

Towards real-time skid resistance forecast

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ABSTRACT

For any given road layout or curvature skid resistance as property of pavement surface and tyre is a decisive factor limiting the speed threshold for safe driving. Skid resistance is no fixed value and is significantly lowered in case of precipitation depending on form and rate. A further influence factor in such cases is the macro texture of pavements due to their capacity to hold precipitation while maintaining contact with the tyre. Snow and ice on roads are the main factors for lowered skid resistance resulting in elevated road accident levels and economic costs. With new methodologies in weather forecasting and RWIS – sensors better winter forecasting models for winter maintenance are already available. These current models consider different road materials mainly in order to specify parameters for solar flux absorption in energy budget calculations for real time road surface temperature estimation. The main emphasis of the paper lies in a determination of the impact of macro texture and amount of snow and ice on skid resistance of flexible and rigid pavements. Based on extensive field and laboratory research a connection between different texture and skid resistance determination methods could be established. The field tests consisted of film thickness and skid resistance measures among others for different weather situations. In the complementing laboratory tests the road surface texture was determined using high precision laser scanning on sample cores as well as other test methods. Based on the findings a real time skid resistance prediction for an entire road network becomes feasible.

Keywords: skid resistance, macro texture, winter maintenance, real time, forecast

1 INTRODUCTION

In order to provide safe roads, planning parameters such as minimum curvature radius or gradients as well as minimum requirements on sight distance are specified in national regulations. For road users however, the critical parameters are braking distance and velocity in curves, both directly related to skid resistance. While the regulations ensure safe driving on new roads (within the speed limit) for dry and wet conditions, this holds not true for snow or ice on the road due to severely lowered skid resistance. Winter maintenance with ploughing and salting is the common way to remove snow and ice and improve road safety and is therefore indispensable for people and economy.

The resulting skid resistance is the key factor for the success of winter maintenance. Common winter maintenance models do not incorporate road surface parameters such as texture and skid resistance and are focused mainly on road surface temperature and deicing. Based on a new developed model at the Vienna University of Technology an estimation of the optimal application rate depending on weather forecast, traffic volume and road texture becomes feasible. Furthermore the developed model goes beyond common approaches aiming at a forecast of skid resistance on road networks as the key factor for road users.

2 ROAD SURFACE TEXTURE AND SKID RESISTANCE

The contact between road surface and tyre allows a transmission of vertical, transversal and longitudinal forces. The available contact area for vertical and horizontal force transmission is limited and results from a flattening of the tyre surface [2]. This small contact area depends on tyre geometry, wheel load, and internal tyre pressure and increases with lowered tyre pressure (Figure 1). For common dimensions radial and diagonal tyres have

almost the same behaviour compared to over wide radial tyres with a somewhat lowered decrease of contact area with increasing tyre pressure. The distribution of vertical lateral and longitudinal tyre pressure can be determined based on Vehicle-Road Surface Pressure Transducer Array (VRSPTA). Figure 2 gives an overview of the vertical, lateral and longitudinal contact pressure distribution between a radial tyre and the road surface.

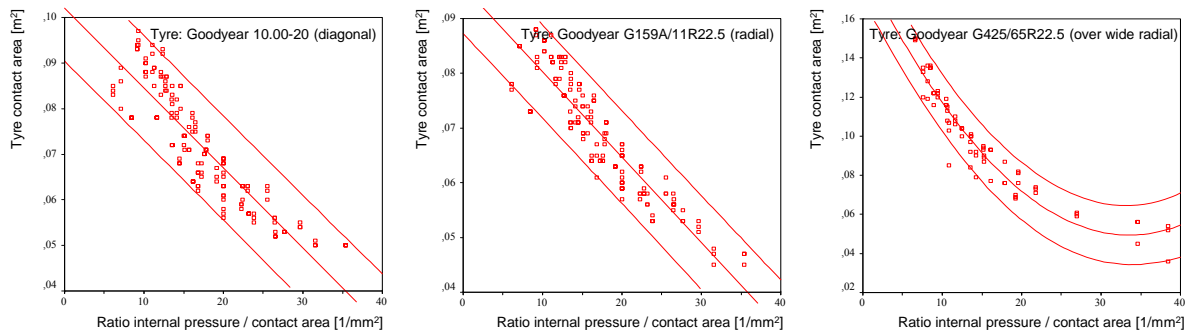


Figure 1. Contact area of typical tyres depending on geometry, wheel load, and internal tyre pressure

