ROAD SURFACE CHARACTERISTICS AND HYDROPLANING

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The report first confirms the importance of micro- and macrotexture and explains its measuring devices, in particular a texture profile measuring device, developed by the Institute of Highways, Railways and Rock Engineering ISETH Zurich, which allows to quantify and to qualify macrotexture. A relation between surface texture values and the thickness of the waterfilm for hydroplaning conditions of a certain speed has been found after a great number of skid resistance measurements on five different pavement surfaces covered with waterfilms of 0.5 to 10 mm depth. The same results are used to show the limits for a classification of pavement surfaces based on standard measurement conditions (waterfilm 0.5 or 1.0 mm).

Introduction

The influence of road and surface characteristics on traffic safety is very complex. In this work we exclude elements such as vertical and horizontal alignment, cross-section, sight distance and so on, because these are topics for planning engineers. Instead we concentrate on two factors which directly concern pavement construction: texture and evenness, and their influence on skid resistance in wet conditions.

While texture directly influences the frictional conditions between tyre and road surface, unevenness has apart from variations of wheel load only an indirect but none the less important effect, due to the thickness of the waterfilm present in surface depressions, wheel-tracks and so on.

Road Surface Texture

The classification of the geometric form of a road surface into micro- and macro-texture is well known.

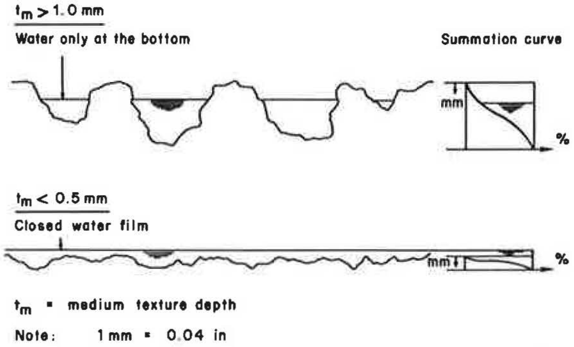
Microtexture

is chiefly connected with the friction force developed both for dry and wet pavements. In wet conditions the microtexture breaks through the last thin waterfilm in the contact zone tyre/road. The results of measurements with the english skid resistance tester (pendulum) or the skid resistance trailer at lower speeds give information on the amount of microtexture.

Macrotexture

makes it possible, on the one hand, to squeeze out quickly the water lying on the road surface, which is important at high speeds, as the tyre tread pattern alone is not sufficient (1), on the other hand it reduces the waterfilm lying on the surface.

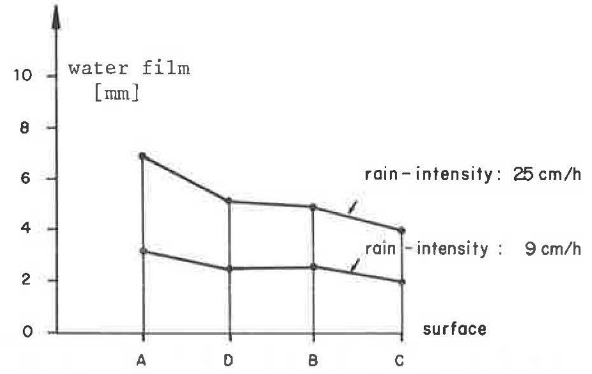
Figure 1. Water Level on Different Surfaces.



For the same rainfall intensity (light to medium rainfall) the water level lies below the gearing scope tyre/road surface for a rough pavement, $t_m > 1.0$ mm (0.04 in) (t_m = medium texture depth), while for a pavement with smooth texture, $t_m < 0.5$ mm (0.02 in), a closed waterfilm exists. This film also has negative outworkings on sight conditions: reflection of light, spray of water. A good macrotexture (possibly complete with grooves (2) or drainage asphalt) can make a significant contribution to the improvement of otherwise insufficient drainage conditions, for example due to small cross slope. This is shown in the following example:

ISETH has examined four test fields on a concrete pavement ungrooved and grooved with variable spacing under two different rainfall intensities, simulated with the aid of spray tubes. The waterfilm, resulting from this simulated rainfall, was measured with a comb - System Road Research Laboratory (3) - and with capillary tubes (accuracy 0.5 mm (0.02 in)). The effect of these surface textures concerning thickness of waterfilm on the pavement is shown in figure 2.

