PROPOSAL FOR A GENERAL LABORATORY TEST PROCEDURE TO EVALUATE ABRASION RESISTANCE AND TRACTION PERFORMANCE OF TIRE TREAD COMPOUNDS

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ABSTRACT

With the Laboratory Abrasion Tester 100 (LAT 100) it is possible to determine the abrasion resistance of tire tread compounds using a rotating rubber wheel. The mass loss is given as a function of the energy input and the speed. Regression analysis allows the plot of either the abrasion loss or the relative rating as a three-dimensional energy-speed-field, corresponding to different severities of a tread wear. By comparing the results of different road tire tests with the results of the LAT 100 a good correlation for the abrasion has been found. This makes a prediction of a relative ranking of the abrasion resistance of tire treads compounds in road tests possible.

In order to determine the wet traction performance of tire tread compounds the traction disk of the LAT 100 is wetted and the side force of the wheels is measured as function of the water temperature. Using the WLF-equation the traction performance of the compounds is evaluated for wet handling, anti-lock braking system and locked wheel braking. These results show an excellent correlation to road results.

This background and examples of a comparison of tire tests results and the LAT 100 measurements will be given. Test settings have been developed to a degree that standard procedures can be formulated, which ensure a high correlation with the road.

INTRODUCTION

The laboratory results of wear and wet traction measurements of tread compounds depend strongly on the experimental conditions and tire testing is time consuming and expensive. Therefore a precise laboratory evaluation has to be created.

Abrasion is a function of the energy dissipation and the sliding speed in the contact area. These functions can be described by power laws, depending on parameters, which differ for the compounds and the structure of the surface, on which the tests are carried out. Comparable data between results of road tests and laboratory results can be achieved if energy consumption, sliding speeds and surface structures can be matched. Since road tests are carried out under a wide range of driving severities, including acceleration and braking force transmissions i. e. energy dissipation and sliding speeds, laboratory test results have to cover the whole spectrum of road test conditions.

It is now well established that the frictional force, which determines the wet traction capability of a tread compound, is dominated by its visco-elastic properties [1, 2, 3]. The friction coefficient is a function of the contact temperature and sliding speed. This function can be obtained experimentally and is represented by a fitted curve as function of the joint temperature and a speed variable, which describes the total friction behavior of the tested compounds. Agreement between laboratory results and tread wear ratings is obtained if the parameters of the road tests are similar to the experimental ones. Since the fitted curve depends also on the track surface, the surface of the wet traction disc should have corresponding properties to that of road surface.

EQUIPMENT AND EXPERIMENTAL PROCEDURE

The instrument produced by VMI/Lang is shown in figure 1 [4]. The details of the working area for the abrasion measurement, the computer display, from where the operation is controlled and the electronic balance for the determination of the mass loss are depicted.

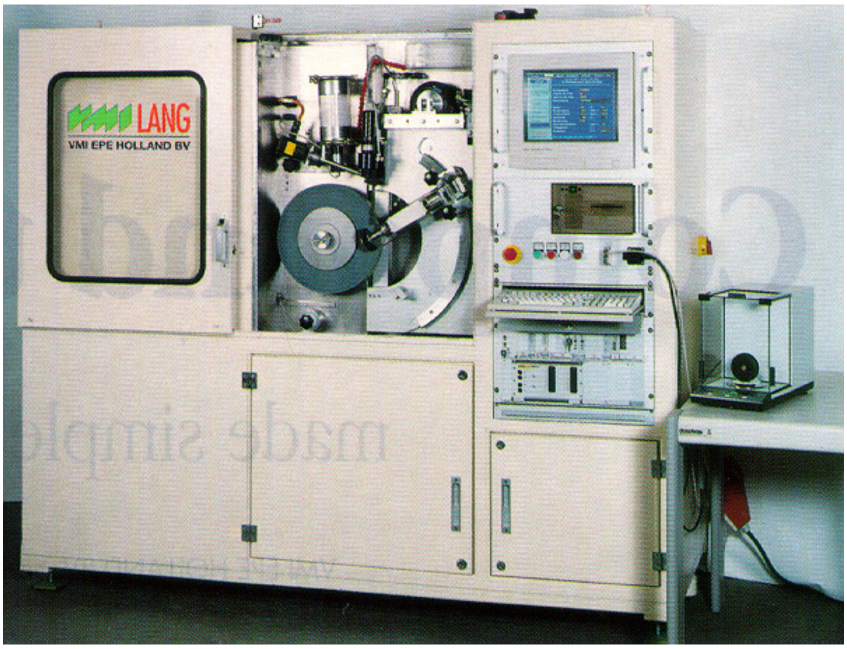


Figure 1 Picture of the apparatus including the electronic balance

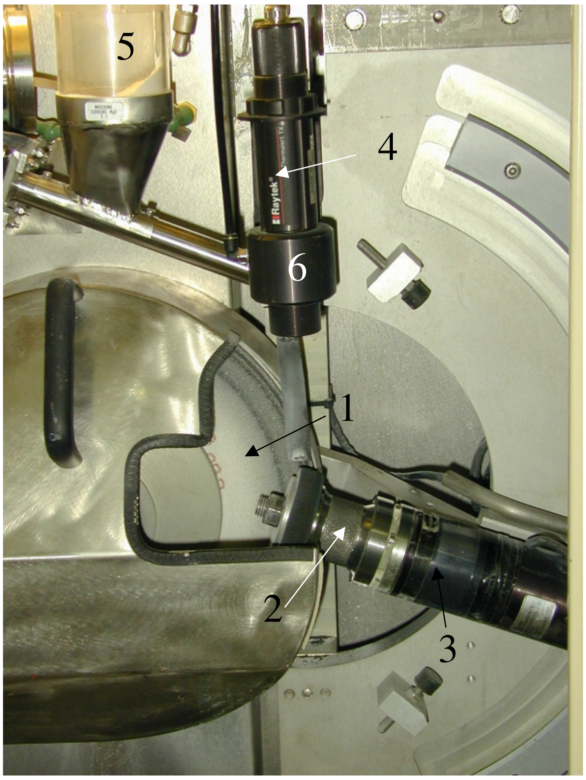


Figure 2 Details of the working area for abrasion tests

Figure 2 shows the sector of the working area for the abrasion test including the abrasion disc (1), the sample wheel (2), the side force transducer (3), the IR-sensor (4) and the powder supply (5) and –feeding (6).

For abrasion experiments the sample runs on a dry disc for a pre-set distance under a given load, slip angle and speed. The weight of the sample before and after the run is weighed out and recorded.

If the interest is concentrated on wet traction, water at a pre-set temperature is pumped onto the disc, is collected in a bath and returned to the thermostatically controlled water tank. A temperature range between +1 °C and 80 °C is possible with water. Figure 3 shows a sketch of the experimental set-up to determine wet traction.