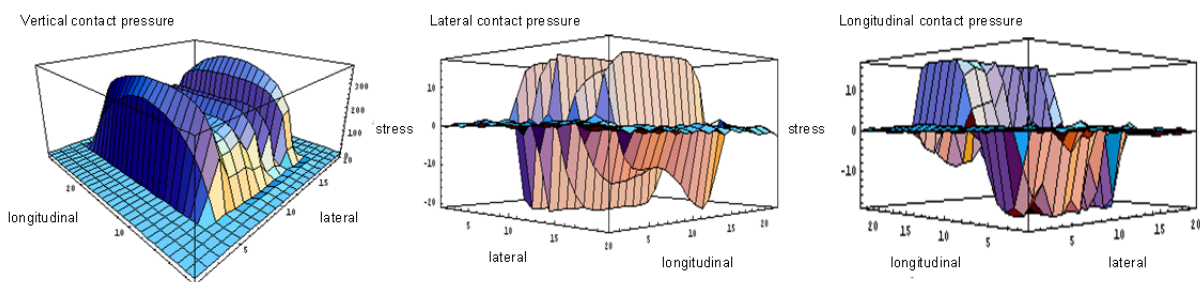


Figure 2. Vertical, lateral and longitudinal contact pressure between tyre and road for a radial tyre

Any interruption of the direct contact between road surface and tyre due to intermediate mediums leading to a decrease in transmittable force and therefore skid resistance. If the medium is liquid, the road surface texture is gradually filled up (Figure 3) reducing contact area and skid resistance depending on the relation of medium volume and texture volume. In winter maintenance precipitation in form of snow and ice are the relevant intermediate mediums.

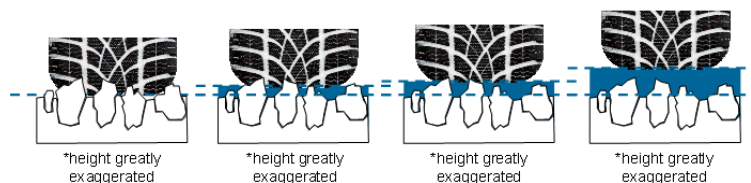


Figure 3. Reduced contact area tyre-road due to filled texture volume

Recent studies [3] using a skid resistance testing device GripTester MKII and Vaisala DSC 111 remote surface state sensors point out the thin line between sufficient skid resistance and slippery roads. If the road texture is filled with snow or ice ploughing and salting raises skid resistance only for a short period of time until persistent snowfall lowers it again. However, until road texture is entirely filled skid resistance remains at a high level giving winter maintenance personal a time buffer to initiate preventive salting. The time buffer is likely to be related with the texture volume and precipitation rate. Therefore an accurate determination of road surface macro texture and precise weather nowcasts are the key to real-time skid resistance forecasting.

The relevant parameters in winter maintenance with impact on skid resistance can be modeled according to the scheme in Figure 4 where road condition is linked to skid resistance. Apart from road texture, the selected application rate, weather conditions, traffic volume, type of de-icer and road surface temperature are part of the model. The applied salt is reduced due to drift and discharge losses. Residual salt and precipitation form a brine on the road with a decreasing concentration over time and traffic volume. The comparison of road surface temperature and brine freezing point allows a risk estimation for potentially lowered skid resistance due to snow or ice on the road. Whether skid resistance is actually lowered even if the brine on the road tends to freeze is entirely up to the remaining contact area depending the filling rate of road surface macro texture.