Figure 2. Reduction of the Waterfilm by Different Types of Grooving.

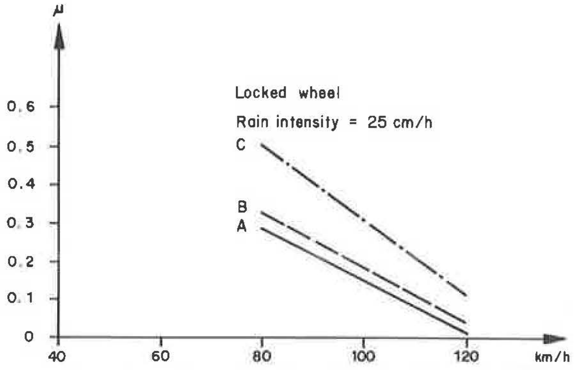


	additional drainage space/meter
A: concrete without grooves	0
B: concrete with grooves, spacing 150 mm 8 x 8	450 mm²
C: concrete with grooves, spacing 40 mm 8 x 8	1600 mm²
D: concrete with rough grooves spacing 25 mm 8 x 3	960 mm²

Note: 1 mm = 0,04 in

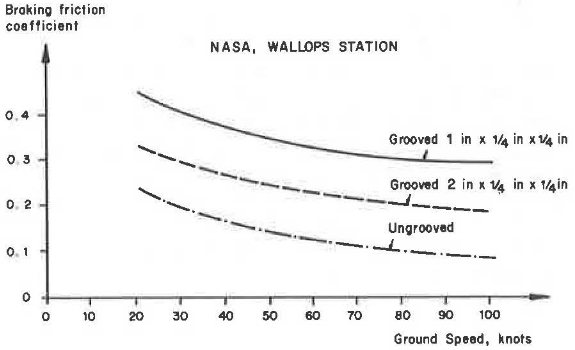
Comparison of fields B and C shows first the reduction of the waterfilm by raising the quantity of drainage space. Moreover, the tests show the influence of rate of drainage (speed). The waterfilm of both fields B and D is approximately at the same level, though the drainage space of field D is double that of field B. Rate of drainage is by the same cross slope (1%) distinctly greater in the cut grooves than in the rough ones. It may be concluded that for short drainage paths, according to Kalender (4), for textures from smooth to 3/4 mm (0.03 in) depth the quantity of drainage space of the pavement surface can keep to a minimum the thickness of a waterfilm. For greater distances the speed of drainage gains in importance, which means that smooth pavement surfaces would be advantageous with regard to waterfilm thicknesses. This condition, however, opposes the one necessary for contact drainage. The tyre has to squeeze out the remaining waterfilm. So there have to be as many drainage channels as possible in the contact zone tyre/pavement. A good distribution of drainage spaces is important. Figure 3 shows the effect of the supply of drainage space on the friction coefficient.
In addition to our tests, figure 4 gives results of research work carried out by NASA (5), which show, that by reducing groove spacing from 2 in to 1 in a great increase of friction is obtained.

Figure 3. Effect of the Supply of Drainage Space on Friction Coefficient.



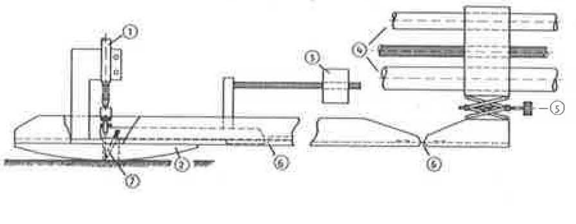
Fields A, B, C as Figure 2
Note: 1 km/h = 6,25 m/h

Figure 4. Effect of runway groove configuration on C-14/A aircraft braking on landing research runway at NASA Wallops Station.



Conscious of the great importance of macrotexture - not only for skid resistance but also for other pavement properties such as wear resistance and noise level - we developed an equipment which draws the profile of the pavement surface. We sought a solution that would not be affected by the disadvantages of the characterisation of texture by the sand patch method, which, taken by itself alone, says nothing about the distribution of drainage spaces and can lead to wrong conclusions.

