Comparison of standardised roughness measurement methods and friction potential tests under real conditions

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Abstract – For the determination of the road surface roughness common methods have been established, like Skid Resistance Tester (SRT) or the Sideway-force Coefficient Routine Investigation Machine (SCRIM). Both methods are used to measure a comparable and reliable maximum friction potential value and to assess the quality of the road surface.
However, the comparison of the measurements under real conditions and the results of measurements with SRT and SCRIM showed only minor correlations. The paper shows the comparison between these standardised methods and real vehicle braking tests and discusses the results.

NOTATION

μ	*friction coefficient*
F_x	*longitudinal force on the tire*
F_y	*lateral force on the tire*
N_z	*normal force on the tire*
a	*acceleration of vehicle*
g	*acceleration of gravity*
r	*correlation coefficient*

INTRODUCTION

Precise knowledge of the friction potential is of great importance for safe longitudinal and lateral control of a car. While today it is mostly the driver who assesses friction values and adapts his driving style accordingly, it will be necessary for future highly automated vehicles to independently obtain information on environmental conditions. Analyses of accident records show that at least 3.6 % of road deaths are due to icy road conditions. However, this number is likely to be significantly higher, since the number of accidents in Germany occurring under icy road conditions without these conditions being identified as primary causes of the accidents, is around 20 % of the total number of accidents [1].
The coefficient of friction μ is defined as the normalised resulting horizontal force which acts between tires and road:

$$\mu := \frac{\sqrt{F_x^2 + F_y^2}}{N_z}$$

and act on the tire as circumferential and lateral forces and is the normal or contact force. The maximum transferable friction μ_{max}, or the friction potential, is the maximum that μ can reach under the specified conditions.
The friction potential is influenced by many factors, such as the tire condition, the type of tire, or the quality of the layer between road and tire, that is to say whether the road condition is dry, moist or wet.
As part of a research project at the Technical University of Berlin that has been financed and given advisory support by Working Group Driving Dynamics of the Research Association for Automotive Technology (FAT), a cause-based estimation procedure for ascertaining the maximum coefficient of friction has been developed which relies solely on information that is available without additional sensors. This information consists of data which is present in the vehicle itself, such as outside temperature, vehicle speed or rain intensity. On the other hand,

the procedure draws on data provided by the surrounding infrastructure. This includes weather data from weather stations or information on road conditions obtained from Environmental Sensor Station. By combining and integrating these fields of information, the range of the maximum coefficient of friction is established using the estimation procedure developed in this project.

For the development of such estimation procedures it is first necessary to obtain detailed knowledge of the influence of the described information on the maximum coefficient of friction [2–5]. To this end, extensive measurement runs have been performed over a period of ten months on a predefined route through urban and rural areas and the outskirts of Berlin. Here, the range of the friction coefficient was ascertained in real-world environments using test braking to establish the coefficient's value under varying conditions.

To investigate the influence of the road surface itself and to find out whether or not results of other friction measurement methods are comparable with the results of braking tests under real conditions two standardised friction tests were conducted and compared: The Skid Resistance Tester (SRT) and the Sideway-force Coefficient Routine Investigation Machine (SCRIM).

FRICTION TESTS UNDER REAL CONDITIONS

In order to perform friction potential measurements, 32 brake points were set along a measurement course. These were positioned in town, out of town and on highways; the drivers braked on the surfaces of asphalt, concrete and cobblestones. Close proximity of the brake points to weather stations (WS) and Environmental Sensor Station (GMA) was ensured. Furthermore, relevant structural features such as bridges, as well as the feasibility of brake tests in everyday traffic were taken into account. For the test runs a route in the southeast of Berlin was chosen that passes through Berlin and Brandenburg and runs further along the motorways A115 and A10. The route chosen is in proximity to the GMA Fahlhorst. Also, all the points along the route were within a distance of less than 10 km from one of the weather stations.

At each of the 32 brake points defined for this route the driver braked once in the course of each test run. At initial speeds between 30 and 120 km/h the brake pedal was pressed in such a way that in the master cylinder a minimum pressure of 175 bar built up and the braking system was reliably taken to the ABS control range. This ensured that the vehicle reaches the maximum possible deceleration. This vehicle deceleration was measured by a servo-accelerometer over a period of 0.5 s, and then averaged (Figure 1).

