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Analysis of the pavement surface texture by 3D scanner

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Abstract

Interaction between vehicle and the pavement surface has the primary effect to the road safety. This phenomenon including adhesive and hysteresis forces influences the contact stresses which are responsible for appropriate interaction between tyre and pavement. Skid resistance of the pavement surface is evaluated by measurements of texture characteristics (depth of texture, morphology) and physical (sliding friction). World Road Association indicates that the friction coefficient decreased on the road below 0.45 will increase the risk of accident 20 times; when it goes below 0.30 the risk is 300 times higher.

The macro-texture measuring is realised at present by non-contact profilometers evaluated texture of surface as a mean profile depth – MPD; and by volumetric method evaluated texture by mean texture depth – MTD. The micro-texture measuring can be realised by direct methods by using of microscope or another equipment with high resolution. However, these methods are used very rarely, indirect methods by pendulum tester is used more frequently. University of Žilina (UNIZA) uses for skid resistance measuring the own equipment TWO that measures the coefficient of longitudinal friction with 17.8% slide.

Slovak Road Administration operated 23 long-time observed road sections for analysis of the pavement serviceability parameters. Friction coefficient is measured by Skiddometer BV11, texture with using one separately laser installed on measurement beam of Profilograph GE. Measuring of texture is along with analysis of surface unevenness. Evaluation of measured data suggests problems with reliability and repeatability of measurements, measuring of texture depth above all.

Concerning these problems new possibilities of texture analysis are tested in UNIZA. Friction coefficient is measured by Traction Watcher One equipment. 3D scanners are tested for texture evaluation, mainly the ZScanner@800. ZScanner is high resolution equipment and measuring of surface texture enables evaluation of the amplitude and wave length of the surface irregularities. All the measured data are processed by algorithm created in MATLAB and compared with results obtained by standardized measuring methods. 3D scanner has a very important characteristic compared with 2D scanners that provides the

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analysis and following evaluation of more parameters (not MPD only). On the other hand the time-consuming of measuring process is a big disadvantage. Request for big data processing is a second problem of 3D scanners, but actual level of hardware and software possibilities can eliminates it.

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1. Introduction

The surface texture has main influence on pavement-tire interaction that represents the primary effect to the road safety. The influence can have many aspects, which depend on wavelength and amplitude of the surface irregularities. In term of skid resistance the main roll play irregularities in scale of micro and macro texture. The pavement texture is usually described by parameters reflecting the mean depth of the surface macrotexture, such as Mean Texture Depth (MTD), or Mean Profile Depth (MPD). However, these worldwide used standardized methods do not consider all surface profile properties, such as the shape of the wearing coarse asperities.

Slovak Road Administration (SRA) operated 23 long-time observed road sections of the 1st and 2nd class roads in Slovakia for analysis of the pavement serviceability parameters, skid resistance including. Friction coefficient is measured by Skiddometer BV11, texture with using one separately laser installed on measurement beam of Profilograph GE. Evaluation of measured data suggests many problems with reliability and repeatability of measurements, measuring of texture depth by one laser of Profilograph above all.

Concerning these problems new possibilities of texture analysis are tested in UNIZA. Friction coefficient is measured by TWO Traction Watcher One equipment, for comparison of interaction between vehicle and surface two types of tyres are used – smooth and pattern. A few 3D scanners are tested for texture evaluation that enables to describe the pavement texture not only by amplitude average parameters (other than MPD), but also by spacing or hybrid parameters.

2. Long-term monitoring sections in Slovakia

The monitored sections are localized in the different territory of Slovakia, with diverse traffic and climatic conditions. All the observed sections have the flexible pavements with different asphalt wearing course. The Road Databank department of SRA realizes yearly diagnostics of the pavement serviceability parameters of sections in regular interval in spring and autumn since 1998. The analysis of the development of parameters is an aim of monitoring which include the measuring of skid resistance, longitudinal and transverse unevenness (Decký, M., Valuch, M., 2000), (Decký, 2003), and bearing capacity (Komačka, 2011). Equipment Kuab FWD 50, and Profilograph GE are used. The skid resistance of the surface is described by longitudinal friction coefficient (μ) measured by Skiddometer BV 11. The parameter MPD describes the texture as a geometric characteristics of the surface.

The article deals with an analysis of the skid resistance parameters. Four monitoring sections were chosen for the analysis. At least two measurements at speed close to 80 km/h were chosen for both spring and autumn periods with aim of mistake elimination. The section near of Žilina was selected for presentation. Fig. 1 shows values of friction coefficient during monitored time interval. The figure is completed by temperature and measured speed of Skiddometer BV11. The red column represents the incorrect measurement. Marked border area specifies the average value of $\mu \pm 10\%$ after elimination of incorrect measurements.

