

Investigation of Impact of Aggregate Coating by Bitumen on Change of Micro Texture Values

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ABSTRACT

Asphalt pavement micro texture values primarily depend on aggregate properties used in asphalt pavement mixture and by aggregate surfaces is secured the basic contact medium with vehicle tires. It often happens that new asphalt surfaces have not required skid resistance properties and is needed a certain period of time to eliminate film of bitumen binder which is coating the aggregate grain on the surface of pavement by action of vehicles. In most cases, the investigation of the aggregate micro texture impact on the pavement skid resistance properties is carried out under laboratory conditions and generally relates only to measurements on natural aggregate samples (without bitumen). However, due to coating of aggregate by bitumen binder, valleys between the individual peaks of aggregate are filled. Obviously, it can be supposed that the usage of high amount of bitumen content can leads to decreasing of aggregate micro texture values. From this point of view, it can be expected that change in micro texture values depends on the content of binder in the asphalt mixture. Particular aggregate grains were taken from asphalt mixtures samples (AC 8, AC 11 and SMA 11) produced in the laboratory, in order to determine the impact of aggregate coating by bitumen binder on micro texture change. Each usage asphalt mixture was produced with three different bitumen binder contents. Digital image analysis method was used for subsequent evaluation. Changes in the micro texture values depending on the amount of used bitumen binder and also on the calculated theoretical bitumen film thickness are investigated in the conclusion.

1. Introduction

Asphalt pavement micro texture ensures elementary friction level between tire and pavement and thus, has the significant influence on the skid resistance properties of asphalt pavement. From the geometric point of view is micro texture defined (EN ISO, 2009) as a configuration of small peaks, valleys and irregularities on the surface of aggregates used in asphalt pavement mixture. According to the National Academies of Sciences, Engineering, and Medicine (2009) micro texture values are primarily influenced by aggregate properties and in high extent, depends on structure of asphalt mixture either maximum grain size, amount of fine aggregates or content and type of bitumen.

The designed bitumen content of the mixture in relation to the specific surface area of the aggregate determines the quality and durability of the asphalt layer. Studies by several authors (Hmoud, 2011; Reyes, 2003; Roberts et al., 1996) have shown, that the asphalt mixture durability is directly related to the thickness of the bitumen film coating the aggregate grains

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and they also concluded that the film thickness decreases as the surface area of the aggregate is increased.

Kandhal et.al (1998) in the review described that asphalt mixtures produced with large surface area of the aggregate and low amount of bitumen content had a thin bitumen binder film and do not had sufficient durability. These mixtures are susceptible to cracking and scouring. Studies (Kandhal & Chakraborty, 1996) of long and short-term binder aging have shown that the thickness of the binder film significantly affects the binder aging process, which has a marked influence on the service life of the asphalt pavement. As the binder content of the mixture increases, the thickness of the film on the aggregate grains is increased and it leads to increasing the durability of the asphalt mixture.

Due to coating of aggregate by bitumen binder, valleys between the individual peaks of aggregate are filled. From this point of view, it can be expected that change in micro texture values depends on the content of binder in the asphalt mixture.

In the case of new asphalt pavement surfaces, it is generally known that they have not the required skid resistance properties and is needed a certain period of time to eliminate film of bitumen binder which is coating the aggregate grain on the surface of pavement by action of vehicles. The time required for the bitumen to be abraded from the aggregate at the road surface depends on a number of factors, including the type of mixture and, in particular, the thickness of the bitumen film on the grains of aggregate. Until the latter has been removed by traffic, the microtexture of the aggregate will not be fully exposed to vehicle tyres. Subsequently, the exposed aggregate surfaces become polished and, within a year, the skid resistance normally falls to an equilibrium level (PeiZhong, 2015) (Figure 1).