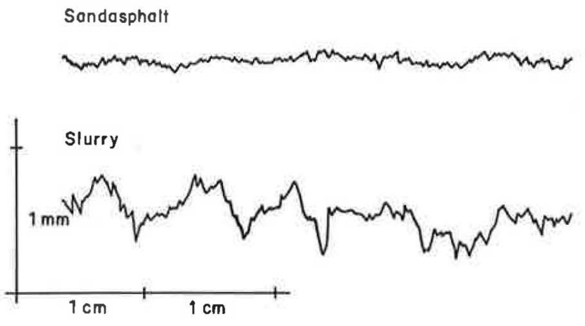
Figure 5. Texture profile measuring device ISETH



1 Transducer
2 Runner
3 Counter weight
4 Guidance
5 Adjustement
6 Articulation
7 Inclined needle

Geometry of the road surface is palpated by an inclined needle, moving slowly over the surface on a length of 50 cm (20 in). The profile is registered on a recording tape for computer processing, and presented graphically (6).

Figure 6. Examples of Profiles

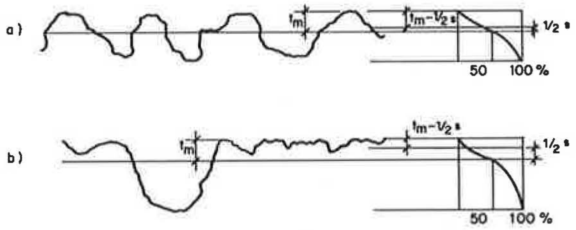


Note: 1mm = 0.04 in

Today the exploitations give us the values medium texture depth as quantity and standard deviation as distribution of drainage spaces.
Standard deviation, a value in vertical direction, has influence on distribution in horizontal direction.
Figures 7a) and 7b) have the same medium texture depth, but a good regularity as in figure 7a) (s = small) is advantageous.
Because regularity in distribution of drainage spaces in horizontal direction is very important, we define macrotexture with the characteristic value

$t_m - {}^1\!/_2\, s$ $\quad t_m$ = medium texture depth
s = standard deviation

Figure 7. Definition of macrotexture



Evenness

Skid resistance measurements with our trailer "Skiddometer" were carried out under a constant waterfilm of 0.5 mm (0.02 in) depth. On this basis classification of pavement surfaces is correct up to waterdepths of 2 or 3 mm (0.08 or 0.12 in). Theoretical studies (4) show, that a rainfallintensity of 5 cm/h (2in/h), that means heavy conditions, produces a waterfilm of 3 mm (0.12 in) for a cross slope of 1% and a drainage path of 10 m (32,8 ft).

Nevertheless, the results of the standard skid resistance measurements may not permit conclusions regarding traffic safety. A road surface is never perfectly even. Today we have, besides unevennesses in longitudinal direction the phenomenon of rutting. In this case we can find corresponding to depth and width of the ruts waterfilm thicknesses of up to 10 mm (0.4 in), even in light rainfall. The following systematic researches show the effect of waterfilm depth on friction coefficients.

Influence of waterfilm thickness on friction coefficients

On five pavements
1. Concrete, new ungrooved
2. Asphalt base course, coarse graded, partially round aggregate
3. Asphalt, coarse graded
4. Asphalt, fine graded, untrafficked area of airfield pavement
5. Concrete, grooved, spacing 4 cm (1.6 in)

a bed filled with water was prepared; length 40 m (131,2 ft), width 0.70 m (2,3 ft). This made it possible to vary waterdepth from 0.5 to 12 mm (0.02 to 0.48 in).