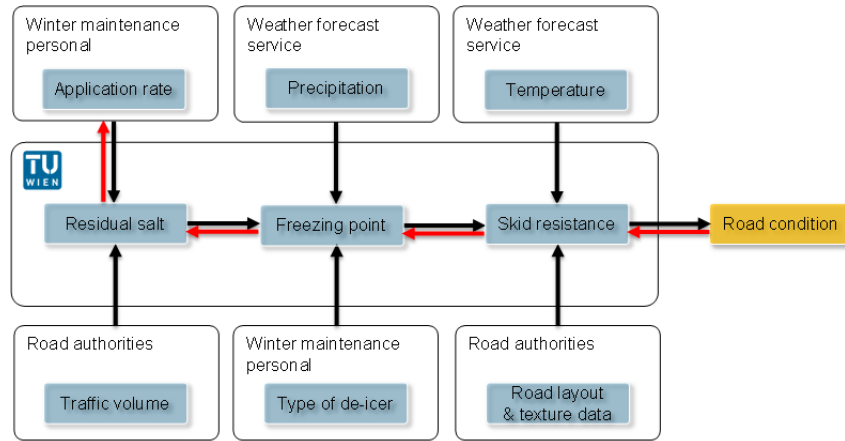


Figure 4. Comprehensive schematic overview of the developed winter maintenance model

2 MACRO TEXTURE OF ROAD SURFACES

2.1 Determination methods

Common methods of macro texture determination are either punctual or do not provide accurate results in order to be used in skid resistance forecasts. In order to avoid the drawbacks of these methods correlations between an accurate approach with sufficient correlation are established. The field research consisted of the sand patch method and texture measures with the RoadSTAR being available for the entire highway network in Austria. Further verification of the field methods based on high precise topography scans on sample cores were conducted in laboratory tests (Figure 5).

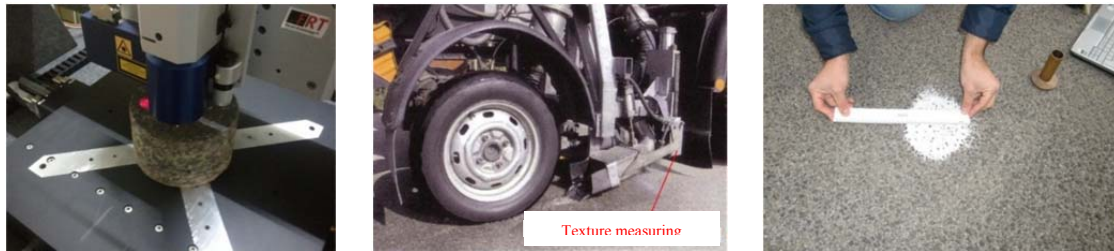


Figure 5. (a) Laser topography scan (b) RoadSTAR texture measuring device (c) Sand patch method

2.1.1 Sand patch method

A fast forward approach to determine the volume of the road surface texture is spreading out a defined amount of “sand” in a circular patch on the road and measure the diameter. The used materials are glass spheres with a diameter of 0.18 to 0.25 mm rather than sand due to their advanced homogeneity and roundness. The more volume the macro texture has, the smaller the diameter of the sand patch becomes. With this volumetric method the mean texture depth (MTD) can be calculated with Equation 1 according to EN 13036-1:2010-05. For each road surface four patches have to be measured and averaged to gain a valid MTD-Value. A MTD-Value of 1.0 mm means that the surface texture has a volume of 1,000,000 mm³ per square meter corresponding to 1 litre water or 1 mm precipitation with just a few road surface spikes left as contact area with the tyre.

$$MTD = \frac{4 \cdot V}{\pi \cdot D^2} \quad (1)$$

MTD	Mean texture depth [mm]
V	Sample volume (Volume of measuring cylinder) [mm ³]
D	Mean diameter of patch [mm]

The main advantage of the sand patch method is its simplicity. Only a handful of items are needed to measure the MTD in a couple of minutes on any specific surface. The downside of the method is the accuracy and modest validity for a whole road network based on punctual MTD-Values.

