

The influence of the pavement surface texture on the Pendulum Test Value

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Abstract. The article deals with the problem of finding a relation between surface texture and skid resistance represented by the Pendulum Test Value. For the texture measurements was used a new device that can capture surface irregularities up to the microtexture level. Besides Pendulum Test Values were also evaluated standard roughness parameters as well as the Mean Profile Depth widely used for pavement surface macrotexture evaluation. The texture parameters were evaluated for both macro- and micro-texture of all tested surfaces. Two groups of surfaces were measured. The first group, represented by reference surfaces with known parameters, was used for evaluation of the reliability of new device as well as for determining the relation between microtexture and pendulum test value. The second group was represented by asphalt mixture specimens designed to create various surfaces with different parameters of both macrotexture and microtexture. The obtained results show that there is no unambiguous direct relation between the size of irregularities and skid resistance. That means that high values of both macro and microtexture won't have to necessarily mean a high level of friction. The proper size and proportion of both parts in their optimal combination are needed.

1. Introduction

Accurate and precise diagnostics of pavement serviceability parameters plays a key role in the aim to keep road safety at the required level for the whole time of their live cycle [1]. Skid resistance is one of the most important parameters for evaluating the quality of road pavement in terms of road safety. Although many features influence the friction on the contact between the wheel and the pavement surface (vehicle speed, tire tread depth and pattern, tire inflation, presence of water film and its depth, temperature, etc.), there is no doubt that pavement surface texture plays a key role in point of view a road pavement surface diagnostics. Pavement surface texture, besides skid resistance, influences also many other important things concerned the quality of life, such as noise production and propagation as well as particulate matter emissions [2]. Even though the main source of emissions is road traffic [3], the wearing of the pavement surface depended on its texture has a significant contribution [4]. All this has a significant influence on air quality and whole environment and climate changes and vice versa these changes should be taken into account when designing a road pavement construction [5]. The knowledge about how the mixture composition affects the pavement surface texture is important in terms of wearing course design because it can positively influence, besides other mentioned factors, also the skid resistance and the ability of the surface to keep the high level of it in long term, what is very important for increasing of road safety and decreasing the risk of car accidents.

There have been many methods and devices designed for pavement texture evaluation. The most common are the methods for contactless texture measurement by the use of laser sensors. There are

also other optical methods, for instance, stereophotogrammetry, but these are affected by boundary conditions such as light uniformity during measurement, image noise or multicolored road pavement surface. For comprehensive and objective evaluation of skid resistance are still mostly used devices measuring a coefficient of friction despite the problems with repeatability and reliability of many of them. On the other hand, these devices are still the only ones that can measure macro- and micro-texture at the same time and the traffic speed. In addition to that, there still hasn't been created a satisfying and objective model or formula for predicting or estimating the skid resistance based on contactless texture measurements only. The main reason is the non-sufficient resolution of currently used devices without the ability to detect surface irregularities up to microtexture level, which seems to be crucial in terms of overall friction level.

The goal of the article is to bring a little more light to the relationship between surface texture and skid resistance. For the purpose to determine the rate of influence of the texture on the coefficient of friction was tested a wide spectrum of surfaces, where besides Pendulum Test Values (PTV) were also evaluated standard roughness parameters as well as the Mean Profile Depth (MPD) widely used for pavement surface macrotexture evaluation.

2. Measuring device and testing surfaces

2.1. Static road Scanner

For the precise and accurate measuring of the tested surfaces was used the Static road Scanner (SRS). The device was designed at the University of Zilina in order to measure both macro and microtexture of the pavement surface and for this purpose uses two different optical methods. The first one uses two red lasers scanning in opposite directions with the resolution up to 15 μm and the second one uses the blue structured light with a resolution up to 2.49 μm in the X and Y -axis. The resolution in the Z -axis is approximately orders of magnitude higher than in the X and Y axes. The maximum captured size of a scanned surface at the one test represents the area of 120×100 mm, whereas the goal is to scan the surface area corresponding to the path of the rubber slider of British Pendulum Tester. The output of the scanning process is a text-file with X , Y , Z coordinates that are used as an input to the algorithm created by authors [6] in MATLAB® software. The algorithm allows calculating standard roughness, spacing, and waviness surface texture parameters [7], including the parameter - Mean Profile Depth (MPD) used for characterization of road pavement texture by use of surface profiles [8]. The algorithm provides a possibility to calculate all texture parameters for irregularities at both scales, i.e. for macrotexture as well as for microtexture.

2.2. Testing surfaces

Two groups of surfaces were measured. The first group was represented by reference surfaces with known sizes of irregularities (grit size). The reference surfaces were used for evaluation of the reliability of new device as well as for determining the relation between microtexture and pendulum test value. The second group was represented by asphalt mixture specimens designed to create various surfaces with different parameters of both macrotexture and microtexture.

