

# THE APPROPRIATENESS OF ACCELERATED PAVEMENT TESTING TO ASSESS THE RUT PREDICTION CAPABILITY OF LABORATORY ASPHALT TESTS

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## ABSTRACT

The reliability of asphalt laboratory tests to predict the rut performance of asphalt mixes in the field, could in the past only be assessed by monitoring the in-situ rut performance of asphalt mixes and comparing the field rutting with laboratory tests that were done on the mixes during the design or on cores from the pavement. Wheel tracking tests created the opportunity to evaluate the ability of laboratory asphalt indicator tests, which are used to predict the rut potential of asphalt mixes and to rank mixes during Hot Mix Asphalt (HMA) design, on a standardized platform by correlating the results obtained with these tests with their rut performance during wheel tracking tests. The rut resistance properties of various asphalt mixes were evaluated by means of a sample of laboratory asphalt tests used to evaluate the cohesive strength and frictional resistance properties of asphalt mixes. Wheel tracking tests were then conducted on the mixes in the laboratory with the one-third scale Model Mobile Load Simulator (MMLS3). The results of the laboratory asphalt tests and the wheel tracking tests were statistically analyzed to find correlation between the results of the tests. During the study standardized draft test protocols for the laboratory and field evaluation of permanent deformation with the MMLS3 were compiled to ensure that results produced by the MMLS3 tests are comparable, repeatable and that there is higher confidence in the results.

## 1. INTRODUCTION

There is a worldwide lack of simple and cost effective test methods which yield reliable results to assess or predict the permanent deformation of asphalt layers. In an earlier study by Thiessen *et al* (2000), they investigated the strength and rutting performance of in-situ asphalt pavements using a variation of the Indirect Tensile Strength (ITS) test. The different environmental and traffic conditions that in-situ pavements have been subjected to, does however make comparing test results difficult.

Wheel tracking tests such as the Asphalt Pavement Analyzer (APA), the Transportek Wheel Tracking Device and MMLS3 are being used increasingly to predict the rut performance of asphalt pavements and to rank mixes during the design phase, but these tests are relatively expensive and are therefore not normally used on smaller asphalt related projects. Wheel tracking tests provide an accelerated indication of the field rutting performance of asphalt mixes. If correlation between a simple laboratory rut performance indicator test protocol and wheel tracking test results can be found, such a test can be

used with more confidence in the design and testing of asphalt mixes for rut performance in the field.

Rutting in asphalt pavements is acknowledged to be a two-phase process consisting of (i) densification accompanied by a decrease in volume and (ii) shear deformation at constant volume (Barnard *et al*, 2001). Of the two processes, shear deformation is believed to be the main contributor to permanent deformation for well-compacted asphalt mixes. This rutting process is resisted mainly by two factors namely: i) Friction caused by aggregate interlock, and ii) Cohesion caused by the binder and the mastic. This paper will focus mainly on the rut related strength and volumetric properties of the asphalt mixes, which relates to the two factors resisting shear deformation.

The study involved MMLS3 rutting tests and other rut indicating asphalt laboratory tests conducted on various asphalt mixes. The applicability of MMLS3 testing to rank asphalt mixes during the design phase compared to simpler laboratory rut test protocols were assessed. The correlation between the rut test results from the MMLS3 and the various laboratory asphalt tests was investigated. This was done in order to assess the use of simple, low cost laboratory tests to measure resistance to rutting of asphalt mixes with acceptable confidence. The rut performance data for the various mixes were compared to the interim protocols by Hugo (2004).

## **2. TEST SELECTION AND SETUP**

Although considerable research related to the evaluation of permanent deformation in asphalt pavements was documented, no one method has been singled out as being the most applicable for predicting the rutting performance of asphalt mixes. The selection of tests for this study was therefore based on the availability of suitable test equipment and the availability of a range of test results in order to statistically analysis.

### 2.1 Laboratory asphalt testing

The selection of laboratory tests to determine the permanent deformation related strength and frictional resistance properties of the asphalt mixes that were tested with the MMLS3 were based predominantly on the following factors:

- i. Economics – The tests had to be done as part of the normal mix design activities for the asphalt projects.
- ii. Applicability – The test had to relate to the rutting performance of asphalt mixes and had to be used by the industry as accepted indicators of the permanent deformation performance of asphalt mixes.