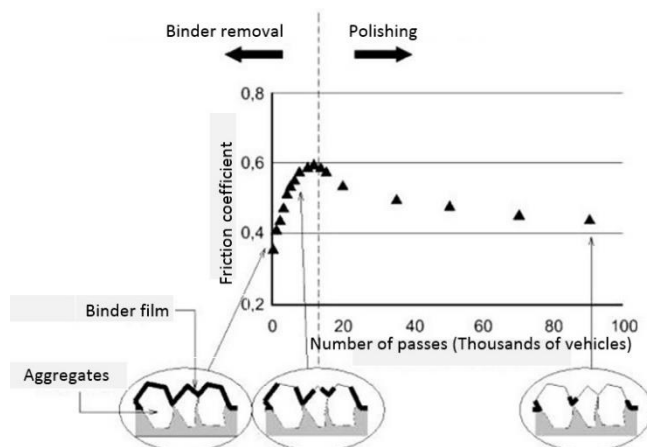


Figure 1. The changes of skid resistance properties of asphalt pavement due to traffic loading (Source: Do, 2009; Kane, 2018)

A lot of different approaches of micro texture evaluation methods have been developed and numerous measurement techniques have been developed for its quantifying. The possibility to direct measurement of the entire micro texture range of the surface on pavements in service is still problematic because of the laser scanning resolution and optical illusion (Li, 2010; Mičechová, 2019; Dudak, 2018). In most cases, the investigation of the impact of micro texture on skid resistance properties is carried out under laboratory conditions and generally relates only to measurements on samples of natural aggregates without bitumen. However, as is mentioned above due to the coating of aggregate grains by bitumen binder, valleys between the individual peaks of aggregate are filled because of reduced skid resistance values of new asphalt pavement surfaces. Here comes the question, how the amount of binder (bitumen content) in the asphalt mixture affects changes in the micro texture values and the associated changes in the skid resistance values of the asphalt pavement surface.

2. Methods

2.1. Investigated aggregate

Particular aggregate grains were taken from three samples of asphalt mixtures produced in the laboratory - AC 8, AC 11 (asphalt concrete), and SMA 11 (stone mastic asphalt), in order to determine the impact of aggregate coating by bitumen binder on micro texture change. Asphalt mixtures AC 11 and SMA 11 were produced with usage of bitumen binder PmB 45/80-75 and AC 8 asphalt mixture was produced with usage of bitumen binder CA 50/70. Each of these asphalt mixtures was produced with three different bitumen contents. The overview is done in following table (Table 1). All types of aggregates used in these mixtures were produced in the same quarry. Ten aggregate grains were used in each group representing by asphalt mixture and bitumen content.

Table 1.

Bitumen content of usage asphalt mixtures

Asphalt mixture	Bitumen content [%]
AC 8	5.3
	5.6
	5.9
AC 11	5.2
	5.5
	5.8
SMA 11	6.4
	6.7
	7.0

2.2. Measurement and evaluation process

It is possible to scan a grain of aggregate by an optical microscope. On the basis of the appropriate software of microscope it is possible to achieve a 3D view of investigated aggregate. The evaluation method was developed in the working background of Matlab program for the purpose of quantification aggregate microtexture. This method allows microtexture evaluation by volumetric parameter Zvd (Z - plane volume difference). This method uses, the 3D model as a basic input in wrml format obtained by microscope measurement (Figure 2).

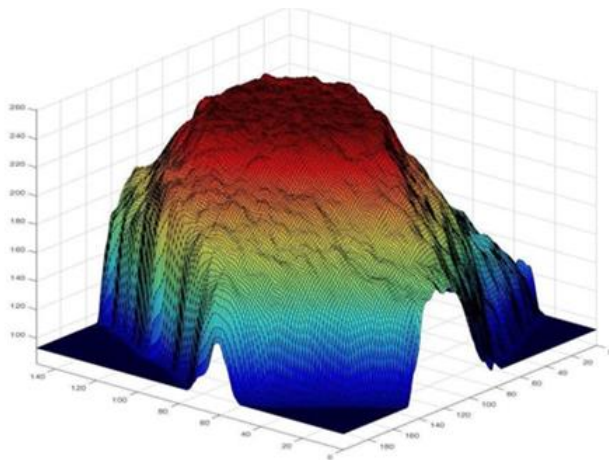


Figure 2. Optical microscope output – 3D model of aggregate grain

The basic principle of this method is in determination of volume between particular peaks on the aggregate surface. In principle, it is a volume between “real” and convex surface of