2.2.1. Reference surfaces. These surfaces were represented by sandpapers with given standardized grit sizes. The texture measurements and pendulum tests were performed on more than 50 sandpapers with more than 20 different grit sizes from P7000 to P16. The grit size of sandpaper is stated as a number that is inversely related to the particle size. The grit size P7000 represents a surface with irregularities corresponding to the particle diameter (grain size) of 3 μm . The grit size P16 represents a surface with irregularities corresponding to the particle size of 1324 μm . Considering the homogeneity of surfaces of factory-produced sandpapers, the surface scanning area was limited to 30×10 mm.

2.2.2. Asphalt mixture specimens. The specimens were designed and produced to create a wide spectrum of surfaces with different macrotexture and microtexture. The different macrotexture was

created by the use of different maximum grain size of aggregates in the mixture. The asphalt mixtures with the smallest macrotexture level were AC8, asphalt concrete with maximum grain size (8 mm). The mixtures AC11 and SMA 11 had the same maximum grain size (11 mm), but different particle size distribution. The mixtures with the roughest macrotexture were AC16 with maximum grain size (16 mm). Mixtures with different microtexture were created by using a different type of aggregates. The roughest microtexture level was obtained by using a Granodiorite (Gra) and the finest one by a Limestone (Lim). The middle level of microtexture was obtained by an Andesite (And) [9]. According to the above-mentioned conditions were created 12 specimens with different macro and microtexture of their surfaces [10].

3. Measuring on reference surfaces

The reliability of the new device was tested on reference surfaces with known values of geometric parameters. One of the goals was the examination of the influence of different measurement conditions on the accuracy of measurement results. Different measurement conditions were represented by different colors of sandpapers (blue, grey, black and red), different light conditions (without covering device – normal conditions, or with covered device for establishing complete darkness).

Skid resistance was measured on all reference surfaces by British Pendulum Tester [11]. The result of a pendulum test is a Pendulum Test Value (PTV).

3.1. Texture measurements and measuring device reliability verification

The reliability of the device was evaluated by comparison of measured roughness parameters with the declared grain size of sandpapers. Examples of relations between values of measured texture parameters and grain size of sandpapers are shown in figure 1 and figure 2. For better visualisation of obtained results are relations showed on semi-log graphs.

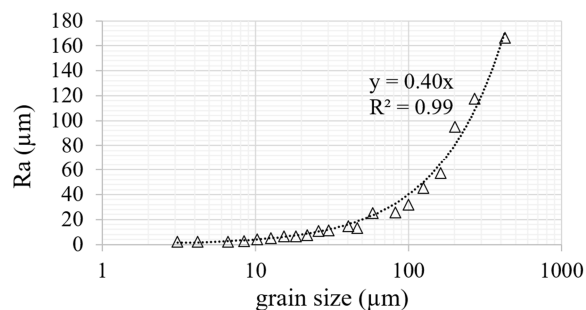


Figure 1. Comparison of measured values of an arithmetical mean deviation (Ra) of the assessed profiles with the grain size of the sandpapers.

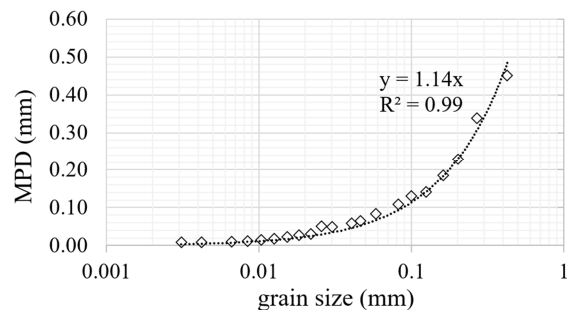


Figure 2. Comparison of measured values of a Mean Profile Depth (MPD) values with the grain size of the sandpapers.

The results obtained on reference surfaces demonstrated the accuracy and reliability of the device. Almost the same results were obtained at all different measurement conditions. Based on these promising results were prepared experiments on asphalt mixture specimens.

3.2. The Pendulum test

After texture measurements were on all reference surfaces performed the Pendulum Tests at wet conditions according to the procedure specified in the standard. Considering the believed fact that microtexture represents the deviation from a true planar surface with the characteristic dimensions along the surface of less than 0.5 mm and peak-to-peak amplitudes are in the range of 0.001 mm to 0.5 mm, the test was performed with the goal to determine the relation between microtexture and skid resistance. All sandpapers were firmly glued to the completely planar base to exclude any influence of

macrotexture. Only two sandpapers (P16 and P24) in the test exceed the size of irregularities characteristic for microtexture. For a better picture, however, values obtained on these surfaces were also taken into account. Pendulum Test Values obtained on sandpapers characterised by grain sizes are shown in figure 3. Comparison of obtained Pendulum Test Values and measured MPD values on the same sandpapers are shown in figure 4. For better visualisation of obtained results are relations showed on semi-log graphs. The dashed line in the chart represents the transition between macro and microtexture.

