Comparison of pavement surface roughness characteristics of different wearing courses evaluated using 3D scanning and pendulum

Matej Brna[1,*] and *Michal* Cingel[1]

[1]University of Žilina, Faculty of Civil Engineering, Department of Highway Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovak Republic

Abstract. Road pavement roughness, in terms of skid resistance, can be described from a geometrical point of view as a texture or from a physical point of view as friction between a tire and a road surface. The paper deals with the comparison of asphalt and concrete pavement surface on selected newly built sections of the D1 motorway near the Ovčiarsko tunnel. Texture measurements were performed with a Static Road Scanner (SRS) capable of recording surface irregularities up to the microtexture level (2.49 μm resolution). A pendulum was used to determine the friction. Subsequently, the texture was evaluated using individual amplitude and wavelength characteristics and the friction was evaluated using the PTV parameter. Finally, correlations were searched between the roughness characteristics of asphalt concrete and cement concrete pavements, but also between texture and friction characteristics.

1 Introduction

In particular, the article deals with roughness, which is a variable parameter that is described either physically as skid friction between the road surface and the vehicle tire, or in geometric terms as the road surface morphology.

Complex expression of road surface morphology is very demanding not only because of the range of amplitudes and wavelengths of surface irregularities, but also because of the extent of the impact on the vehicle-road system interaction. The boundary between the texture and the inequality consists of a wave length approximately corresponding to the length of the vehicle's tire footprint, with road surface profiles with wavelengths greater than 0.5 m defined as road roughness and wavelengths less than 0.5 m defined as road texture. Depending on the wavelength ranges, we further distinguish surface irregularities on microtexture (0.001 - 0.5 mm), macrotexture (0.5 - 50 mm) and megatexture (50 - 500 mm) - (Fig. 1). In terms of operational capability, only the first two components of the texture, i.e. wavelengths from 0.001 mm to 50 mm, affect the anti-slip properties. Larger wavelengths mainly affect driving comfort [1].

[*]Corresponding author: matej.brna@uniza.sk

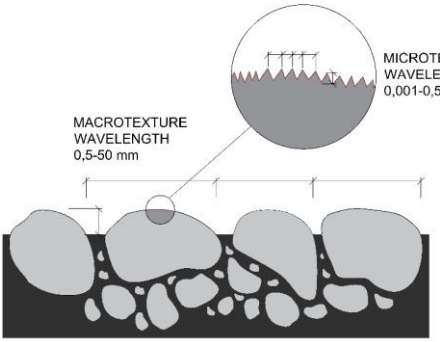

Fig. 1. Road surface texture.

Determining the magnitude of the impact of roughness is important for the safety of moving vehicles on the road. As mentioned, skid friction characterizes the roughness from a physical point of view. We can measure this friction in several ways, for our measurement we used a pendulum device (Fig. 9), which uses a rubber friction slider to determine the amount of road surface resistance. After sliding the pendulum arm at a given slip length, the PTV value can be read from the device, which characterizes the skid friction of the surface.

The actual road morphology or roughness from a geometrical point of view can be recorded using the new SRS - Static Road Scaner (Fig. 3). Unlike other devices used to measure the road surface profile (eg Profilograph), this device can record 3D surfaces up to the microtexture level. The SRS operates at a resolution of up to 15μm ($15\cdot10^{-6}$ m) with laser scanner and up to 2.49 μm ($2.49\cdot10^{-6}$ m) with optical sensor. The measured surface is then evaluated and its basic characteristics are determined on the basis of which the given surface is evaluated.

These experimental measurements were carried out on the newly built section of the D1 motorway, at two stations in front of the Ovčiarsko tunnel portal and at two stations inside the Ovčiarsko tunnel building (Fig. 2). Before the tunnel, measurements were carried out on two types of surfaces, namely the asphalt-concrete surface and the cement-concrete surface of the road. Inside the tunnel, measurements were only made on the cement concrete pavement. All measurements were made both on the vehicle's wheel path and lane center zone. These measurements were made to compare the roughness characteristics on different road covers. In the future, measurements can be repeated to determine the magnitude of the impact of degradation on different types of road coverings. It will also be possible to determine the degradation difference only from traffic (inside the tunnel), but from the climatic effects and traffic (before the tunnel).