Tests were chosen based on these criteria in order to assess the permanent deformation performance of the asphalt mixes and to relate the results to the MMLS3 rut performance of the mixes. Not all of the asphalt mixes were designed by the participating laboratories used in this study and the full range of rut related test results, such as ITS, stability and flow, Voids Filled with Binder (VFB), dynamic creep and gyratory compaction results were not always all available for all the mixes that were tested with the MMLS3. The mixes tested with the MMLS3 during this study were therefore grouped into two different sets of data.

The first range of mixes (Data set A) that were selected for the evaluation of strength and frictional resistance properties included six mixes on which, among others, ITS, VFB and stability and flow tests were done. ITS relates to the cohesive strength, while VFB relates

to the frictional resistance to permanent deformation of an asphalt mix (Barnard *et al*, 2001). Stability and flow tests give an indication of the stiffness of the mix and therefore also an indication of resistance the mix will give to deformation under the action of traffic and higher temperatures. ITS tests were also used in the study by Thiessen *et al* (2000). Their decision to use ITS tests to determine the strength properties of asphalt cores was predominantly based on the availability of the ITS test equipment and the simplicity of the test protocol. ITS tests were conducted on samples at 25 °C. During testing the samples were loaded on their diametric axis at a fixed rate of 50 mm per minute until a significant loss in applied load was noted. The applied load at that point was then recorded and the ITS value for the mix calculated.

The second set of mixes (Data set B) consisted of five bitumen treated base (BTB) mixes that were all tested with the dynamic creep test. Results of the voids after the mixes have been compacted with 300 gyrations with the Gyratory compactor were also available. During the dynamic creep test, test samples were subjected to repeated loads in the axial direction at 100 kPa loading at a test temperature of 40°C. A square wave load shape with duration of 1 second and a rest period of 1 second (0.5 Hz) were used to load the sample. The accumulated permanent deformation was monitored as a function of the number of load repetitions. In the standard test procedure the permanent strain that develops during the initial surface conditioning of 30 load applications was subtracted from the total permanent deformation after 3600 cycles in order to calculate the dynamic creep modulus. The slope between 2000 and 3000 cycles was however used as an indication of the asphalt performance for the samples tested in this study. This method is sometimes preferred as it is less influenced by the initial setting in curve at the start of the test and more indicative of what the long term performance of the pavement will be (SRT, 2004). The voids in a mix after 300 gyrations of the Gyratory compactor, is used in South Africa as an indication of what the voids at the end of the design life of the pavement will be (SRT, 2004). A mix with higher voids content will probably be more susceptible to rutting as there is more voids for the mix to compact.

## 2.2 Wheel tracking tests

For wheel tracking tests the MMLS3 was used, firstly because of the availability of the test equipment and secondly because test results can be related to the field performance of the mixes (Molenaar, 2004). All MMLS3 testing was done according to the draft test protocol, DD-MMLS-PD-O2 (SRTc, 2004), compiled from work also done during this study. A detailed discussion of the draft test protocol for field rut testing with the MMLS3, DD-MMLS-PD-O1 (SRT, 2004b), which is similar to DD-MMLS-PD-02, has been done by Kruger *et al* (2004).

MMLS3 tests were conducted on all the mixes according to the proposed protocol (DD-MMLS-PD-O2). The tests temperature was kept at 50°C ( $\pm 2^\circ\text{C}$ ) and monitored on a regular basis – at least every half an hour. Samples were loaded at a rate of 7200 load repetitions per hour under a wheel pressure of 690 kPa and a wheel load of 2.1 kN. Twenty load applications were applied first to ensure complete seating of the cores and the profilometer zero measurement was then taken. Rut depth profiles were measured for each of the nine briquettes tested for each sample after 100, 1000, 2500, 5000, 10 000, 20 000, 50 000 and 100 000 thousand axle loads. Transverse rut measurements were taken at 3 mm intervals.

