Analyze of Aggregate Texture Results Measured by Three Dimensional and Two-Dimensional Methods

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ARTICLE INFO

ABSTRACT

At the present time, a lot of laboratory measurement and evaluation approaches exist for investigation of aggregate texture, which is necessary to assecurate a basic level of friction between tire and asphalt pavement. In this contribution, two laboratory methods based on three dimensional and two dimensional analyses of aggregate texture investigation are presented. The values of three dimensional texture parameter were compared with the values of the two dimensional texture parameters. The measurements by both these methods were performed on the same grains of aggregates. Three dimensional evaluation outputs were obtained from measurement by optical microscope method and two dimensional evaluation outputs were obtained from measurement by profilometry method. All of analyzed aggregate texture parameters (three dimensional and two dimensional) give information about texture depth and therefore can be compared to each other. Parameters of regression and correlation analysis were used to find relation between the three dimensional and two dimensional texture parameters and obtained results were analyzed and discussed.

1. Introduction

The texture of aggregates used in asphalt pavement relates to a friction on an interface between tyre and pavement and subsequently influences safety of traffic. The significance of aggregate texture in relation to a tyre/pavement friction is closely described in (Hall et al., 2009). According to EN ISO (2009), is aggregate texture characterized as an asperities on the surface of particular aggregates and is defined by wavelengths and amplitudes in the range 1µm – 0.5 mm. These asperities are essential especially under wet conditions to disconnect the thin water film and to enhance the contact between tyre rubber and pavement surface (Merritt, 2015). It stands to reason, that the type of used aggregate predetermines the level of micro texture of pavement surface and the knowledge of the aggregate texture is very important from traffic safety point of view. Account on that, the methods for its accurate detection are necessary.

In Kim and Souza (2009) the method using the angularity of aggregate grain is described. It has been concluded the more shaped surface of the aggregate, firmer and also sharper material of surface means that better and more lasting friction can be expected. The possibility to measure the surface texture in the range of micro texture (aggregate texture) on pavements in service is still problematic because of the laser scanning resolution and optical illusion (Li, 2010; Mičechová, 2019; Dudak, 2018). Problems with optical illusion were identified and the authors concluded the more suitable approach is to use the contactless digital image analysis methods.

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Various approaches (laser scanner (Anochie-Boateng et al., 2010), complex digital analysis systems (Maerz & Zhou, 2001; Tutumluer et al., 2000) and photogrammetry (McQuaid et al., 2013)) can be used to obtain a digital image of aggregate surface that is obviously transferred into three dimension (3D). Although, 3D surface models of aggregate grain are available the texture evaluation is mostly based on the shape of aggregate grain (Al-Rousan et al., 2007) or an analysis of two dimensional (2D) profiles (Fletcher et al., 2002). Despite the fact that a lot of measurement and evaluation approaches have been developed the possibility to accurate aggregate texture evaluation has still some gaps.

2. Methods

2.1 Evaluation of aggregate texture based on three-dimensional (3D) image analysis

It is possible to use the optical stereomicroscope to obtain the 3D model of aggregate grain. Than the appropriate software of microscope allows exported this 3D model into the Wrml (Virtual Reality Modelling Language) format. It is a basic input for following evaluation in the MicroSYS calculating program which has been developed specially for this aim.