The analysis of 10 years measurement confirms that using of long-term monitoring of surface friction is very limited for deterioration models determination above all (Čelko, J., Slabej, M., 2013). Decreasing of friction coefficient values due to traffic loading was not confirmed and variability of the values after data filtration was very high. These facts show the repeatability of μ measuring is extremely depending on unified boundary conditions.

2.1. Effect of the air temperature

Besides the development of friction coefficient an effect of temperature was observed. The relation between Mu value and temperature was not confirmed. Approximately the same values of the friction at time were achieved at different temperatures. Closely before the measurement the surface of the pavement is moistened by 1 mm of water with approximately constant temperature during measuring. So the surface is measured at the very similar temperature. The influence of temperature on Mu value was verified during experimental measurement described in the next part of article. Fig. 2 shows relation between air temperature, surface temperature, and Mu value.

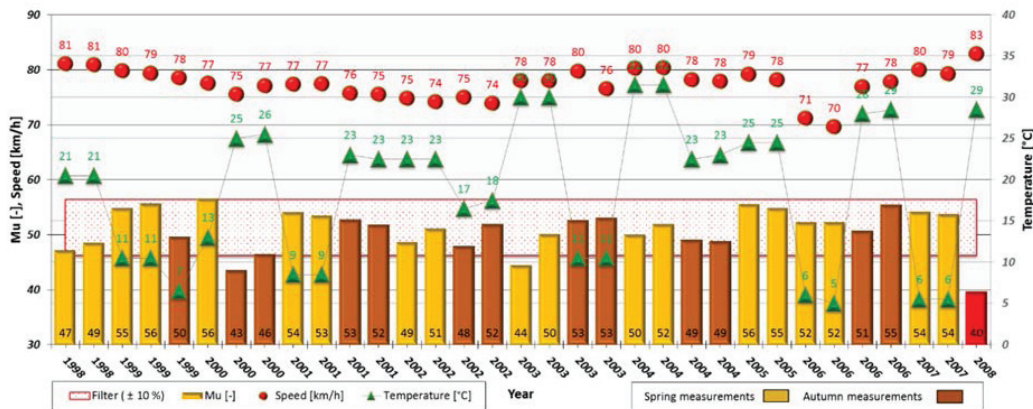


Fig. 1. Friction coefficient of sections (Kotek, 2015).

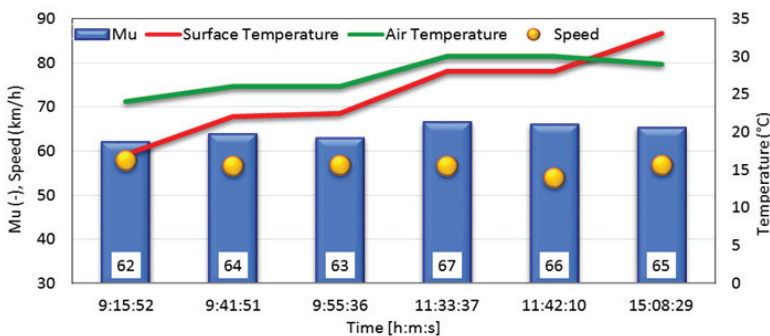


Fig. 2 Relation between temperature and friction coefficient Mu, (Kotek, 2015).

3. Skid resistance measurements

For the investigation of the ability of 3D scanners to evaluate the skid resistance of the pavement surfaces were performed measurements on 10 selected road sections (A – J). For the purpose of wide comparison were performed measurements with all methods used in Slovakia within the Pavement Management System. The macrotexture was measured by volumetric method (MTD – Fig. 3a) (STN EN 13036-1, 2010) and by use of Profilograph GE (MPD – Fig. 3b) (STN EN ISO 13473-1, 2005) owned and operated by Slovak Road Administration. The coefficient of friction was measured by British Pendulum Tester (PTV - Fig. 3c) (STN EN 13036-4, 2012) and Skiddometer BV11 (MU - Fig. 3d). Skiddometer BV11 is also owned and operated by Slovak Road Administration. The device measures a coefficient of longitudinal friction with 17% slip ratio and uses a tire with tread pattern.

3D scanners were represented by ZScanner® 800 (Fig. 4) and by new movable measuring platform UNIZA.