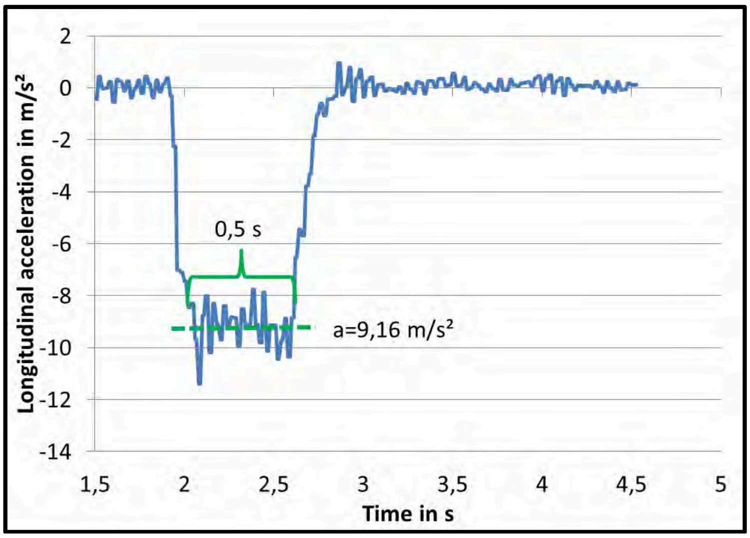

Figure 1: Time sequence of vehicle deceleration at emergency braking

From this value the average maximum possible coefficient of friction was obtained using

$$\overline{\mu_{max}} = \left|\frac{\bar{a}}{g}\right|$$

Since the test runs were performed over a period of 14 months, a wide range of different weather conditions could be taken into account. These include various rain intensities and the resulting different water heights, measurements on closed snow cover or slush, as well as different surface temperatures under dry conditions. Summer and winter tires were exchanged regularly over the whole measurement period so that results are available now for both types of tires for the weather conditions referred to above.

Results of the test runs

For the evaluation of the brake tests 2,080 brake measurements and the associated data sets were available. Each of these sets contains 45 parameters that describe all significant variables which affect the coefficient of friction. These are weather information, vehicle-specific data and information on road surfaces. Figure 2 shows an overview of the measurements of the maximum friction coefficients on dry roads with surfaces of asphalt, concrete and cobblestones as a function of velocity.

It is apparent that under dry conditions the maximum friction value is higher than μ = 0.5 for all three road surfaces and all velocities. The measurements on cobblestone pavements were taken within a speed range around 40 km/h. The measured friction coefficients vary considerably for this surface and are found within a range of values from 0.53 to 0.85. The values measured for asphalt, of which there are a lot more due to the brake point distribution, were determined at initial speeds between 30 and 190 km/h. The range of values here is 0.66 to 1.05. The large scatter is due to the fact that along the measurement path, different varieties of asphalt were driven on. The values measured for concrete were recorded at higher initial speeds, since this type of surface was found only on the highway part of the test section. Here the range of values for the maximum friction coefficient runs from 0.67 to 0.99. None of the surfaces under consideration shows any significant speed dependency.

A comparison of the maximum friction coefficient for different road conditions shows, as expected, that the maximum is considerably lower for moist or wet surfaces than for dry pavement (Figure 2). A road surface is classified as moist when it is obviously no longer dry but no water is being sprayed by moving vehicles, the pores of the road surface are not closed by water, and no reflective surface has formed yet.

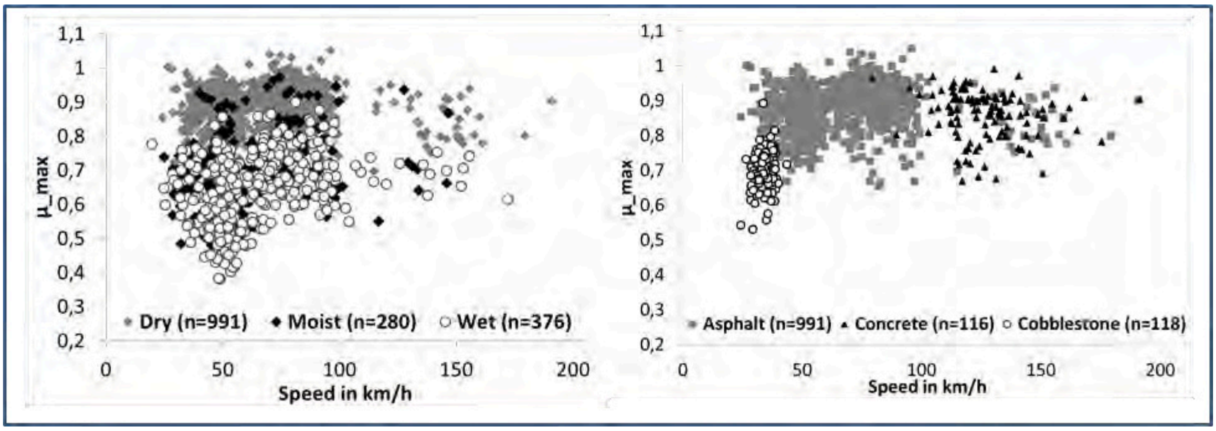

Figure 2: Maximum coefficient of friction for dry road surfaces as a function of vehicle velocity (right)
Maximum coefficient of friction on asphalt for different road conditions (left)