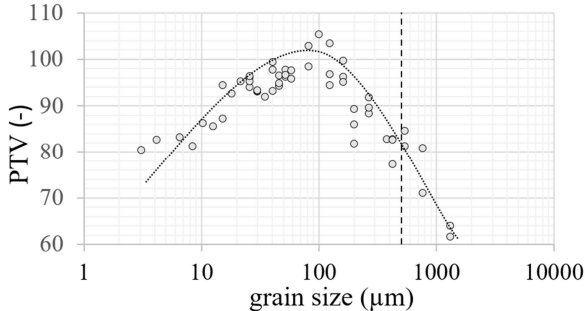


Figure 3. Pendulum Test Values measured on reference surfaces represented by the grain size of sandpapers.

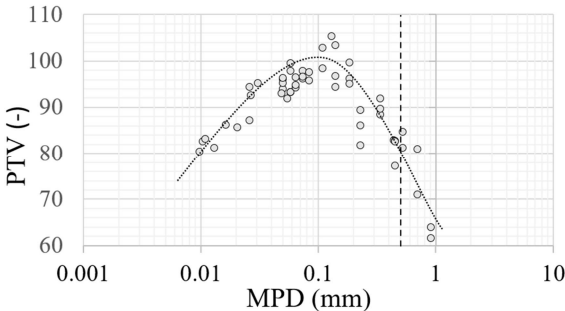


Figure 4. Comparison of Pendulum Test Values and MPD values measured on reference surfaces by the new device.

As can be seen in figure 3 and figure 4, contrary to the expected result, there is no only increasing trend of Pendulum Test Values within the whole spectrum of increasing grain sizes or MPD values. PTV increases up to grain size of approximately 125 µm and from there begins a steep decrease of Pendulum Test Values. Differences between obtained Pendulum Test Values reached up to 40 %. The highest values of PTV were obtained at surfaces with the size of irregularities in range of 80 to 125 µm. Relatively high Pendulum Test Values were also measured on surfaces with grain sizes in the range of 50 to 150 µm. As expected, on surfaces with very small values of texture parameters (3 - 20 µm) were obtained relatively small PTV. However, surprisingly low Pendulum Test Values were measured on surfaces considered as more harsh, i.e. with surface irregularities bigger than 150 µm. All this suggests that it will not be possible to make a prediction of skid resistance based only on simple profile high parameters, since high values of texture don't have to necessarily mean a high level of friction.

Clear increasing tendency where can be find a relatively close correlation between microtexture and skid resistance using mentioned parameters is when considering surfaces with the size of irregularities up to 125 µm. For the best fit was used a power function of the regression curve shown in figure 5 and figure 6.

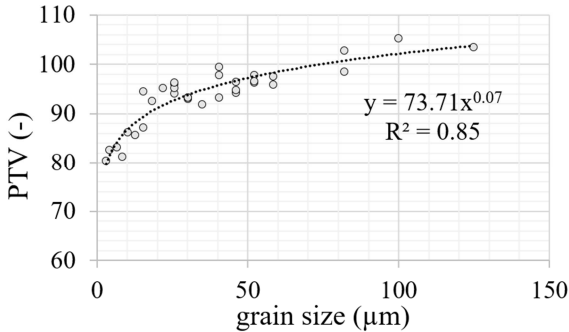


Figure 5. The relation between Pendulum Test Values and the grain size of sandpapers with the limited size of surface irregularities to 125 µm.

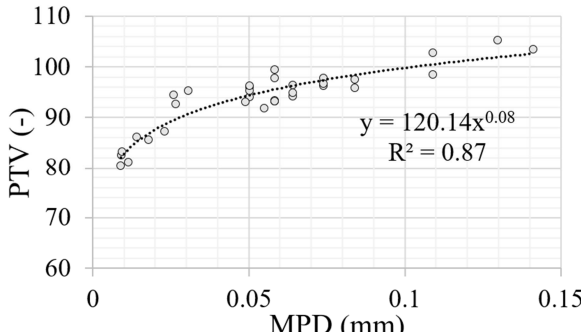


Figure 6. The relation between Pendulum Test Values and MPD values with the limited size of surface irregularities up to 125 µm.