aggregate grain. Then, this volume presented microtexture of aggregate grain and is determined by parameter Zvd (Z - plane volume difference). It is a volumetric microtexture evaluating parameter which determines aggregate microtexture value by percentage difference of two volumes. The particular volumes are calculated from the defined comparative plane. First volume is determined as the volume of the aggregate grain and the second volume is determined as the volume of wrap (volume under the wrapping plane) (Figure 3). Then, smaller value of Zvd parameter defines lower suitable microtexture and vice versa. That, higher value of Zvd parameter defines angular aggregate with more peaks on the aggregate surface in comparison to polished or rounded aggregate. For more simply and practically calculation of Zvd parameter was developed the program MicoSYS. This program allows evaluation of aggregate microtexture only a selected part of aggregate grain by options of height adjustment of comparative (cutting) plane in the Z-axis direction. The principle of used evaluation method, determination of Zvd parameter and program MicroSyS are in detail described in Florková and Jambor (2017).

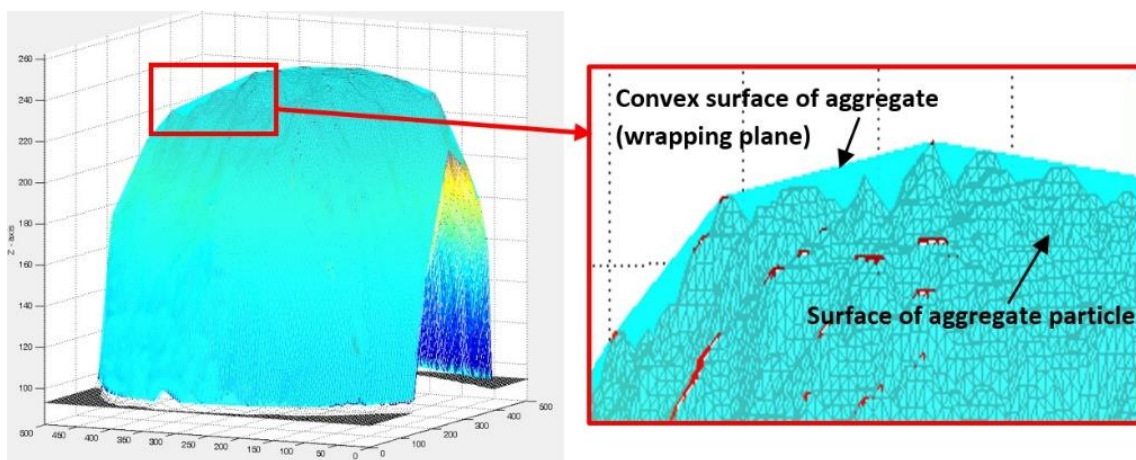


Figure 3. “Real” and convex surface of aggregate grain

Outputs in the 3D form of investigated aggregate grains taken from three asphalt mixtures AC 8, AC 11 (asphalt concrete), SMA 11 (stone mastic asphalt) were obtained by optical microscope scanning. The measurements were carried out in two parts. Firstly, the aggregate grains coated by bitumen binder were scanned. In the second step, the bitumen binder was cleared. The clear aggregate grains (i.e. aggregate grain without bitumen binder) were scanned in the same position on the microscope stage as the coated aggregates. The measurement process was the same in the case of all scanning aggregates and was performed with the total magnification of 12.5 for the purpose of capturing the largest surface area of scanned aggregate. This magnification represents accuracy 57 μm in x-axis and y-axis direction (in relation to dimensions of scanned area). The scanning range was divided into 400 steps. It represents 10-30 μm accuracy in z-axis direction (in relation to aggregate height). Thereafter, the MicroSYS program was used to calculate value of microtexture volumetric parameter Zvd for each tested aggregate grain. The position of the comparative plane was chosen in the same position for all aggregate grains to have comparable results.

Ten aggregate grains were used in each group representing by asphalt mixture and bitumen content. The determined differences in volumes were transformed to differences in percentage of volume.