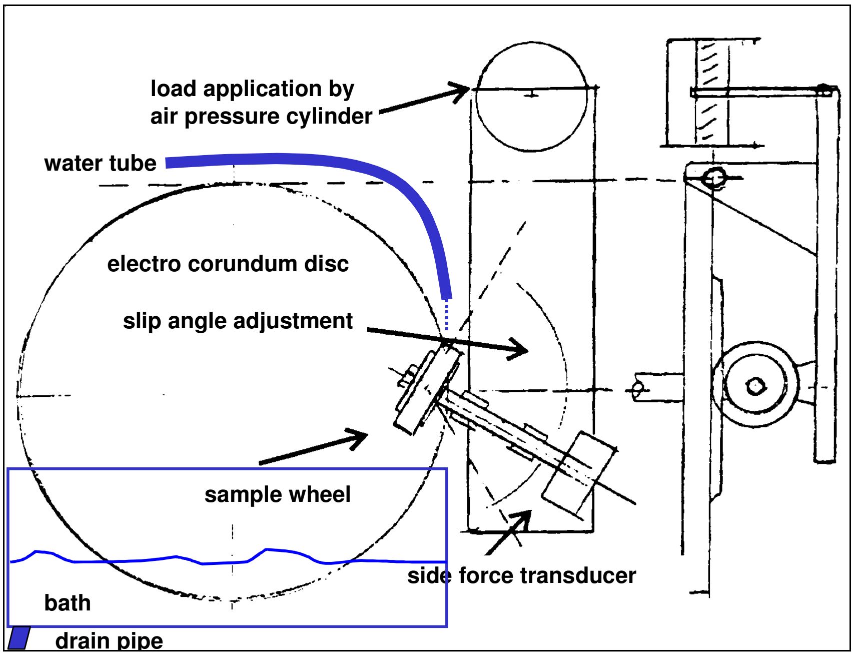


Figure 3 Sketch of the basic experimental arrangement

A rubber wheel cured from the test compound in a suitable mold runs on the flat side of a grinding wheel under a pre-set slip angle, speed and load [5]. The grinding wheel is 350 mm in diameter, the sample wheel has a diameter of 84 mm and a thickness of 18 mm. For stabilization the rubber wheel is fixed between two lateral steel plates (figure 4).

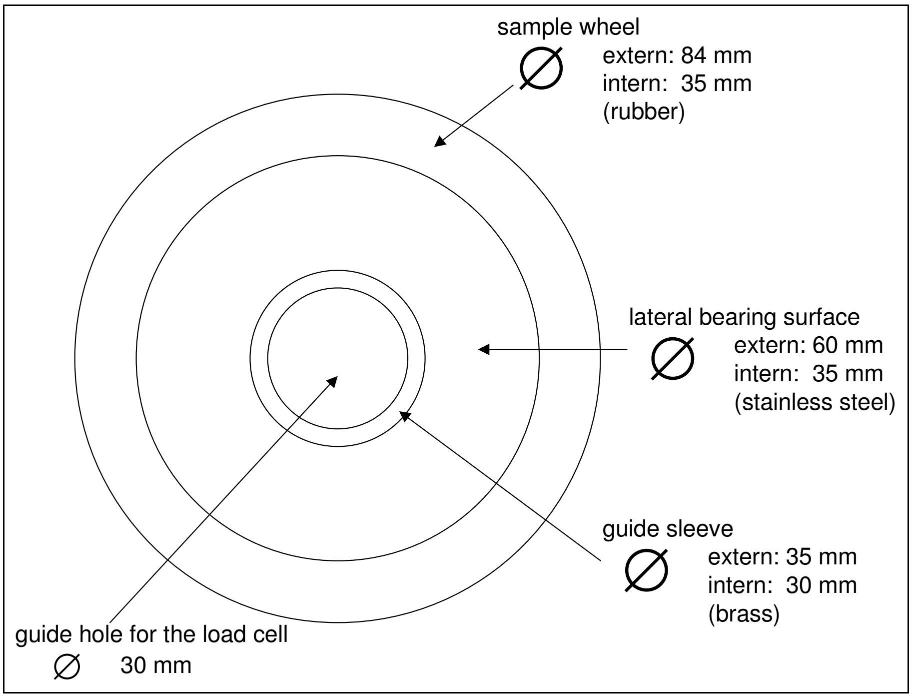


Figure 4 Dimensions of the sample wheel incl. the guide facilities

Slip angle, load and speed can be varied over a wide range as shown in table 1.

Load		(10 – 150) N
Slip Angle		(-45 - +45) °
Speed -	Range I	(2 – 100) km/h
	Range II	(0.002 – 2) km/h

Table 1 General equipment conditions

There are two speed ranges: from 2 km/h to 100 km/h, used mainly for abrasion tests, and very low speeds from 0.002 km/h to 2 km/h, used primarily for wet traction experiments. A three component measuring device monitors continuously the load, the side force and the force along the plane of the sample, the rolling resistance of the sample wheel or, if the wheel is locked, its friction force. The load set on the computer activates a valve, which controls a pneumatic cylinder applying the load to the sample. The side force is monitored and averaged continuously during a test run. Actual load, average side force and its standard deviation are plotted in each test.

All parameters are computer controlled. The slip angle is set by hand but the value is read electronically and recorded on a data file. After all parameters have been entered into the computer the test run is carried out automatically. A software program is supplied with the machine, which sorts the data of a complete testing program into tables according to testing conditions, carries out regressions, assembles friction fitted curves if required and carries out road test simulations.

To use this equipment in a productive manner it is necessary to use it as a tool for "Predictive Testing". Therefore, a standard set of test conditions is required, which guarantee a good correlation between road data and laboratory data, a diversification of the results and a time and costs saving test in comparison with the expensive tire test.

CONTEXT AND EVALUATION OF DATA

ABRASION EXPERIMENTS

Theory

The figures given by the abrasion experiments are the abrasion loss A (as abrasion per unit distance), the side force coefficient

$$f = \frac{F}{L} \qquad \textit{(Eq. 1)}$$

with F = side force
L = load

and the surface temperature of the sample T_{su} (detected by the IR-thermometer).

Generally, wear of a tire or test sample running under slip is a function of the energy dissipation in the contact area [6]. To obtain measurements at different energy levels with the laboratory equipment it is necessary to vary the slip angle and/or the load in a defined manner and to measure the resulting side force F.

The energy dissipation in the contact surface per unit distance is expressed by:

$$W = F \cdot \sin\alpha \quad [\mathrm{kJ/km}] \qquad \textit{(Eq. 2)}$$

- with α for slip angle.

Because side force and slip angle are measured directly, the energy dissipation is clearly defined.

To describe the abrasion loss per distance A [mg/km] as a function of dissipated energy the following equation can be defined:

$$A = A_{0W} \cdot \left\{\frac{W}{W_0}\right\}^n \qquad \textit{(Eq. 3)}$$

In this case W represents the energy loss in the contact surface of the sample and A_{0W} the abrasion loss of the reference energy W_0. The parameters A_{0W} and n depend on the sample, the tread, the tread temperature and the speed.

The speed dependence is expressed in a similar way to the energy dependence:

$$A = A_{0v} \cdot \left\{\frac{v}{v_0}\right\}^m \qquad \textit{(Eq. 4)}$$

Similarly, the parameters A_{0v} and m depend on the sample, the tread, the tread temperature and the energy, as described for A_{0W}.

The combined influence of energy and speed is expressed by the equation

$$z = a + b_1 \cdot x + b_2 \cdot y + b_3 \cdot x \cdot y \qquad \textit{(Eq. 5)}$$

with z = log abrasion
x = log energy dissipation
y = log speed

A multiple regression analysis gives the coefficients of the above equation for all compounds together with correlation coefficients between measured and calculated abrasion losses.

The equation is used to calculate abrasion losses over a given range of energies and speeds and the results can be presented as a table for each compound, whereby it is useful to show abrasion and variables on a log basis.