4. Measuring on surfaces of asphalt mixture specimens

On 12 surfaces of asphalt mixture specimens with different macro and microtexture, created according to conditions mentioned above, were performed the 3D scanning by SRS and the Pendulum Test. All tests were performed on the brand new specimen surfaces where the aggregates were coated by a bitumen film, as well as on the same surfaces with revealed microtexture of the aggregates after the removal of bitumen film by perchloroethylene. The scanning of macrotexture was performed by use of red laser sensors at the area corresponding to the rubber slider path of the pendulum. The microtexture was measured only on few (4 – 8) aggregate grains due to the small depth of focus of structured light sensor. The Pendulum tests were performed on both, dry and wet surfaces, at two places in two opposite directions at each specimen. Obtained results of all measurements are shown in table 1.

Table 1. Results of texture measurements and pendulum test.

Mixture	COATED				REVEALED			
	MPD _{macro} (mm)	MPD _{micro} (mm)	PTV _{DRY} (-)	PTV _{WET} (-)	MPD _{macro} (mm)	MPD _{micro} (mm)	PTV _{DRY} (-)	PTV _{WET} (-)
AC8-And	0.85	0.092	92	61	1.07	0.098	81	66
AC8-Lim	0.88	0.066	92	58	1.15	0.077	82	65
AC8-Gra	1.23	0.075	86	60	1.35	0.123	83	66
AC11-And	1.69	0.044	88	58	1.29	0.114	80	67
AC11-Lim	1.58	0.059	85	58	1.22	0.099	84	62
AC11-Gra	1.41	0.055	88	56	1.34	0.112	81	64
SMA11-And	2.08	0.107	86	63	1.55	0.117	81	68
SMA11-Lim	2.01	0.090	85	65	1.41	0.123	82	64
SMA11-Gra	1.80	0.099	88	66	1.42	0.125	84	68
AC16-And	1.86	0.109	89	70	1.38	0.148	83	68
AC16-Lim	1.75	0.155	87	65	1.26	0.150	83	63
AC16-Gra	1.62	0.142	86	67	1.33	0.111	84	68

4.1. Texture measurements results

The texture of measured surfaces was evaluated by MPD value for both macro and microtexture. Results of macrotexture measurements for coated and revealed surfaces of asphalt mixture specimens are shown in figure 7 and figure 8.

As can be seen in figure 7, the macrotexture level of the coated surfaces of specimens corresponds to the maximum grain size of the asphalt mixture. The smallest MPD values are obtained at specimens denoted as AC8 for all used aggregate type. As expected, second in order with higher MPD values are specimens AC11. However, surprisingly highest MPD values were obtained at stone mastic asphalt specimens denoted as SMA 11, even though specimens AC16 has a bigger maximum grain size. This can be explained by the fact that the stone mastic asphalt is a gap graded hot mix asphalt and contains only a small percentage of aggregate particles in the mid-size range what can influence the average profile height and then the overall MPD value.

Results of macrotexture measurements obtained on revealed surfaces after the removal of the bitumen film are presented in figure 8. It can be seen the same order of the specimens according to MPD values depended on grading and maximum grain size, however, the differences between mixtures are much less than at coated specimens. The MPD increased only for specimens AC8 and for all other mixtures MPD values decreased. This could be caused by sufficient removal of the bitumen film only from the surface of the aggregates and at the same time by insufficient film removal from valleys and cavities.

MPD values of microtexture level of specimen surfaces are shown in figure 9 and figure 10.

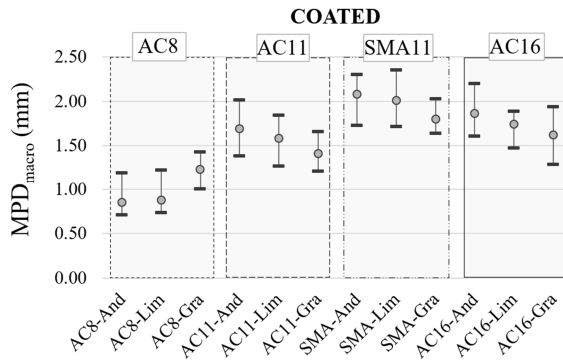


Figure 7. MPD values of macrotexture measured on surfaces of mixtures with bitumen film on the aggregate grains.

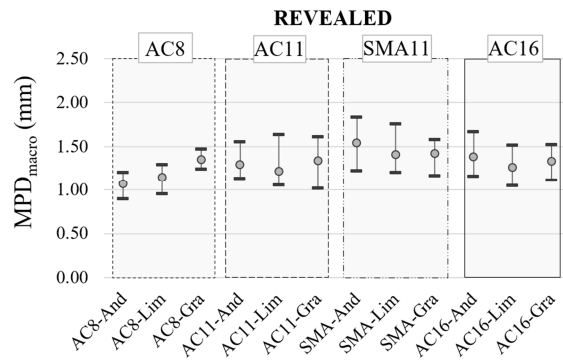


Figure 8. MPD values of macrotexture measured on surfaces of mixtures after removal of bitumen film from the aggregate grains.