2.1.2 RoadSTAR

The RoadSTAR is a truck – based measurement system for periodic and precise monitoring of road conditions developed and operated by the Austrian Institute of Technology (AIT) that provides infrastructure operators with condition assessment data for kind of failure types. The condition assessment including skid resistance and macro texture is performed in a single run per lane with a constant speed of 60 km/h without considerable disruptions of traffic flow. The condition assessment includes cracking, skid resistance, transverse and longitudinal evenness, surface distress and mean profile depth periodically every 5 years [4]. To convert the MPD - value (based on 2-dimensional data processing) into an estimated texture depth according to EN ISO13473-1 Equation 2 can be used.

$$ETD = 0.8 * MPD + 0.2 \quad (2)$$

ETD Estimated texture depth [mm]
MPD Mean profile depth [mm]

2.1.3 High resolution topography scans

The determination of macro texture with the highest precision was performed in the laboratory using a white chromatic light topography sensor with a resolution depth of 300 nm and x, y-axis of 12 μm. Thus delivering an exact 3 dimensional model of the scanned surface where the texture volume can be calculated. The drawback of this accurate method is the need of sample cores and the gained punctual information on the road network. Figure 6 gives a graphical overview of the accuracy of the applied methods for macro texture measurements. Whereas both laser scan methods are geometrical methods calculating the texture volume with different methods, the sand patch method is a volumetric approach measuring the volume itself.

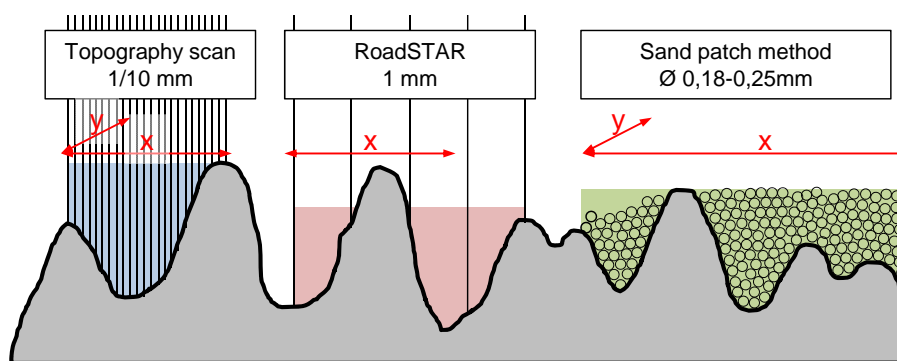


Figure 6. Methods of determining the macro texture volume of a road surface

2.2 Correlation between Laser topography scan, RoadSTAR and Sand patch method

The skid resistance forecasting process on an entire road network requires precise and network-wide road surface texture data. Based on the results of the described methods a combination of precise punctual measurements with network-wide measurement campaigns becomes feasible. The established correlations between volumetric and geometric texture volume determination methods (Figure 7) show a high goodness of fit ($R^2=0.9799$) on basis of 7 samples. However the volume calculated based on topography scans is slightly higher. The difference can be explained based on the difference of the measurement methods. In the precise 3D-Model the highest peak of the surveillance area is used to calculate the volume compared to the sand patch method with several local peaks determining the diameter of the patch (Figure 6). The linear relationship between these two methods is described in Equation 3. The sand patch method as a simple, cheap and fast forward field method is suited perfectly for the local determination of road macro texture volume.

$$V_L = 1.335 * V_{SP} + 101.3 \quad (3)$$

V_L Geometric determined volume (Laser scan) [mm^3]
 V_{SP} Volumetric determined volume (Sand patch) [mm^3]

