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A Universal Method to Predict Wet Traction Behaviour of Tyre Tread Compounds in the Laboratory

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Wet grip is one of the most important properties relevant to tyre safety. The slip dependency of the side force coefficient was investigated with extra attention to Antilock Braking System (ABS)-breaking. A set-up which enables the simulation of wet road properties leads to a fair prediction of wet grip. A laboratory test method has been developed which uses a rotating disk against which a rubber sample wheel runs under a given load, slip angle and speed. The side force component acting on the wheel during the tests was recorded. The surface can be wetted with water at different temperatures and the side force at a slipping wheel is measured over a wide range of temperatures, slip and speed. Low water temperatures and low slip speed settings in the laboratory produce side force ratings, which correlate excellently with ABS braking on the road. Median and high slip speeds give ratings in close agreement with locked wheel braking on the road.

Keywords: wet traction; tyre tread compounds; prediction; laboratory; road

The braking behaviour is one of the main safety features relevant to tyre properties. It is now well established that the frictional force, which determines traction capability of a tread compound, is dominated by its visco-elastic properties[1–3]. The friction coefficient is a function of the contact temperature, sliding speed and the road surface constitution (*Figure 1*).

As tyre testing is time consuming and expensive, it appeared necessary to search for a meaningful laboratory test and an easily understood evaluation of the obtained laboratory results. Since laboratory results of wet traction strongly depend on the experimental conditions, a test method which gives a good correlation to tyre results, without regard to the composition of the tread compounds has to be established.

Nowadays, tyre tread compounds frequently contain polymer blends and/or filler blends. This leads to fundamental new demands on prediction of wet traction behaviour of tyre tread compounds. A prediction of wet traction behaviour based on the results of a linear friction tester or dynamic mechanical analysers[4,5] is no longer possible.

In this paper, laboratory test equipment – the LAT 100 – enabling the prediction of wet

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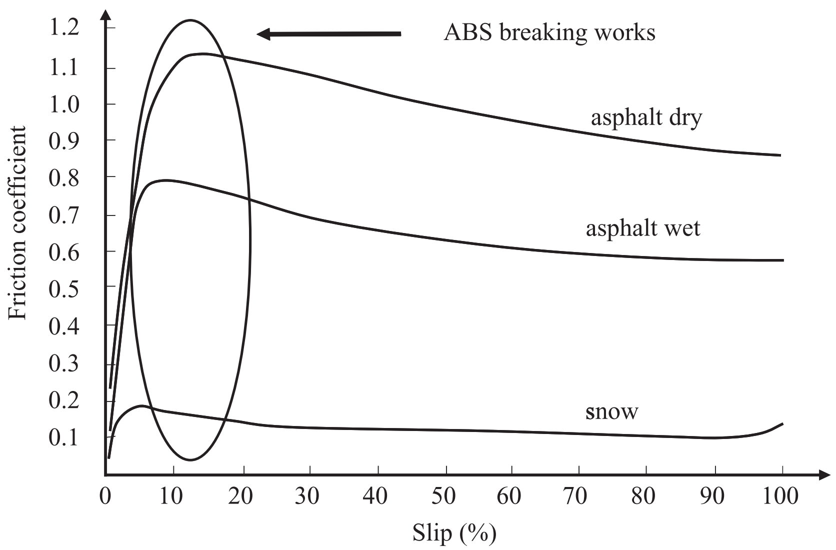

Figure 1. Friction coefficient for different road surface conditions.

grip behaviour of any composed compound is described, as well as useful test parameters, obtained results and their evaluation. Special attention is paid to the maximum value of friction coefficients for ABS braking (*Figure 1*). Finally, correlations between tyre test results and laboratory results are shown.

EXPERIMENTAL

The details of traction as side force or friction measurements on wet surfaces have been detailed previously[6–8] and will be described here only with regard to their now established procedures and the correlation with road test ratings.

The sample (*Figure 2*) is a rubber wheel, which is stabilised by a lateral bearing surface and prepared with a guide hole for a load cell, which records the forces of all three spatial directions.

Figure 3 shows the actual apparatus (LAT 100) with the auxiliary equipment to make up the testing system. The test apparatus consists of a driven disk against which a rubber test wheel is pressed under normal load L at a slip angle α (*Figure 4*). Speed $v = \omega \cdot r$, slip angle and load can be varied over a wide range. Only the slip angle has to be adjusted by hand to the prescribed value and the sample has to be removed. This operation is used to change the rotational direction of the sample by turning the marked side from left to right and vice versa, ensuring that the surface remains flat during the experiments.