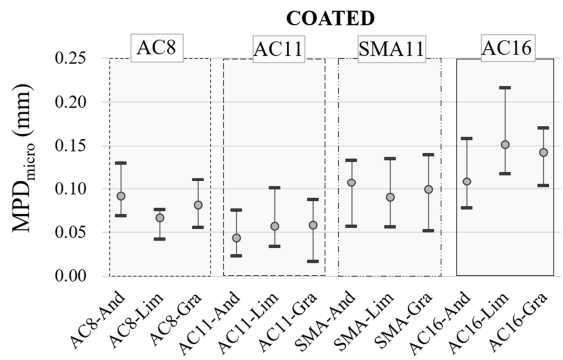


Figure 9. MPD values of microtexture measured on surfaces of mixtures with bitumen film on the aggregate grains.

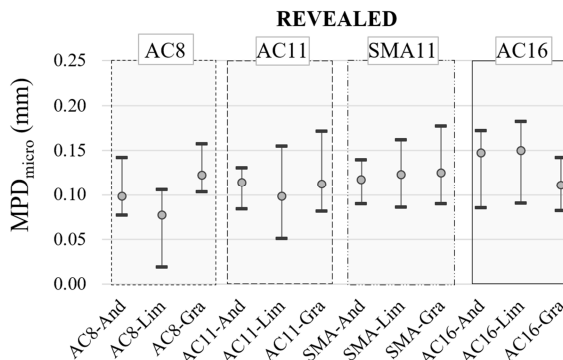


Figure 10. MPD values of microtexture measured on surfaces of mixtures after removal of bitumen film from the aggregate grains.

The premise was that at coated surfaces will be obtained approximately the same and low levels of microtexture at all specimens, regardless of types of aggregates. The results didn't confirm the expectations and microtexture levels vary significantly. The second premise was that after removing the bitumen film from grain surfaces the microtexture level will increase at all specimens and the levels will be in the order: the least for the Limestone, the middle for Andesite and the highest for Granodiorite. As was expected, the average microtexture level increased at all revealed surfaces, however, the measured values show a very high level of dispersion. Also, the expected order of microtexture levels for aggregate types was confirmed only at mixtures AC8 and AC11. In addition to that, the high dispersion set the examined surfaces of different aggregates approximately at the same level. This could be caused by calculating of microtexture parameters based on raw measured data without filtering the longer wavelengths (although measured by the sensor with low depth of field) where were taken into account bigger surface irregularities than are representative for microtexture level. Also, the amount of measured data for this purpose turned out to be insufficient.

4.2. Pendulum test results

Results of measured Pendulum Test Values on coated and revealed surfaces of all specimens at dry conditions are shown in figure 11. As expected, the Pendulum Test Values measured on dry surfaces were significantly higher than on wet surfaces for both, coated and revealed aggregate grains. At coated surfaces with bitumen film were obtained higher PTV at all dry specimens than on surfaces with revealed aggregate grains. This is due to adhesion forces which are highest at dry an smooth

surfaces. The highest PTV were obtained on mixtures AC8 with fine grading influencing the area size of contact with a rubber slider. Pendulum test values on rest of mixtures reached a little lower but very similar level. After revealing the bitumen film from grain surfaces the Pendulum Test Values decreased, which was caused by revealing the microtexture, the surfaces were not so smooth anymore and adhesion forces decreased. Pendulum Test Values are still relatively high and at a similar level for all mixtures. According to obtained results, it is hard to claim what type of aggregates and hence the microtexture level has the most beneficial influence on the overall level of skid resistance.

A quite different situation is after getting surfaces wet (figure 12). As expected, there were obtained significantly lower values of PTV on all surfaces in comparison with dry surfaces. Contrary to the measurements on dry surfaces, Pendulum Test Values measured on wet and coated surfaces are highest on mixtures with the highest level of macrotexture, i.e. SMA11 and AC16. Considering the missing contribution of microtexture, this can be caused by better drainage properties and a higher decrease in the kinetic energy of rubber slider after bumping into the bigger particles. After the microtexture revealing by the bitumen film removal from grain surfaces, the Pendulum Test Values are higher almost at all specimens.

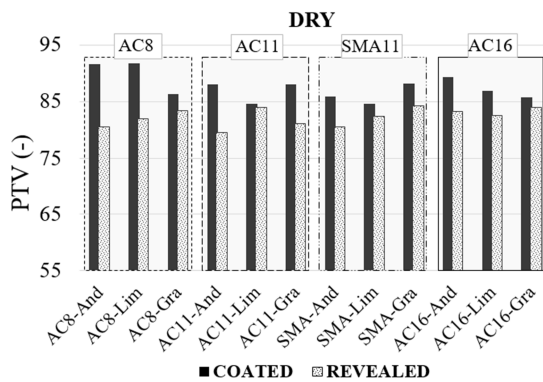


Figure 11. Pendulum Test Values measured on dry surfaces of mixtures with bitumen film on aggregates (COATED) and after its removal.