The correlation between RoadSTAR and Sand patch shown in Figure 7b with $R^2=0.646$ has a lower goodness of fit. The confidence interval (95%) for the prediction bound however is narrow indicating a stable functional relationship. For a practical implementation of the established correlations in a winter maintenance model for the calculation of a time buffer to initiate preventive salting the stochastic distribution of measure results has to be

taken into account. Depending on the accepted remaining risk a 80% or 90 % prediction interval on the lower bound can be used to calculate texture volume with an adequate safety margin based on RoadSTAR measurements of MPD. Equation 4 proves the means to calculate the mean texture depth of the sand patch method based on a 90% single sided confidence interval of MPD – measures being available for the entire network of highways and a majority of regional roads in Austria.

$$MTD = 1.1354 * MPD - 0.4685 \quad (4)$$

MTD Mean texture depth (Sand patch) [mm]
 MPD Mean profile depth (RoadSTAR) [mm]

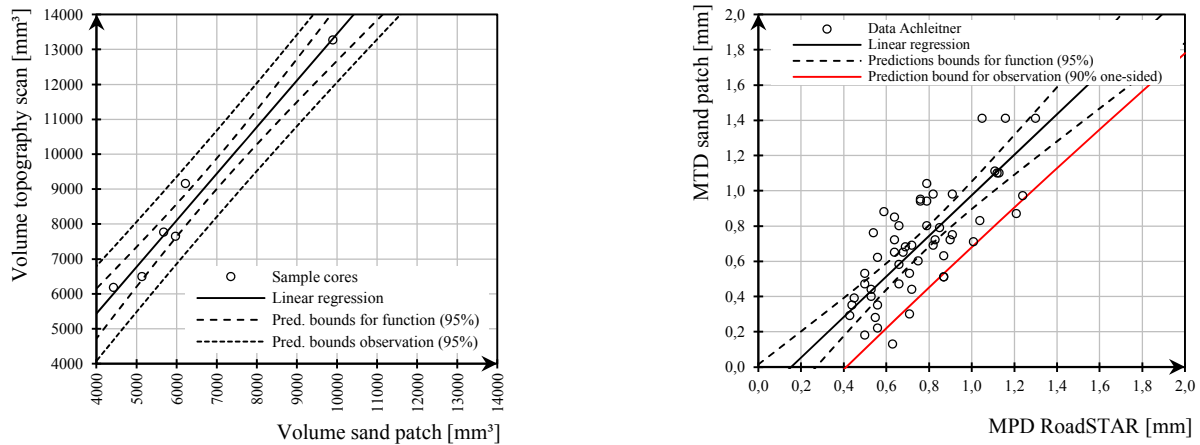


Figure 7. (a) Correlation between volumetric (sand patch) and geometric (topography scan) determined volume $n=7$ $R^2 = 0.9799$ $\sigma=449.7$
 (b) Correlation between MTD (sand patch) and MPD (RoadSTAR) $n=53$ $R^2=0.646$ $\sigma=0.2231$ [1]

3. MACRO TEXTURE AND SKID RESISTANCE

3.1 Surface texture volume and filled surface area

The difference in volume of road macro texture tends to result in a different threshold of precipitation being absorbed without complete leakage of the contact area between tyre and road (see Figure 3). The profile of a 10 year old asphalt pavement (Figure 8a) and a 2 months old concrete pavement (Figure 8b) show the need of a differentiated view in road condition forecasts. To include this road surface parameter alone the described parameters MTD or ETD are used. The macro texture volume of 7 tested road surfaces (with 2-3 cores per surface) give a range of 500 to 1.200 cm^3/m^2 depending on the type of road surface material and mix design.