3. Results and Discussion

The main purpose of presented evaluation was to determine the microtexture change due to coating aggregate grains by bituminous binder. Taking into account that, the basic parameter

for the evaluation was determined as a microtexture change value (MCV in table), microtexture change value was calculated as a difference of values of volumetric parameter Zvd between coated and clear aggregates. The average value of microtexture change value (MCV in table) was calculated for each sample and used for next comparison. Average values of volumetric parameter Zvd determined as an average value of ten values measured on particular aggregate grains are presented in the following table (Table 2). Based on these values, the relation between bitumen content and average value of microtexture change value was investigated.

Table 2.

Values of volumetric parameter Zvd for coated and clear aggregate grains and determination of average value of microtexture change value (MCV)

Bitumen content			5.3 %			5.6 %			5.9 %		
AC 8	Coated	Clear	Difference	Coated	Clear	Difference	Coated	Clear	Difference		
	Zvd	Zvd	MCV	Zvd	Zvd	MCV	Zvd	Zvd	MCV		
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		
Average value	6.54	7.88	1.34	8.09	8.50	0.41	7.97	9.91	1.94		
Bitumen content			5.2 %			5.5 %			5.8 %		
AC11	Coated	Clear	Difference	Coated	Clear	Difference	Coated	Clear	Difference		
	Zvd	Zvd	MCV	Zvd	Zvd	MCV	Zvd	Zvd	MCV		
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		
Average value	4.85	5.87	1.02	5.10	6.93	1.83	4.04	4.99	0.95		
Bitumen content			6.4 %			6.7 %			7.0 %		
SMA11	Coated	Clear	Difference	Coated	Clear	Difference	Coated	Clear	Difference		
	Zvd	Zvd	MCV	Zvd	Zvd	MCV	Zvd	Zvd	MCV		
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		
Average value	6.30	6.86	0.56	6.63	7.09	0.46	4.20	5.86	1.66		

By reason of lucidity, the following figure (Figure 4) shows only some values of volumetric parameter values Zvd of coated and clean aggregate grains, but it is sufficient for illustration of values difference within investigated grains. In the figure, the difference between the individual columns represents the micro texture change for particular aggregate grains.

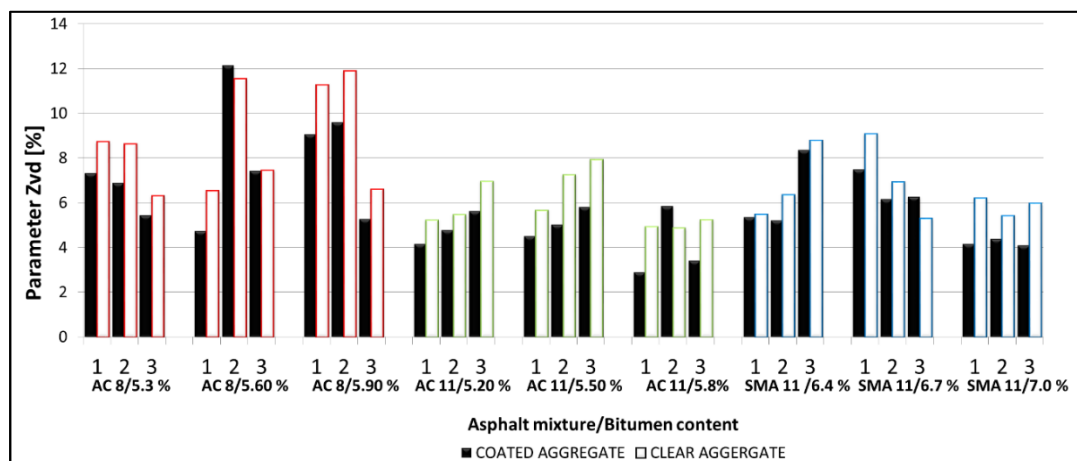


Figure 4. Comparison of parameter Zvd values of coated and clear aggregates for some measured aggregate grains.

It is evident in Figure 4, that higher values of parameter Zvd (i.e. higher values of micro texture) were observed for clear aggregates. Account on that, it can be argue, the decreasing of microtexture values occurs due to coating of aggregate by bituminous binder. It can be seen also from the comparison of the obtained 3D microscope outputs in Figure 5. In this Figure 5,

it can be clearly seen (red) that the area between the particular peaks has been filled with bitumen binder.

