the following was concluded in terms of expected performance. The downward rutting of the pavements that were tested would not exceed 10 mm when the surfacing is subjected to 1,7 million E80s under the expected environmental conditions in the area where the highway is located. Moisture damage or stripping is unlikely to be a problem provided the density specification is met. The added lime will further enhance the performance.

Performance beyond 1,7 million E80's is expected to be good, but more tests and analysis would have to be done to conclude this with the same level of confidence.

The successful application of APT to enhance decisions in the design and construction of a highway is an example of the innovative application and implementation of research. It would be prudent to monitor long term performance of the pavement surface and the underlying base course at a number of cross sections of the traffic lane in proximity of the test sections. This application of the MMLS3 is yet another step towards improved performance of hot mix asphalt as surfacing on a highway. It will also serve to increase confidence in the use of the MMLS3 system and the related performance protocols.

8. ACKNOWLEDGEMENTS

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