All briquettes for MMLS3 testing, except for mixes A1, A2 and A4, were gyrated to the 7% voids, typically used as field specification for compaction e.g. 97% compaction specification minus approximately 4% design voids. The briquettes for samples A1, A2 and

A4 were gyrated to  $5 \pm 0.5\%$  voids. Less gyrated voids were requested as these three surfacing mixes were tested for use on an airport. All samples were gyrated to a height of 63 mm and cut to a width of 105 mm to fit into the MMLS3 sample mounting clamp.

### 3. TEST RESULTS

Suitable asphalt mixes for use in this study were selected from a range of mixes that were tested for asphalt projects with the MMLS3 at the time of the study from the participating laboratories used in this study. The results from these tests are summarized in Tables 1 and 2 to follow. In Figure 2 the MMLS3 rut results taken after 100 000 (100k) repetitions are summarized in bar chart fashion for all samples. The results have been adjusted by a factor of 1.5 times (field to core 1.25, core to briquette 1.2) the rut test results of the laboratory MMLS3 trafficked briquettes. Molenaar et al (2004) established these relationships between the performances of similar materials in the respective MMLS3 trafficking modes. Interim protocols by Hugo (2004) suggest that the field rutting performance at the critical temperature ( $50^{\circ}\text{C}$  or more) and 7200 load applications per hour should be less than 3 mm after 100 000 MMLS3 load repetitions on highways and less than 1.8 mm on airports.

Only mixes A2, A6 and B2 complied with the 3 mm rutting criteria for highways, while only mix A6 complied with the 1.8 mm suggested criteria for airports.



**Figure 1: Briquettes after 100 000 MMLS3 test axle loads.**

**Table 1: Summary of mix characteristics and laboratory test results - Data Set A**

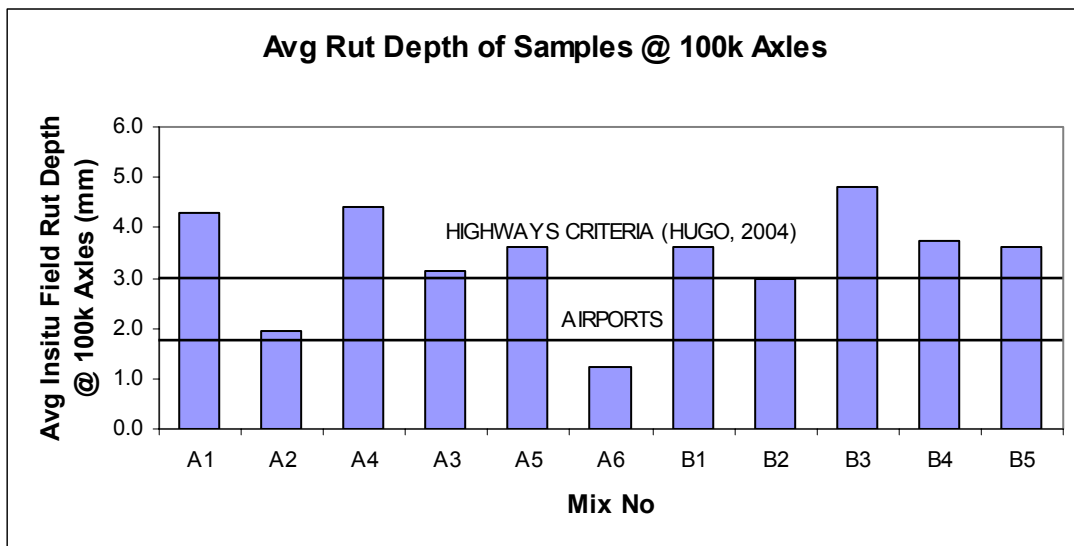
Mix No.	Mix Type	Binder Type	BC (%)	BRD (kg/m <sup>3</sup> )	Max TRD (kg/m <sup>3</sup> )	VIM (%)	VMA (%)	VFB (%)	ITS (kPa)	Stability (kN)	Flow (mm)	Stab/ Flow Ratio
A1	Colto MED W/C	60/70	5.9	2351	2417	2.9	16.1	82.2	1098	14.1	3.3	4.3
A2	Colto MED W/C	60/70 + 4% SBS	5.9	2346	2421	3.1	16.4	81.1	1186	15.0	3.3	4.5
A3	TRH 8 AC Course Grade	60/70	4.8	2595	2734	5.1	16.6	69.4	1251	12.2	2.6	4.7
A4	Colto MED W/C	60/70	5.5	2360	2434	3.0	15.6	80.5	1220	13.8	3.0	4.6
A5	BTB	40/50	4.2	2610	2715	3.8	14.2	73.5	1072	10.1	2.9	3.5
A6	BTB	60/70	4.1	2459	2575	4.5	14.1	68.0	1228	12.0	3.0	4.0