For the actual wet traction tests, water at a set temperature, controlled by a thermostatically heating unit was pumped onto the track in an open circuit. The different velocities of the sample wheel (circumferential velocity, forward velocity, slip velocity) generate forces (*Figure 5*). To determine wet traction, the side forces were measured, collected and evaluated.

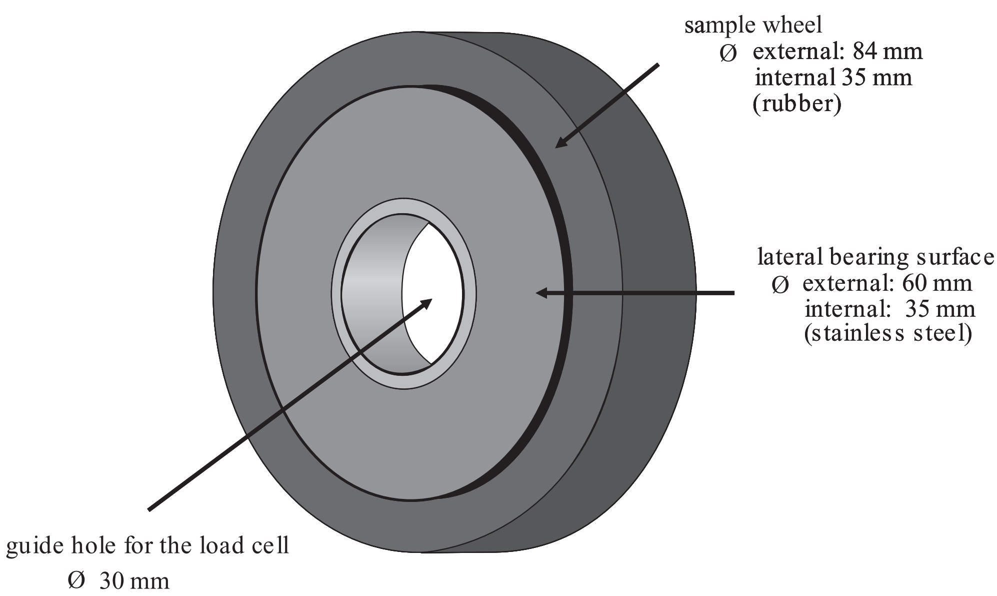

Figure 2. Test specimen including bearing facilities.

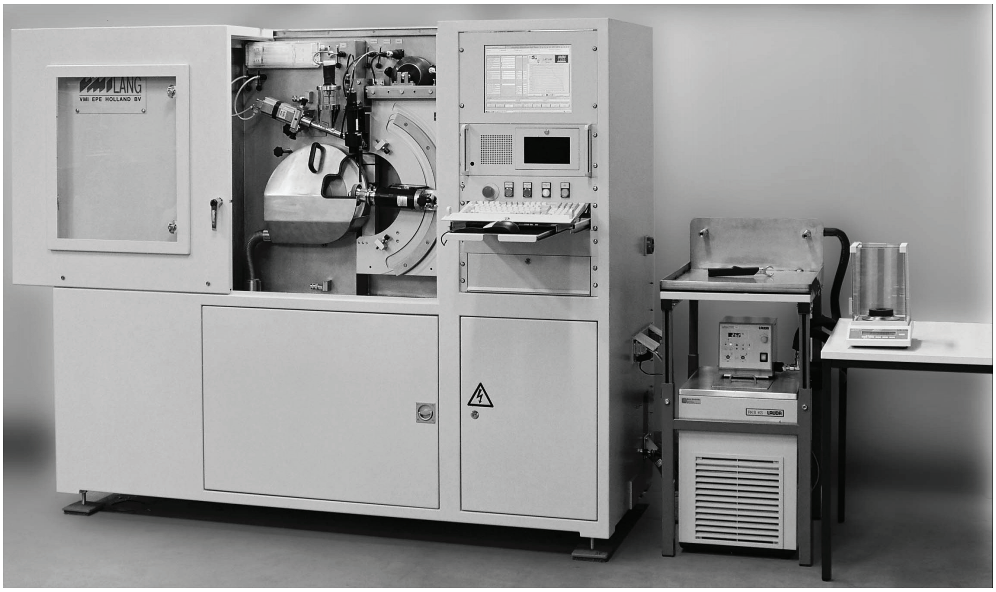

Figure 3. Photograph of the test equipment (LAT 100).