FRICTION TESTS WITH SRT

The Skid Resistance Tester (SRT) is a standardised measuring device. The basic principle of that measuring method is, that a defined rubber cube slides over the wet road surface. This rubber cube is connected with a pendulum. Depending on the friction coefficient between rubber and road surface the pendulum reaches different deflections (Figure 3).

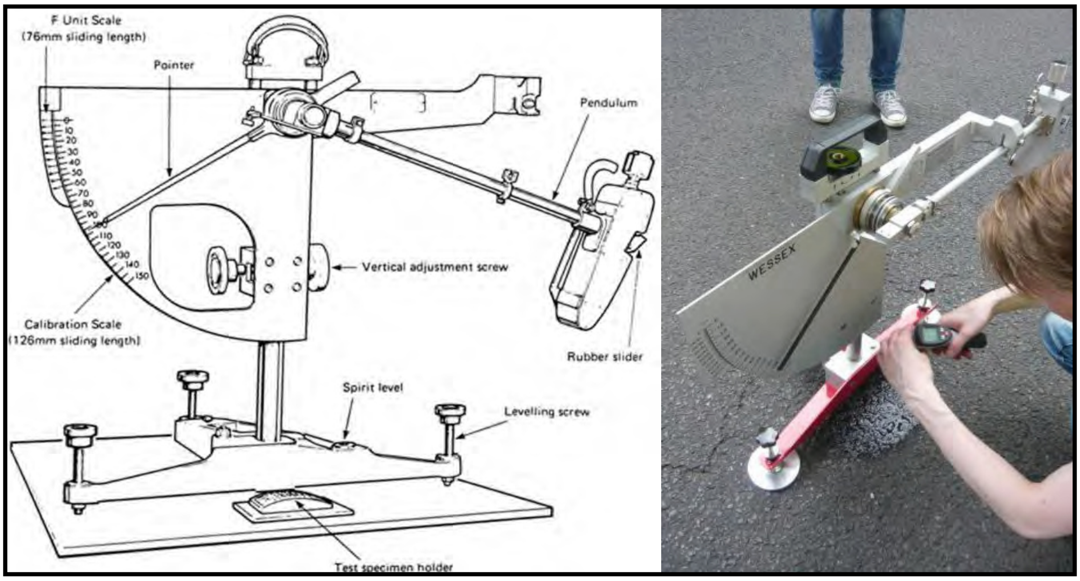

Figure 3: Skid Resistance Tester (SRT)

Within the project a total of 24 road sections were tested for their grip. Here at each braking point road sections of approximately 10 – 40 m length were measured with the SRT. The length of the measuring range varied, depending on the stopping distance achieved at the point of a fully developed deceleration. At three measuring points (at the start, in the middle and end of each braking distance) five measurements were carried out. This results in 15 measured values each braking point.

The range of values of the SRT measurements is between 20 and 60. Therefore, a quantitative comparison of the measured values with those of the tests under real conditions is not possible. However, there should be a correlation between both data sets.
The results of the SRT measurements showed a good reproducibility. For the 15 values of each breaking point only minor scatterings occurred (Figure 4).