BC = Binder Content; VIM = Voids in Mix; N<sub>300</sub> = After 300 Gyration

**Table 2: Summary of mix characteristics and laboratory test results – Data Set B**

Mix No.	Mix Type	Binder Type	BC (%)	BRD (kg/m <sup>3</sup> )	Max TRD (kg/m <sup>3</sup> )	VIM (%)	Gyration Voids N <sub>300</sub> (%)	Dynamic Creep Slope (µε/cycle)
B1	BTB	40/50	4.0	2619	2746	4.6	2.0	0.33
B2	BTB	40/50 + 3% Sasobit	3.9	2614	2730	4.2	1.4	0.15
B3	BTB	60/70	4.1	2628	2738	4.0	2.0	0.44
B4	BTB	60/70 + 4% Durasphalt	4.1	2597	2729	4.8	1.6	0.44
B5	BTB	40/50	4.2	2610	2715	3.8	2.0	0.33

BC = Binder Content; VIM = Voids in Mix



**Figure 2: The average insitu rut depth\* of the mixes after 100 000 MMLS3 axle loads**

\*Avg. insitu rut depth = Avg. laboratory briquette rut depth x 1.5

Some of the mixes were trafficked wet with the MMLS3 (refer Tables 3 and 4) to test for the potential stripping of the samples under these conditions. The stripping phenomenon however falls outside the scope of this study.

### 3.1 Data Set A

The MMLS3 rut test results for Data Set A are given in Table 3 along with the results of three other test methods. ITS and VFB results are normally used to indicate rut susceptible mixes. The Marshall Stability and Flow ratio also gives an indication of the rut resistance of a mix. The criteria for these tests are 1100 to 1500 kPa for ITS, 70% maximum VFB (Barnard *et al*, 2001) and 2.5 minimum stability/flow ratio (SRT, 2004a).

**Table 3: MMLS3 Rutting – Data Set A**

Mix No.	Wet/Dry	Avg Voids (%)	Avg Rut Depth ( $\mu$ ) @ 100k axles (mm)	VFB (%)	ITS (kPa)	Marshall Stability/Flow Ratio
A1	Dry	5.0	2.86	82.2	1186	4.3
A2	Dry	4.8	1.31	81.1	1098	4.5
A3	Dry	7.9	2.10	69.4	1251	4.7
A4	Dry	5.4	2.93	80.5	1220	4.6
A5	Wet	-	2.40	73.5	1072	4.6
A6	Dry	6.9	0.83	68.0	1228	4.0

The interpretation of the combination of the results from these tests indicate that mix A3 should have the highest rut resistance under trafficking of the surfacing mixes and mix A6 should have the highest over all rut resistance. Although mix A3 has a higher rut resistance than two of the other surfacing mixes, mix A2 showed better rut performance under the MMLS3 trafficking. Possible reasons for this include:

- The briquettes for mixes A1, A2 and A4 were gyrated to 5% voids, while mix A3 were compacted to 7% voids.

- Mix A2 was mixed with a modified binder and modified binders have been shown to give higher rut resistance even though it does not give higher ITS values or stiffer stability/flow ratios.

### 3.2 Data Set B

In Table 4 the MMLS3 test results for five BTB mixes are given. The percentage of voids the mix has after it has been gyratory compacted with 300 gyrations and the dynamic creep results are also given as the dynamic creep slope between 2000 and 3000 cycles.