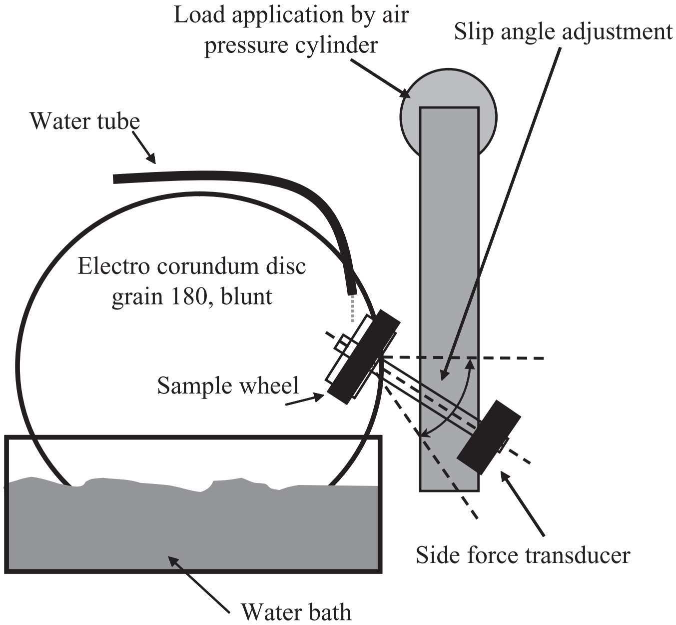

Figure 4. Arrangement of the test equipment.

Basics of Evaluation

The tyre traction on wet roads depends not only on slip behaviour and speed, but also on temperature. To simulate this, side force measurements on wet surfaces are carried out by keeping slip angle and normal load constant whereas speed and temperature are varied. The side force is determined directly and the side force coefficient is given by

$$\mu_s = \frac{F_s}{F_n} \qquad \ldots 1$$

where F_s is the side force and F_n the normal load.

The slip speed is given by

$$v_s = v_f \cdot sin\ \alpha \qquad \ldots 2$$

where v_f is the side force and α the slip angle.

For evaluation, it is convenient to consider temperature and speed as independent variables. The temperature dependence is then represented by an empirical based square relation and the speed dependence by a linear log(v) term (*Figure 6*):

$$\mu_s - a + b_1 . T + b_2 . T^2 + b_3 \log(v) \qquad \ldots 3$$

There are two more possibilities for the data evaluation, which take the characteristics of polymers into account. The WLF (Williams, Landel, Ferry) transformation, which is based upon the time-temperature equivalence for dynamic behaviour of elastomers[9], is given with a reasonable degree of accuracy when the data are presented as a function of $\log(a_T v)$, where a_T is the shift factor to transform the dynamic information of rubber from the glass transition temperature, T_G to the relevant temperature T_{rel}. Since no mathematical expression exists for the shape of the master curve of the side force coefficient, a quadratic equation is

