A PREDICTIVE TEST METHOD FOR WET TRACTION AS A TIME-DEPENDENT MATERIAL PROPERTY OF TIRE TREAD RUBBER COMPOUNDS

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INTRODUCTION

Paying attention to safety aspects of tire behavior good dry and wet grip and secure braking is demanded. Therefore, a strong frictional connection between the road surface and the tread of the tire has to be established. To realize this target tread rubber compounds must guarantee good traction for actual side and brake acceleration of tires.

Each acceleration of a tire represents an excitation of the tread rubber. The response of rubber to such an excitation is both time-dependent and instantaneous [1]. Therefore, rubber is called a viscoelastic material. The instantaneous response is the elastic component, while the time dependent response is the viscous component.

The relation between the elastic and the viscous share of such a system depends on the glass transition temperature. This temperature is not a fixed value but a function of cooling or heating rate, stress time or frequency. Thermodynamically, the glass status is described as being in a state of non-equilibrium [2].

This forms the basis of the time/temperature superposition principle, which for pure polymers transforms to the WLF correlation [3]. For filled systems, this relationship can at best be taken as an approximation.

To date, determination of the glass transition temperatures and the dynamic properties of rubber samples generally involve the use of different test equipment. Depending on the test conditions, this makes it possible to cover different frequency ranges which, assuming the existence of theoretical correlation, are then extrapolated for practical properties, in particular those of tires.

The method of measuring the wet-grip properties using a Laboratory Abrasion Tester 100 (LAT 100) tackles this shortcoming, which results when theoretically derived data are applied to the practically properties of tires.

THEORETICAL BACKGROUND

To evaluate data of the side force measurements, which can be used to identify the wet traction capability, the corresponding side force coefficients

$$f = \frac{F}{L} \tag{1}$$

with F = side force and L = load are determined.

It has been shown that side force coefficients determined at different speeds and temperatures can be transformed using the WLF equation

$$\log a_T = -\frac{8{,}86\,(T - T_S)}{101{,}6 + (T - T_S)} \tag{2}$$

where a_T = shift factor, T = actual contact temperature and T_S = standard reference temperature [2, 4].

Using this equation to determine the shift factor in dependence on the temperature the time/temperature superposition principle gives information about the time dependence of the system.

It is assumed that a correlation with road data is obtained if the $\log(a_T v)$ values of a laboratory test correspond to the operating $\log(a_T v)$ in the contact area of the slipping tire of the road test.

The average slip speed v_s in the contact area can be determined from geometric considerations as

$$v_s = sl \cdot vf \tag{3}$$

with sl = slip and vf = maximum forward speed.

The resulting contact temperature can be estimated using

$$t_{cont} = c_1 \cdot m \cdot p \cdot \sqrt{sl \cdot vf} + t_a \tag{4}$$

with c_1 = empirically determined constant, μ = friction coefficient, p = tire pressure and t_a = current outdoor temperature.

Because the progression of the side force coefficient's fit curve is not known and only a relatively small segment can be determined from the measurements, the wet slide condition data on the road have to be calculated with the regression equation

$$f = a + b_1 \cdot x + b_2 \cdot x^2 \quad (5)$$

with $x = \log(a_T v)$ and a, b_1, b_2 = coefficients of the regression analysis.

EQUIPMENT AND EXPERIMENTAL PROCEDURE

A rotating system is used to measure real forces having an effect on a sample wheel. To investigate wet traction behavior water at a pre-set temperature in a range between +1 °C and 80 °C is used. Figure 1 shows a sketch of the experimental set-up to determine wet traction.

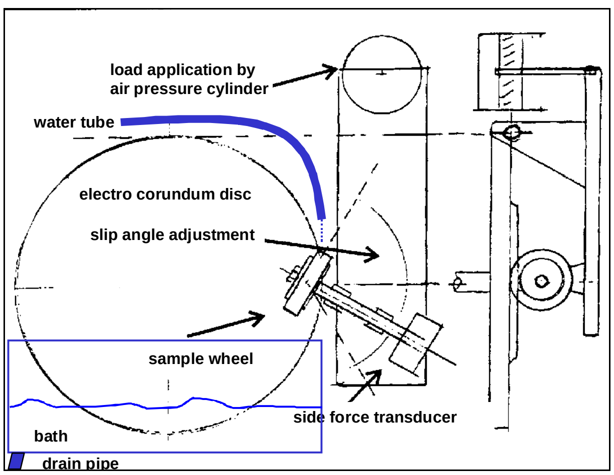

Figure 1 Sketch of the basic experimental arrangement to investigate wet traction

A rubber wheel runs on the flat side of a grinding wheel under a pre-set slip angle, speed and load [4]. A three component measuring device monitors continuously the load, the side force and the force along the plane of the sample. All parameters are computer controlled, recorded on a data file and analyzed with a special software program.