**Table 4: MMLS3 Rutting – Data Set B**

Mix No.	Wet/Dry	Avg Voids (%)	Avg Rut Depth ( $\mu$ ) @ 100k axles (mm)	VIM (%)	Gyrations Voids N <sub>300</sub> (%)	Dynamic Creep Slope ( $\mu\epsilon$ /cycle)
B1	Wet	6.5	2.4	4.6	2.0	0.33
B2	Wet	6.7	2.0	4.2	1.4	0.15
B3	Wet	7.1	3.2	4.0	2.0	0.44
B4	Wet	6.6	2.5	4.8	1.6	0.44
B5	Wet	-	2.4	3.8	2.0	0.33

As can be seen from Table 4, the dynamic creep slope test and the MMLS3 rated the performance of the five mixes more or less equally. Admittedly, mix B2 had a very low dynamic creep slope, but it did not have a significantly lower rut value than the other mixes. Therefore the dynamic creep test does not seem to be discriminatory or reliable enough as a rut potential indicator.

## 4. STATISTICAL ANALYSIS

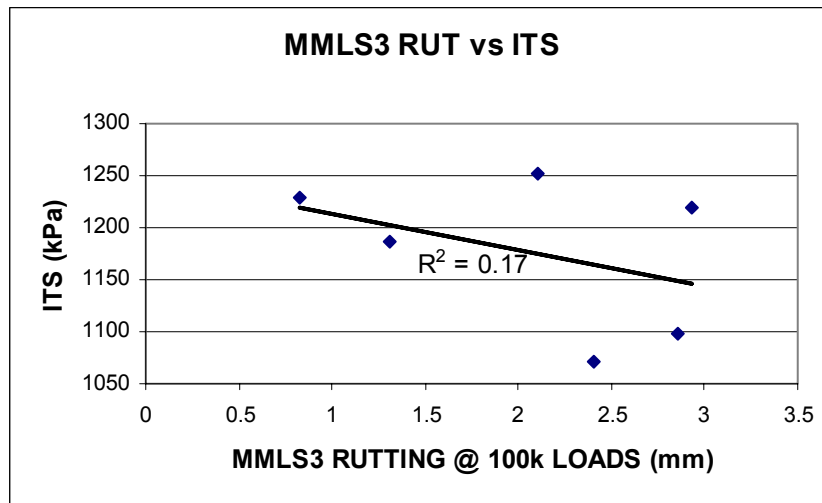
Linear regression analyses of the test results shown in Tables 3 and 4 were performed to identify tests that correlate best with the rutting results of the MMLS3. Rutting will, however, probably not increase linearly as rut related variables change. A non-linear trend line for the analysis may therefore give a better fit. For these small data sets a linear trend line was however chosen to measure correlation, as the addition or omission of a single data point in small data sets influences a non-linear trend line more than a linear trend line.

### 4.1 Data Set A

The result of the MMLS3 rutting and ITS linear regression analysis revealed a low  $R^2$  value, indicating poor correlation between ITS and MMLS3 rut results. This is shown in Figure 3 to follow. Although the data available for statistical analysis was limited, the results compared favorably with the findings of Thiessen *et al* (2000) from their study into the strength and rutting performance of in-service asphalt pavements. In their study they found even lower correlation ( $R^2 = 0.01$ ) between ITS and the rate of rutting. Thiessen (2000) describes this lack of correlation as not surprising, because rutting is generally associated with shear response to a sustained load rather than to a tensile strength.

The correlation between VFB and MMLS3 rutting, as well as Marshall Stability and Flow showed just as little correlation ( $R^2 = 0.27$  and  $0.22$  respectively). These correlations are shown graphically in Figure 4 and 5 to follow. This could have been the result of the modified binders used in the samples. The lack of a range of data from tests done on similar samples may make the significance of the results questionable. These results did however correlate with suggestions in the literature (e.g. Barnard *et al*, 2001), which

indicated that these three tests can not reliably predict rutting when modified binders are used.