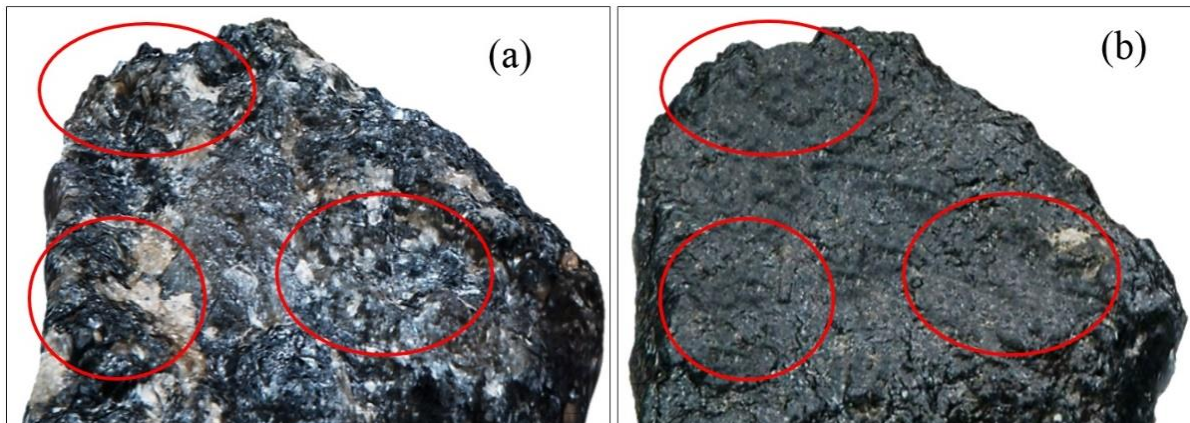


Figure 5. Decrease (red) of micro texture values due to coating of aggregate by bituminous binder, (a): clear aggregate, (b) coated aggregate

As can be seen also in Figure 6, only in the cases of tree aggregates (AC 8/5.6 % - grain 2, AC 11/5.8 % - grain 2 and SMA 11/6.7 % - grain 3) are the micro texture values of clear aggregates higher than the micro texture values of coated aggregates. It related probably to uneven accumulation of bitumen and to affixing of fine grains on the edges of coarse aggregate grain by production process of mixture. It can lead to creation of a new peaks on the edges of aggregate grain and then to higher micro texture values determined by method presented in this article. It can be seen also from the comparison of the obtained 3D microscope outputs in figure 6 (red). In Figure 6 it can be also seen that the area between the particular peaks has been filled with bitumen binder (green).

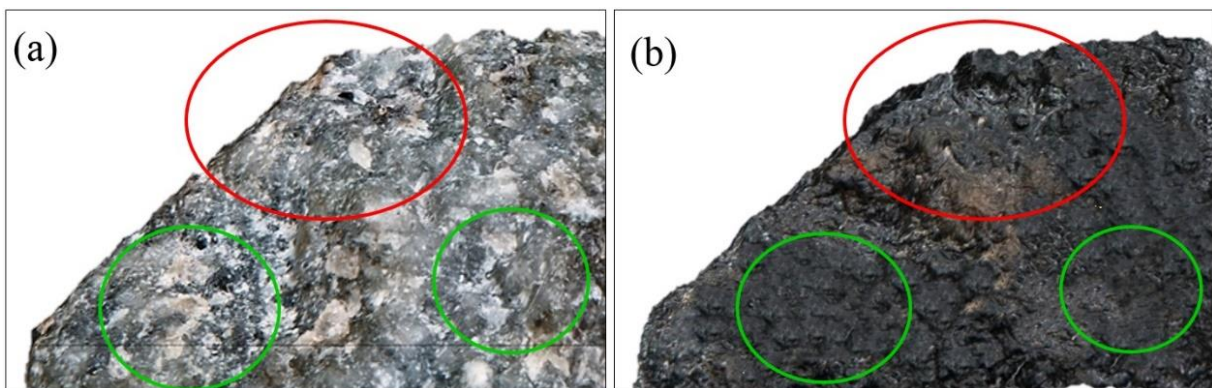


Figure 6. Increase (red) of micro texture values due to coating of aggregate by bituminous binder, (a): clear aggregate (b) coated aggregate

It should be noted that, all results can be influenced also by measurement errors (different reflection or variance light conditions) because of optical microscope method, mainly in the case of coated (black) aggregate. In spite of equal measurement and evaluation conditions, another reason can be probably related with total magnification of 12.5. As noted previously, this magnification represents accuracy 57 μm in x-axis and y-axis direction and 10-30 μm accuracy in z-axis direction (in relation to aggregate height). It can lead to the lack of micro texture information by usage a low microscope scanning magnification.