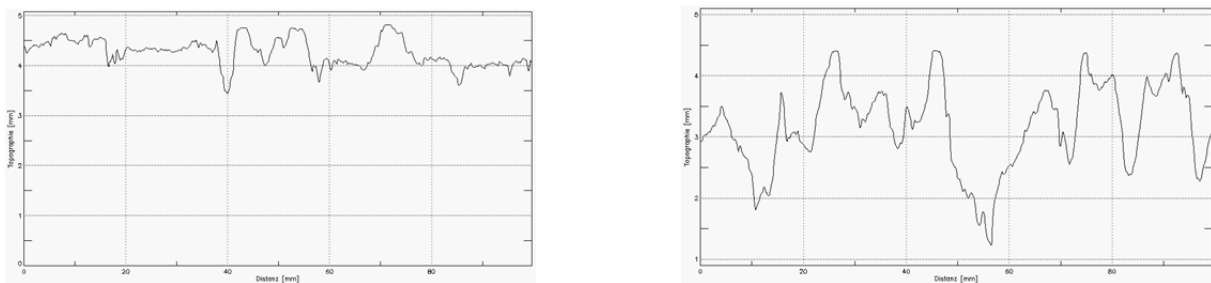


Figure 8. (a) Profile of sample core “AA” SMA (b) Profile of sample core “G1” Concrete

The relation between surface texture volume and filled surface area is even more interesting. Filled surface area in this case is defined as the liquid surface area in relation to the total area when the liquid begins to fill the lower parts of the macro texture (e.g. small holes, valleys). With virtually filling up the 3D – texture from laser topography scans in 150 steps from the lowest point of the surface to the highest peak it is possible to establish a relation between filled surface area and macro texture volume (Figure 9).

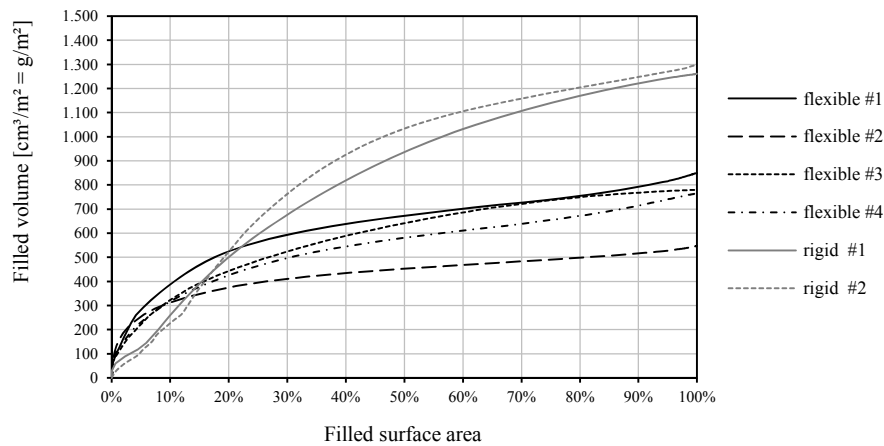


Figure 9. Relation road surface texture and filled surface area for 6 samples.

The first noticeable thing in this relation is the difference in the characteristics of the two sample cores of rigid pavements compared to the four other cores of flexible pavements. The tested rigid pavements have a considerable higher absolute texture volume due to exposed aggregates. Under the assumption of a constant precipitation rate the time buffer from the time of starting precipitation and a comparable texture filling rate with significantly lowered skid resistance is 60% higher.

The relation between filled texture volume and filled surface area is related to the material structure with several tiny potholes and large, more or less plain areas. If precipitation fills the tiny potholes in the macro texture of asphalt up to 80 % there are still 85 to 90% of uncovered road surface area left. With the remaining 20% texture volume the rate of filled surface area increases resulting in a sudden drop of skid resistance at this point. Thus even a constant precipitation rate leads to a sudden drop in skid resistance if the macro texture potholes are filled and the remaining available volume is only a fraction of total macro texture volume.

3.2 Reduced skid resistance

The impact of different brines on skid resistance has been tested using sample cores and a SRT-Pendulum in the laboratory under dry conditions as reference for measurements with partial or total filled texture volume. For each point in Table 1 the average of 5 measurements was calculated comparing sodium chloride and calcium chloride brine with water. For both brines the skid resistance drops with the first brine (25% texture volume filled) to a level of 50 to 60% compared to SRT-Values on dry surface. With further addition of brine the skid resistance does not drop much further. Water alone lowers skid resistance down to 70% in the first step with 60% being reached only for a 100% filled texture.

