# Determination of Rutting and Water Susceptibility of Selected Pavement Materials using MMLS3

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ABSTRACT: Accelerated pavement testing (APT) has become an increasingly important research tool to evaluate and validate pavement materials. Model APT devices, such as MMLS3, which can be used in situ and in the laboratory, have been used very successfully for this purpose recently. This paper describes the results of testing 48 cores from different Swiss pavement structures (hot and cold thin surfacings, porous asphalt, gussasphalt and stone mastic asphalt SMA) using the MMLS3 load simulator. The research was conducted at Stellenbosch University where the MMLS3 test set-up has been modified to provide the ability for accelerated pavement tests on cylindrical asphalt specimens. Furthermore, the test set-up enables the study of the susceptibility to water damage of an asphalt structure. The aim of the investigation presented in this paper, was the comparison of dry and wet asphalt pavement materials in order to determine their susceptibility to rutting.

First results clearly indicate that the influence of water may reduce the performance of asphalt structures. In one case an increase of rutting up to 50% compared to dry testing was found.

KEY WORDS: Accelerated pavement testing, MMLS3, water susceptibility.

## 1 INTRODUCTION

Accelerated pavement testing (APT) has become an increasingly important research tool to evaluate and validate pavement materials. Model APT devices have recently been used very successfully for this purpose in situ and in the laboratory.

In the frame of a research cooperation between the Swiss Federal Laboratories for Materials Testing and Research EMPA and the University of Stellenbosch in 2003, an investigation with the Model Mobile Load Simulator MMLS3 was conducted using cores from different Swiss asphalt pavement structures (hot and cold thin surfacings, porous asphalt, gussasphalt and stone mastic asphalt SMA). The research was conducted at Stellenbosch University where the MMLS3 test set-up has been modified for accelerated pavement tests on cylindrical asphalt specimens under dry and wet conditions (MLS Test

Systems, 2002). This test set-up enables to investigate the susceptibility to water damage of an asphalt structure.

The study presented in this paper consisted of two parts:

The aim of the first part, was the comparison of different dry and wet asphalt pavement surface structures with respect to rutting susceptibility with the MMLS3. This is an extremely important consideration in countries such as Switzerland, where heavy and frequent rainfall may lead to safety problems.

In a second part of the investigation all cores were tested in a special 3-point bending test to establish the damage due to wet trafficking.

## 2 MATERIALS

For the investigation 48 cores from Swiss pavements with different structures and various surfaces courses were used. The cores include hot and cold thin surfacings (Raab and Partl, 2004), porous asphalt, mastic asphalt (gussasphalt), stone mastic asphalt as well as conventional asphalt concrete taken from two heavily trafficked pavement sections of two motorways (Partl and Fritz, 1997) and from a motorway in the valley of an alpine region (WA).

Table 1 gives an overview of all materials. Since this investigation was performed before the introduction of the European Standards in January 2005 and the layers had been constructed according to the previously valid standards, the original terms for the material declaration according to the old Swiss standard SN 640431 are given in table 1 and maintained throughout this paper (e.g. AB, HMT,...). The air void content of all layers according to the above mentioned standard was between 3.0 and 5.0 Vol-%, except for the porous asphalt with an air void content of 25 Vol-% and the mastic asphalt with an air void content of less than 1.5 Vol-%.

Table1: Materials used for the investigation.

| Surface course | Core No. | Pavement structure of test specimens | Thickness of surface course [mm] |
|---|---|---|---|
| *Cold micro surfacing* | | Existing damaged (cracked) road structure was overlayed with a cold micro surfacing | |
| Basel (B) | Ba, Bb | cold micro surfacing, AB 16, HMT 40 | 8 |
| St. Gallen (S) | Sa, Sb | cold micro surfacing, AB 8, AB 10 | 8 |
| Frauenfeld (F) | Fa, Fb | cold micro surfacing, AB 10, AB 16 | 10 |
| Zürich (Z) | Za, Zb | cold micro surfacing, AB 10, AB 16 | 8 |
| *Hot thin surface courses* | | New construction: Base course HMT and thin surface course | |
| Würenlingen (WL) | WLa, WLb | SMA 8, HMT 22 | 25 |
| Würenlos (WS) | WSa, WSb | MR 6, HMT 32 | 25 |
| *New pavements* | | New pavements construction, untrafficked | |
| Stone mastic asphalt (SMA) | SMAa, SMAb | SMA 11, HMT 22 | 40 |
| Porous asphalt (DRA) | DRAa, DRAb | DRA 11, HMT 22 | 40 |
| Mastic asphalt (GA) | GAa, GAb | GA 11, GA 16 | 40 |
| *trafficked pavements* | | Old pavements , trafficked >10 years | |
| slab F (F1.2) | F1.2a, F1.2b | AB 16, HMT 40 | 50 |
| slab G (G2.2) | G2.2a, G2.2b | AB 16, AB 16 | 30 |
| Wallis (WA) | WAa, WAb | AB 16, AB 25 | 30 |