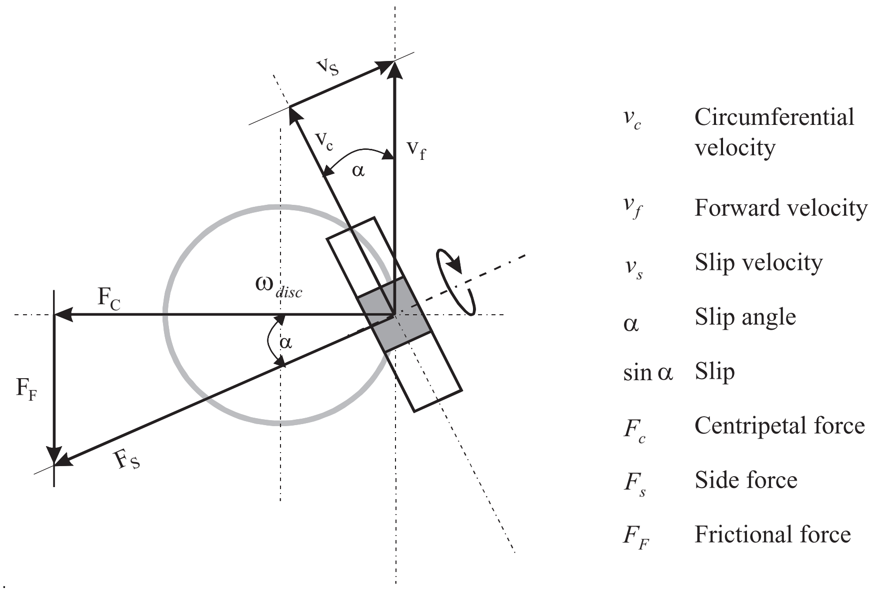

Figure 5. Velocities of the sample wheel and the resultant forces.

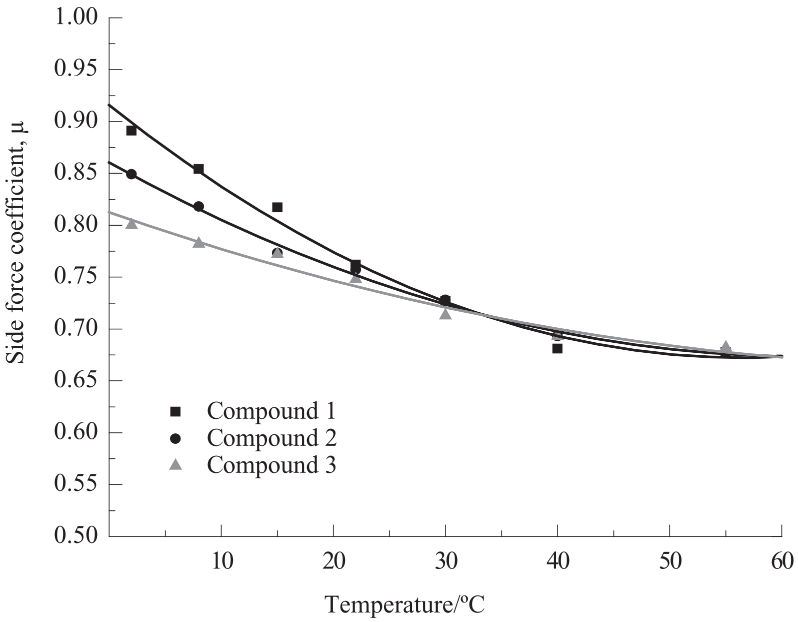

Figure 6. Side forces dependency on temperature.

used to represent the experimentally covered range:

$$f_s = a + b_1 \cdot log(a_T v) + b_2 \cdot [log(a_T v)]^2 \quad \ldots 4$$

This is shown in *Figure 7* for the side force coefficient of a tyre tread compound using the WLF equation.

For the third evaluation it is assumed that a high correlation is obtained if the temperature and the slip speed in the contact area of the tyre during the road test condition are similar to the temperature-speed condition in the laboratory.

In a road test, the contact temperature during traction test will depend on the heat generated and the heat transfer between tyre and wet road.

The contact temperature can be estimated according to the following equation[10]:

$$T_{cont} = k_o \cdot \mu_s \cdot p_r \cdot \sqrt{s_l \cdot v_f} + T_a \quad \ldots 5$$

where μ_s is the side force coefficient, p_r is the ground pressure which is set equal to the inflation pressure, s_l is the slip, v_f is the vehicle forward speed, T_a is the ambient temperature and k_o contains the fraction of heat generated entering the tyre and the dimensions of the real contact area. It depends on the road surface structure and the state of lubrication. For the performed tests, k_o = 7ºC/(bar · $\sqrt{m/s}$) represents a mean value and describes the tyre behaviour very accurately. The formula calculates the maximum temperature between a moving pad sliding under a load and speed over a flat surface with a given friction coefficient. The sliding speed is assumed to be the slip speed, which is equal to the vehicle speed in the case of locked wheel braking and is the product of slip and vehicle speed in case of ABS braking or cornering tests (*i.e.* 0.12 • vehicle speed).