However, it is often more instructive and useful to consider the abrasion loss relative to a reference compound. These relative abrasion ratings of the individual compounds are defined in comparison with the chosen reference (= 100 %) as:

$$Rating = 10^{(\log A_R - \log A_{TM} + 2)} \qquad \textit{(Eq. 6)}$$

or expressed as:

$$\frac{R_{TM}}{R_R} = \frac{A_R}{A_{TM}} \qquad \textit{(Eq. 7)}$$

$$R_{TM} = \frac{10^{\log A_R}}{10^{\log A_{TM}}} \cdot 100 \qquad \textit{(Eq. 8)}$$

with R_{TM} = Rating of test compound
R_R = Rating of reference compound (= 100)
A_{TM} = Abrasion of test compound
A_R = Abrasion of reference compound

For an easier interpretation these ratings again are best presented as tables of log energy and log speed to show how the relation depends on the severity of the test conditions. It is also possible to create three-dimensional diagrams of the test results.

Experimental Procedure

To carry out the abrasion experiments successfully with a high repeatability, it is very important to choose a suitable abrasion disc. It must have sharpness (severity) in accordance to road properties and its roughness (mesh size) should also be similar to road properties. Care is taken to avoid contamination with the abrasion debris and applied powder. Experience has shown that an **electro-corundum disc** with a **grain of 60** fulfills these demands. It is necessary to use the ultra hard sintered electro-corundum disc, because normal corundum discs get blunt very quickly. Nevertheless, disks have to be changed after ca. 150 hours use on each side.

Abrasion results tend to be falsified by smearing. The abraded surface and particles are thermally and oxidatively degraded and become sticky. Both track and sample surface change their abrasive properties. In order to avoid this a powder is applied, which absorbs the degraded debris and helps to keep the surface of the sample dry and non-sticky and the track surface clean. Since the powder is often also a lubricant and thus reduces abrasion, a careful choice of type and amount is necessary. The powder is supplied to the track by an automatic dosing device, which can be pre-set to deliver amounts of powder per unit time corresponding approximately to the expected rate of abrasion

The mixture of the dust components and the applied mass are decisive. A successful mixture is a combination of MgO and Al_2O_3 (table 2). The required mass depends on the test conditions.

Component	Part of Volume	Part of Mass	Specification
Al_2O_3	2	4	electro-corundum powder white grain: 120
MgO	1	1	heavy powder type 90 grain: 120

Table 2 Characterization of the powder components

For the reason that the slip angle, the load and the speed influence the temperature of the sample, which also influences the abrasion, an IR-thermometer monitors the surface temperature during the abrasion run.

The determination of the four coefficients of equation 5 requires at least four test conditions. First tests with only a small set of test conditions often leaded to results, which were not repeatable. Therefore, the following scheme of test conditions has been fixed as a standard (table 3). Although more time consuming, it produces uniform results.

Test	Load (N)	Slip angle (°)	Speed (km/h)	Distance (m)	Dust dose
run-in	70	-13	30	1000	0,5
1. abrasion	120	-6	1,5	500	0,03
2. abrasion	70	-20	30	500	0,7
3. abrasion	70	-9	15	700	0,2
4. abrasion	100	-6	30	500	0,1
5. abrasion	100	-20	1,5	250	0,05
6. abrasion	70	-20	3	500	0,1
7. abrasion	70	-13	30	500	0,5
8. abrasion	100	-6	3	700	0,01
9. abrasion	100	-9	7	700	0,2

Table 3 Standard abrasion test program

All tests are repeated four times - right hand, left hand, right hand, left hand. If the test sequence need more than one day, a run-in is done daily once on the right hand rotation and once on the left-hand rotation.

Results

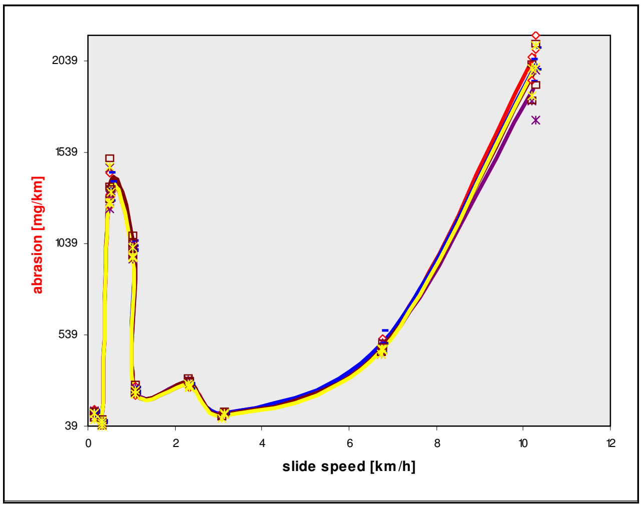
First of all the repeatability of a carbon black compound and a silica compound was tested under the above mentioned conditions. The formulation is given in table 4.

Stage I		
	1	**2**
BUNA 5025-1	96	96
BUNA CB 24	30	30
N 220	80	-
High dispersible silica	-	80
X 50-S	-	12.8
ZnO RS RAL 844 C	3	3
Stearid Acid	2	2
Naftolen ZD	10	10
Softener	1.5	1.5
Wax	1	1
Stage II		
Remill Stage		

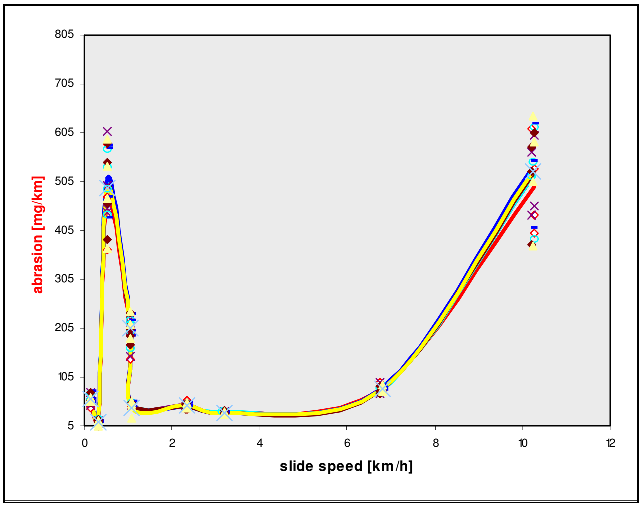
Stage III		
DPG	2	2
TBZTD	0.2	0.2
CBS	1.5	1.5
Sulphur	1.5	1.5

Table 4 Compound formulations for the repeatability tests

The measured values are shown in figures 5 a and 5 b. The abrasion weight loss per unit distance is given as a function of the sliding speed of the sample. Each test was done four times as described above and repeated with five sample wheels of the carbon black compound and five sample wheels of the silica compound.



5 a Carbon black compound



5 b Silica compound

Figure 5 Repeatability test for the abrasion loss

The different levels of abrasion are due to different slip angle settings. Each five repeated curves are nearly congruent, the individual values for the silica compounds scatter a little bit stronger - which is typical for silica compounds. Using the multiple regression equation (Eq. 5) and calculating relative ratings with the first sample wheel as the reference, tables 5 and 6 show the ratings of the other four samples as function of log energy and log speed for the carbon black and the silica compound respectively.