Most of the cores were taken directly after the pavement construction or, in case of rehabilitation, directly after the application of the new surface course. On the other hand, there were also cores from roads which had been under traffic for a couple of decades (cores F1.2, G2.2 and WA). All pavements were taken from motorways or roads with a high traffic volume.

Before shipping to South Africa all cores with a diameter of 150 mm were cut to a height of 63 mm. Hence, only the surface course and parts of the next course(s) remained. At Stellenbosch University two opposite lateral parallel cuts were made leaving a width of approximately 100 mm (cs. Figure 2.).

## 3 EXPERIMENTAL

### 3.1 Model Mobile Load Simulator MMLS3

The MMLS3 (Figure 1) as it was developed by Hugo at Stellenbosch University is an Accelerated Pavement Testing (APT) device that applies a scaled load on four single tires. The tires are smaller than standard truck tires, having a wheel diameter of 300 mm. The machine is 2.4 m long by 0.6 m wide by 1.2 m high and applies approximately 7200 load applications per hour. The MMLS3 applies a load of up to 2.7 kN on each of its tires that are inflated up to 800 kPa. The distance between the tires is 1.05 m, and the MMLS3 operates at a speed of 2.6 m/sec that corresponds approximately to a 4 Hz frequency of loading for a measured tread length of 0.11m. The machine is used for accelerated testing of pavement structures in situ and in the laboratory in order to determine the mechanical properties under a wheel load, especially the rutting behavior of surface courses (Smit et al, 2003)

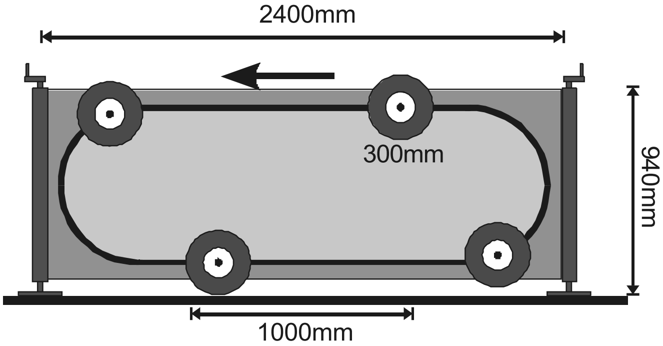

Figure1: Principle of MMLS3

The MMLS3 test set-up has been modified to allow testing on cylindrical asphalt specimens in the laboratory. The test bed consists of a metal base with nine segmental cylindrical clamps, designed to hold the asphalt test specimens prepared from cores. Specimens are individually held in position by tightening bolts pressing onto the segmental clamps.

Tests were conducted under wet condition, thus enabling the study of the susceptibility to water damage of an asphalt mix (Smit, A. de F et al, 2002). In addition, tests were also preformed under dry condition where the temperature of the specimens was kept at a constant level. In the first case the test bed is placed in a water bath that fits perfectly under the MMLS3 allowing trafficking of all nine specimens simultaneously. The water in the test bath can be circulated and heated to pre-selected temperatures by an electric heater and control system. When testing in dry conditions hot air was blown over the specimens while the bottom of the specimens was kept to test temperature with a water heated base.

For the MMLS3 tests a temperature of 40°C was chosen. In order to monitor the temperature of the specimens during the test, thermocouples were installed inside the specimen at 25 mm and 40 mm distance from the specimen surface. In case of wet tests in addition a temperature measurement was installed in the water bath. The temperature achieved during testing was 40 ± 2 °C. The test was run up to a maximum of 50 000 load repetitions with a wheel load of 2.1 kN and a tire pressure of 690 kPa. No lateral wander was implemented in the test.