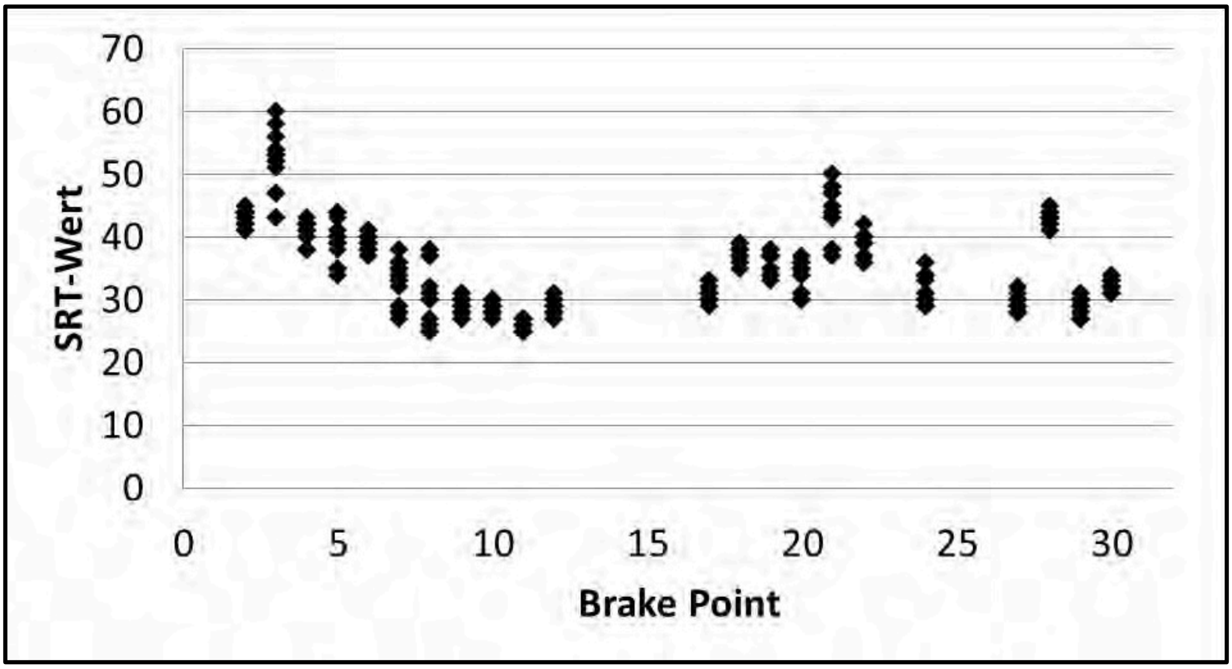

Figure 4: Results of SRT measurements for 24 brake points (scatter)

FRICTION TESTS WITH SCRIM

The Sideway-force Coefficient Routine Investigation Machine (SCRIM) is a standardised measurement method which is used e.g. in Germany by the Federal Highway Research Institute (BASt) to observe the condition of motorways and national roads.
In this measurement method, a wheel is pulled under a defined slip angle of 20° on the road surface by a truck (Figure 5). The occurring side force is the value of the measured friction of the road.

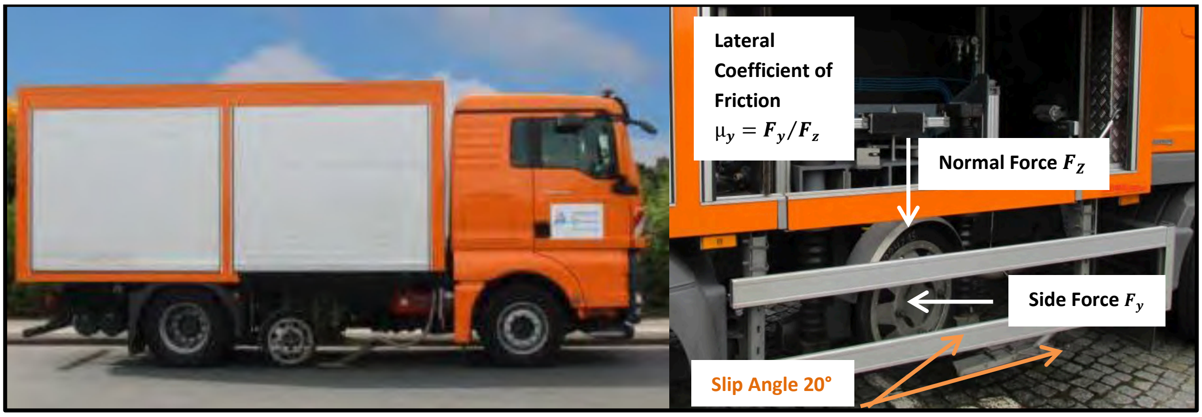

Figure 5: SCRIM and measurement method

The measuring wheel is a profile-free narrow measuring tire which is loaded with a normal load of 1.96 kN [6]. This results in a slip of about 34%. At speeds of 40, 60 and 80 km/h (for urban, extra-urban and motorway), the road surface is wetted with a water film of approximately 0.5 mm and the lateral force F_y is measured. The lateral friction coefficient is used to evaluate the friction potential of the road surface and results from the quotient of the measured lateral force and the normal force [7]. Since the normal force is held constant, the calculated lateral friction coefficient depends only on the measured lateral force, which is mainly influenced by the properties of the road surface, the tire and the interlayer between tire and road surface (dry, wet, snow). The resolution achieved in the measurements is approximately 1 m.

The range of values of the SCRIM measurements is between 0 and 1, which is equal to the braking tests under real conditions.

For each of the 30 braking points 21 measurements were averaged to evaluate the SCRIM value. That means there were 10 values in front and 10 values behind the actual braking point evaluated (Figure 6, left). The results of the measurement drive with SCRIM truck are shown in Figure 6, right.