Site No 1
(Bitumen pavement)

Site No 2
(Concrete pavement)

Site No 3 - 4
(Inside the tunnel Ovčiarsko)

Fig. 2. Experimental measurement sites in the tunnel Ovčiarsko.

2 Morphology of selected pavement

As mentioned in the introduction, the surface morphology includes all irregularities characterized by a wavelength up to 50 mm. Microctexture is described by small irregularities on grains of aggregates and tells about how the grains are smooth or rough and it contributes to the friction between tire and pavement surface. Macrotecture issues basic drainage of pavement surface. It is expressed by summary of irregularities on the pavement surface and describes how single aggregate grains are organized on the pavement surface. Megatexture affects ride comfort and punishment of some vehicle parts and is important by the view of interaction between wheel and pavement. It mainly goes about reduction of wheel pressure. Unevennesses affect vehicle dynamic i.e. amplitude of suspended vehicle parts (body) what has great effect on safety and ride comfort [2].

Irregularities in the road surface in conjunction with changes in climatic characteristics [3-5] also affect airborne particulate matter (PM), according to research in articles [6,7]. The optimum texture value reduces the number of solids in the air. These solids are produced by abrasion of the road surface when interacting with the tire. Therefore, it is extremely important to check the texture of the road surface during its life.

Surface irregularities can be recorded in various ways. Currently, mainly profilometers are used, which indicate the average depth of the macrotexture profile (MPD). For example, the Profilograph GE from a Danish manufacturer is used in Slovakia to measure surface macrotexture. This device is primarily designed to measure road unevenness, but is also capable of recording macrotexture. One result from the device is the MPD parameter.

To measure the results of the measurements, the measuring method, which determines the average texture depth, is still used today. The principle of the test is to spread the glass beads of the given fraction and volume over the road surface. Subsequently, the diameter of the spreading circle is measured from the balls, the proportion of the volume and area of the circle being a number which represents the average texture depth (*MTD*).

$$MTD = (4 \times V) \div (\pi \times D^2) \tag{1}$$

Skid friction is not only affected by the macrotexture of the surface, but also by the microtexture of the surface. Therefore, it is necessary to know the texture in the resolution characterizing the wavelengths of the microtexture to describe the surface roughness based on the texture. However, standard methods can only describe the texture surface at the border of the macrotexture. Therefore, there is an attempt to invent a device that can operate with a resolution at the microtexture level. Before this research, the ZScanner®800 was used, but it did not have sufficient resolution [8]. For this purpose, a Static Road scanner (Fig. 3) was constructed at the University of Žilina. In addition to the development of a static scanner, a dynamic scanner has been developed (DRS) [9].

Fig. 3. Static Road Scanner.

The SRS is used to record the texture of a high-resolution road surface. The device resolution of 2.49 μm (0.00249 mm) allows you to capture the texture at the microtexture level. Another indisputable advantage of this device is undoubtedly also the high (combined) depth of field, and thus the ability to simultaneously capture both texture (micro and macro) components.

The static road scanner consists of a hardware device and a software application (Fig. 4) to scan the road surface at high resolution. The hardware device consists of a scanning head that moves in three perpendicular axes. This head is composed of a macro scanner and a micro scanner [10]. The location of the measuring surface is ensured by means of a made-up iron grid which precisely determines the measuring surface.

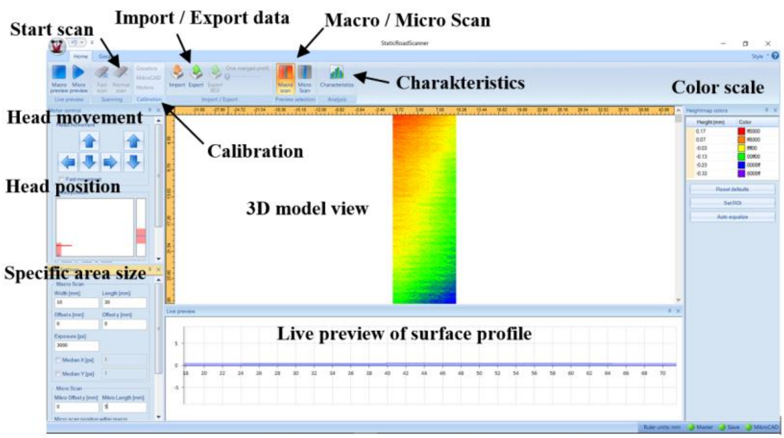

Fig. 4. SRS software.