3.1. 3D scanners

ZScanner® 800 is a laser handheld self-orienting 3D scanner with high resolution developed by the company Creaform Inc. The scanning process is performed by use of three cameras, which are shooting the laser cross (Fig. 4, on the right). The scanning process begins with pre-scanning of the reflective positioning targets. The system is creating the coordinate system according the position of scanned target points. The principle of the surface scanning is based on the triangulation process. If the „trinoocular” cameras are capturing at least 4 reflective points, the system is able to determine the position of the points of the scanned surface. Every point has the unique X, Y, Z coordinates. The polygon mesh of the scanned surface is automatically recalculated according to captured position of all points and according to selected resolution. It is displayed as a real-time on-screen image of the surface being scanned. The process with real-time surfacing shows the scanning progress as you go, revealing hidden spots and ensuring a complete scan the first time. The scanner is provided with the „VXelements- 3D Digitizing Software“. Technical specifications of the 3D scanner is showed in the Table 1. The software allows to export data of measured surface in several data format (.dae, .fbx, .ma, .obj, .ply, .stl, .txt, .wrl, .x3d, .x3dz, .zpt), which are used as an input data in the next processing and evaluation (Kováč, M., Kotek, P., Decký, M., 2015). The scanning process was performed with resolution 0.2 mm, and the scanned surface area was limited by the template wit dimensions of 200x60 mm, which means that there were scanned 300 profiles with length 200 mm providing 600 baselines for texture parameters calculation.

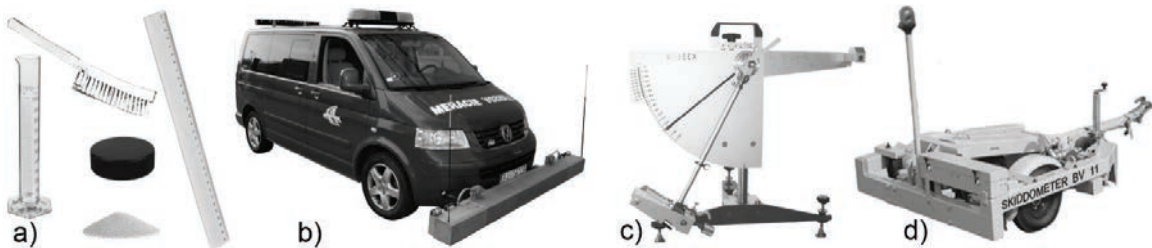


Fig. 3. Equipment for standard methods measurements: a) Volumetric method, b) Profilograph GE, c) British Pendulum Tester, d) Skiddometer BV11 (Kováč, Decký, Remišová, & Kotek, 2014).

Table 1. Technical specifications of 3D ZScanner® 800.

Weight/ Dimensions:	1.25 kg/171 x 260 x 216 mm	Resolution X,Y,Z:	up to 50 microns
Measurements:	25 000 Measurements /s	Accuracy XY:	up to 40 microns
Laser class:	II (eye safe)	Data transfer:	FireWire
Number of cameras:	3	Field Depth:	30 cm



Fig. 4. 3D scanner ZScanner® 800.

The movable measuring platform UNIZA was developed at University of Žilina for creating of 3D models of buildings and roads (Hruboš, M., Janota, A., 2014). The equipment contains control part with data storage and measurement part with six cameras, exact position navigator, and two 2D scanners (Fig. 5). One scanner and one camera are used for scanning of pavement surface. Surface monitoring is realised at a walking speed. During testing process the different surfaces were measured. Evaluation shows serious faultiness of surface texture detection. Fig. 6 presents measuring of pavement surface with special smooth bands. Graphical evaluation shows presentation of the surface with notable signal noise effect.

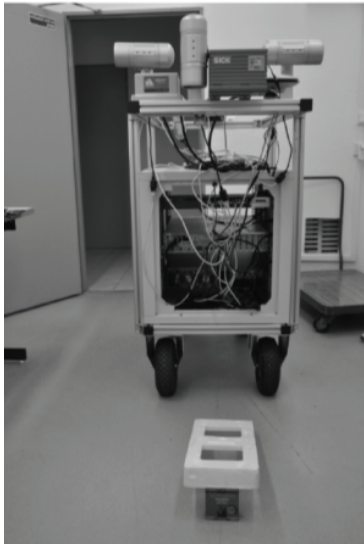


Fig. 5. Movable measuring platform UNIZA.