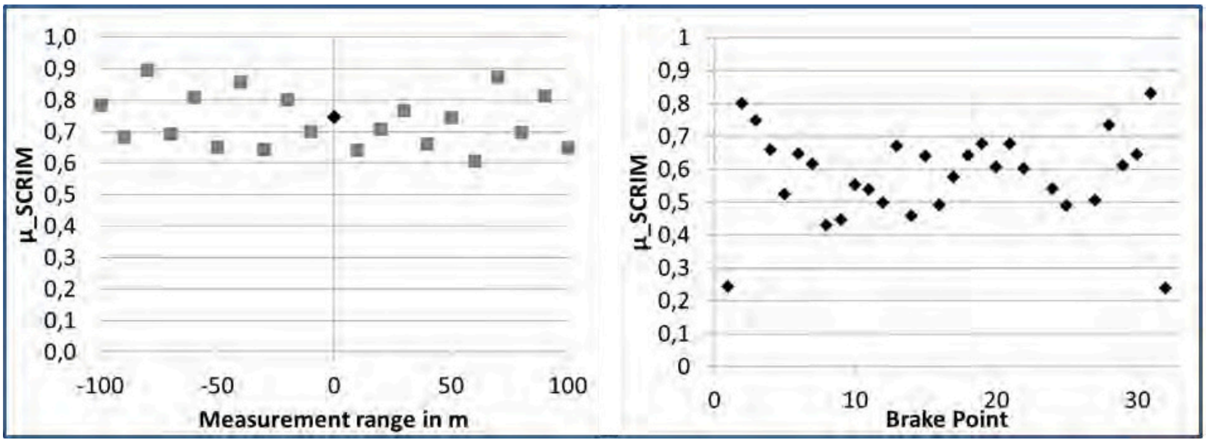

Figure 6: Results of SCRIM measurements, 100m in front of and after brake point number 28 and results of SCRIM measurements for 30 brake points (mean)

COMPARISION OF SRT AND REAL BRAKING TESTS

For the 22 braking points where measurements with the SRT pendulum were conducted only minor correlations between SRT and real braking tests can be found. In Figure 7 the test values and the correlation of SRT and braking tests under different conditions are shown. For all braking tests summer tires were used. The maximum friction values μ_{max} are the average of several tests under the same conditions on the same braking point.

For braking tests under dry conditions there is nearly no correlation with the SRT tests (r=0.07). For moist and wet conditions, the correlation between both parameters rise (r=0.25; r=0.34). However, it seems, that the SRT does not allow a reliable statement about the ability of a certain road surface to decelerate a car.