In the MicroSYS calculating program, the surface of aggregate is expressed in the analytical form and for the evaluation purpose is replaced by a wrapping plane that is a convex approximation of the analytical function determining the surface of aggregate. It is an iterative process where only the concave parts of analytical function are chosen and replaced. The radial base function called "Thin plate spline (TPS)" is used in the approximation process. Thereafter, the area of interest of assessed aggregate grain is divided into local areas with the concave course of analytical function. The values of wrapping function are calculated for all local concave areas. Finally, these are connected into the final approximation function that covers the assessed surface of aggregate. The stiffness of TPS function is optimized using null difference between the values of analytical function of aggregate surface and wrapping function part at the borderlines of the local concave areas. The result of this process is a wrapping plane of aggregate surface chosen for evaluation (Florková & Jambor, 2017).
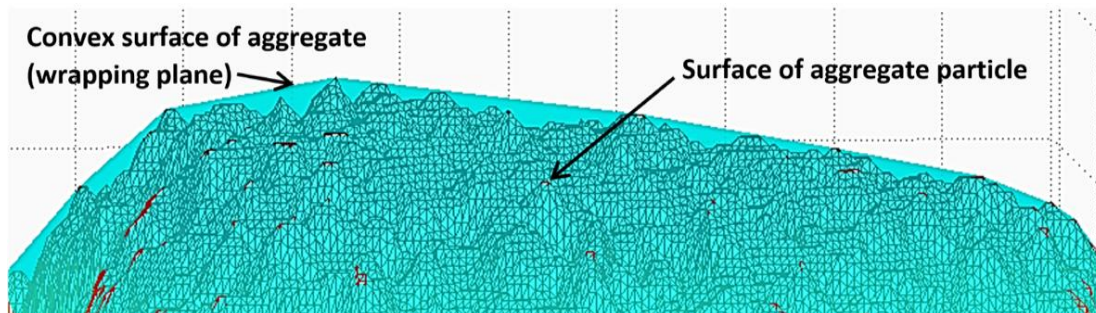

Figure 1. Illustration of convex and real aggregate surface in the three-dimensional model of aggregate grain

Then, volumetric difference between two planes (wrapping plane and aggregate surface) can be used as a parameter for evaluation of aggregate texture (Figure 1). This volumetric difference named as a volumetric parameter Zvd (Z - plane volume difference) determines aggregate texture value by percentage difference of two volumes calculated under the wrapping plane and the plane characterized the aggregate surface. The value of volumetric parameter Zvd relates to number of local concave areas and difference in height inside these ones. Lower values express a less propitious texture (small difference between the minimal value at a local area and the value at the borderline of a local area) and vice versa (Florková & Jambor, 2017).

2.2 Two-dimensional (2D) evaluation of aggregate texture

The contact profilometry device can be used for the aggregate texture quantification in the form of profile of aggregate surface. The obtained profile is then expressed by x and z coordinates.

Subsequently it is possible to used statistical texture parameters to evaluate of aggregate texture from obtained profiles. These parameters are generally used for evaluation of surface texture and are described in the Table 1. These statistical texture parameters (in detail described in (ISO, 1997 A; ISO, 1997 B)) characterized a group of evaluation parameters of profile which reflected basic description of asperities of profile and related with distribution of vertical coordinates of surface profile. The obtained profile of particulate aggregate grain captures also the shape of aggregate and thus the wavelengths and amplitudes that are out of the defined aggregate texture range (1µm – 0.5 mm (EN ISO, 2009)). For that reason, it is essential to filter these data before the evaluation.

Table 1.
Statistical texture parameters used for texture evaluation

Statistical parameters	Equation	Description of equation parameters
Mean arithmetic deviation of a profile Ra (µm)	$Ra = \frac{1}{n}\sum_{i=1}^{n}\lvert y_i - \bar{y}\rvert$ (1)	y_i = the individual values of the profile (µm)
Variance of profile σ^2 (µm)	$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2$ (2)	$\bar{y}$ = average value (µm) n = number of points
Root mean square Rq (µm)	$Rq = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}$ (3)	Rq = root mean square (µm) M1 = maximum profile value of first half of baseline (µm)
Skewness - asymmetry of the profile R_{sk} (-)	$Rsk = Rq^{-3}.\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^3$ (4)	M2 = maximum profile value of second half of baseline (µm)
Kurtosis R_{ku} (-)	$Rku = Rq^{-4}.\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^4$ (5)	PP = average profile value of second half of baseline (µm)
Mean profile depth MPD (µm)	$MPD = \frac{(M1+M2)}{2} - PP$ (6)	