As the point where the MMLS3 wheel touches down might damage the first sample, a dummy and 8 cores were installed. For every pavement type two dry and two wet samples were tested. Figure 2 depicts the test set-up.

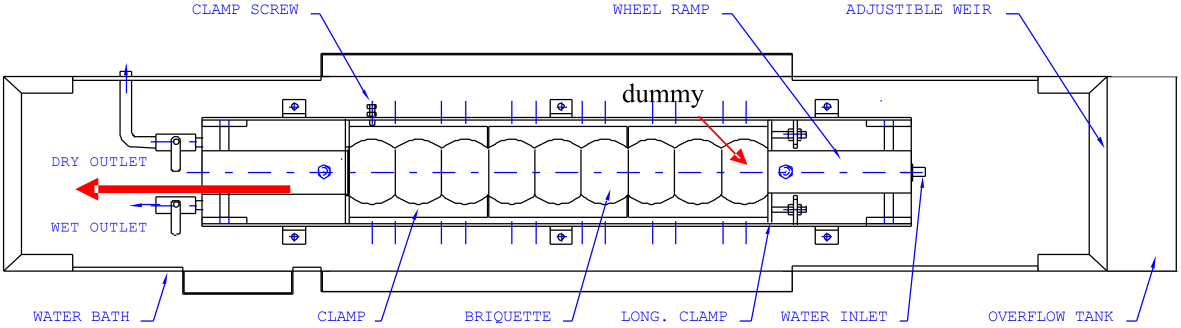

Figure 2: Partial plan view of test bed.

### 3.2 Mechanical Testing: 3- Point Bending Test

In a second part all specimens after being exposed to the rutting test were tested in a 3-point bending test (distance between the supports: 110 mm). Figure 3 shows the test set-up. All specimens were tested upside down, e.g. the force was applied on the lower layer and the original trafficked surface was subject to tension loading. This set up was chosen to examine if surface damage and cracks resulted in a water-related weakening effects of the specimen, such as change in bending failure strength. The test was conducted as follows: All specimens were tested at 25°C and a frequency of 10 Hz. Firstly sinusoidal load of an amplitude of 0.3 (0.1… 0.4 kN) was applied 100 times, then the force was increased with a speed of 4 mm/min until the specimen broke. The force at failure was measured and neglecting the influence of the transverse shear force the nominal stress at break was calculated using the simple beam equation $\sigma = M/W$ (1), where M denotes the moment and W the section modulus

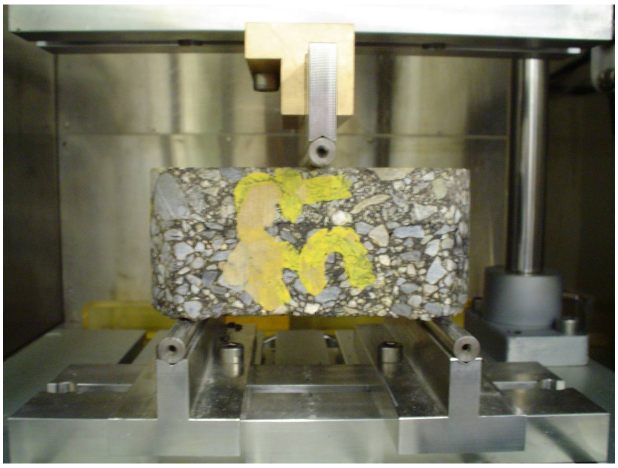

Figure 3: Test set-up for 3-point bending.

# 4 TEST RESULTS

## 4.1 MMLS3 Test Results

The rut profile was measured with a profilometer, which was placed at predetermined positions across the specimens. Rut depth was determined at the following intervals: 1000, 2000, 5000, 10 000, 25 000 and 50 000 load repetitions. According to an experimentally based bedding procedure the specimens were pre-loaded with 100 load repetitions before starting the measurements.