**Figure 3: MMLS3 Rutting vs ITS**

A regression was also done to find correlation with MMLS3 rut results if all three tests were included. The regression revealed a higher correlation ( $R^2 = 0.627$ ) if ITS, VFB and Marshall Stability and Flow is used as input into the regression. However, the test statistic (t-stat) values of the coefficients were all below two, indicating that none of the variables are significant. The higher correlation obtained if more variables are used in the rut regression does however seem reasonable as more of the properties are tested when a wider range of tests are used. The use of various rut related test results as input into the Expert systems approach to rutting evaluation (Barnard *et al*, 2001) therefore appears to be a valid method to predict the rut susceptibility of mixes. The poor rut prediction correlation of tests used in the method when modified binders are used does however reduce the applicability to use the method for mixes with modifiers, though.

#### 4.2 Data Set B

The output of the regression analysis to correlate MMLS3 rutting with the dynamic creep slope indicated better correlation with MMLS3 rut testing results than the tests from Data Set A. A  $R^2$  value of 0.66 was observed. This is shown graphically in Figure 6. Again, more available data would confirm this correlation, especially because research work done in recent years has raised some doubts concerning the ability of the dynamic creep test to properly and consistently evaluate the rutting potential of different mix types (Barnard *et al*, 2001). The main reasons for these concerns include the absence of a confining pressure as well as the apparent insensitivity of the test results to low void contents. The correlation between MMLS3 rutting and voids in a mix after 300 gyrations had a lower correlation (0.37), but as suspected rutting increased as the percentage voids after 300 gyrations increased. This is shown graphically in Figure 7 to follow.

A regression analysis was again performed to find correlation with MMLS3 rut results if the dynamic creep slope and the voids after 300 gyrations were included. The regression revealed good correlation ( $R^2 = 0.70$ ) if both these tests are used as input into the regression. The t-stat values of the coefficients were again both below two, indicating that none of the variables have significance.



## 5. CONCLUSIONS AND RECOMMENDATIONS

Transportation authorities are looking worldwide for a simple, low cost laboratory test to assess the resistance of mixes to rutting. The MMLS3 seems to offer some potential as an accelerated testing device to measure and predict rut potential of mixes. A protocol for testing has been established and was used in the limited correlation study. Laboratory tests such as ITS and dynamic creep, which test properties that are related to permanent deformation, are much simpler and cost effective to perform than wheel tracking tests. There is an obvious reduction in the reliability of the results obtained through these tests related to their simplicity and lower cost. Because these tests do not measure rutting directly as wheel tracking tests do, the usefulness of the results obtained can only be measured after the pavement has been in service for a period of time. Even then the reliability of the results cannot be measured in full as pavements in service are subjected to various differential external factors such as temperature, traffic, loading etc. It is suggested that this limited study be expanded to improve the correlations between the MMLS3 tests and other standard mix design tests (ITS, VFB, dynamic creep and gyratory compaction). It is also suggested that the protocol of MMLS3 testing be used as standard mix design test to evaluate rut potential.