Rating (logAbrieb) [%]   applied to the reference (100 %)

Compound B	log km/h								
logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	126.3	122.2	118.2	114.3	110.5	106.9	103.4	100	96.7
0.2	123.7	120	116.3	112.8	109.4	106.1	102.9	99.8	96.7
0.4	121.1	117.8	114.5	111.4	108.3	105.3	102.4	99.5	96.8
0.6	118.6	115.6	112.7	109.9	107.2	104.5	101.8	99.3	96.8
0.8	116.1	113.5	111	108.5	106.1	103.7	101.3	99.1	96.8
1	113.7	111.5	109.3	107.1	105	102.9	100.8	98.8	96.9
1.2	111.4	109.4	107.6	105.7	103.9	102.1	100.3	98.6	96.9
1.4	109	107.5	105.9	104.3	102.8	101.3	99.8	98.4	96.9
1.6	106.8	105.5	104.2	103	101.8	100.5	99.3	98.1	97

Compound C	log km/h								
logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	102.4	102.1	101.8	101.5	101.1	100.8	100.5	100.2	99.9
0.2	102.2	101.9	101.5	101.2	100.8	100.5	100.1	99.8	99.4
0.4	102.1	101.7	101.3	100.9	100.5	100.1	99.7	99.4	99
0.6	101.9	101.5	101	100.6	100.2	99.8	99.4	99	98.5
0.8	101.7	101.3	100.8	100.3	99.9	99.4	99	98.5	98.1
1	101.5	101	100.6	100.1	99.6	99.1	98.6	98.1	97.7
1.2	101.4	100.8	100.3	99.8	99.3	98.8	98.2	97.7	97.2
1.4	101.2	100.6	100.1	99.5	99	98.4	97.9	97.3	96.8
1.6	101	100.4	99.8	99.2	98.7	98.1	97.5	96.9	96.4

Compound D	log km/h								
logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	87.5	89.9	92.4	94.9	97.6	100.3	103	105.9	108.8
0.2	89.2	91.3	93.4	95.5	97.7	100	102.3	104.7	107.1
0.4	91	92.7	94.4	96.1	97.9	99.7	101.6	103.5	105.4
0.6	92.8	94.1	95.4	96.7	98.1	99.5	100.8	102.3	103.7
0.8	94.6	95.5	96.4	97.3	98.3	99.2	100.1	101.1	102
1	96.5	97	97.4	97.9	98.4	98.9	99.4	99.9	100.4
1.2	98.4	98.4	98.5	98.5	98.6	98.6	98.7	98.7	98.8
1.4	100.3	99.9	99.5	99.2	98.8	98.4	98	97.6	97.2
1.6	102.3	101.5	100.6	99.8	98.9	98.1	97.3	96.5	95.7

Compound E	log km/h								
logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	90.1	93.5	97	100.6	104.4	108.3	112.3	116.5	120.9
0.2	92	94.8	97.6	100.5	103.5	106.6	109.8	113.1	116.5
0.4	94	96.1	98.3	100.5	102.7	105	107.4	109.8	112.2
0.6	96	97.5	98.9	100.4	101.9	103.4	104.9	106.5	108.1
0.8	98.1	98.8	99.6	100.3	101.1	101.8	102.6	103.4	104.1
1	100.2	100.2	100.2	100.2	100.2	100.3	100.3	100.3	100.3
1.2	102.3	101.6	100.9	100.2	99.4	98.7	98	97.3	96.6
1.4	104.5	103	101.5	100.1	98.6	97.2	95.8	94.4	93.1
1.6	106.8	104.5	102.2	100	97.8	95.7	93.7	91.7	89.7

Table 5 Relative rating of the carbon black compound for the repeatability test

Rating (logAbrieb) [%]   applied to the reference (100 %)

Compound B logW	log km/h 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	108.2	108.3	108.4	108.4	108.5	108.5	108.6	108.6	108.7
0.2	106.5	106.6	106.7	106.8	106.9	107	107.1	107.2	107.3
0.4	104.9	105	105.1	105.3	105.4	105.5	105.7	105.8	105.9
0.6	103.2	103.4	103.5	103.7	103.9	104.1	104.2	104.4	104.6
0.8	101.6	101.8	102	102.2	102.4	102.6	102.8	103	103.2
1	100	100.2	100.5	100.7	100.9	101.2	101.4	101.7	101.9
1.2	98.4	98.7	98.9	99.2	99.5	99.8	100.1	100.3	100.6
1.4	96.8	97.1	97.5	97.8	98.1	98.4	98.7	99	99.4
1.6	95.3	95.6	96	96.3	96.7	97	97.4	97.7	98.1

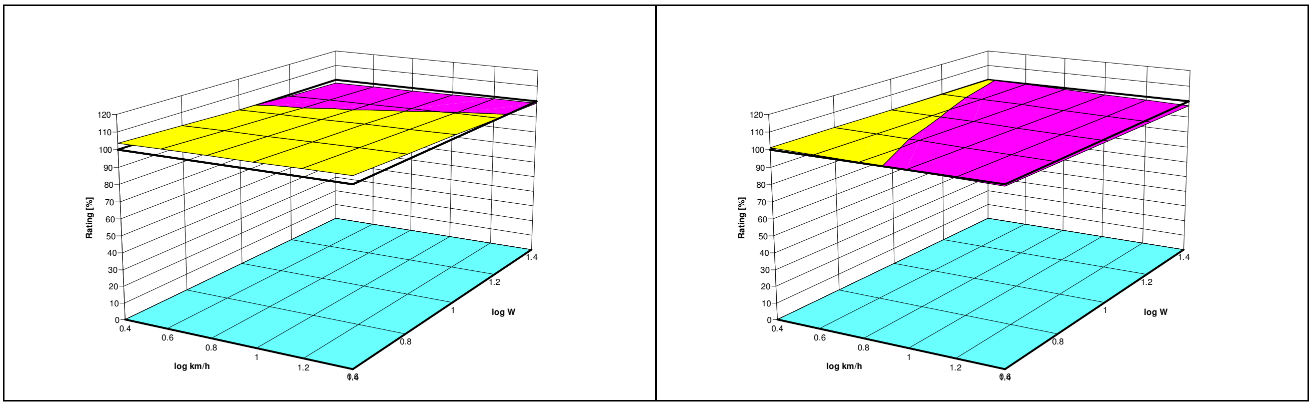
Compound C logW	log km/h 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	121.6	118.1	114.7	111.3	108.1	105	102	99	96.1
0.2	117.7	114.9	112.2	109.6	107	104.4	102	99.6	97.2
0.4	113.9	111.9	109.8	107.8	105.8	103.9	102	100.1	98.3
0.6	110.3	108.9	107.5	106.1	104.7	103.4	102	100.7	99.4
0.8	106.8	106	105.2	104.4	103.6	102.8	102	101.3	100.5
1	103.4	103.1	102.9	102.7	102.5	102.3	102.1	101.9	101.6
1.2	100	100.4	100.7	101.1	101.4	101.7	102.1	102.4	102.8
1.4	96.8	97.7	98.6	99.4	100.3	101.2	102.1	103	103.9
1.6	93.8	95.1	96.5	97.9	99.3	100.7	102.1	103.6	105.1

Compound D logW	log km/h 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	108.8	109.7	110.6	111.4	112.3	113.2	114.1	115	115.9
0.2	107.2	107.9	108.6	109.4	110.1	110.9	111.6	112.4	113.1
0.4	105.5	106.1	106.7	107.3	108	108.6	109.2	109.9	110.5
0.6	103.8	104.3	104.9	105.4	105.9	106.4	106.9	107.4	107.9
0.8	102.2	102.6	103	103.4	103.8	104.2	104.6	105	105.4
1	100.6	100.9	101.2	101.5	101.8	102.1	102.4	102.6	102.9
1.2	99.1	99.3	99.4	99.6	99.8	100	100.2	100.3	100.5
1.4	97.5	97.6	97.7	97.8	97.9	97.9	98	98.1	98.2
1.6	96	96	96	96	96	95.9	95.9	95.9	95.9