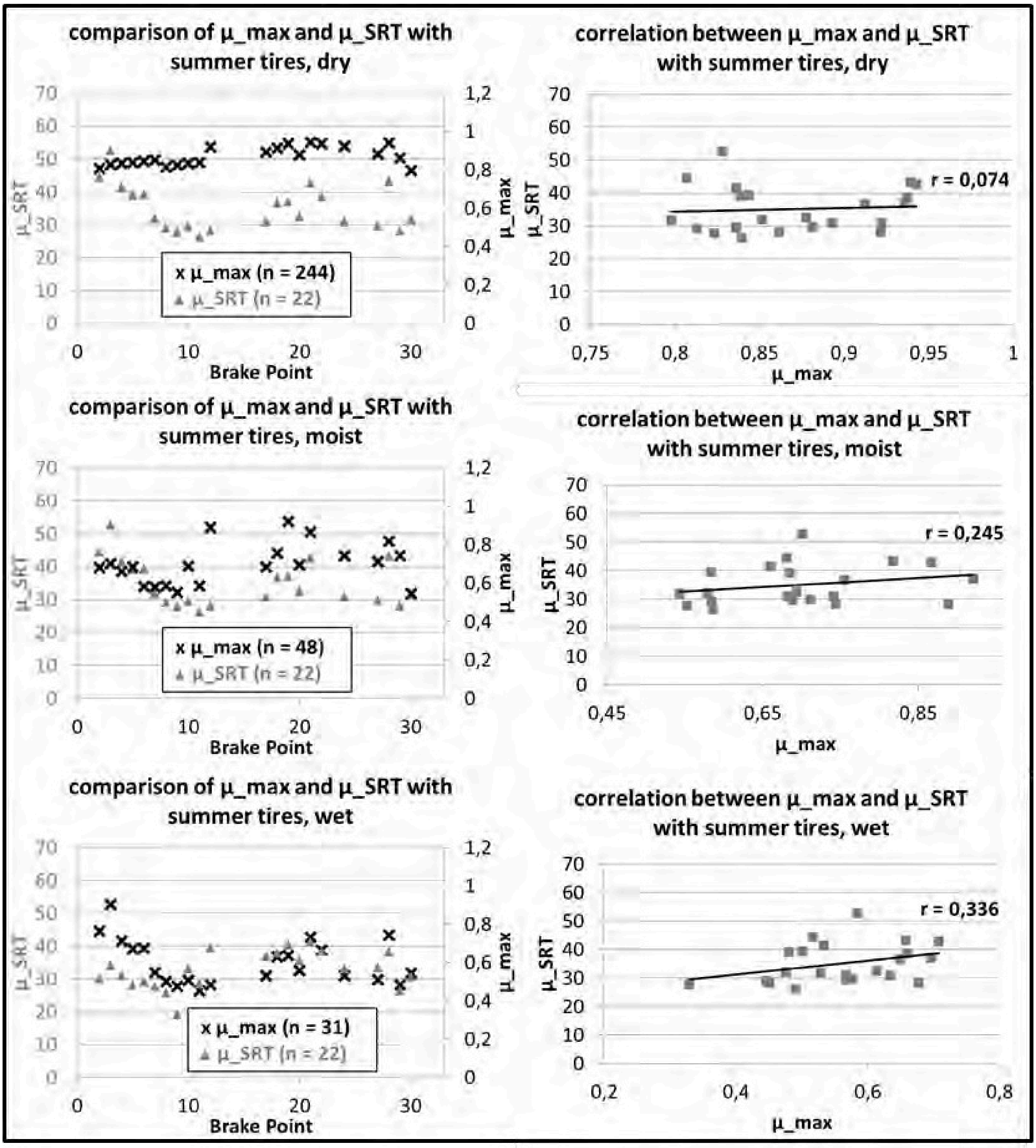

Figure 7: Comparison and correlation of µ_max and µ_SRT with summer tires for dry, moist and wet road conditions

COMPARISON OF SCRIM AND REAL BRAKING TESTS

The tests with the SCRIM truck were conducted at the same time as braking tests under real conditions. With that procedure it was guaranteed, that both tests were conducted under the same conditions. However, the test car braked under dry conditions, while the track for the test wheel was moistened as described above.

The comparison of both test methods is shown in Figure 8.

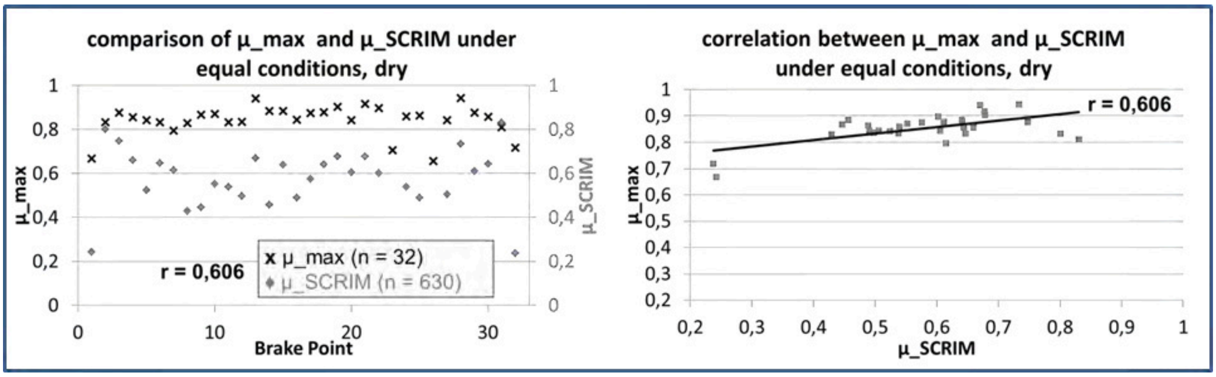

Figure 8: Comparison and correlation of µ_max and µ_SCRIM under equal conditions

Compared to the SRT tests, with SCRIM there is a much higher correlation (r=0,61) with the braking tests under real conditions.

As for the SRT tests it makes sense to look to data on different road conditions and to data from more than one test drive.

In Figure 9 and Figure 10 a comparison of several test drives under real conditions for different interlayers and different tire types is shown.