For each material type the mean rut depth value for both tested specimens in the wet as well as in the dry test was calculated. Figure 4 shows an example of the rut progression versus the number of load repetitions for a specimen with cold thin surfacing. The data was then processed to determine the rut progression with increasing load repetitions using a trend line. With regard to the uncertainty of the rutting behavior under the initial load repetitions the trend for the rut progress up to 100 000 load repetitions was calculated between 2500 and 50 000 load repetitions using a power law regression approach. As an example the logarithm of the load repetition is plotted versus the logarithm of the number of load repetitions, see figure 5. This graph depicts the results of a new pavement with a stone mastic asphalt SMA wearing course together with the power law regression curves.. In table 2 all rutting test results as well as the coefficients of the trend lines following the equation $y = a\,x^b$ (2) are given (also give is the coefficient of correlation $r^2$).

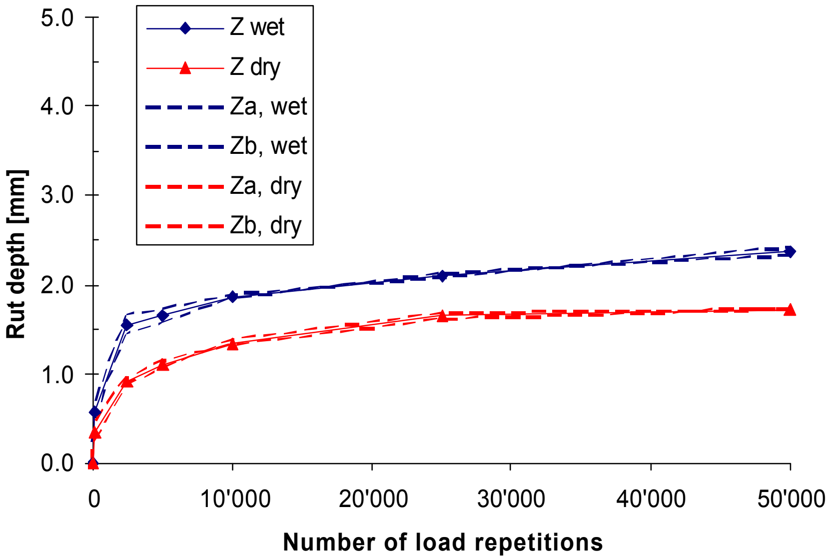

Figure 4: Rut progression versus number of load repetitions in dry and wet test for a pavement with cold thin surfacing (full line: mean value of two specimens, dotted lines: single values)

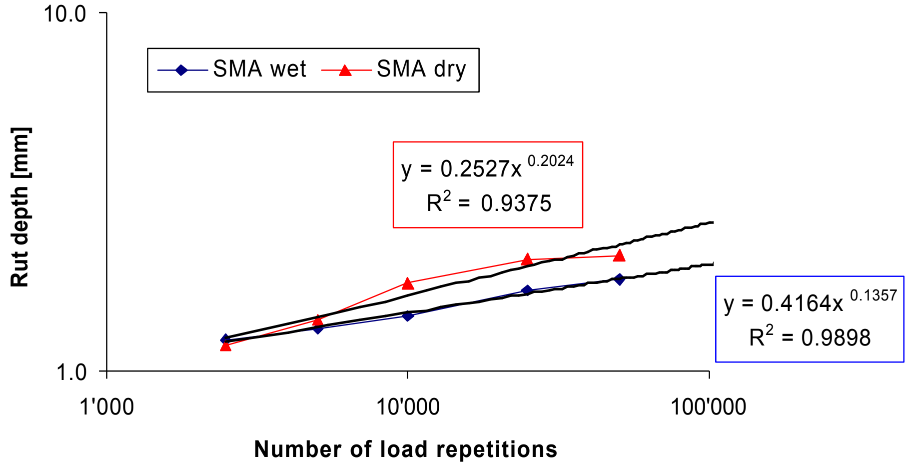

Figure 5: Trend line showing the rut progression versus number of load repetitions in dry and wet test for a new pavement with a stone mastic SMA wearing course.