Compound E logW	log km/h 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	115.3	115	114.8	114.5	114.2	114	113.7	113.4	113.2
0.2	113	112.8	112.7	112.5	112.4	112.3	112.1	112	111.8
0.4	110.6	110.6	110.6	110.6	110.6	110.6	110.6	110.5	110.5
0.6	108.4	108.5	108.6	108.7	108.8	108.9	109	109.1	109.2
0.8	106.2	106.4	106.6	106.8	107	107.3	107.5	107.7	107.9
1	104	104.3	104.6	105	105.3	105.7	106	106.3	106.7
1.2	101.8	102.3	102.7	103.2	103.6	104.1	104.5	105	105.4
1.4	99.8	100.3	100.8	101.4	101.9	102.5	103.1	103.6	104.2
1.6	97.7	98.4	99	99.6	100.3	101	101.6	102.3	102.9

Table 6 Relative rating of the silica compound for the repeatability test

The frames in these two tables represent the field of the nine measuring points given by the set of the standard test conditions. As an example for the repeatability figures 6 a and 6 b show the ratings for one carbon black compound and one silica compound compared to the reference.



6 a Carbon black compound

6 b Silica compound

Figure 6 Repeatability of the multi correlation under standard test conditions

To investigate the plausibility of the ranking of the abrasion results determined in a laboratory test three carbon black compounds and three silica compounds were tested.

On the basis of the experiences that the wear resistance of carbon black compounds increases with the surface area, the tested compounds contain N 115, N 220 and N 330. A clear gradation of the abrasion loss was expected. In figure 7 the results are depicted.

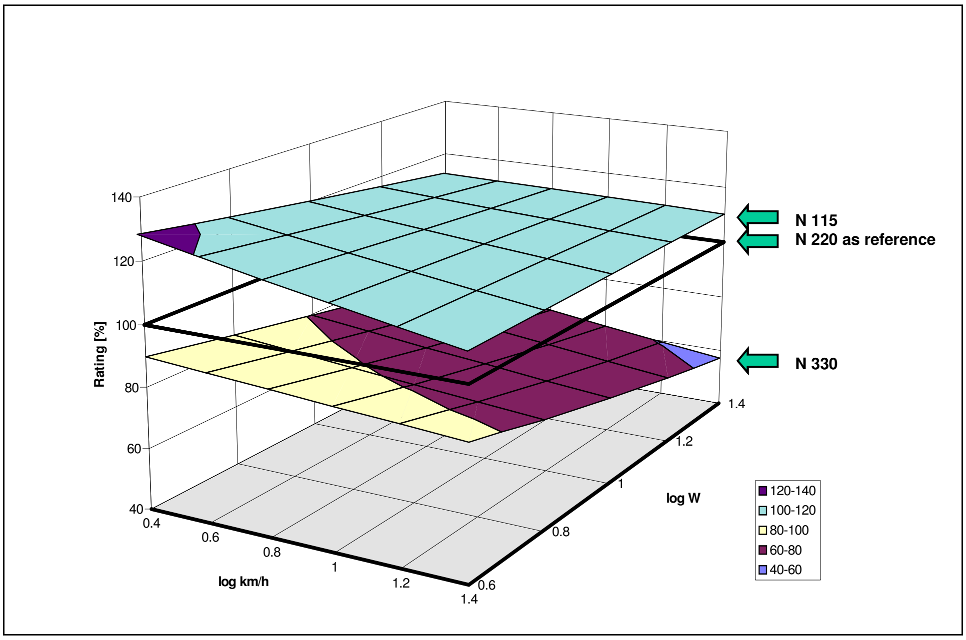


Figure 7 Results for carbon blacks with different surface areas

The N 220 is used as the reference = 100 %. The wear resistance for the N 330 is poorer over the whole speed and energy spectrum. The N 115 compound shows a higher rating of abrasion resistance hence a lower abrasion loss for the total calculated field.

To characterize the wear resistance of white fillers a conventional silica compound, a semi high dispersible silica compound and a high dispersible silica compound were tested (figure 8).

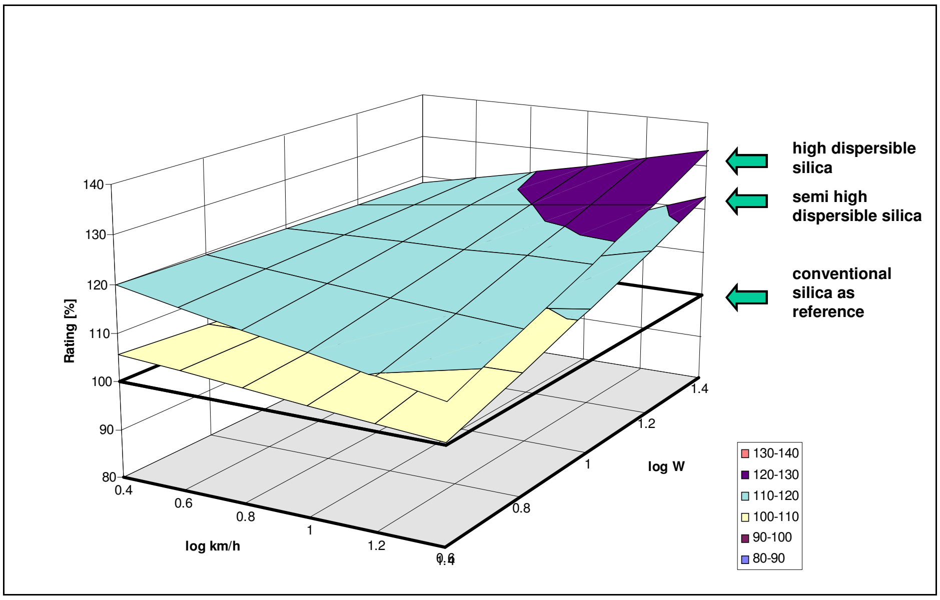


Figure 8 Results for different silica types

These results give the expected relative rating with an optimum for the high dispersible silica at high speeds and high energies.

Comparing laboratory results with road results it has to be considered that a road test traditionally gives only one value as a result. It is usually the average abrasion loss of the tires for different axle and side positions. In addition a range of steering-, braking- and driving accelerations, which lead to a range of energy and speed influences on the abrasion are also averaged. A variation of the average results of about ± 5 % to ± 8 % seems to be realistic.

Finally, different testing routes (a mountainous route is different to a motorway route, for example) will result in different acceleration and force transmission distributions between tire and road. This may shift the whole spectrum of energy dissipation and slip speeds in the contact area to an other level.

The following example compares road results of medium severity with laboratory values (table 7).