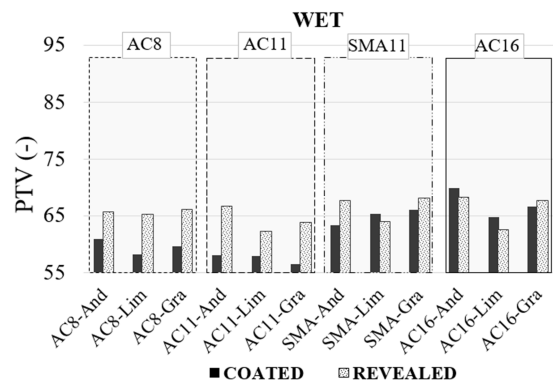


Figure 12. Pendulum Test Values measured on wet surfaces of mixtures with bitumen film on aggregates (COATED) and after its removal.

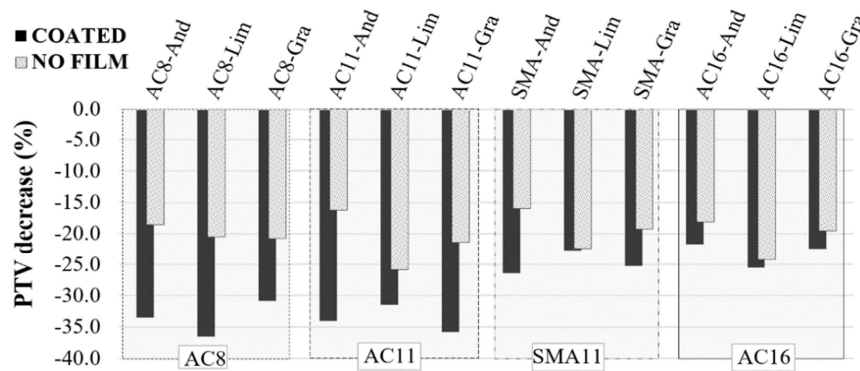


Figure 13. Decrease of Pendulum Test Values after getting surfaces wet.

The ratio of the decrease of Pendulum Test Values after getting surfaces wet is shown in figure 13. As can be seen in figure 13, as expected, there is a decrease of Pendulum Test Values after getting surfaces wet on all surfaces no matter the surfaces are coated or revealed. However, the decrease in PTV on specimens without bitumen film is significantly lower than on coated specimens, especially on mixtures with fine grading (AC8 and AC11, mixtures with low macrotexture level). The decrease of PTV after getting surfaces wet on the coated surfaces can reach up to 37 % (AC8-Lim, AC11-Gra), while the decrease at the same mixtures with revealed microtexture was only about 21 %. The

microtexture and the bigger contact area at these mixtures complement the low macrotexture. Lower differences between the decreases at coated and revealed mixtures SMA11 and AC16 show the bigger influence of macrotexture at these specimens.

Comparing different types of aggregates, the lowest decrease within individual mixtures show specimens with Andesite and the highest show specimens with Limestone. Although the differences between results compared on revealed surfaces are not very significant there can be seen an inalienable benefit of microtexture on skid resistance at wet conditions.

The ratio of the decrease of Pendulum Test Values, or the increase respectively, according to measurements on dry and wet surfaces after removing a bitumen film from the surface of the aggregate grains and hence the revealing a microtexture is shown in figure 14.

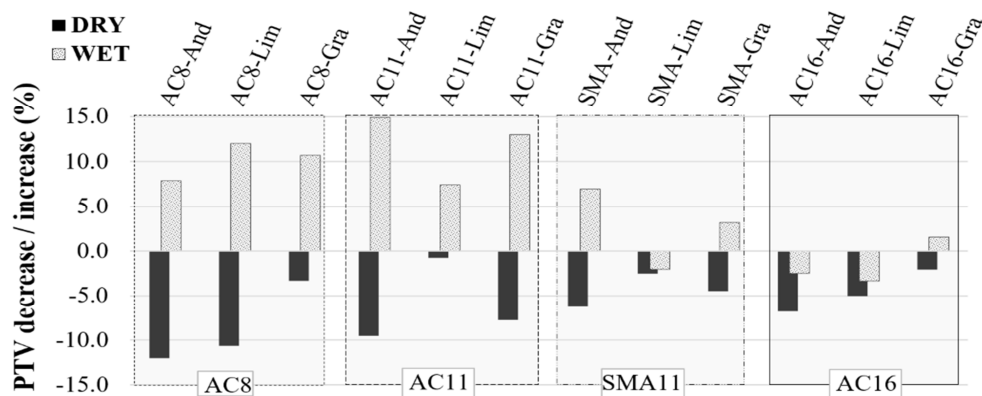


Figure 14. Decrease/Increase of Pendulum Test Values after removing a bitumen film from the surface of the aggregates and hence revealing a microtexture.