The special algorithm was developed for calculation of texture statistical parameters in the work background of computing program and the calculation was performed in two parts. The primary profile obtained from the profilometry measurement was filtered to remove the wavelengths that are out of the defined aggregate texture range (1µm – 0.5 mm (EN ISO, 2009) and subsequently the statistical texture parameters were calculated from the filtered data. The filtration process is shown in the Figure 2.
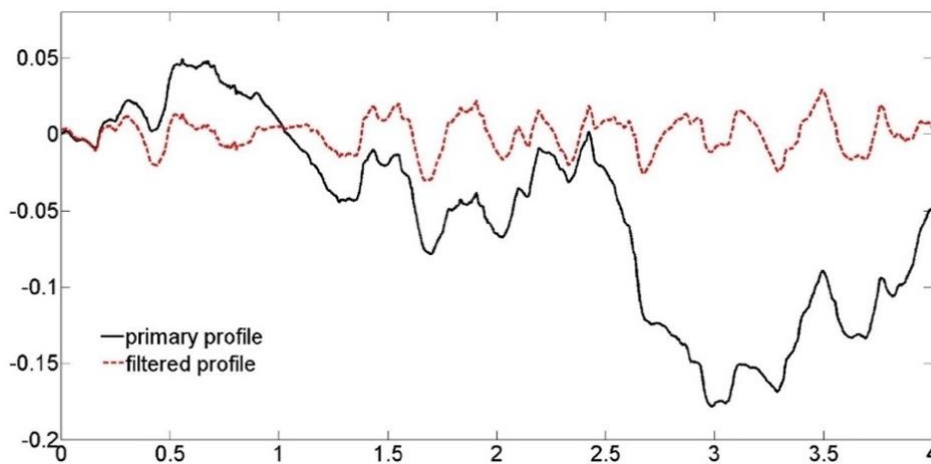

Figure 2. Filtration of profile

3. Results and discussion

In this part of article, the values of volumetric parameter Zvd obtained from measurement by microscope method were compared with the values of the statistical texture parameters obtained from measurements by profilometry device.

The measurements by both of presented methods were carried out on aggregate samples taken from eleven different quarries in Slovak republic and two aggregate fractions 4/8 and 8/11 taken from each quarry were tested. The aggregates differed from level of texture. Six aggregate grains represents the sample of each quarry. The representative value of statistical texture parameters for each fraction from particular quarries was determined as a mean value from eighteen values obtained from individual profiles. The representative value of volumetric parameter Zvd for each fraction from particular quarries was determined as a mean value from six values of volumetric parameter Zvd determined on particular aggregate grains.

Statistical texture parameters represent a group of parameters of the profile evaluation based on the distribution of the vertical coordinates of the surface profile. The higher value of statistical texture parameter indicates the occurrence of higher asperities on the analysed profiles. The volume difference represented by the volumetric parameter Zvd relates to the number of local concave areas and difference in height inside these ones. The higher values represent a high difference between the minimal value at a local area and the value at the boundary of a local area and thus more suitable aggregate texture. In a simplified way, it is possible to argue that the volume difference and the area under which the volume is calculated are defined the depth of the texture.

Based on the above, it is clear that all of these parameters (volumetric parameter Zvd and statistical texture parameters) give information about texture depth and therefore can be compared to each other (microscope measurements and profilometry measurements were performed on the same grains).

The relation between the volumetric parameter Zvd and statistical texture parameters was expressed using a linear function. The results of the comparison are shown in the Table 2 by the coefficient of determination and coefficient of correlation.

Table 2.
Characteristics of regression and correlation analysis

Parameter		*Ra*	σ^2	*Rq*	*RMS*	*MPD*	*Rsk*	*Rku*
Coefficient of correlation r	Fraction 4/8	0.133	0.157	0.119	0.119	0.069	0.501	0.117
	Fraction 8/11	0.704	0.690	0.669	0.669	0.723	0.303	0.081
Coefficient of determination R^2	Fraction 4/8	0.018	0.025	0.014	0.014	0.005	0.251	0.014
	Fraction 8/11	0.495	0.477	0.448	0.448	0.522	0.092	0.007