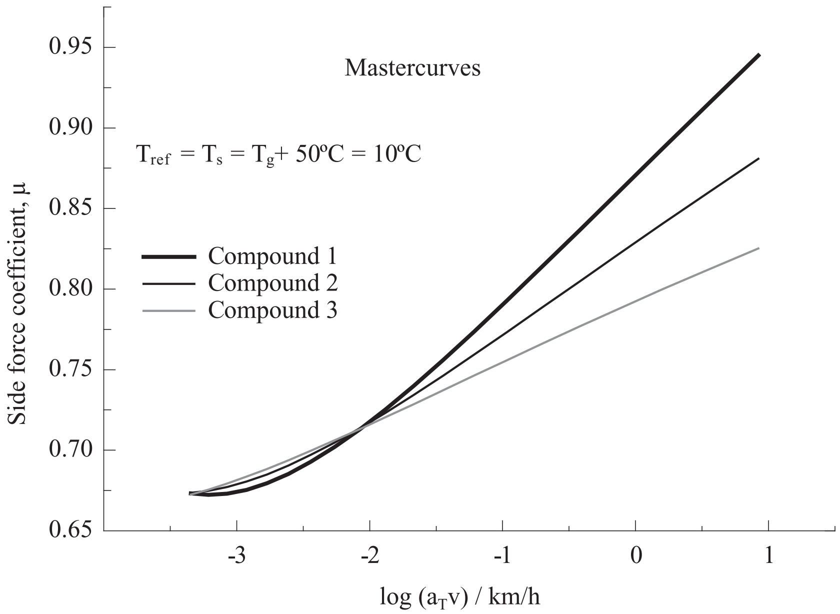

Figure 7. Side forces at wet traction in accordance to WLF equation.

Test Parameters

To find out which test parameters are relevant to describe the maximum of the friction coefficient (*Figure 1*) a wide range of possible parameter sets were investigated. As a maximum slip angle, the test equipment allows 45º; 44º represents a slip of 70% and this value is chosen as maximum.

The individual test parameters are shown in *Table 1* or – converted to slip speeds – in *Table 2*. For all tested compounds, a set of an individual array of curves can be observed which represents the complete slip behaviour of the compound and finally generates an envelope. *Figure 8* exemplifies the individual test results and the resulting envelope of an NR-compound filled with silica (*Table 3*).

TABLE 1. TEST PARAMETERS

Temperature (ºC)	Slip (%)	Slip (º)	Disk speed (km/h)
2	0	0	1.5
22	10	6	4
45	20	12	8
	30	17	16
	40	24	
	50	30	
	60	37	
	65	41	
	70	44	

TABLE 2. CORRESPONDING SLIP SPEEDS OF THE TEST PARAMETERS

Slip (º)	Slip speed (km/h) for 1.5 km/h	4 km/h	8 km/h	16 km/h
0	0.00	0.00	0.00	0.00
6	0.16	0.42	0.84	1.67
12	0.31	0.83	1.66	3.33
17	0.44	1.17	2.34	4.68
24	0.61	1.63	3.25	6.51
30	0.75	2.00	4.00	8.00
37	0.90	2.41	4.81	9.63
41	0.98	2.62	5.25	10.50
44	1.04	2.78	5.56	11.11

TABLE 3. RECIPE OF THE NR-COMPOUND FILLED WITH SILICA

1st Stage	
NR (SMR 10)	100 p.h.r.
ULTRASIL® 7000 GR	52 p.h.r.
Si 69®	4.16 p.h.r.
Stearic Acid	3 p.h.r.
ZnO	3 p.h.r.
Vulkanox 4020/LG	1 p.h.r.
Vulkanox HS/LG	1 p.h.r.
Protektor G 3108	1 p.h.r.
2nd Stage	
batch 1st stage	
3rd Stage	
DPG	2.6 p.h.r.
TBBS-80	1.2 p.h.r.
Sulfur	1.5 p.h.r.

These investigations allow the setting of commonly used test parameters (*Table 4*).

TABLE 4. COMMON TEST PARAMETER SET

$F_n = 75$ N
T = 2 - 55ºC
$v_f = 1.5$ km/h
a = 15º
$\Rightarrow v_s = 0.39$ km/h

RESULTS

Numerous investigations have been carried out to determine the wet traction properties of tyre tread compounds. The most important aim of the test was to find out to what extent carbon black and silica play a role as a reinforcing filler with regards to wet grip.