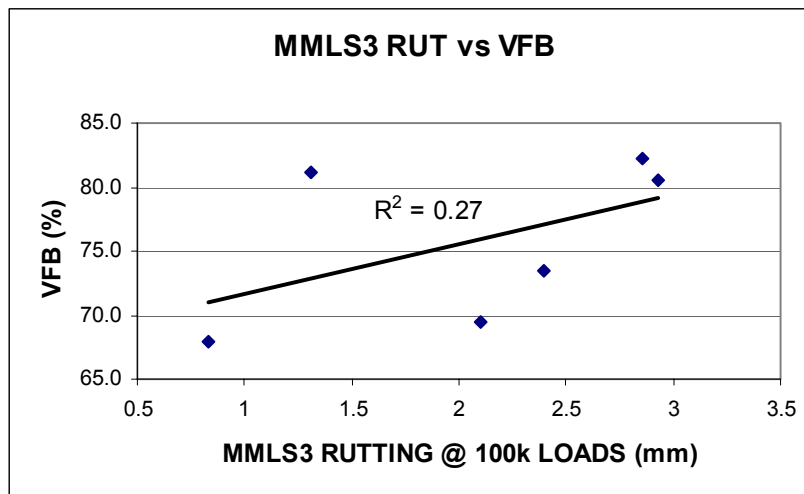


Figure 4: MMLS3 Rutting vs VFB

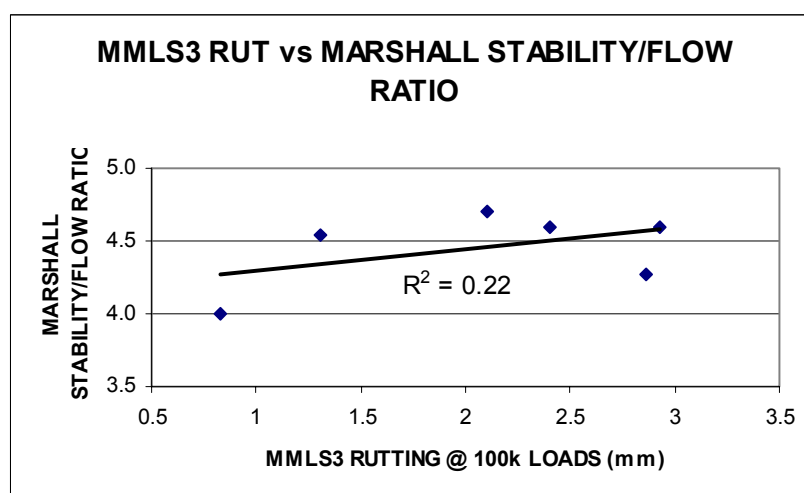


Figure 5: MMLS3 Rutting vs Marshall Stability and Flow

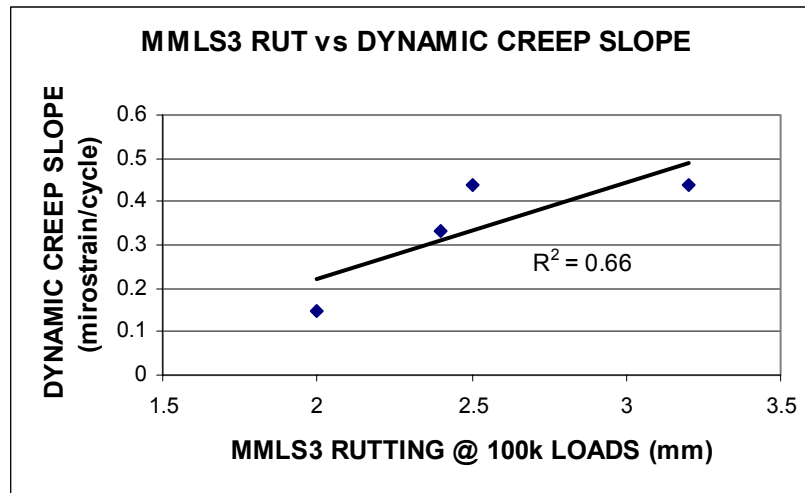


Figure 6: MMLS3 Rutting vs Dynamic Creep Slope

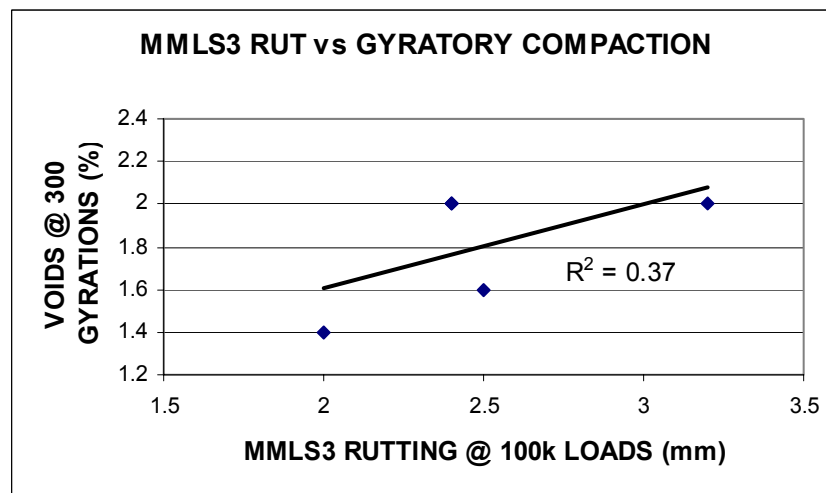


Figure 7: MMLS3 Rutting vs Voids at 300 gyrations

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