Figure 8. View of the Test Pavement 3

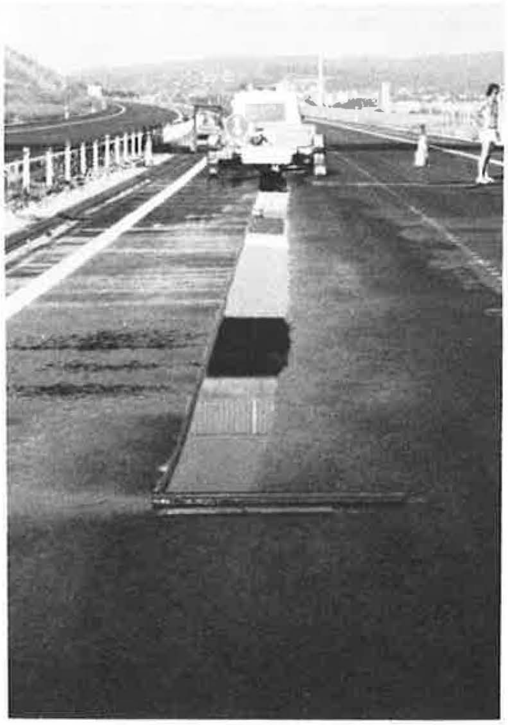


Figure 9 shows the results of one measurement and the dependence of the friction coefficient from waterfilm thickness.

In figure 10 friction coefficients are given as a function of speed and waterfilm thickness for pavement 3 and for measurements with locked wheel. All other pavements examined give similiar curves; level and curvature of the curves are a function of surface texture. Measurements with locked wheel were chosen, because today abrupt braking still can lead to the danger of wheel-locking.

Figure 9. Results of one measurement on pavement 1

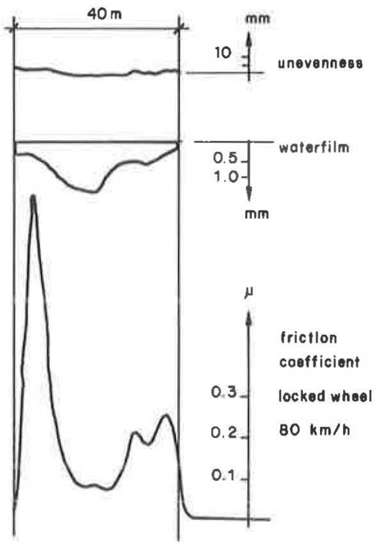
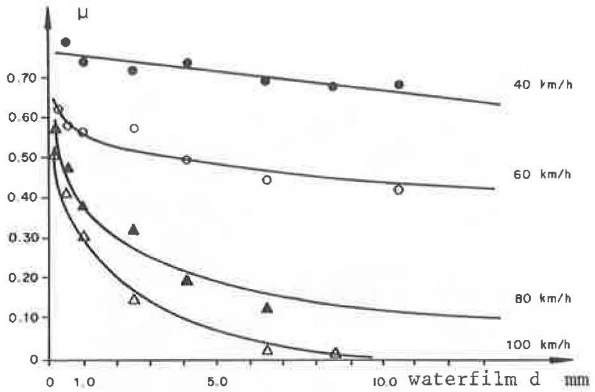


Figure 10. Friction Coefficient as a Function of Waterfilm and Speed; Pavement 3



Measurements of this kind will obviously remain restricted to special research work. Because of the importance of the results under extreme conditions (high speeds and thick waterfilms) for traffic safety a correlation between some relevant data from a standard test is sought by which an extrapolation to these conditions would be possible.

The curves of figure 10 for μ/d can adequately be formulated mathematically as follows:

40 km/h (25 mph) $\mu_i = a_i + b_i\, d$ (1)

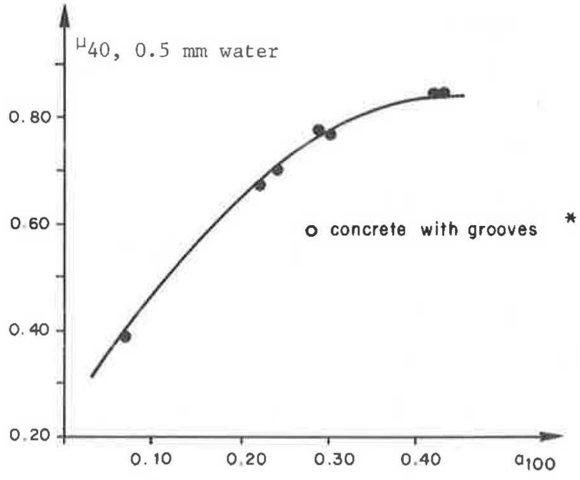
60, 80, 100 km/h (37.5;50;62.5 mph) $\mu_i = a_i + b_i \ln d$ (2)

i = speed, d = waterfilm thickness
a, b depend on surface texture.