<i>Filled texture volume</i>	<i>0 %</i>	<i>25 %</i>	<i>50 %</i>	<i>75 %</i>	<i>100 %</i>
Water	100%	70%	62%	60%	58%
NaCl	100%	60%	55%	54%	54%
CaCl	100%	54%	52%	51%	49%

Table 1. Road conditions as a function of filled volume and filled surface area

Field studies [3] show the impact of snow or ice layers on skid resistance and the development after winter maintenance treatments. On the first measurement run the road was covered with snow resulting in a skid resistance of 0.13 with a release coating of 0.2 mm thickness beneath the snow layer. After the treatment the snow was cleared and skid resistance rose to 0.37 within 30 minutes after treatment (Figure 10). Continuous snowfall however thinned the brine until the freezing point was above surface temperature leading to a thin layer of ice and further decreasing skid resistance.

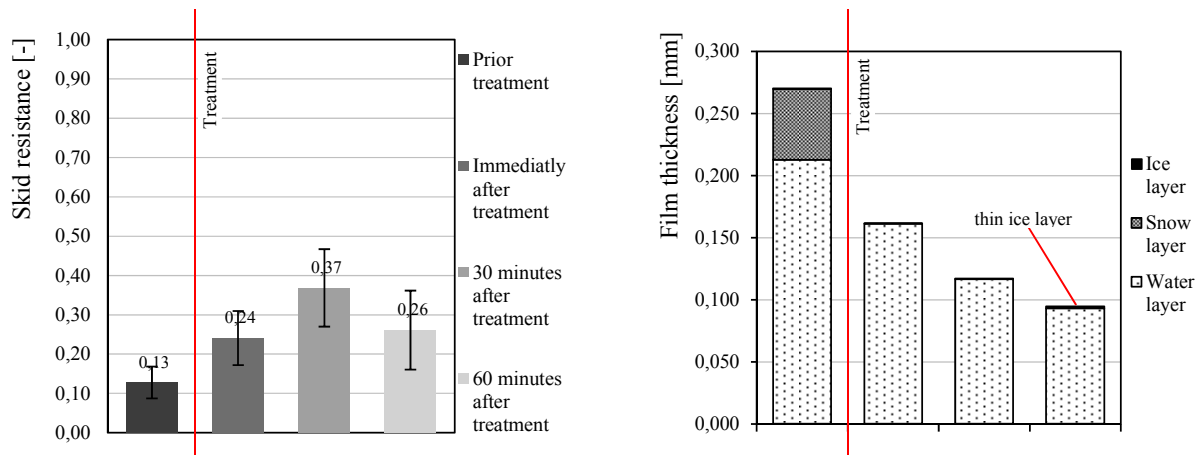


Figure 10. Skid resistance and film thickness measured in field tests.

The first modelling approach of practical skid resistance tests is based on an allocation of characteristic skid resistance values for dry road and snow or ice as relevant surface medium. Figure 11 the relation of filled volume to filled surface area on the average values of 4 asphalt pavements is shown together with the skid resistance correlating to the filled volume. The three solid lines represent roads with good (0.8), average (0.6) and poor (0.4) skid resistance under wet measurement conditions. With increasing macro texture filling rate the contact area is gradually covered with snow or ice leading to a sudden drop of skid resistance between 60 to 90% of filled macro texture volume. The combined skid resistance of a macro texture partially filled with snow or ice and the remaining contact area road surface-tyre can be calculated using Equation 5.

$$SR = SA_{snow} * SR_{snow} + (100\% - SA_{snow}) * SR_{wet} \quad (5)$$

SR	Resulting combined skid resistance [-]
SA_{snow}	Surface area covered with snow/ice [%]
SR_{snow}	Typical skid resistance of snow covered roads [-]
SR_{wet}	Skid resistance of a road under measuring conditions [-]