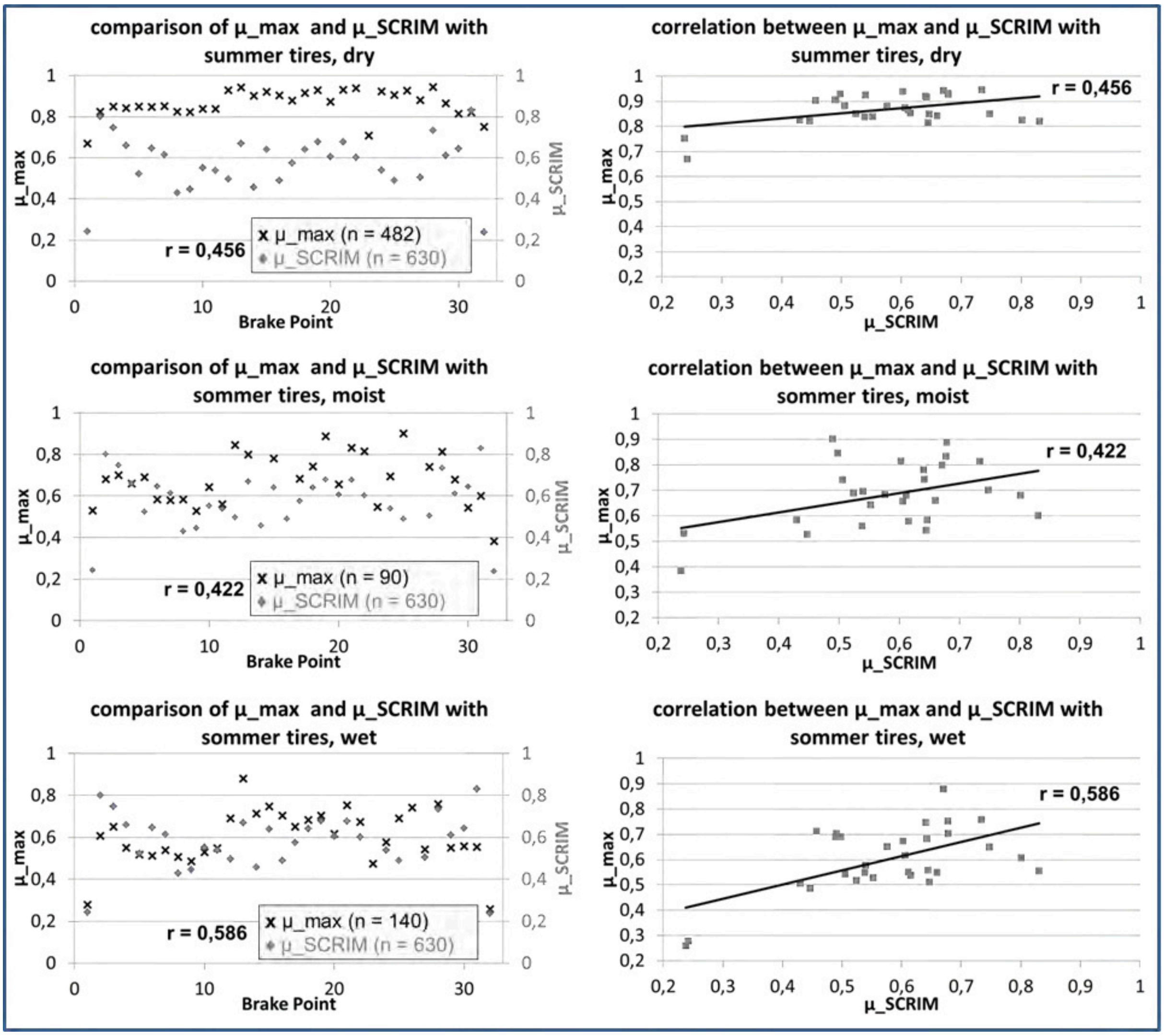

Figure 9: Comparison and correlation of µ_max and µ_SCRIM with summer tires, dry, moist and wet