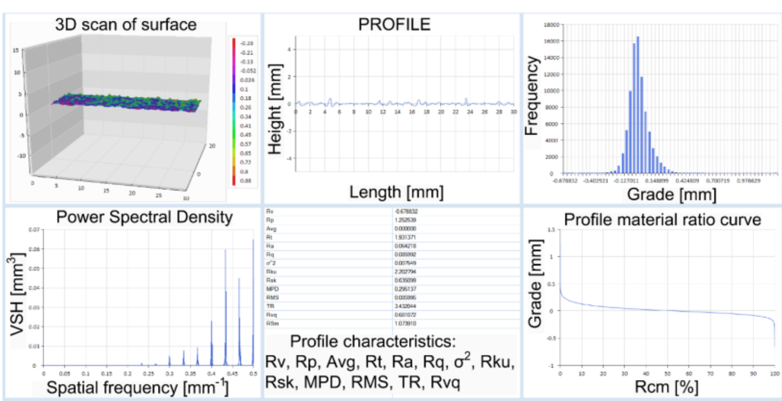

Fig. 5. Basic characteristics of scanned surface.

2.1 Selected characteristics for assessment of surface roughness

There are many different kinds of parameters for surface texture evaluation, such as the height (amplitude) parameters (MPD, Ra, Rq), the height distribution shape parameters (Rsk, Rku), wavelength parameters (PSD), functional parameters (Rmr), hybrid parameters (Rq). For the determination of the influence of the pavement surface texture on noise emissions production were chosen: Ra, Rq, Rsk, Rku, and the parameter MPD [11].

These characteristics have been used in previous research. Its purpose was to compare three basic types of road coverings (SMA, AC, PA). The result of the texture comparison between the considered roads can be seen in Fig. 6.

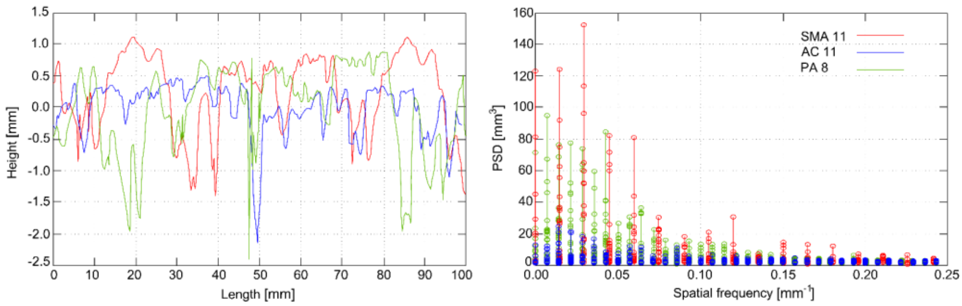

Fig. 6. Surface profile of the SMA and wavelength analysis (PSD) [8].

In our case, we used the same characteristics as in the previous research to assess the pavement texture. This makes it possible to compare the surface texture not only between the concrete and asphalt concrete cover, but also between the surfaces used in the previous research.

2.2 Results of texture of the road pavements

Surfaces were scanned using the SRS. 3D Surfaces are color-coded according to the coordinates for better clarity. (Fig. 7)

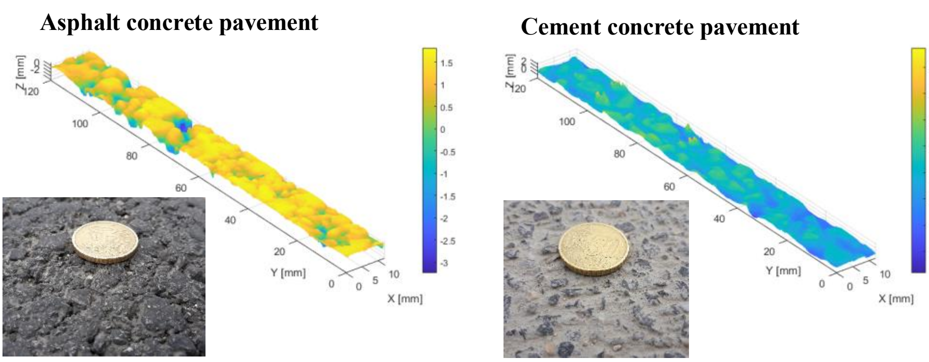

Fig. 7. 3D pavement scans of Asphalt / Concrete pavement.