A correlation can be found between the factors a_i and friction coefficient μ obtained by standard measurement (0.5 mm (0.02 in) waterfilm) and a speed of 40 or 60 km/h (25 or 37.5 mph). Figure 11 shows this correlation for $a_{i=100\ \mathrm{km/h}}$ and $\mu_{40\ \mathrm{km/h}}$.

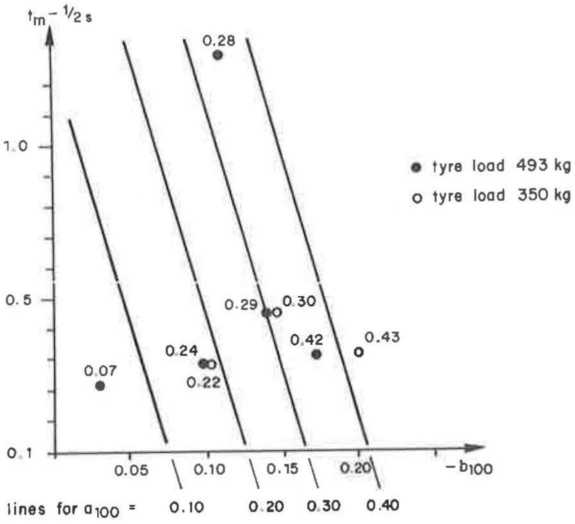
Drainage capacity of a surface influences the factor b and is represented by $t_m - \frac{1}{2}s$, obtained with the aid of our texture profile measuring device. The gradient of the curve μ/d is related to the initial level of skid resistance (factor a_{100}); so that if a curve already has a very low initial level (film thickness 0.5 mm (0.02 in)) a large further decrease is not possible. Figure 12 shows the correlation between microtexture and macrotexture to the factor b, again for a speed of 100 km/h (62,5 mph).

Figure 11. Correlation between a_{100} and μ_{40}



Note (*) not exactly comparable, because waterfilm was measured from the highest points of texture; that means the quantity of water inside the grooves was neglected.

Figure 12. Correlation of $t_m - \frac{1}{2}s$ and a_{100} with b_{100}



All this (fig. 11, 12) enables us to estimate a friction coefficient at high speeds and great waterdepths from a standard skid resistance measurement (0.5 mm (0.02 in) water) at low speed (40 km/h (25 mph)) and a measurement of texture.

Our example for 100 km/h:

from $\mu_{40\ \text{km/h},\ 0.5\ \text{mm water}}$ + figure 11 → a_{100}

from $t_m - \frac{1}{2}s$ and a_{100} + figure 12 → $-b_{100}$

It is difficult to determine in an objective manner the critical level of skid resistance when hydroplaning occurs. In the present case a friction coefficient of 0.10 was chosen as the critical level. If we require that $\mu_{100} \geq 0.10$, the maximal permissible waterfilm results from equation (3).

Summarizing, we can now obtain from figure 13 the maximal permissible waterfilm as a function of $t_m - \frac{1}{2}s$ and $\mu_{40,\ 0.5}$.

Figure 13. Critical Waterfilm

Calculated with (3) and completed with measured values of table 1

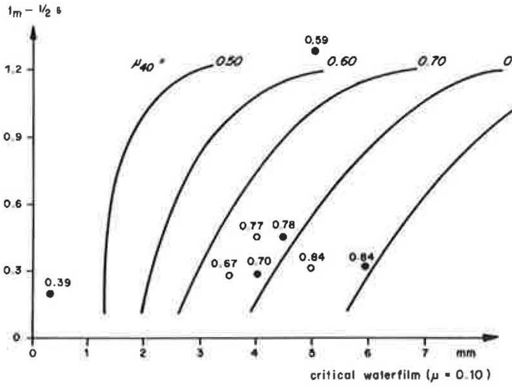


Table 1. Critical Waterfilm (μ = 0.10) on the five test pavements

No.	Pavement	Micro texture	Macro texture	Critical Waterfilm mm	
		$\mu_{40,0.5}$	$t_m - \frac{1}{2}s$	80 km/h (50 mph)	100 km/h (62,5 mph)
1	Concrete	0.40	0.2	2	0.3
2	Asphalt base coarse	0.70	0.3	7÷11 (*)	3.5÷4 (*)
3	Asphalt	0.77	0.45	8÷11	4÷4.5
4	Asphalt untrafficked (airfield)	0.85	0.35	11÷19	5÷6
5	Concrete grooved	0.60	1.3	no hydro planing	5

Note: 1 mm = 0.04 in

(*) The smaller values refer to a wheel load of 350 kg, which is about the average for passenger cars. The higher values refer to a wheel load of 493 kg.