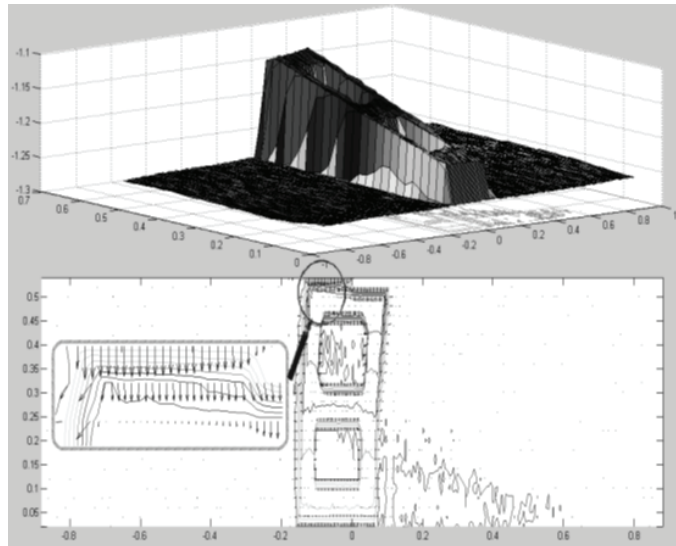


Fig. 6. Surface profile, (Hruboš, M., Janota, A., 2014).

In this case the signal noise is too high and current software is not able to filter it. The platform is not usable at the present for exact measurement of surface texture.

3.2. Traction Watcher One

A device for comparison and for measurements of longitudinal coefficient of friction was used the TWO - Traction Watcher One (Fig. 7) owned by University of Žilina. TWO is a measuring equipment developed by a Norwegian company Pon-CAT which is commonly used in northern countries for measurements on roads and airports with possible use on icy surfaces. The measuring wheel is braked during measurement with a constant slip ratio 17.8%. The result reached by measurement by the equipment is directly a coefficient of the friction (μ) which can be get by speeds from 2 to 100 km/h with load of measuring wheel 60 kg. Measurements with TWO were performed on all road sections at speed 60 km/h with both, smooth tire and tire with tread pattern, as well.

The measurements were performed on 10 selected road sections with different asphalt wearing course. All wearing courses differ from each other by used asphalt mixture composition (aggregate type, aggregate particle size distribution, maximum aggregate size and on type of bitumen binder and its content in the mixture). The road sections differ in the traffic volume, road category and the age of the pavement construction. On all selected roads were measured 100m long sections. By non-continuous methods were performed measurements on 10 points in the same wheel path as were performed measurements by Profilograph GE, Skiddometer BV11, or TWO respectively. The example of 5 surfaces are showed in the Fig. 8.

4. Texture measurements evaluation

On all measured sections were evaluated 18 parameters describing surface texture, or friction respectively. The processing of all collected data measured by 3D scanner was performed in the MATLAB® software by algorithm created at UNIZA. As an example of one of available outputs of the created algorithm are showed in the Fig. 9 – 3D surface, profile and power spectral density diagram of the scanned wearing course.

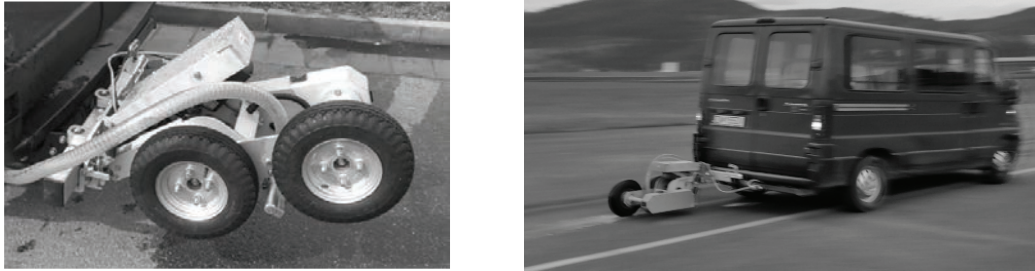


Fig. 7. TWO – Traction Watcher One.

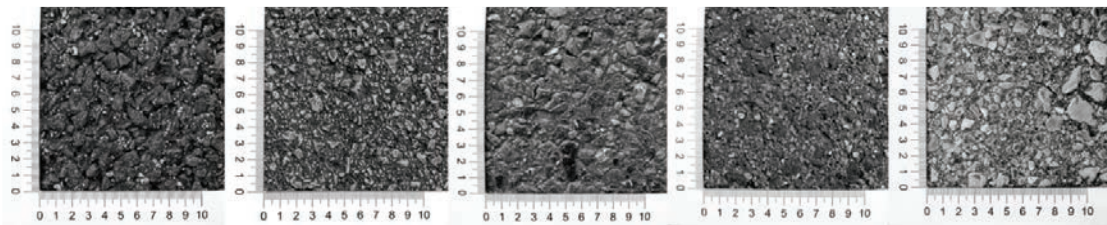


Fig. 8. Surfaces of five selected road section wearing courses (Kotek, 2015).