Table 2: Results of the rutting test (mean values), rutting prediction and coefficients of trend lines

| Surface course | Max. rut at 50 000 load repetitions [mm] | | Calculated max. rut at 100 000 load repetitions [mm] | | a | | b | | $r^2$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | dry | wet | dry | wet | dry | wet | dry | wet | dry | wet |
| *Cold micro surfacing* | | | | | | | | | | |
| B | 1.09 | 2.21 | 1.28 | 2.39 | 0.151 | 0.549 | 0.186 | 0.128 | 0.98 | 0.99 |
| S | 1.08 | 1.22 | 1.43 | 1.53 | 0.082 | 0.162 | 0.247 | 0.196 | 0.96 | 0.90 |
| F | 2.79 | 2.96 | 3.57 | 3.62 | 0.120 | 0.288 | 0.300 | 0.219 | 0.98 | 0.99 |
| Z | 1.71 | 2.41 | 2.12 | 2.62 | 0.171 | 0.487 | 0.219 | 0.145 | 0.96 | 0.99 |
| *Hot thin surface courses* | | | | | | | | | | |
| WL | 1.80 | 2.12 | 2.17 | 2.25 | 0.232 | 0.603 | 0.194 | 0.114 | 0.97 | 0.98 |
| WS | 1.21 | 1.19 | 1.50 | 1.23 | 0.150 | 0.333 | 0.200 | 0.114 | 0.86 | 0.94 |
| *New pavements* | | | | | | | | | | |
| SMA | 2.11 | 1.83 | 2.60 | 2.20 | 0.253 | 0.416 | 0.202 | 0.136 | 0.94 | 0.99 |
| DRA | 1.11 | 1.12 | 1.24 | 1.40 | 0.079 | 0.262 | 0.250 | 0.135 | 0.97 | 0.99 |
| GA | 4.36 | 4.41 | 5.72 | 5.86 | 0.046 | 0.106 | 0.421 | 0.346 | 0.99 | 0.99 |
| *Old, trafficked pavements* | | | | | | | | | | |
| F1.2 | 1.23 | 0.52 | 1.24 | 0.71 | 0.249 | 0.021 | 0.012 | 0.339 | 0.85 | 0.98 |
| G2.2 | 4.09 | 3.11 | 5.03 | 3.85 | 0.106 | 0.162 | 0.335 | 0.275 | 0.99 | 0.99 |
| WA | 1.33 | 0.52 | 1.39 | 0.71 | 0.435 | 0.021 | 0.101 | 0.305 | 0.91 | 0.77 |

From the MMLS3 test results in table 2 as well as figures 4 and 5 it follows that wet testing does not always cause more rutting compared to dry testing for all mixes. On the other hand, it is clearly shown that water can reduce the rutting performance of asphalt structures by 30% to 50% as compared to dry testing (see result for B and Z).

In figure 6, the maximum rut depth at 50 000 load repetition for dry and wet testing is presented. One can clearly observe in the figure that for the pavements which had been overlaid with cold micro surfacing less rutting in the dry test than in the wet test occurs, whereas for the old trafficked roads the opposite seems to be the case. For all new pavement constructions including the ones with hot thin surface courses a trend can not be stated, i.e. in some cases the performance in the dry test or in the wet test is better. Furthermore, for new pavements, there are also specimens which show a very comparable behavior in wet and dry testing, e.g. WS, DRA and GA.

The finding that all pavements with cold micro surfacing appear to have a better rutting performance in the dry test can be explained by the fact that water damage here occurs due to cracks in the old original pavement structure and that the overlay, obviously, was not able to protect the lower layer sufficiently. This confirms the fact, that overlays are only a short term measure of rehabilitation that does not contribute significantly to long term durability of pavements

The findings that the rut depth in the wet test of the old trafficked pavements is less than in the dry test, cannot be understood completely. One explanation could lie in a shift between the wet and the dry curves as presented in figure 7 which may have occurred due to the bedding during the pre-loading process with 100 load repetitions. However, due to the restricted number of specimens, this point could not be verified, but would certainly need further consideration in refining the test protocol. On the other hand, from table 2 it follows that the slopes for wet testing of the old pavements F1.2 and WA are higher than the one for dry testing. This would mean that the rutting rate in the wet state is higher than in the dry state. This is not true for G2.2 where neither the trend for the rutting deformation nor the rutting rate appears to follow a plausible trend. In this case the deformations in the dry state are clearly higher and the rutting rate clearly lower that in the wet state. Since this pavement proved generally very susceptible to rutting this behavior could have been influenced by the adjacent stiffer specimens, which might have influenced locally the dynamics and vertical impact of the wheel.