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. To simplify the practicability of the test one fixed slip angle is used. The test conditions are given in table 1.

Disc	electro-corundum 180 blunt
Load [N]	70
Slip angle [°]	-15
Speed [km/h]	0.015, 0.15, 1.5 , 10
Temperatures [°C]	2, 8, 15, 22, 30, 40, 55

Table 1 Test conditions for wet traction experiments

RESULTS

Investigations of typical carbon black and silica compounds showed that there is a good repeatability for the data of the wet traction experiments [5].

A set of compounds with well-known practical wet traction behavior was chosen to determine the time dependence and the discrimination of this test method.

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 2 Compounds to check the time dependence and the discrimination

The fit curves for the different slip speeds of the samples were evaluated in accordance to equation 5 and the really measured segments of the fit curves (equation 2) were depicted in figure 2.

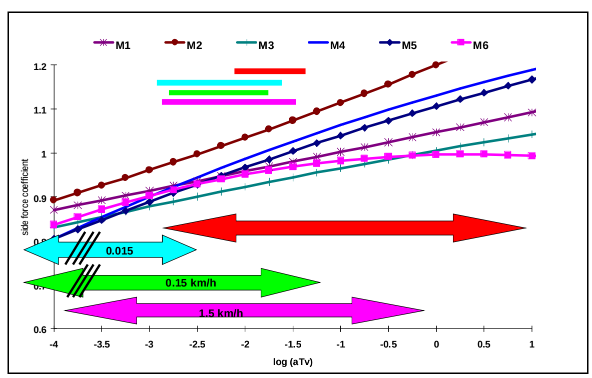

Figure 2 Speed and temperature dependent values of the side force coefficient

The arrows characterize the range of the results measured with the indoor experiments for the different speeds. The experience with road results shows a relevant area of log(a_Tv) values between –4 and +1. Therefore, the results of the tests with a speed of 0.015 km/h and 0.15 km/h are not in the relevant sector. The thick stokes in figure 2 show the field to determine the relative ranking for the simulated wet traction behavior given in table 3.

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

Table 3 Conditions of wet traction calculation

The speed of 1.5 km/h covers a relevant sector of the log(a_Tv) values and gives the largest spreading of the calculated results.

The results of the investigation are given in table 4. For the silica compounds an increase of wet traction properties with an optimum for silica without silane is to be expected from experience.

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 4 Results for the relative rating

The results, obtained by the LAT 100 prove the compound M 2 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 exception. 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 all these results a correlation factor of 0.95 or better could be achieved. Figure 3 shows a set of about 40 data pairs to demonstrate this fact.

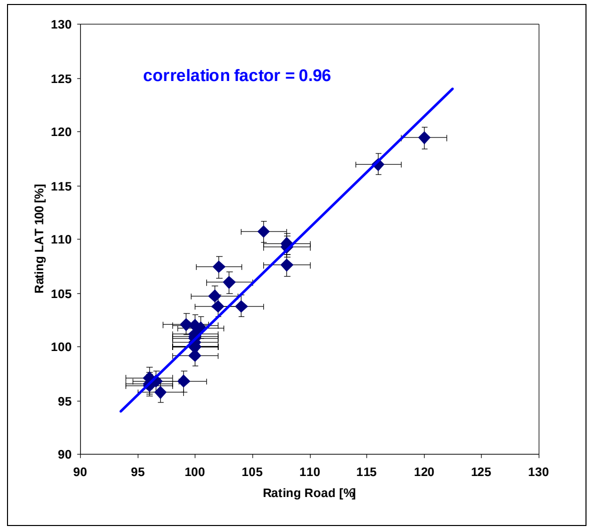

Figure 3 Correlation between road and laboratory results of wet traction properties

CONCLUSION

The presented laboratory test procedure allows the prediction of wet traction properties of tires on the road using the temperature/time superposition principle and the knowledge about the real outdoor temperature. Special attention is given on the slip speed of the sample to characterize the time dependence of the tire behavior on the road.

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