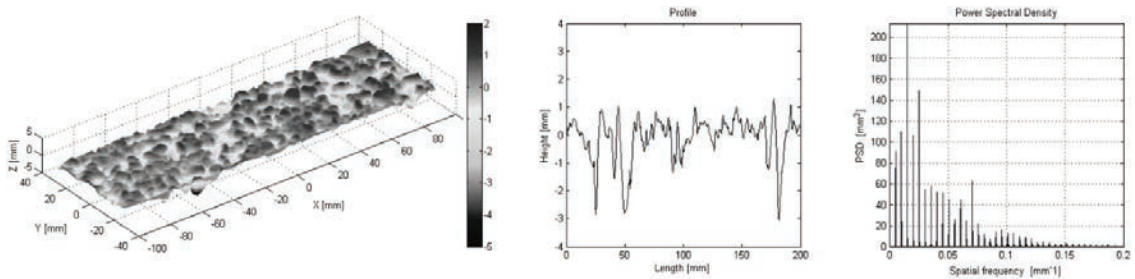


Fig. 9. 3D surface, profile and power spectral density diagram.

Using created algorithm it was possible to evaluate, besides MPD parameter, also the height (amplitude) parameters, such as Maximum profile peak height – R_p , Maximum profile valley depth – R_v , Total height of profile – R_t , Arithmetical mean deviation – R_a , Root mean square deviation – R_q etc., the height distribution shape parameters, such as Skewness – R_{sk} , Kurtosis – R_{ku} , wavelength parameters, such as power spectral density – PSD, hybrid parameters, such as Texture ratio – TR, or Root mean square slope – $R_{\Delta q}$, or spacing parameters, such as Mean width of the profile elements – R_{Sm} . All these texture characteristics (Table 2), commonly used by mechanical engineers for roughness and wear evaluation, were subsequently compared with parameters evaluated by standard methods for texture and skid resistance evaluation, see Table 3.

Table 2. Texture parameters obtained by 3D scanning.

Road Section	MPD _{ZS}	Rv (mm)	Rp (mm)	Rt (mm)	Ra (mm)	Rq (mm)	RMS (mm)	σ^2 (mm ²)	Rku (-)	Rsk (-)	TR (-)	RΔq (-)	RSm (mm)
A	1.13	-4.96	1.59	6.55	0.62	0.84	0.84	0.74	3.37	-1.40	1.37	0.54	11.07
B	0.72	-3.02	1.20	4.22	0.32	0.43	0.43	0.19	2.84	-0.98	1.69	0.45	6.44
C	1.09	-6.35	1.70	8.08	0.69	1.02	1.02	1.08	6.71	-2.21	1.09	0.52	13.31
D	0.66	-2.80	1.15	3.95	0.27	0.38	0.38	0.15	5.16	-1.17	1.76	0.27	8.38
E	0.56	-3.28	0.93	4.21	0.28	0.39	0.39	0.16	6.88	-1.86	1.43	0.35	7.53
F	0.42	-1.68	1.00	3.35	0.18	0.26	0.26	0.07	8.21	-1.59	1.61	0.25	6.53
G	0.81	-2.18	1.16	3.87	0.43	0.55	0.55	0.30	1.17	-1.00	1.48	0.47	8.54
H	0.75	-1.87	1.32	3.57	0.28	0.37	0.37	0.14	1.90	-0.18	1.91	0.28	8.67
I	1.10	-3.58	1.81	5.40	0.55	0.71	0.71	0.50	1.40	-1.00	1.55	0.59	8.57
J	0.80	-6.16	1.22	7.38	0.49	0.79	0.79	0.67	14.59	-3.13	1.03	0.50	11.41

Table 3. Parameters obtained by standard methods.