Furthermore it is important to note that the old pavement structures did not show severe damage (cracks) in the field apart from permanent deformations which occurred in the road where G2.2 was taken from. For the specimens G2.2 and F1.2 the field performance and the rutting behavior in the test seem to match very well: F1.2 was taken from a road section showing only small permanent deformation after nearly 20 years of trafficking, whereas G2.2 was derived from a section with major deformation problems (Partl and Fritz 1997).

For the new motorway constructions, specimen SMA, DRA and GA, rutting behavior is very much dependent on the surface course material. Whereas mastic asphalt is known as a material which can be quite sensitive to rutting, if poorly designed, the aggregate structure of SMA and porous asphalt may produce reasonably good rut resistance.

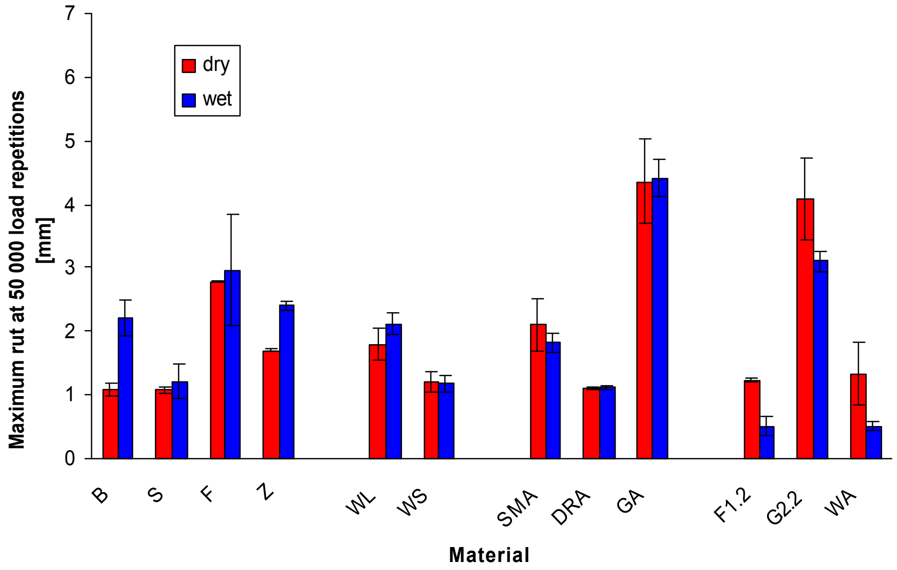

Figure 6: Comparison of maximum rut at 50 000 load repetitions for dry and wet testing, bars: standard deviation.

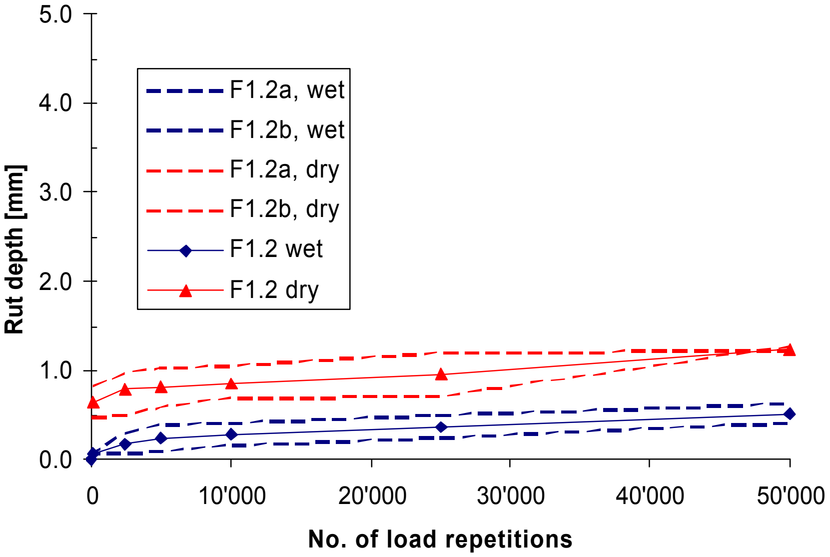

Figure 7: Rut progression versus number of load repetitions in dry and wet test for the trafficked pavement F1.2 (full line: mean value of two specimens, dotted lines: single values), note the shift on the y-axis between the dry and the wet test.