Compound A		log km/h								
	logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	0	101.7	101.8	102	102.1	102.3	102.4	102.6	102.7	102.9
	0.2	96.7	97.4	98.2	98.9	99.6	100.4	101.1	101.9	102.6
road	0.4	92	93.2	94.5	95.7	97	98.3	99.7	101	102.4
94 %	0.6	87.5	89.2	90.9	92.7	94.5	96.4	98.2	100.2	102.1
	0.8	83.2	85.3	87.5	89.7	92	94.4	96.8	99.3	101.9
	1	79.1	81.6	84.2	86.9	89.6	92.5	95.4	98.5	101.6
	1.2	75.2	78.1	81	84.1	87.3	90.6	94.1	97.7	101.4
	1.4	71.5	74.7	78	81.4	85	88.8	92.7	96.8	101.1
	1.6	68	71.4	75	78.8	82.8	87	91.4	96	100.9

Compound B		log km/h								
	logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	0	68.5	68.1	67.6	67.2	66.8	66.4	66	65.6	65.2
	0.2	68.8	68.7	68.6	68.4	68.3	68.1	68	67.8	67.7
road	0.4	69.2	69.4	69.5	69.6	69.8	69.9	70	70.2	70.3
70 %	0.6	69.6	70	70.4	70.9	71.3	71.7	72.1	72.6	73
	0.8	70	70.7	71.4	72.1	72.8	73.6	74.3	75	75.8
	1	70.4	71.4	72.4	73.4	74.4	75.5	76.5	77.6	78.7
	1.2	70.8	72	73.4	74.7	76	77.4	78.8	80.3	81.7
	1.4	71.2	72.7	74.4	76	77.7	79.4	81.2	83	84.9
	1.6	71.5	73.4	75.4	77.4	79.4	81.5	83.6	85.9	88.1

Compund C		log km/h								
	logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	0	68.9	71.3	73.7	76.3	78.9	81.7	84.5	87.4	90.4
	0.2	70.4	72.4	74.5	76.7	78.9	81.2	83.6	86	88.5
road	0.4	71.9	73.6	75.3	77.1	78.9	80.[illegible]	82.7	84.7	86.7
81 %	0.6	73.5	74.8	76.1	77.5	78.9	80.4	81.8	83.3	84.8
	0.8	75	76	77	77.9	78.9	79.9	81	82	83
	1	76.7	77.2	77.8	78.4	78.9	79.5	80.1	80.7	81.3
	1.2	78.3	78.5	78.6	78.8	78.9	79.1	79.3	79.4	79.6
	1.4	80	79.7	79.5	79.2	78.9	78.7	78.4	78.2	77.9
	1.6	81.7	81	80.3	79.6	78.9	78.3	77.6	76.9	76.3

Repeated reference		log km/h								
	logW	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
	0	109	108.2	107.4	106.6	105.8	105	104.3	103.5	102.7
	0.2	108.3	107.5	106.6	105.8	105	104.2	103.3	102.5	101.7
road	0.4	107.6	106.7	105.9	105	104.1	103.3	102.4	101.6	100.7
100 %	0.6	106.9	106	105.1	104.2	103.3	102.4	101.5	100.6	99.8
	0.8	106.2	105.3	104.3	103.4	102.4	101.5	100.6	99.7	98.8
	1	105.5	104.5	103.5	102.6	101.6	100.7	99.7	98.8	97.9
	1.2	104.8	103.8	102.8	101.8	100.8	99.8	98.8	97.9	96.9
	1.4	104.1	103.1	102	101	100	99	98	97	96
	1.6	103.5	102.4	101.3	100.2	99.2	98.1	97.1	96.1	95.1

Table 7 Results of a middle severity road test in comparison to laboratory results

The results of road tests are given in the boxes of the left side of the table. These results can be found around the blue points in the table, which represents the evaluation of the results of the laboratory tests. Bearing in mind the likely scattering of the road results a good agreement between road and laboratory tests is obtained in the range of medium to high speed and low to medium energy (figure 9).

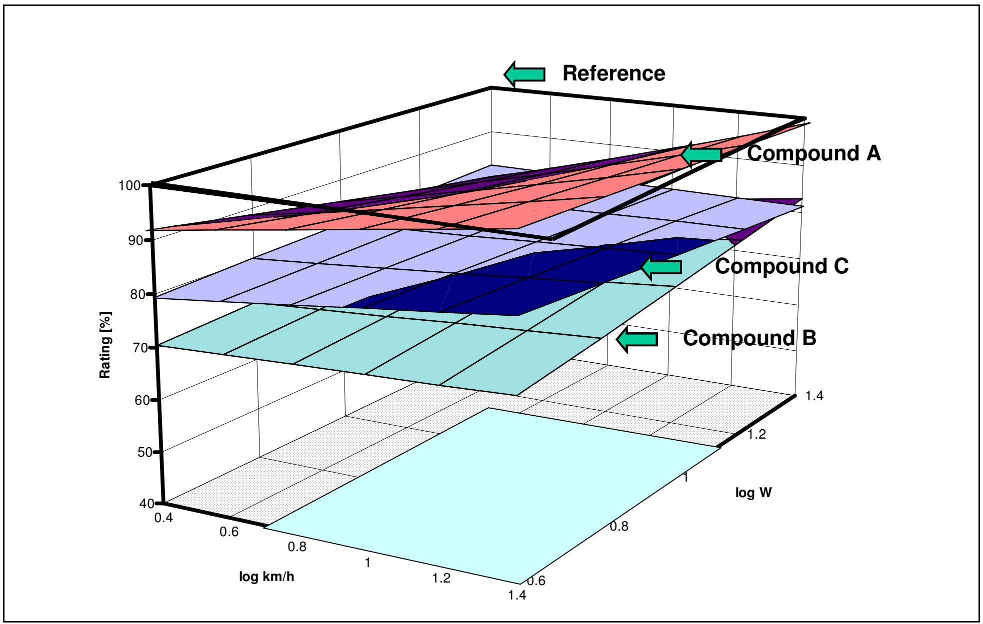


Figure 9 LAT 100 results of different compounds

The results of a more detailed road test analysis, differentiating between driven and non-driven axles are as shown in table 8:

Compound	Rating – driven axle	Rating – non-driven axle
Reference	100	100
Compound A	114	97
Compound B	130	106

Table 8 Road results for driven and non-driven axles

Table 9 shows the corresponding laboratory test results and the marked positions of the road test results. The laboratory test results reflect exactly the road test results with the additional information about the compound behavior over a wide range of severities not covered by a single road test. Precise correlation between the results of the non-driven axis for a middle severity and the driven wheels for a high severity can be found. This detailed analysis is important for the description of the tire tread properties at different driving conditions.

road
d [illegible]4 %
u[illegible]7 %

Compound A logW	log km/h 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	42.7	47.5	52.9	59	65.7	73.2	81.5	90.8	101.1
0.2	51.7	56.3	61.2	66.6	72.4	78.8	85.8	93.3	101.5
0.4	62.6	66.6	70.7	75.2	79.9	84.9	90.2	95.9	101.9
0.6	75.9	78.8	81.8	84.9	88.1	91.5	94.9	98.5	102.3
0.8	92	93.2	94.5	95.8	97.2	98.5	99.9	101.3	102.7
1	111.4	110.3	109.3	108.2	107.1	106.1	105.1	104.1	103
1.2	135	130.6	126.3	122.2	118.2	[illegible]	110.5	106.9	103.4
1.4	163.5	154.5	146	137.9	130.3	123.1	116.3	109.9	103.8
1.6	198.2	182.9	168.7	155.7	143.7	132.6	122.4	112.9	104.2

road
d [illegible]0 %
u[illegible]06 %

Compound B logW	log km/h 0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6
0	75.5	74.4	73.4	72.3	71.2	70.2	69.2	68.2	67.2
0.2	89	87.2	85.4	83.7	81.9	80.3	78.6	77	75.4
0.4	104.9	102.1	99.4	96.8	94.3	91.8	89.4	87	84.7
0.6	123.6	119.6	115.7	112	[illegible]	104.9	101.6	98.3	95.1
0.8	145.6	140.1	134.7	129.6	124.7	120	115.4	111	106.8
1	171.5	164	156.9	150	143.4	137.2	[illegible]	125.4	119.9
1.2	202.1	192.1	182.6	173.6	165	156.8	149.1	141.7	134.7
1.4	238.1	225	212.6	200.8	189.8	179.3	169.4	160	151.2
1.6	280.6	263.5	247.5	232.4	218.3	205	192.5	180.8	169.8

Table 9 Laboratory test results splitted for different severities

WET TRACTION EXPERIMENTS

Theory

Generally, the actual friction force can only be determined at 100 % slip i. e. if the sample wheel is locked. However, the friction coefficient already influences the side force at moderate slip angles and this increases with increasing slip. Therefore, to determine the wet traction capability the side force can also be used. Measurements are easier to handle and are more reproducible than friction coefficients at 100 % slip.