As can be seen in figure 14, at all specimens was noticed a decrease of PTV measured on dry surfaces after revealing a microtexture. As mentioned above, this was due to the decreasing of adhesion forces which are biggest at dry and smooth surfaces. The biggest decrease of PTV on dry surfaces was recorded on most mixtures with fine grading and biggest contact area (AC8 and AC11) where were obtained the highest values at coated surfaces. Nevertheless, the overall Pendulum Test Values stayed at a very high level. Contrary to the measurements on dry surfaces, after the microtexture revealing the Pendulum Test Values on wet surfaces increased at all specimens of mixtures AC8 and AC11, at two specimens of mixtures SMA11 and one specimen of mixture AC16. This is proof of the important role of microtexture to provide sufficient friction at wet conditions. An unexpected decrease in PTV on wet specimens SMA11-Lim, AC16-And, AC16-Lim show the bigger influence of macrotexture then the revealed microtexture at the smaller contact area than on mixtures with fine grading.

5. Relations between MPD and PTV

To determine the rate of influence of texture on skid resistance were examined correlations between MPD and PTV measured on both, dry and wet surfaces. Correlations between these variables for macrotexture are shown in figures 15 and 16.

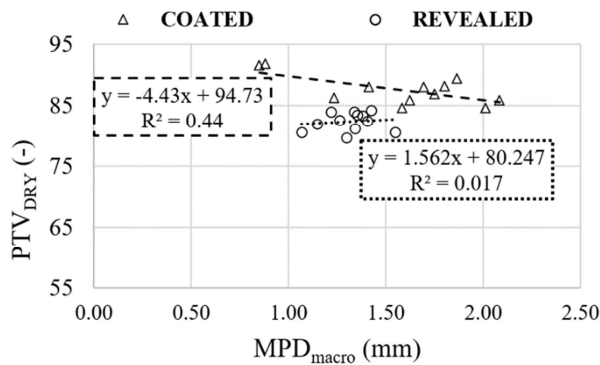


Figure 15. Relations between MPD values of macrotexture and Pendulum Test Values measured on dry surfaces.

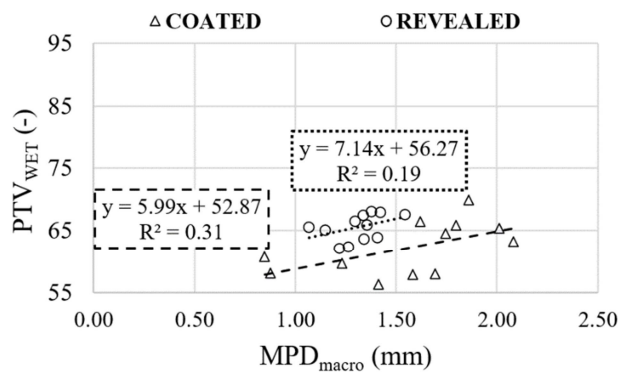


Figure 16. Relations between MPD values of macrotexture and Pendulum Test Values measured on wet surfaces.

As can be seen, the strength of an association between macrotexture characterised by parameter MPD and skid resistance characterised by PTV is very low for all examined cases. The highest value R^2 was obtained from the relation between MPD and PTV measured on dry and coated surfaces what was explained above by the influence of high adhesion and bigger contact area at fine grade mixtures. However, it is still not satisfying strength of the association between these variables. There wasn't found any significant relation between variables measured at dry and revealed surfaces. The main reason is the small range of macrotexture levels over the spectrum of the surfaces as well as the fact that the differences between obtained Pendulum Test Values are also not very high. Relations between MPD values of macrotexture and Pendulum Test Values measured on wet surfaces are also not very significant. A certain upward trend can be seen on coated surfaces, which can be explained by better water drainage from the surfaces of mixtures with higher macrotexture level. However, the R^2 value is still very low. There also wasn't found any significant relation between variables measured at wet and revealed surfaces due to the same reason as at dry surfaces i.e. the small range of measured values.

Examined correlations between MPD and PTV measured on both, dry and wet surfaces according to microtexture level are shown in figures 17 and 18.