Road Section	MPD _{PROF} (mm)	MTD (mm)	PTV (-)	Mu (-)	μ_{pattern} (-)	μ_{smooth} (-)
A	1.11	1.31	64	0.81	0.42	0.38
B	0.79	0.88	37	0.51	0.20	0.14
C	1.05	1.25	55	0.77	0.36	0.32
D	0.66	0.68	50	0.58	0.28	0.19
E	0.60	0.72	42	0.61	0.28	0.22
F	0.43	0.43	38	0.34	0.22	0.15
G	0.85	1.01	57	0.67	0.33	0.27
H	0.90	1.02	65	0.80	0.42	0.37
I	0.96	1.27	57	0.79	0.41	0.39
J	0.88	0.99	51	0.68	0.36	0.29

As it can be seen from Table 2, Table 3, there is a wide range of macrotexture observed on selected road sections. For example the road section marked as an “F” has the value obtained by volumetric patch method MTD=0.43mm, while the road section marked as an “A” has the value MTD=1.31mm. Likewise, the microtexture level described by PTV value is in wide range from 37 on road section “B” to 65 on road section “H”. These wide range of micro and macro texture level of wearing course surfaces on selected road sections makes good prerequisite for comparison of results reached by different methods and for investigation of the influence of parts of texture on skid resistance. Interesting fact is that all measured surfaces show a negative texture (based on Rsk value, Table 2). The closest to positive texture is the road section “H” (Rsk = -0.18) where the Texture Ratio has value of TR = 1.91. This leads to an idea to move threshold for distinguishing between positive or negative pavement texture to TR = 2.00, instead of 0.95 for negative, or 1.05 for positive texture according to (McGhee & Flintsch, 2003).

5. Results analysis and comparison

Based on reached results, besides road sections (wearing courses) comparison, we can also compare devices measuring coefficient of friction, devices measuring texture, the ability of different texture parameters to evaluate sliding friction, and we are able to investigate the influence of parts of surface texture on sliding friction, as well.

The comparison of friction coefficient measured by the device Skiddometer BV11 with values measured by the device TWO was performed twice, for smooth tire and tire with tread pattern. For the comparison was chosen a linear dependency, while for comparison of measurements with tread pattern tires was omitted the y-intercept. The omitting of the y-intercept came from the logical assumption that the measured values on a perfect smooth surface would be zeros for both measured methods. Reached correlations are showed in the Fig. 10.

As it can be seen in the Fig. 10, there is a very strong correlation between the national reference device Skiddometer BV11 and the new device TWO owned by UNIZA. The statement is confirmed by high value of coefficient of determination $R^2 = 0.845$ for tire with tread pattern and $R^2 = 0.867$ for smooth tire. Although, it should be noted that the obvious trend is disturbed by one value, where probably an incorrect measurement by one of the devices was performed. However, the device Skiddometer BV11 was for a long period out of service, there was no opportunity to repeat the measurements at the critical road section. The lower value of coefficient of determination for comparison with tread pattern tire is caused by omitting the y-intercept, however both devices did the measurement with tread pattern tire. Values measured by smooth tire were overall lower than values measured with tread pattern tire in range from 6 to 27% depending on the surface texture. The average decrease was 17%.

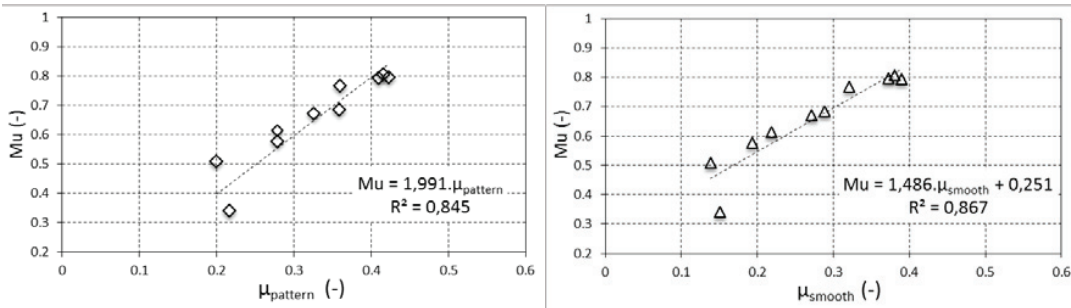


Fig. 10. Dependencies between Skiddometer BV11 and TWO device with pattern and smooth tire.

The other comparison was concerned by texture measurements. Slovak Road Administration uses the device Profilograph GE, which provides the MPD value. University of Žilina uses the 3D ZScanner®, which besides the MPD value provides also other texture parameters listed above. As a reference value of macrotexture level was considered the MTD value obtained by the patch technique (STN EN 13036-1, 2010). Determined dependencies are showed in the Fig. 11.