To evaluate the data of the side force measurements the corresponding side force coefficients (Eq. 1) are determined. It has been shown that side force coefficients determined at different speeds and temperatures can be transformed using the WLF equation.

$$\log a_T = -\frac{8{,}86\,(T - T_S)}{101{,}6 + (T - T_S)} \qquad \textit{(Eq. 9)}$$

where T_s is a standard reference temperature related to the glass transition temperature

$$T_s \approx T_g + 50 \qquad \textit{(Eq. 10)}$$

giving a fitted curve, which depends on the compound and on the surface on which the results are obtained.

For routine compound evaluation only one speed and a range of temperatures are used and converted to $\log(a_T v)$. Since only a small portion of the fitted curve is determined it is replaced over the required range of $\log(a_T v)$ values by a quadratic equation:

$$f = a + b_1 \cdot x + b_2 \cdot x^2 \qquad \textit{(Eq. 11)}$$

with x = $\log(a_T v)$

a, b_1, b_2 } coefficients of the regression analysis

It is assumed that a correlation with road data is obtained if the $\log(a_T v)$ values in the laboratory correspond to the operating $\log(a_T v)$ in the contact area of the slipping tire of the road test. Whilst the average slip speed v_s in the contact area can be determined from geometric considerations as

$$v_s = sl \cdot vf \qquad \textit{(Eq. 12)}$$

the resulting temperature can only be estimated using

$$t_{cont} = c_1 \cdot \mu \cdot p \cdot \sqrt{sl \cdot vf} + t_a \qquad \textit{(Eq. 13)}$$

with c_1 = empirically determined constant (benchmark constant)

μ = friction coefficient

p = tire pressure at ground

sl = slip

vf = maximum forward speed before braking

t_a = current outdoor temperature

Experimental Procedure

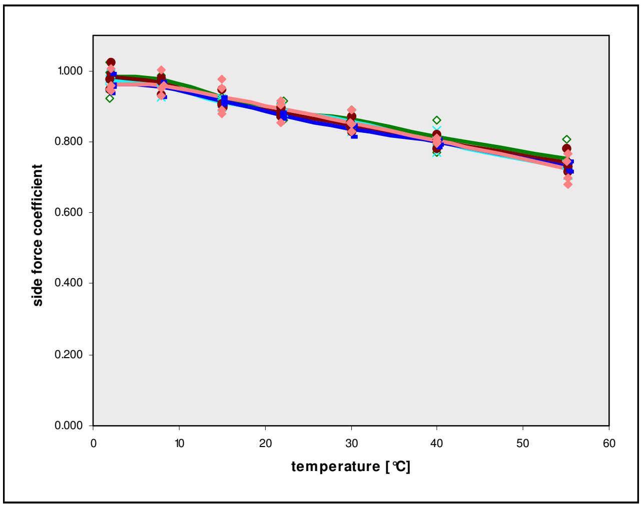
Side force coefficients and compound discrimination depend strongly on the surface structure of the disc used to carry out the experiments. It was found that a blunt electro-corundum 180 disc gives a compound resolution close to practical experience. Sharp corundum increases the deformation friction too strong and does not give a good correlation with road experience. Sand blasted glass plates give a high degree of compound differentiation but also a lower repeatability. Therefore, a blunt electro-corundum is used for standard tests. The routine conditions are given in table 10.

Disc	electro-corundum 180 blunt
Load	70 N
Slip angle	-15 °
Speed	1.5 km/h
Temperatures	2 °C, 8 °C, 15 °C, 22 °C, 30 °C, 40 °C, 55 °C

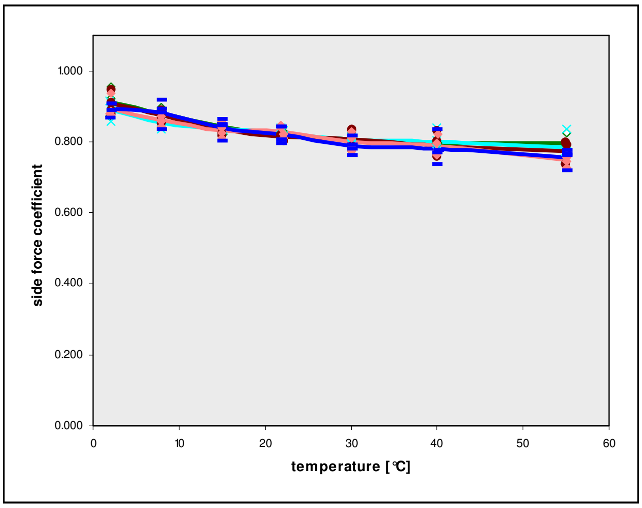
Table 10 Standard test conditions for the wet traction experiments

Results

For the compounds shown in table 4 the results of the repeatability tests for the wet traction experiments are given in figure 10.



10 a Carbon black compound



10 b Silica compound

Figure 10 Repeatability test for wet traction

It has been shown that for various road test conditions (wet handling, anti-lock or lock wheel braking) and laboratory surfaces, different benchmark constants c_1 have to be used to obtain the best possible correlation with a road test. However, the compound ratings change only slightly in relation to changing c_1 values [7]. To simulate results under road test conditions the contact temperature had to be calculated using a benchmark constant as outlined above. With a c_1 value of 7, a tire pressure of 2.5 bar and the different road testing conditions defined by approach speed and slip during braking as shown in table 11 results are expected, which reflect road properties.

Speed	Slip	
45	0,12	simulates wet-handling
30	0,12	
65	0,12	simulates anti-lock or peak-braking
100	0,12	values
30	1	
65	1	simulates lock or slide-braking values
100	1	

Table 11 Different conditions of wet traction calculation

The results of the calculation in accordance to Eq. 11 are given in tables 12 and 13.

Corresponding to	km/h	Slip	M1	M2	M3	M4	M5
Wet handling	45	0.12	100	99.6	99.9	100	100.1
(circle)	30	0.12	100	99.5	99.9	100	100.1
ABS braking	65	0.12	100	99.6	99.9	100	100.1
	100	0.12	100	99.7	99.9	100	100.1
Block braking	30	1	100	100	99.9	100	99.9
	65	1	100	100.1	99.7	99.7	99.6
	100	1	100	100.1	99.5	99.4	99.2

Table 12 Relative rating of the carbon black compound for the repeatability test

Corresponding to	km/h	Slip	M1	M2	M3	M4	M5
Wet handling	45	0.12	100	99.2	98.9	98.3	99.9
(circle)	30	0.12	100	99.2	98.9	98.2	99.9
ABS braking	65	0.12	100	99.2	98.9	98.3	99.9
	100	0.12	100	99.2	98.8	98.3	99.9
Block braking	30	1	100	99.2	98.8	98.3	99.9
	65	1	100	99	98.7	98.2	99.7
	100	1	100	98.9	98.7	98.2	99.5

Table 13 Relative rating of the silica compound for the repeatability test

As it is the case for the abrasion results there is also a good repeatability for the data of wet traction experiments.