Two exemplarily investigations will be presented. A control S-SBR/BR summer tyre compound was filled with a carbon black (N 234). This carbon black was gradually substituted by a highly dispersible silica with an external surface of about 175 m^2/g CTAB and an adjusted amount of silane. For an ambient temperature of 15ºC, the wet traction rating was determined in accordance to *Equation 4*. The results are shown in *Figure 9*. The wet grip rises with increasing content of silica as filler. This is in line with the experience of tyre manufacturers.

Other S-SBR compounds with different carbon blacks and a highly dispersible silica were used, combined with the two different silanes Triethoxysilylpropyltatrasulfan (TESPT and Propyltriethoxisilan (PTEO). The rating for wet traction behaviour for the ambient temperatures of 15ºC and 30ºC is shown in *Figure 10*, calculated in accordance to *Equation 5*. Compared to the N234 filled compound, the N550 containing compound has slightly lesser wet traction. All silica filled compounds exceed the wet grip of the carbon black compounds. In addition, different wet grip behaviour is seen

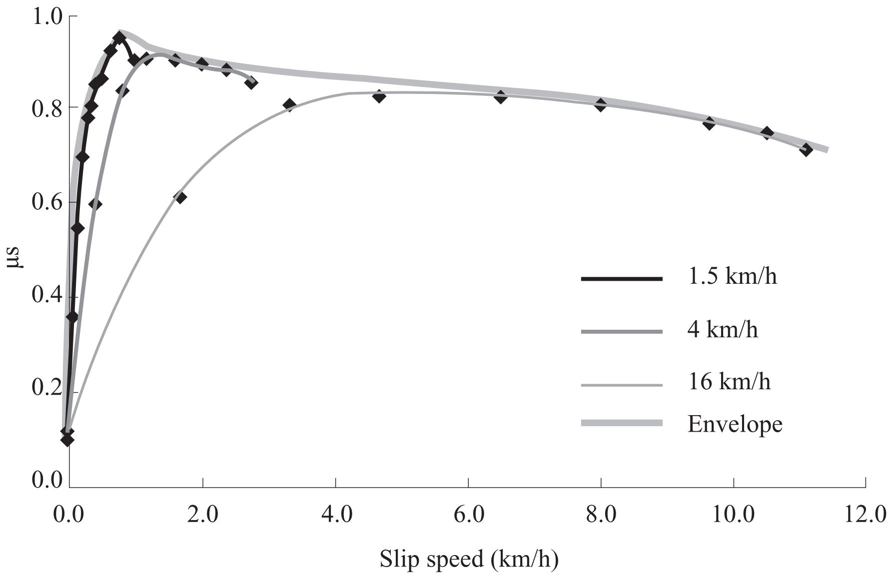

Figure 8. Envelope of μs for different test parameter sets for a silica compound.

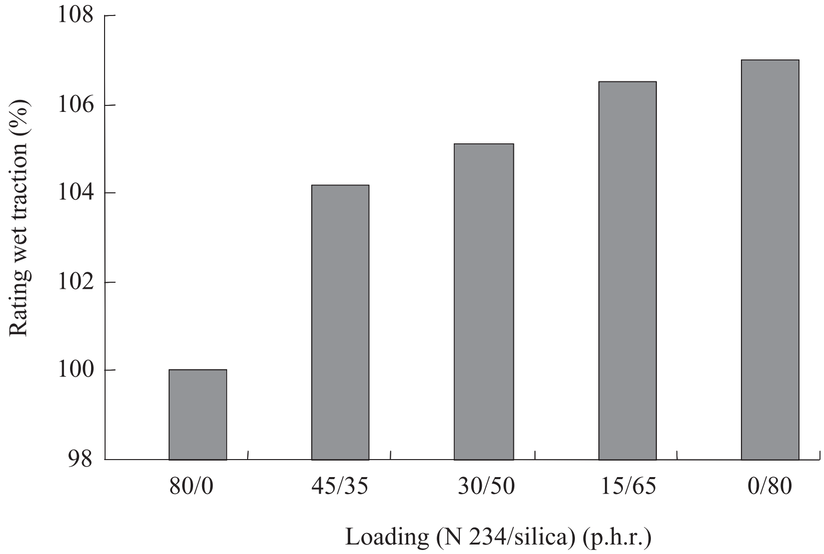

Figure 9. Wet traction results of carbon black / silica blends in an S-SBR/BR compound.