The results of the characteristics of the test surfaces were divided into the type of surface and the place where the experiment was performed. Experiments were performed in the profile in the track and in the middle of the lane, i.e. outside the track (Table 1).

Table 1. Texture parameters required for different pavement.

Type of pavement:	**Asphalt concrete**		**Cement concrete**	
Location:	**Wheel path**	**Lane center zone**	**Wheel path**	**Lane center zone**
MPD	1.09	1.01	1.00	0.91
Ra	0.45	0.41	0.21	0.22
Rq	0.59	0.54	0.26	0.27
Rsk	-0.81	-0.86	0.42	0.25
Rku	1.13	1.30	0.73	0.23

Next, the profile of the test surface on the left is shown in Fig. 8. On the right is Power Spectral Density (PSD).

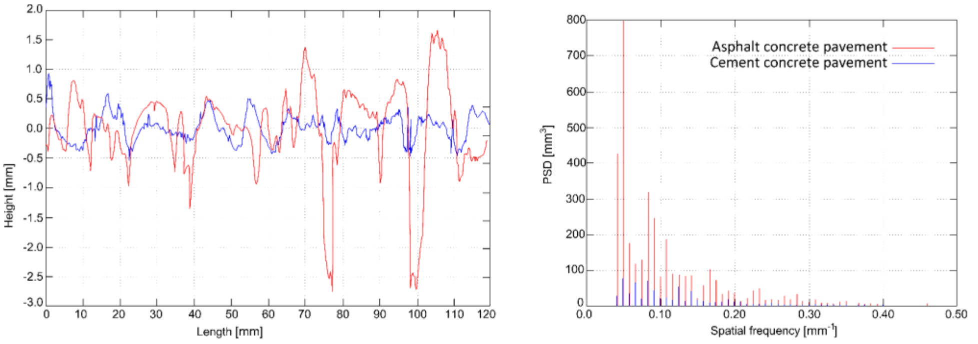

Fig. 8. Surface profile of the asphalt / concrete pavement and wavelength analysis (PSD).

3 Friction on the surface - Pendulum

At present, the pendulum test for assessing the quality of the road network in terms of skid resistance is almost no longer used. However, it is still used in the research of road surface roughness and will therefore be used to measure and evaluate the road surface. In the pendulum test, the skid resistance is measured by means of a pendulum arm at the end of which is fitted with a spring-loaded slide shoe made of standardized rubber. When the pendulum is released from its horizontal position, its kinetic energy is lost when the friction slider passes over the moistened surface at the prescribed rearrangement length, thus determining the degree of surface resistance to skid as the Pendulum Test Value (PTV*)* determined by the pointer's position on the scale [12].

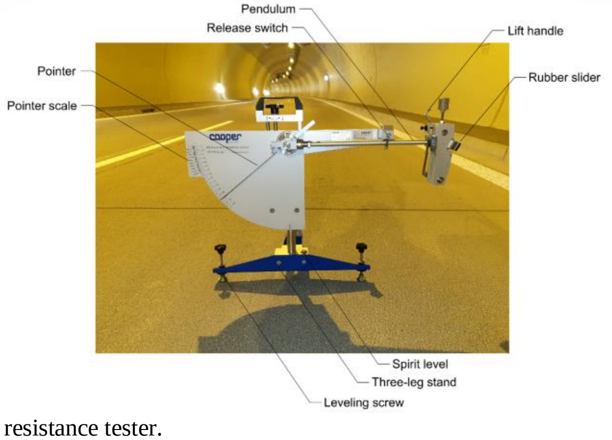

Fig. 9. Pendulum skid resistance tester.

In the pendulum test the values in the Table 2 were recorded.

Table 2. PTV test evaluation.