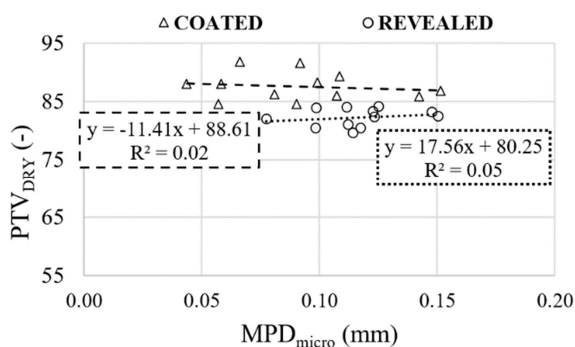


Figure 17. Relations between MPD values of microtexture and Pendulum Test Values measured on dry surfaces.

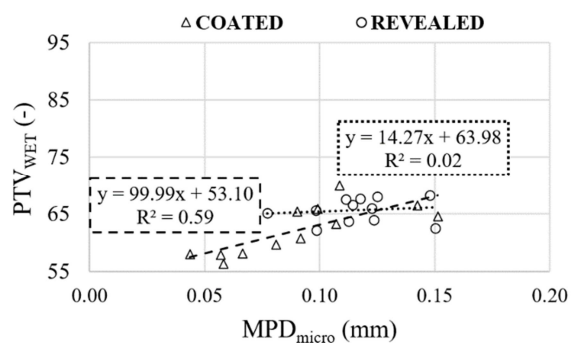


Figure 18. Relations between MPD values of microtexture and Pendulum Test Values measured on wet surfaces.

As can be seen, the strength of an association between microtexture characterised by parameter MPD and skid resistance characterised by PTV is in most cases even lower than at macrotexture evaluation. The main reason at dry surfaces is that even though there is a relatively wide range of measured values of microtexture obtained Pendulum Test Values were approximately at the same level. The average values of microtexture after revealing was in the range of 80 – 150 μm , which

corresponds to the range of grain sizes of reference surfaces where were also obtained Pendulum Test Values not with big variance. That means that change of microtexture depth in such range didn't cause any significant change of PTV.

Relations between MPD values of microtexture and Pendulum Test Values measured on wet surfaces are also not very significant. Practically, there wasn't found any relation between considered MPD values for microtexture and PTV on revealed surfaces. The relatively high value of R^2 obtained for the relation between MPD and PTV we consider as a coincidence due to a very high level of dispersion of measured values at individual specimens.

6. Conclusions

The main goal of the article was to analyze the influence of surface texture on skid resistance represented by Pendulum Test Value. For this purpose were analysed results of texture measurement by use of a new device designed at the University of Zilina. Texture measurements were performed on two groups of surfaces. The first group was represented by reference surfaces with known sizes of irregularities. The second one was represented by specimens of asphalt mixtures designed and produced to create surfaces with different macrotexture and microtexture. The different macrotexture was created by the use of different maximum grain size of aggregates in the mixture. Mixtures with different microtexture were created by using a different type of aggregates. For the evaluating of the relation between texture and skid resistance were compared parameters MPD and Pendulum Test Value.

According to obtained results, we can state the following conclusions and recommendations for further research:

- The new device, Static Road Scanner is reliable and can be used for measurement of pavement surface texture. However, measurements on specimens by the use of structured light showed the need to change the methodology of microtexture measurement and evaluation.
- Measurements on reference surfaces (without macrotexture) showed that there is no only increasing trend of Pendulum Test Values within the whole spectrum of increasing values of microtexture.
- The highest values of PTV were obtained at surfaces with the size of irregularities in range of 80 to 125 μm . A steep decrease of Pendulum Test Values was observed on surfaces considered as more harsh, i.e. with surface irregularities bigger than 150 μm .
- Clear increasing tendency where can be find a relatively close correlation between microtexture and skid resistance was found at surfaces with the size of irregularities up to 125 μm .
- Measurements on created asphalt mixture specimens confirmed some expected results such as level of macrotexture corresponding to aggregate grading, a decrease of PTV on wet surfaces, an increase of PTV after revealing the bitumen film. However, a lot of results didn't end up as was anticipated. Especially microtexture evaluation didn't confirm expected levels of microtexture for different types of aggregates at all specimens and showed a very high dispersion of measured values.
- The strength of an association between macrotexture characterised by parameter MPD and skid resistance characterised by PTV was very low for all examined cases. The main reason was unreliable microtexture data and a small range of different levels of both macro and microtexture achieved on created specimens.

All this suggests that it will not be possible to make a prediction of skid resistance based only on simple texture parameters, since as showed up that high values of texture don't have to necessarily mean a high level of friction. The proper size and proportion of both parts in their optimal combination are needed. In further research, we will focus on the evaluation of 3D areal (volume and feature) parameters on more surfaces with a wider range of macrotexture and microtexture.

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