Our test tyre, with four longitudinal grooves, represents rather unfavorable conditions, that means for practise: values in figure 13 are very conservative.

$$\mu_{100} = a_{100} + b_{100}\ln d \quad (3)$$

Conclusions

1. It has been shown, that it is meaningful to classify surface texture by: microtexture (obtained from μ-measurements with locked wheel, standard waterfilm 0.5 mm (0.02 in), speed 40 km/h (25 mph)) and macrotexture (obtained from medium texture depth and distribution of drainage spaces = standard deviation from profile record). Microtexture has above all considerable importance for the level of the curves μ/d, but this also affects curve inclination. The significance of macrotexture (quantity and distribution), its interrelationship with microtexture and its upper limits of effectiveness are presented in figure 13. For small microtexture the curves are very steep, which means: on pavement surfaces without sharpness even a very good macrotexture cannot improve the friction ration.

2. Classification of pavement surfaces based on standard measurements with a waterfilm of 0.5mm (0.02 in) is correct for speeds up to 60 km/h (37.5 mph) also for thicker waterfilms (up to 10 mm (0.4 in)). In this field influence of tyre and load is of low significance. For speeds greater than 60 km/h (37.5 mph) the friction coefficient is distinctly influenced by waterfilm thickness. Macrotexture, tyre mould (limited up to 3 mm (0.12 in) waterfilm) and load gain in importance. Extrapolation using measurements with 0.5 mm (0.02 in) waterfilm to other film thicknesses may underestimate the effect of those factors, and can lead to wrong conclusions (figure 15 and Table 2).

Figure 15. Locked wheel friction coefficients of different pavements as a function of waterfilm depht, speed 80 km/h (50 mph).

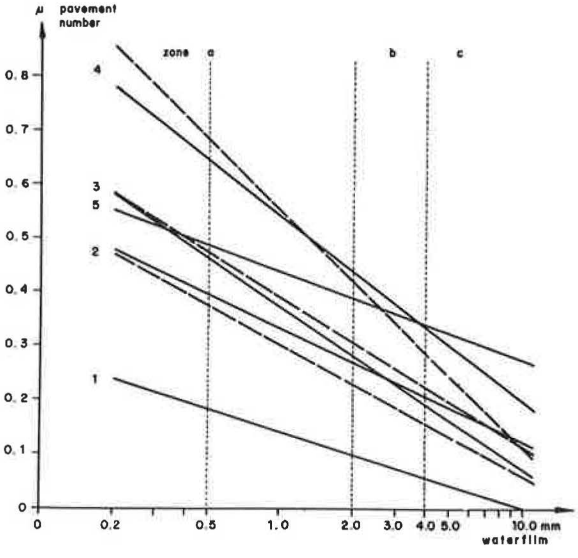


Table 2. Classification of the Pavement Surface

water mm	zone	Pavement good ⟶ bad			
0.5	a	4	3 + 5	2	1
2-4	b	4+5	3 + 2		1
4	c	5	4	3+2	1

3. For engineering practice we can conclude: On a pavement with a friction coefficient of about 0.70 (locked wheel, 40 km/h (25 mph), 0.5 mm waterfilm) and a texture $t_m - \frac{1}{2}s$ of about 0.4 (corresponds to the recommended $t_m = 0.5$ and a good distribution of drainage spaces $\frac{1}{2}s = 0.10$), the waterfilm should not be greater than 3 mm (0.12 in) for a sufficient safety for speeds of about 100 km/h (62.5 mph). This demands very high quality of evenness, especially transversally to the road axis (ruts) in case of low cross slope.

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