The comparison of the average micro texture values (volumetric parameter Z_vD) between coated and clear aggregates for each sample (represented by asphalt mixture and bitumen

content) can be found in Figure 7. It is obviously, as is mentioned above, the degradation of micro texture values occurs due to coating of aggregate by bituminous binder for each evaluated sample.

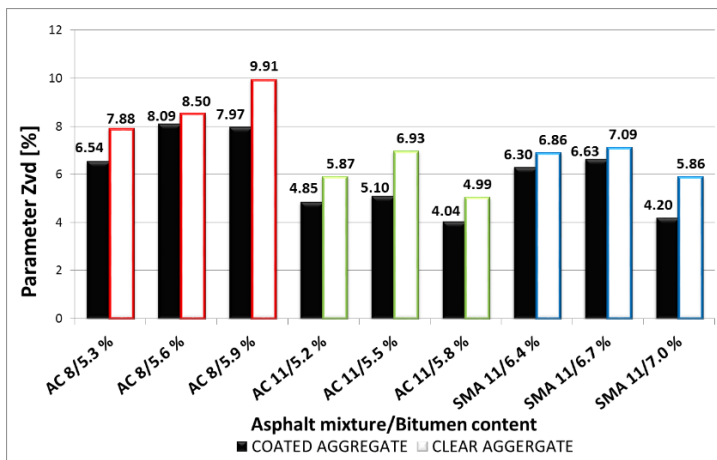


Figure 7. Comparison of the average values of parameter Zvd (microtexture values) between coated and clear aggregates for each mixture sample

Data in Figure 7 shows that the microtexture change value due to coating aggregate grain by bituminous binder is characterized by the difference of microtexture values between coated and clear aggregates. The average values of microtexture change (Figure 8) were calculated for each mixture sample and used for next comparison. Based on these values, the relation between bitumen content, the calculated theoretical bitumen film thickness and average value of microtexture change was investigated (Table 3).

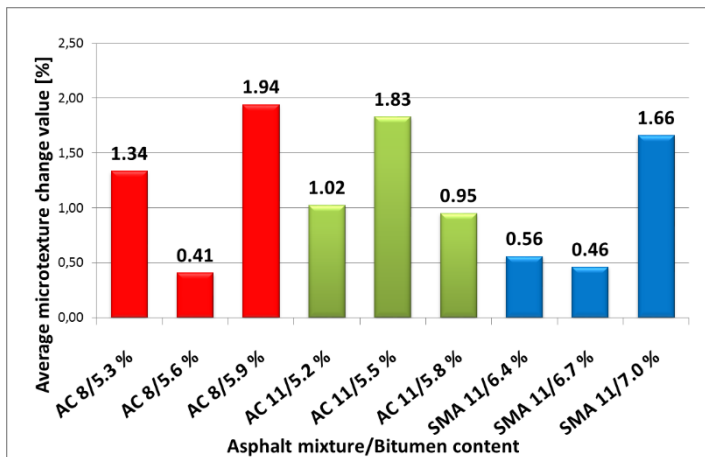


Figure 8. Average value of microtexture change for each evaluated mixture sample

The bitumen film thickness is a function of the bitumen binder content in the asphalt mixture and the specific surface area of the aggregates. A method to calculate the bitumen binder film thickness of an asphalt mixture, based on the surface area factors, was developed by Hveem (ASTM, 1992). The following formula was used to calculate the theoretical bitumen binder film thickness (Hunter et al., 2015; Hmoud, 2011; Reyes, 2003; Roberts et al., 1996).

$$T = \frac{b_b}{100 - b_b} \cdot \frac{1}{\rho_b} \cdot \frac{1}{SA} \quad (1)$$

Where:

- T - theoretical bitumen film thickness (m),
 ρ_b - density of bitumen (kg/m^3),
 SA - specific surface area of the aggregate (m^2/kg), according to (BSI, 2003)
 b_b - bitumen content (%).