It is obviously from data in the Table 2, there is no relevant relation between the amplitude parameters and the volumetric parameter Zvd. However, it is clear that the coefficients of determination for Ra, σ^2, Rq, RMS and MPD parameters (Table 1) are higher in the case of results determined on fraction 8/11, compared to the values determined for fraction 4/8. It could be influenced by the aggregate grain size. The grain sizes of aggregates of fraction 8/11 are larger and thus the larger area of aggregate surface is entered into the resultant evaluation (compared to grains of fraction 4/8). Whereas in the case of microscope measurements, the scanning area is the same for both fractions 4/8 and 8/11 (scanning with the same total magnification for both fractions). By reason of lucidity, the Figure 3 shows relation of the values of volumetric parameter Zvd only with the values of statistical texture parameters Ra and MPD.
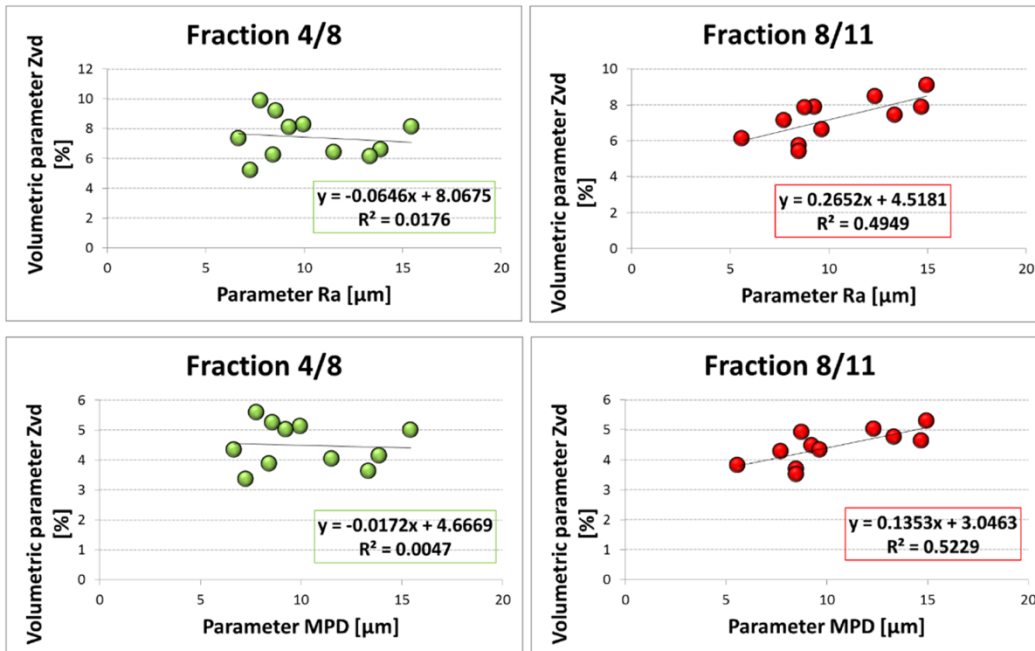
Figure 3. Comparison of the values of volumetric parameter Zvd with the values of statistical texture parameters Ra and MPD – fractions 4/8 and 8/11