Type of pavement:	Asphalt concrete		Cement concrete	
Location:	**Wheel path**	**Lane center zone**	**Wheel path**	**Lane center zone**
PTV	73.80	70.40	63.0	67.40

From the measurements it can be concluded that higher values of skid friction reached pavements with asphalt concrete cover.

4 Conclusions

Measurements were made on the road surfaces from two different pavements. In front of the tunnel it was a pavement made of asphalt concrete, but also a pavement made of cement concrete. Inside the tunnel, measurements were made at two different positions at different distances from the tunnel portal. Measurements were made with both the pendulum device and the SRS in all of the sites to describe in detail the surface texture at the site. These measurements were performed for both macrotexture and microtexture. The observed characteristics are listed in Table 3 (macrotexture) and Table 4 (microtexture).

Table 3. Macrotexture characteristics.

Location:		Rv	Rp	Avg	Rt	Ra	Rq	σ2	Rku	Rsk	MPD	RMS	TR	Rvq	RSm	PTV
Outside	ACP_W	-3.030	1.839	-0.002	4.869	0.450	0.593	0.362	1.132	-0.813	1.085	0.593	1.837	1.566	4.854	73.80
	ACP_L	-2.787	1.953	0.011	4.740	0.407	0.537	0.301	1.298	-0.861	1.008	0.537	1.872	1.253	5.111	70.40
	CCP_W	-2.867	3.333	-0.003	6.199	0.205	0.259	0.068	0.727	0.423	0.996	0.259	3.839	1.761	3.478	63.00
	CCP_L	-1.960	2.278	0.000	4.237	0.216	0.267	0.072	0.234	0.250	0.909	0.267	3.401	1.545	4.021	67.40
Inside	CCP_1_W	-1.739	2.481	0.006	4.220	0.223	0.277	0.079	0.142	0.092	0.848	0.277	3.044	1.095	5.130	52.00
	CCP_1_L	-2.019	2.539	0.001	4.558	0.236	0.296	0.089	0.688	0.366	1.046	0.297	3.538	1.554	4.848	52.00
	CCP_2_W	-2.747	2.581	-0.005	5.328	0.227	0.279	0.079	-0.055	0.142	0.860	0.279	3.078	1.335	4.525	56.80
	CCP_2_L	-2.958	2.658	0.005	5.616	0.237	0.296	0.089	0.779	0.422	1.083	0.296	3.662	1.743	4.809	53.20

* W - Wheel path/ L - Lane center zone
ACP - Asphalt concrete pavement
CCP - Cement concrete pavement

For better clarity, the results are shown graphically in Fig.10 (Macrotexture) and Fig.11 (Microtexture).

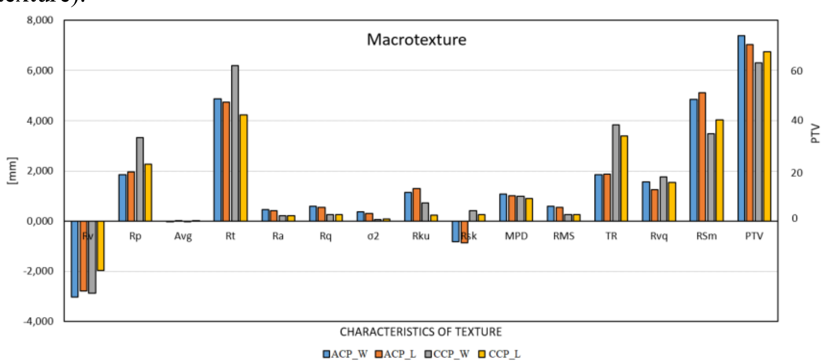

Fig. 10. Surface macrotexture characteristics.

The macrotexture of the test surfaces shows a difference, in particular with the characteristics Rsk, TR and RSm. However, the difference in PTV is low in order to clearly determine the characteristic that affects it. The following table shows the surface microtexture characteristics.

Table 4. Microtexture charakteristics.