The determined rut depth after 50 000 load repetitions and the predicted rutting behavior after 100 000 load repetitions, shown in figure 8, lead to the conclusion that most of the tested pavement structures are not very critical to rutting under both dry and wet condition. As mentioned above, there can be problems with mastic asphalt and the asphalt concrete material G2.2 taken from a road section that showed insufficient rutting performance in the field. The range of rutting performance with these tests is compatible with the results of MMLS3 tests that were conducted on the NCAT test track in Alabama, USA and elsewhere. It also provides support for the protocols that have been proposed for the adjudication of performance under MMLS3 trafficking (Hugo et al, 2004).

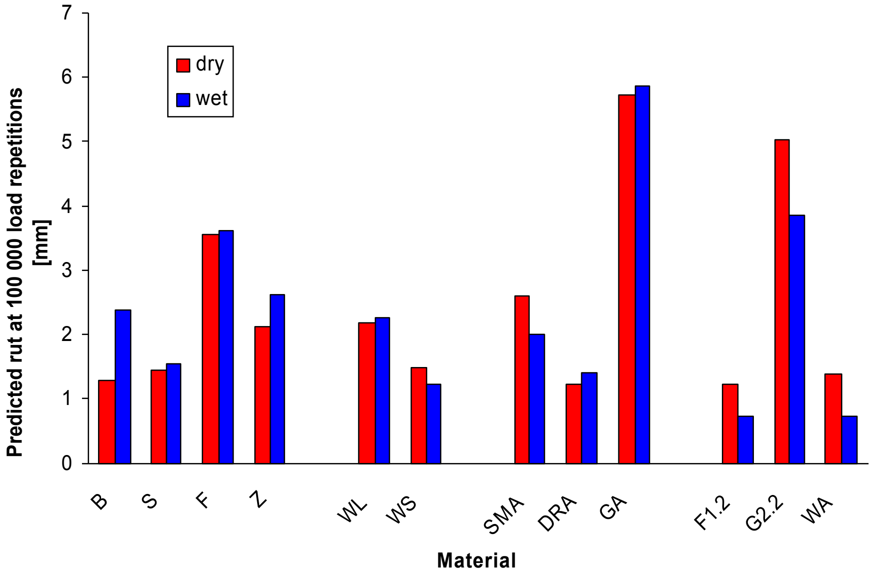

Figure 8: Comparison of predicted rut at 100 000 load repetitions for dry and wet testing.

## 4.2 Mechanical Test Results

Table 3: Mechanical Test Results, Stress at Break

| Surface course | Stress at break [N/mm²] | |
|---|---|---|
| | dry | wet |
| *Cold micro surfacing* | | |
| B | 2.64381 | 3.10243 |
| S | 1.80142 | 1.74426 |
| F | 1.66806 | 1.53154 |
| Z | 2.18273 | 2.12192 |
| *Hot thin surface courses* | | |
| WL | no value | 2.05104 |
| WS | 2.56871 | 2.52376 |
| *New pavements* | | |
| SMA | 2.24448 | 2.24169 |
| DRA | 1.39694 | 1.53472 |
| GA | 2.82592 | 2.86864 |
| *Old, trafficked pavements* | | |
| F1.2 | 3.73480 | 3.87367 |
| G2.2 | 1.59019 | 1.54070 |
| WA | 2.78626 | 2.92472 |

Comparing the mechanical test results between the dry and the wet tested specimens, apart from specimens B, no big differences could be stated. The considerable difference for the specimens coincides with the finding from the MMLS3 tests where material B had more than 50% increased rutting due to its high water susceptibility.

## 5 CONCLUSIONS

MMLS3 rutting test under dry and wet conditions appear to be a suitable tool for assessing the rutting performance of pavements. In the research carried out the rutting behavior in the test was similar to the rutting performance observed in the field. Especially in case of new pavement constructions the rutting performance could be assessed quite well.

The results show that wet testing does not always cause more rutting compared to dry testing for all mixes. However, it was found that water can reduce the rutting performance of asphalt structures between 30% and 50% compared to dry testing. Here mainly structures with cracks are mostly endangered.

It was also observed, that obviously, micro surfacings were not able to protect the lower layer sufficiently and do certainly not contribute significantly to long term durability of pavements

The mechanical test results confirm that the mechanical strength is related to the water susceptibility of the material and the material performance in the rutting test to a certain extent.

Although the test results seem to be quite promising, it is important to be aware of the limited amount of data, to say, for each material only two specimens had been tested.

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