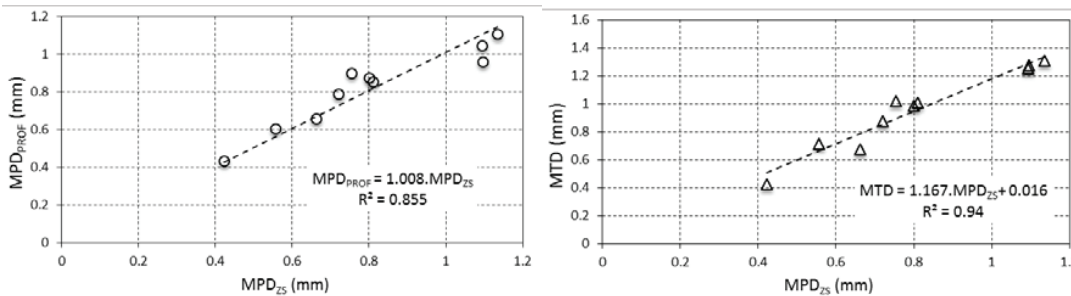


Fig. 11. Correlations between MPD values measured by ZScanner® 800 and Profilograph GE and comparison with MTD value.

As it can be seen in the Fig. 11, there is a very strong correlation between MPD values measured by Profilograph GE and by ZScanner® 800. Even stronger correlation is between MPD values measured by ZScanner®800 (MPD_{ZS}) and MTD values by volumetric patch method. The lower value of coefficient of determination for comparison MPD_{ZS} and MPD_{PROF} is caused by reason that Profilograph GE is a high speed working device, while the ZScanner®800 is a static method. And again, it is also caused by omitting the y-intercept. However, there is still a logical assumption that on a perfect smooth surface should be the MPD value (unlike MTD value) equal zero.

As mentioned above, measurements performed by ZScanner®800 allow to calculate many other texture parameters. All these parameters were compared with results reached by standard skid resistance methods. The result of comparison in form of correlation and determination coefficients is listed in the Table 4.

Table 4. The comparison of texture parameters with values measured by standard skid resistance methods

Parameters		MPD _{ZS} (mm)	Rv (mm)	Rp (mm)	Rt (mm)	Ra (mm)	Rq (mm)	RMS (mm)	σ ² (mm ²)	Rku (-)	Rsk (-)	TR (-)	RΔq (-)	RSm (mm)
MTD (mm)	r	0.969	-0.580	0.878	0.664	0.893	0.826	0.826	0.761	-0.314	0.022	-0.377	0.835	0.686
	R ²	0.940	0.337	0.771	0.441	0.798	0.683	0.683	0.580	0.099	0.000	0.143	0.697	0.471
MPD _{PROF} (mm)	r	0.925	-0.610	0.836	0.687	0.878	0.829	0.829	0.773	-0.265	0.006	-0.374	0.780	0.737
	R ²	0.855	0.373	0.699	0.471	0.771	0.687	0.687	0.598	0.070	0.000	0.140	0.608	0.543
PTV (-)	r	0.707	-0.223	0.634	0.325	0.563	0.501	0.500	0.452	-0.354	0.257	-0.056	0.363	0.589
	R ²	0.5	0.050	0.402	0.106	0.317	0.251	0.250	0.205	0.125	0.066	0.003	0.132	0.347
Mu (-)	r	0.832	-0.473	0.734	0.535	0.723	0.673	0.672	0.609	-0.278	0.083	-0.251	0.593	0.670
	R ²	0.691	0.224	0.539	0.286	0.523	0.452	0.452	0.371	0.078	0.007	0.063	0.352	0.449
μ _{pattern} (-)	r	0.744	-0.379	0.706	0.470	0.632	0.592	0.592	0.542	-0.182	0.077	-0.206	0.474	0.639
	R ²	0.553	0.143	0.498	0.221	0.399	0.350	0.350	0.294	0.033	0.006	0.042	0.225	0.409
μ _{smooth} (-)	r	0.794	-0.375	0.771	0.478	0.679	0.621	0.621	0.570	-0.253	0.108	-0.212	0.547	0.615
	R ²	0.630	0.141	0.595	0.229	0.461	0.386	0.386	0.325	0.064	0.012	0.045	0.300	0.379

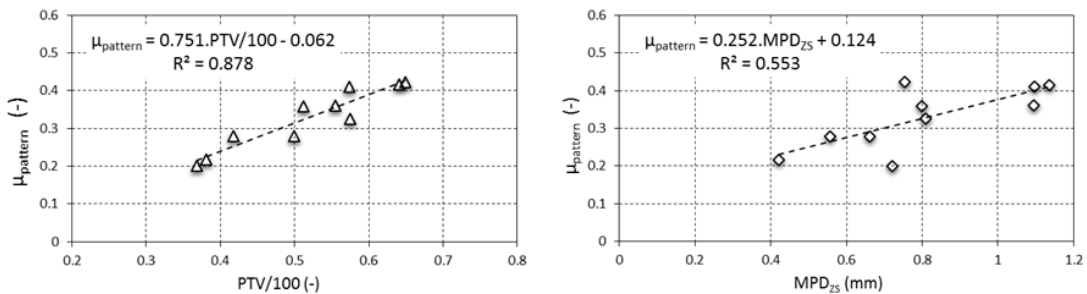


Fig. 12. Comparison of coefficient of friction measured by TWO (pattern tire) with PTV and MPD value measured by ZScanner@800.