Location:		Rv	Rp	Avg	Rt	Ra	Rq	σ2	Rku	Rsk	MPD	RMS	TR	Rvq	RSm	PTV
Outside	ACP_W	-0.150	0.142	0.000	0.292	0.005	0.008	0.000	7.972	-0.317	0.029	0.008	3.700	0.891	0.061	73.80
	ACP_L	-0.256	0.254	0.000	0.511	0.007	0.012	0.000	10.268	-0.055	0.048	0.012	4.153	1.290	0.099	70.40
	CCP_W	-0.231	0.192	0.000	0.423	0.004	0.005	0.000	10.291	0.192	0.023	0.005	4.282	0.685	0.072	63.00
	CCP_L	-0.311	0.298	0.000	0.609	0.009	0.016	0.000	9.004	0.257	0.077	0.016	4.359	2.345	0.094	67.40
Inside	CCP_1_W	-0.143	0.127	0.000	0.271	0.003	0.005	0.000	12.044	-0.200	0.021	0.005	3.846	0.801	0.087	52.00
	CCP_1_L	-0.024	0.036	0.000	0.059	0.002	0.003	0.000	2.895	0.209	0.013	0.003	4.124	0.468	0.062	52.00
	CCP_2_W	-0.173	0.135	0.000	0.308	0.004	0.006	0.000	5.038	0.041	0.023	0.006	3.912	0.884	0.055	56.80
	CCP_2_L	-0.226	0.369	0.000	0.596	0.004	0.007	0.000	13.289	0.570	0.034	0.007	4.452	1.020	0.064	53.20

* W - Wheel path/ L - Lane center zone
ACP - Asphalt concrete pavement
CCP - Cement concrete pavement

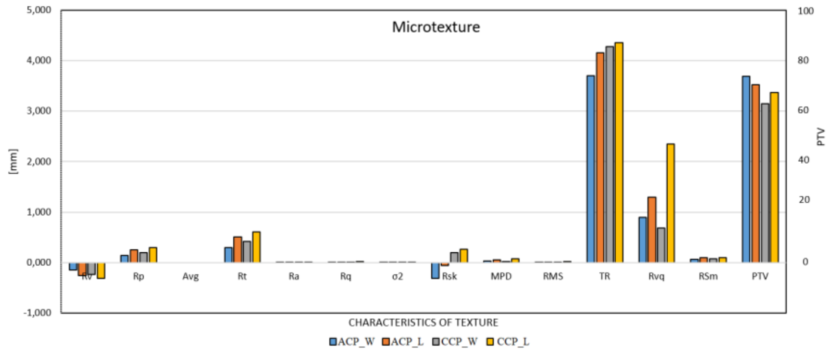

Fig. 11. Surface microtexture characteristics.

The paper is a result of the research supported by the research project VEGA 1/0537/17 „The influence of pavement surface morphology on pavement serviceability and emissions production"

References

1. M. Kováč, E. Remišová, *Roughness of asphalt pavements* (EDIS Žilina, 2016, in Slovak)
2. P. Kotek, M. Kováč, Procedia Engineering, XXIV R-S-P seminar, Theoretical foundation of civil engineering, **111**, 436-443 (2015)
3. E. Remišová, M. Decký, L. Podolka, M. Kováč, T. Vondráčková, L. Bartuška, WMESS, book series Procedia Earth and Planetary Science, **15**, 3–10 (2015)
4. M. Trojanová, M. Decký, E. Remišová, 24th Russian-Polish-Slovak Seminar on Theoretical Foundation of Civil Engineering, **111**, 770-776 (2015)
5. J. Grosek, A. Zuzulova, I. Brezina, MATERIALS, **12**, 10, Publisher: MDPI, St Alban-Anlage 66, Ch-4052 Basel, Switzerland.
6. D. Jandačka, D. Durčanská, Civil and environmental engineering, **10**, 26-39 (2014)
7. D. Jandačka, D. Durčanská, Atmosphere, **10** (10), art. no. 583 (2019)
8. M. Slabej, M. Grinč, M. Kováč, M. Decký, Š. Šedivý, Contributions to geophysics and geodesy, **45**, 3, 237-254 (2015)
9. M. Kováč, M. Decký, B. Leitner, Transport means 2016. Proceedings of the 20th international scientific conference, 450-453 (Lithuania, 2016)
10. KVANT s.r.o. **-** Static Road Scanner, User Guide (in Slovak)
11. E. Remišová, M. Decký, M. Kováč, SGEM, Section Air pollution and Climatehange. **17- 26, II**, 583-590 (2014)

12. STN EN 13036-4 (736171)