To investigate whether the results agree with the practical experience, the following set of compounds was chosen:

Sample	Filler	T_G
M 1*)	N 234	-45
M 2	Silica without silane	-40
M 3	Experimental black	-42
M 4	Silica with silane	-42
M 5	½ M 3 + ½ M 4	-42
M 6 (repetition M 1)	N 234	-45

*) reference = N 234

Table 14 Compounds to check the plausibility of the results

For the silica compounds an increase of wet traction properties with an optimum for silica without silane is to be expected. Table 15 shows the results for the calculated contact temperature in accordance to Eq. 13 and the relative rating.

Contact temperature [°C]
Current outdoor temperature: 15 °C

corresponding to	km/h	slip	M1	M2	M3	M4	M5	M6
wet handling	45	0.12	35.6	37.6	35.1	36.6	36.1	35.5
(circle)	30	0.12	31.9	33.6	31.4	32.6	32.3	31.7
ABS braking	65	0.12	39.8	42.1	39.1	40.8	40.3	39.6
	100	0.12	45.6	48.3	44.7	46.7	46.2	45.4
Block braking	30	1	62.7	66.3	61.3	63.9	63.1	62.4
	65	1	1	88.5	82.1	84.8	83.8	83.7
	100	1	100	104.7	97.3	99.9	98.8	99.2

Rating [%]
Current outdoor temperature: 15 °C

corresponding to	km/h	slip	M1	M2	M3	M4	M5	M6
wet handling	45	0.12	100	109.7	97.2	104.4	102.3	99.2
(circle)	30	0.12	100	110	97.2	104.6	102.5	99.2
ABS braking	65	0.12	100	109.3	97.2	104.1	102.1	99.3
	100	0.12	100	108.8	97.2	103.7	101.8	99.3
Block braking	30	1	100	107.6	97	102.4	100.7	99.4
	65	1	1	106.3	96.9	101	99.5	99.2
	100	1	100	105.6	96.8	100	98.8	99

Table 15 Results for the calculated contact temperature and relative rating

These results prove the compound M 2 = silica without silane to be the best of the whole test spectrum. M 4 seems to be better concerning low speed and low slip conditions and equal to the reference for the hard lock braking conditions. For the chosen conditions the blend M 5 drops below the level of the reference. These ratings correspond to the expectation. The deviation between the reference and its repetition (M 1 and M 6) is 1 % at most.

Up to now more than 200 results of road tests have been compared to laboratory test results. The test spectrum includes road speeds between 20 km/h and 120 km/h and the whole range of wet handling, anti-lock braking and lock braking. For these tests it is possible to determine one individual value for each measurement and so to use the classical correlation analysis.

For all these results a correlation factor of 0.95 or better could be achieved. Figure 11 shows a set of about 40 data pairs to demonstrate this fact.

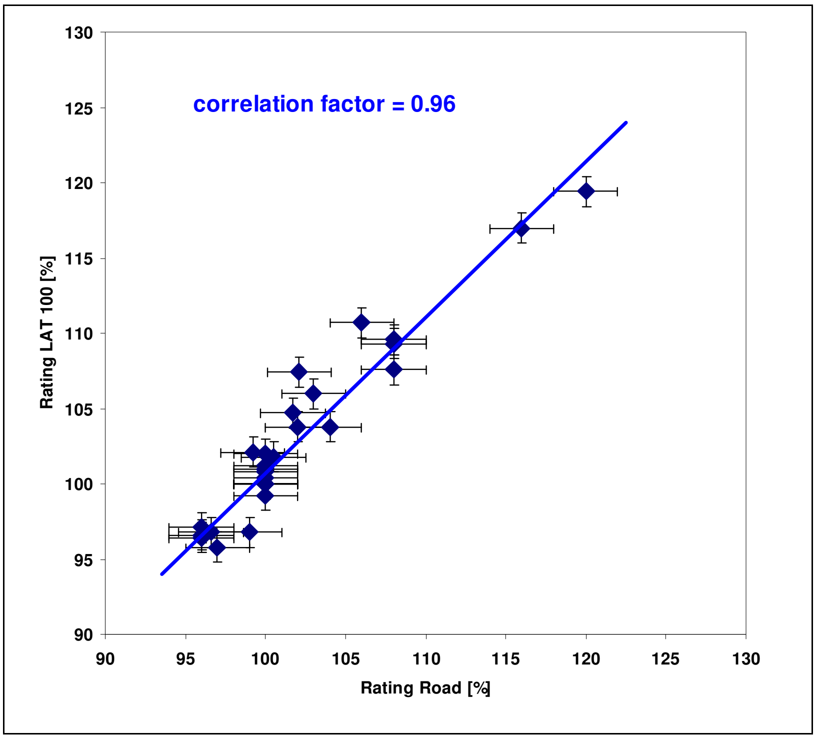


Figure 11 Correlation between road and laboratory results of wet traction properties.

CONCLUSION

The instrumentation of LAT 100 allows the evaluation of wear and wet traction performance over a wide range of testing variables including surface structure, temperature, speed, load and slip. This complexity is necessary in order to meet the fact that compounds can reverse their rating and ranking in road testing, both for wear and wet traction, with changing testing conditions. By laboratory testing it is possible to obtain a broad view of the compounds capabilities and its likely performance on the road under diverse usage conditions with relatively low costs. A comprehensive software packet helps to analyze the data and to show how the performance depends on the different road testing conditions.

Wear simulation indicates that this process is in fact quite severe. Comparisons between laboratory investigations and actual road tests give a good correlation, bearing in mind that for most road tests the conditions are not well defined and often have to be guessed for the laboratory.

The simulation of wet traction road tests based on the laboratory data shows the role of the contact temperature during the test and the influence of the surface structure, both for road and laboratory. Close correlation is obtained if the $\log(a_T v)$ values between road and laboratory are matched. In addition, the surface structures of road and laboratory have to be similar in structure.

Altogether, the laboratory data give a broad insight in the wear and wet traction behavior of compounds and allow reasonable judgments at a much shorter and less expensive testing period than road data can ever do.

REFERENCES

[1] K. A. Grosch, Proc Royal Soc., **A 274** (1963).

[2] H. G Moneypenny, J. Harris and S. Laube, presented at a meeting of the Rubber Division American Chemical Society, Oct. (1995).

[3] O. Lemaître, presented at the 3rd German-French Rubber Symposium, Oct. (1993).

[4] VMI EPE Holland BV, **Compound testing made simple**, The Technology International (1998) 199.

[5] K. A. Grosch, Kautsch. Gummi, Kunstst. **6** (1996) 432.

[6] A. Schallamach; Matériaux méchaniques électriques (1972), Numéro spécial l'usure 77, Gummi, Asbest, Kunstst. **25** (1972) 442.

[7] K. A. Grosch, Eine neue Labormethode zur Bestimmung der Abrieb- und Rutschfestigkeit von Laufflächenmischungen, presented at a DKG Meeting (1995).