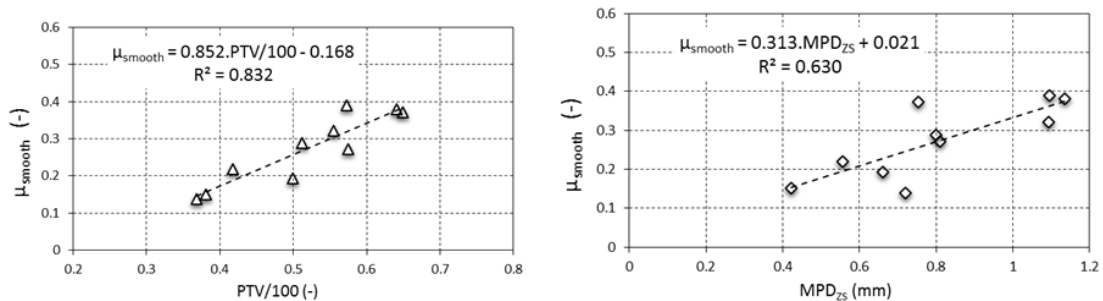


Fig. 13. Comparison of coefficient of friction measured by TWO (smooth tire) with PTV and MPD value measured by ZScanner@800.

As it can be seen in the Table 4, texture characteristics commonly used in mechanical engineering for roughness and wear evaluation have no use for evaluation of skid resistance in term of pavement surface quality assessment. Coefficients of correlation are quite high as far as macrotexture evaluation concerned. However in general, correlations are not very strong, especially at comparison with coefficients of friction. The main reason is that the resolution of ZScanner@800 is not high enough for detection of microtexture level, which seems to have a main influence on sliding friction. This statement was confirmed by further investigation. According to relationships in the Fig. 12 and Fig. 13, it is obvious that the coefficient of friction measured by TWO device is more influenced by PTV values, which are considered as an approximation of a microtexture level. The response of friction coefficient values is much more sensitive to variation of PTV values than to variation of MPD values. This is confirmed by coefficient of determination $R^2 = 0.878$ for μ_{pattern} and PTV in comparison with $R^2 = 0.553$ for μ_{pattern} and MPD_{ZS}. For the same comparison with measurements with smooth tire it can be seen a bigger influence of

macrotexture on coefficient of friction ($R^2 = 0.630$, Fig. 13, on the right) than it was for tread pattern tire. This speaks about the fact that the tread pattern tire is less sensitive to macrotexture. However, the influence of microtexture on coefficient of friction (measured at speed 60 km/h with slip ratio 17.8%) is still for both type of tires bigger, which shows the requirement on quality of aggregates in asphalt mixture used for wearing course.

6. Conclusions

The article was concerned about new devices used by University of Žilina for skid resistance evaluation. The TWO device is used for measuring of longitudinal coefficient of friction and was compared on 10 selected road sections with national reference device Skiddometer BV11 owned and operated by Slovak Road Administration. The correlation between these two devices showed up as very strong, based on which it was possible to determine a conversion equations for both, smooth and tread pattern tire. For the texture measurements was used 3D scanner ZScanner@800. Based on created algorithm were besides MPD parameter evaluated also other texture characteristics. However, usability of these parameters for skid resistance evaluation turned out at least as disputable. Although, the correlation between MPD parameters measured by Profilograph GE (reference device) and ZScanner@800 was very strong. Also the comparison MPD_{ZS} with MTD values showed very strong correlation ($r = 0.969$, $R^2 = 0.94$). The influence of single parts of texture was investigated by comparison of coefficients of friction and values representing micro and macrotexture level. The conclusion is that if we consider PTV values as an indicator of pavement micro texture level, the sliding friction represented by coefficient of friction is more influenced by microtexture than by macrotexture of the wearing course.

Other tested equipment are unable for exact measuring of surface texture at present and a follow-up investigation is necessary.

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