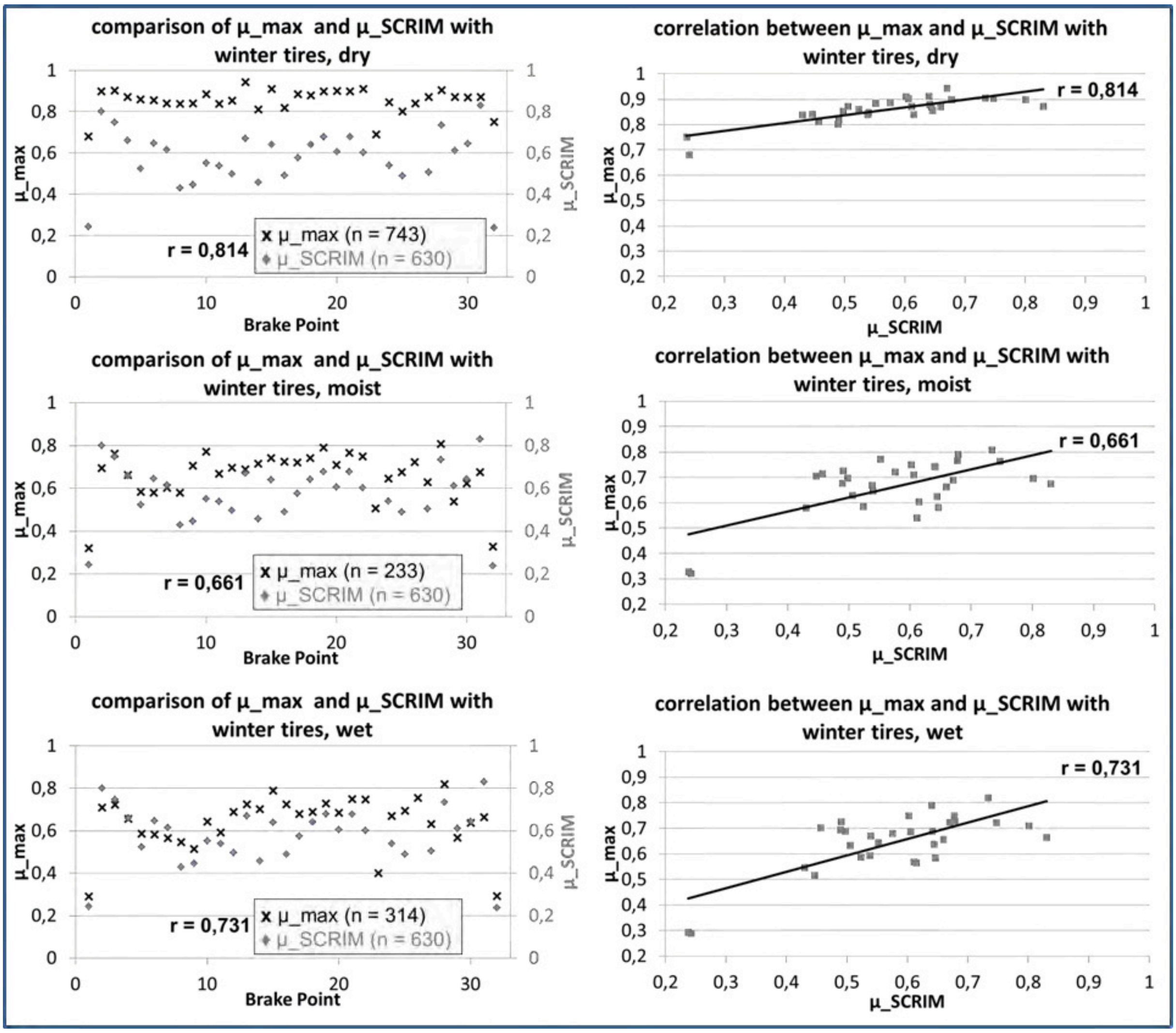

Figure 10: Comparison and correlation of μ_max and μ_SCRIM with winter tires, dry, moist and wet

Looking at the graphs of the figures above shows that the correlations of both test methods are better for winter tires than for summer tires used for these tests. This is true for all interlayer types. Except for winter tires on dry surface the figures show, that the correlation increases for moist and wet conditions. This was also the case for the SRT tests.

CONCLUSIONS

Three methods for friction potential measurements were presented and compared. The friction potential measurements based on braking tests under real conditions show the actual ability of the tire-road-combination to decelerate a car in longitudinal direction. From the perspective of car safety this is the important and most interesting value. However, the values shown in this paper are only valid for specific tires used for the braking tests. Depending on the interlayer (dry, moist, wet) the maximum friction coefficient differs between 0.5 and 1.05. The comparison between braking tests and SRT showed only a minor correlation. Although the SRT tests showed a good repeatability it seems to be questionable whether or not this method generates reliable data for the actual friction potential. It is possible that a method, where a rubber cube is sliding over the surface instead of rolling, like a real tire, is only minor suitable for the measurement of the friction potential.

In contrast, the SCRIM method showed a much better correlation with the braking tests. Especially for most of the moist and wet conditions and for winter tires correlations higher than 0.55 were achieved. However, this value is still defined as “medium correlation” [8] which means that tests with the SCRIM have only a “medium” reliability for the actual estimation of friction potential. It must be noted, that the SCRIM method was defined in the 70s. The test tire and its rubber compound were also defined at that time. It might be likely, that a more modern tire type would lead to better results.

For the future it should be investigated how friction potential could be measured with new or modified standardized test procedures.

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