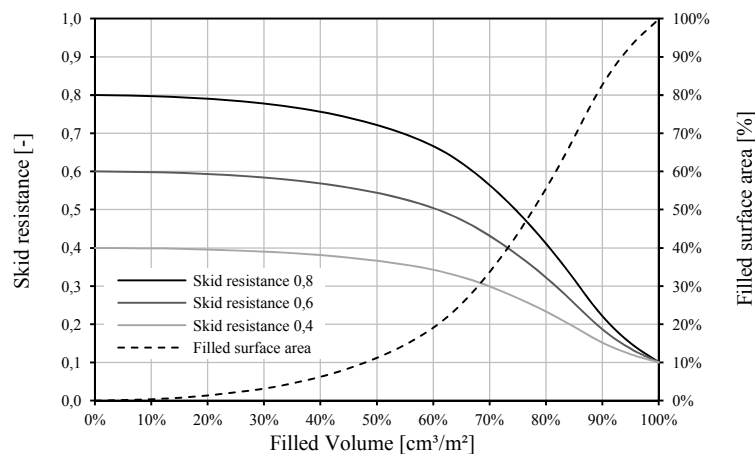


Figure 11. Road conditions as a function of filled volume and filled surface area

3.3 Road condition based on filled volume and filled surface area

Based on the presented findings road conditions can be defined including the available macro texture volume and relations to skid resistance. Using these definitions the same amount of snowfall results in different road conditions due to a different geometry and volume of road surface texture. Based on the skid resistance and MPD - measurements (RoadSTAR) on network level it is now possible to estimate the texture volume based on the established correlations. The decreasing skid resistance can be calculated in a second step based on precipitation rates and resulting filled macro texture volume.

4 CONCLUSIONS AND OUTLOOK

For any given road layout or curvature skid resistance as property of pavement surface and tyre is a decisive factor limiting the speed threshold for safe driving. Skid resistance is no fixed value and is significantly lowered in case of precipitation depending on form and rate. A further influence factor in such cases is the macro texture of pavements due to their capacity to hold precipitation while maintaining contact with the tyre. Snow and ice on roads are the main factors for lowered skid resistance resulting in elevated road accident levels and economic costs. With new methodologies in weather forecasting and RWIS – sensors better winter forecasting models for winter maintenance are already available. These current models consider different road materials mainly in order to specify parameters for solar flux absorption in energy budget calculations for real time road surface temperature estimation.

The main emphasis of the presented approach lies in a determination of the impact of macro texture and amount of snow or ice on skid resistance of flexible and rigid pavements. Based on extensive field and laboratory research a connection between different texture and skid resistance determination methods could be established. The field tests consisted of film thickness, skid resistance measures (RoadSTAR, Griptest) for different weather situations. Furthermore the sand patch method was applied in order to determine macro texture volume in the field. In the complementing laboratory tests the road surface texture was determined using high precision laser scanning on sample cores as well as SRT – pendulum test for different brines and texture filling rates. The established correlations between accurate laboratory measurements and available MPD – measures on network level allow an estimation of macro texture volume for the entire road network for different types of road surface materials. In a next step the relation between macro texture volume and filled surface area can be used as an indicator of reduced skid resistance in the contact area of road surface and tyre.

Laboratory experiments using the SRT-Pendulum on sample cores show that brines (sodium chloride and calcium chloride) lower the skid resistance more than water especially when the texture volume is only filled sparsely. Compared to a dry surface the skid resistance decreases to 50 % to 60 % for the brines with slightly better results for sodium chloride and 75 % to 60 % for water. Field tests using the GripTester MKII and Vaisala DSC 111 during snowfalls showed the low level of skid resistance with snow or ice on the road and the increase after treatment. Further snowfall however lowers skid resistance again until the next treatment is conducted. The presented model of skid resistance forecasting is based on skid resistance under wet measurement conditions gradually declining with increasing macro texture filling rate to the typical skid resistance of snow and ice. Based on the established correlation between macro texture volume and covered contact area with snow or ice the observed sudden drop of skid resistance could be established between 60% to 90% of filled macro texture volume. Based on extensive research in field and laboratory measurements during the next year the findings and presented approaches will be verified for an application on network level.

5 REFERENCES

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