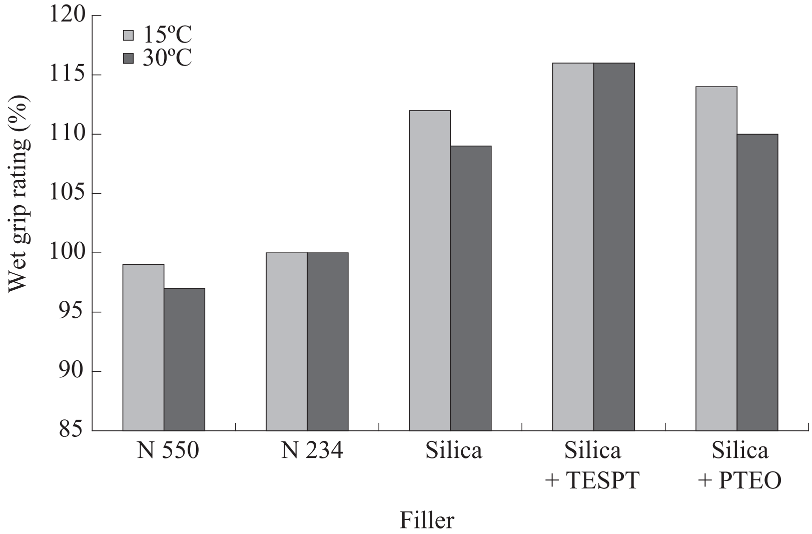

Figure 10. Wet traction results of carbon black and silica in an S-SBR compound.

with change in coupling agent and ambient temperature. This points out that fine differences in wet grip behaviour for special applications can be predicted with this equipment.

Correlation to tyre results

Finally correlations between results of tyre tests and LAT 100 tests were examined.

Wet traction tyre testing was carried out at 12ºC for winter tyres. The braking distance was determined with the car stopping from a speed of 75 km/h and using ABS, which corresponds to a slip of 12%. LAT 100 tests and numerous other "in rubber" laboratory tests were carried out at the same time with the same tyre tread compounds. The results of the LAT 100 correlate well ($r^2 = 0.93$) with the tyre results (*Figure 11*).

Correlations to tyre test results were also examined against other common rubber tests such as glass transition temperature, of loss modulus at 0ºC and ball rebound at 0ºC (*Figure 11*). As it can be seen, these tests show no correlation.

Consequently these values cannot be used to predict wet traction behaviour.

A considerable number of passenger car tyre tread compounds of different tyre manufactures have been tested with the LAT 100 for years and the results have been compared with the tyre test results. *Figure 12* shows results of these tests carried out at an ambient temperature of about 15ºC. The braking distance was determined and the relative rating evaluated. The stopping distance was from 100 km/h and a slip of 12% was achieved using ABS.

Over a period of about eight years and based on results obtained from different tyre producers, it is clear that the LAT 100 test results are in line with the tyre test results