The low coefficient of determination between volumetric parameter Zvd and Rsk and Rku parameters for the 8/11 fraction compared to other statistical texture parameters can related with characterization of this parameters. Whereas statistical texture parameters *Ra*, *Rq*, σ^2 and *MPD* characterizes asperities of profile by mean values of profile heights, the Rsk and Rku parameters characterizes the texture indirectly by the symmetry of the profile heights on the mean line (Rsk) and by the probability density sharpness of the profile (Rku). Relation of values of the volumetric parameter Zvd with the values of statistical texture parameters Rsk and Rku is shown in following Figure 4.
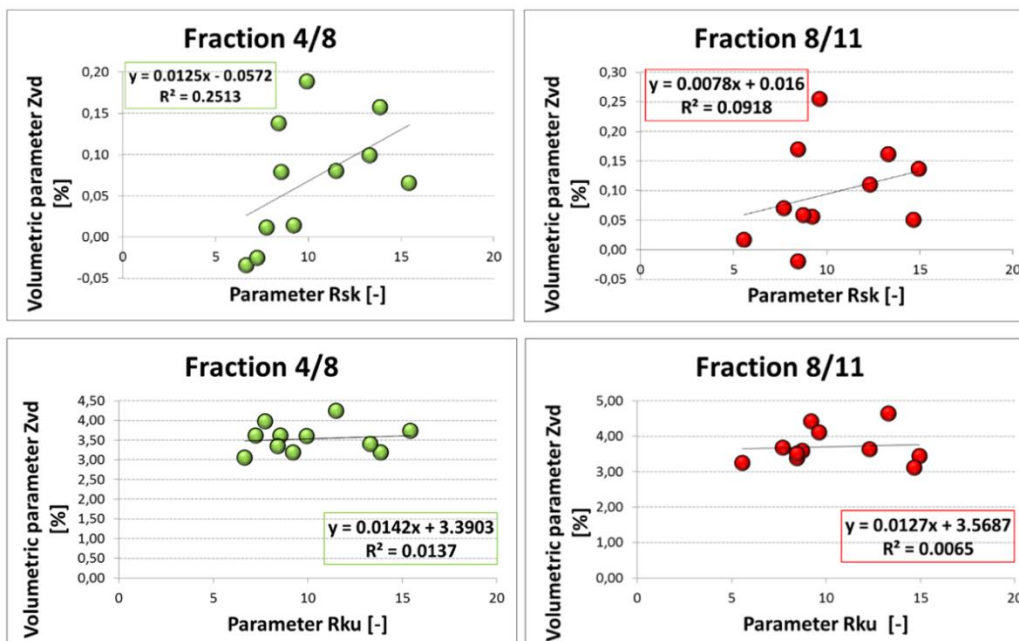

Figure 4: Comparison of the values of volumetric parameter Zvd with the values of statistical texture parameters Rsk and Rku – fractions 4/8 and 8/11

The above described results of comparison can be affected mainly by the low total scanning magnification. The outputs obtained by micorsocpe measuurement with total magnification 12,5 included entire surface of invetigated aggregate and thus besides of texture information can included also information about shape of invetigated aggregtae grains. Whereas in the evaluation process based on the profiles investigation are primarry otputs filtered to remove the wavelengths that are out of the defined texture range.

4. Conclusions

The paper deals with comparison of aggregate texture evaluation approach based on 3D image analysis and 2D profile based evaluation. The microscope method uses 3D image analysis to aggregate texture evaluation by the volumetric parameter Zvd. This parameters was determined as a volumetric difference between two planes (wrapping plane and aggregate surface). The profilometry method uses the statistical texture parameters to aggregate texture evaluation and the filtration approach was used in calculation process. The microscope measurements and the profilometry measurements were performed on the same grains and results obtained from both methods were compared. The obtained results have shown, that there is no relevant relation between the volumetric parameter Zvd and the statistical texture parameters, but there are some differences between comparisons of fractions. The coefficients of determination were higher in the case of results determined for fraction 8/11 compared to the values determined for fraction 4/8. In general, the results of comparison can probably related with low resultant magnification by microscope measurements. In case of measurements with the total magnification of 12.5 each aggregate grain has different size and thus always different surface area enters in the evaluation. It causes that basic input entering in the resultant evaluation is always different especially when fractions 4/8 and 8/11 are compared. Another problem is that, the outputs obtained by microscope measurement with lower total magnification can included also information about shape of investigated aggregate grains.

For the purpose of obtaining relevant information form this comparison, it is necessary to carry out new measurement by microscope method. It is needed practise measurements with higher total magnification because of with increasing of total magnification is decreasing the size of scanning area. The depth of focus is also decreasing with increasing of total magnification and it also leads to removing the wavelengths that are out of the defined texture range because of higher accuracy of scanning resolution.

Acknowledgment

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