Table 3, summarizes a calculated values of theoretical bitumen film thickness and also bitumen content, specific surface area of the aggregate and average value of microtexture change for each investigated mixture sample.

Table 3.

Calculated values of theoretical bitumen film thickness and average value of microtexture change

Asphalt mixture	Bitumen content (%)	Specific surface area of the aggregate (m^2/kg)	Theoretical average film thickness (microns)	Average value of microtexture change (%)
AC 8	5.3	11.205	5.00	1.34
	5.6		5.29	0.41
	5.9		5.60	1.94
AC 11	5.2	13.265	4.14	1.02
	5.5		4.39	1.83
	5.8		4.64	0.95
SMA 11	6.4	14.9500	4.57	0.56
	6.7		4.80	0.46
	7.0		5.03	1.66

It is obviously from data presented in the Table 3 and the Figure 8, there is no relevant relation between the bitumen content (thus also theoretical average film thickness) and the average value of microtexture change. Possible cause can be a low number of grains (ten) representing of investigated mixture samples and therefore these results cannot be confirmed certainly. As mentioned above, the results can be influenced also by measurement errors because of optical microscope method.

4. Conclusion

The article deals with the analysis of impact of aggregate coating by bitumen on microtexture change. Measurements by optical microscope method and subsequent evaluation by volumetric parameter Zvd were performed on aggregate grains with and without bitumen in order to obtain the value of microtexture change by coating of the aggregate by bitumen. Aggregate grains were taken from three asphalt mixtures AC 8, AC 11 (asphalt concrete), SMA 11 (stone mastic asphalt) produced with different bitumen contents. Based on the measured values, the relation between bitumen content, the calculated theoretical bitumen film thickness and average value of microtexture change was investigated.

The results have shown the differences between the microtexture values between coated and clear aggregate. The better microtexture values (i.e. higher values of volumetric parameter Zvd) were observed in the case of clear aggregates (i.e. aggregates without bitumen) for each evaluated sample. Therefore, it is possible to argue that, the degradation of microtexture values is occurs due to coating of aggregate by bituminous binder. It can be observed also by comparison of some 3D visual outputs obtained by the optical microscope, and thus the results of evaluation are also supported by visual comparison. On the basis of these comparison, it can

be stated that by used method it possible to distinguish the microtexture differences for samples of clean and coated aggregates grains.

It was also supposed that, the increasing amount of bituminous binder usage in mixture (and thus theoretical average film thickness) is connected to increasing of change of microtexture values. It means, when are the different of sizes aggregates coated by the same amount of bitumen binder, the difference in microtexture changes is expected. It stands to reason, that the smaller is size of aggregate grain, the higher is bitumen film thickness, which coated the aggregate grain and is expected that it leads to considerable degradation of microtexture values. The results have shown, there is no relevant relation between the bitumen binder content (thus also theoretical average film thickness) and the average value of microtexture change.

For the purpose of confirmation of impact of aggregate coating by bitumen on microtexture change additional and next test have to be carried out to extend the current database of results. It is also necessary to carry out measurements on a numerous aggregate grain and to carry out measurements on the asphalt mixture samples with very low, very high and optimum bitumen content in order to obtain sufficiently representative results.

However, question is, importance of this research problem because of relatively short period of time, to eliminate film of bitumen binder which is coating the aggregate grain on the surface of pavement by action of vehicles (Figure. 1). Appears, it is more applicable to investigate this relevance in terms of time, respectively the number of vehicles passes needed to expose the microtexture at the required level.

For the purpose to improve measurement accuracy by optical microscope scanning method it is necessary to set the constant light conditions during all measurement process. It can allow to eliminate measurement errors mainly in the case of coated (black) aggregate. It is necessary also take measurements with higher magnification because the accuracy of the obtained output depends on the size of scanning area thus on the required magnification. With increasing of magnification is decreasing the size of scanning area and also is decreasing the depth of focus. It leads to higher accuracy of scanning resolution and also to the constant scanning area of aggregate surface for the all investigates grains.

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