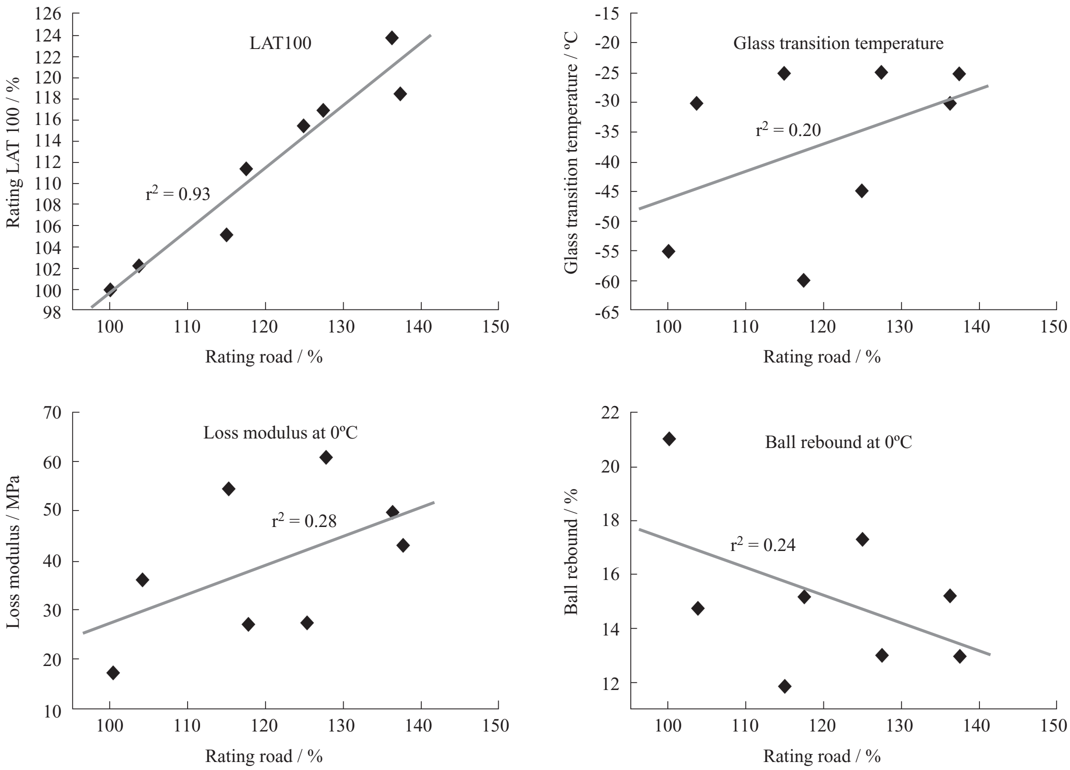

Figure 11. Comparison between tyre tests, LAT 100 and other rubber tests for winter tyre tread compounds.

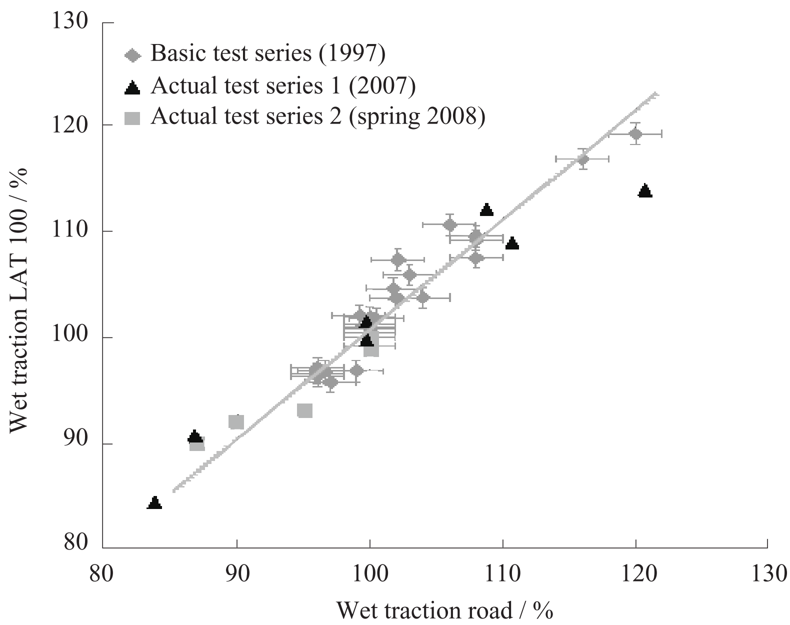

Figure 12. Comparison between tyre tests and LAT 100 results for summer tyre tread compounds.

(r^2 = 0.92). Consequently the LAT 100 can be used to predict wet grip properties of tyre tread compounds if the tests are done in an accurate and consistent way.

CONCLUSION

It is of crucial importance to be able to predict the wet traction behaviour of tyre tread compounds due to the important safety relevance of this property. On the other hand, the fact that tyre testing is time consuming and expensive makes a reliable laboratory test method extremely valuable. Especially since for silica filled tread compounds, a forecast of wet grip of tread compounds was not possible until now with traditional laboratory methods.

Research over 10 years has allowed us to optimise the testing methods with the LAT 100, thus making it a sophisticated test method offering a broad view of the performance of particular compounds, and simultaneously contributing to considerable financial savings by reducing road testing.

Ratings are presented in tabular form showing where potential for improvement can be found or conversely where there is no need to invest in more R&D work. With these data the compound developer can decide whether or not a noticeable improvement of tyre performance can be expected with this compound.

The LAT 100 makes compound testing on roads much less extensive since guide-line results can be obtained in the laboratory both quicker and cheaper. The paper has shown the values of the LAT 100 and its correlation with actual tyre test results.

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