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The Influence of the mastic properties and grain geometry on the durability of porous asphalt

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Abstract

Porous Asphalt (PA) is characterized by its open structure. It is used for noise reduction and higher travelling comfort in rainy conditions. Alongside these benefits the service life of PA is shorter than other motorway surfaces which is caused by the clogging of the pores and ravelling. The open structure of the PA is created by the grain skeleton, which consists only of one grain class, and asphalt mastic. The mastic has the function to connect the grain skeleton without clogging the air voids. Therefore both components – grain skeleton and mastic – are of great significance in terms of durability. For this reason the grain skeleton, particularly the grain geometry, is under the focus of this research. To analyze the grain geometry a computer-based test method without laser scans is used. The results are compared with tests for geometrical properties of aggregates such as shape index (DIN EN 933-4). The grain shapes are also examined on the basis of sectional images of drill cores from asphalt test plates. In addition, the computer-based test method determines the distribution of the individual phases of the specimens. CT images are used to verify the results. Furthermore, the supporting component of porous asphalt – the mastic – is considered in this research. The composition of the mastic can have a major impact on ravelling, thus these mastic properties are considered in more detail. The mastic as well as the binder will be tested in the dynamic shear rheometer (DSR). One the one hand, they are tested in the virgin condition. On the other hand, they are claimed by different boundary conditions before testing. Results of the mastic properties and grain geometry should reveal a composition of PA, which provide a longer service life.

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1 INTRODUCTION

High demands are made on the cavity-rich structure of porous asphalt regarding durability. Due to the coarse single grain mix and the high void content of porous asphalt, there are less grain contact points in the finished wearing course than in dense asphalt wearing courses. In porous asphalt these grain contact points have to provide sufficient structural durability. By closer examination of these grain contact points, it becomes obvious that two components in particular have a major influence. On the one hand, the particle shape, because it influences the interlocking of the aggregate and thus also has a high impact on the void content. On the other hand, the mastic is of great importance because it connects the individual aggregates and thus gives the asphalt its stability. Additionally, the quantity of mastic is decisive for structural durability and the void content of the porous asphalt. Too little mastic content can promote substance loss in the form of ravelling, as the aggregate is not sufficiently bonded in this case and too much mastic reduces the void content, so that the acoustic properties of the porous asphalt will deteriorate.
Due to the low filler-bitumen ratio in porous asphalts the adhesion of the mastic is highly determined by the bitumen. The stiffness of mastic, however, can be influenced in addition to the bitumen by the type of filler. It is therefore advisable to have a closer look on these components regarding to the durability of porous asphalts.

2 EXAMINATION

The investigation programme can be divided into two sections. In the first section, the influence of the particle shape on durability of porous asphalt was investigated. While in the second section the influence of mastic was examined in more detail.

2.1 Photo-optical determination of the shape index of loose aggregates

The determination of the shape index SI according to [1] is a very time-consuming test in the laboratory, as every single aggregate has to be analysed individually by hand. Requirements for the shape index of porous asphalt in particular are even more stringent (SI = 10), so an alternative photo-optical analysis method should be considered. For this purpose, [2] developed a template on which an aggregate sample can be randomly distributed. The step height of the template was chosen in such a way that no step, from the fixed position of the camera (cf. figure 1), could conceal the aggregates behind it. For the image acquisition, an aggregate sample was randomly distributed three times on the template and photo-optically recorded. MATLAB® was used to develop a procedure (cf. figure 3) which enables the L/E ratios (grain length L; grain thickness E) of the individual aggregates to be analysed.

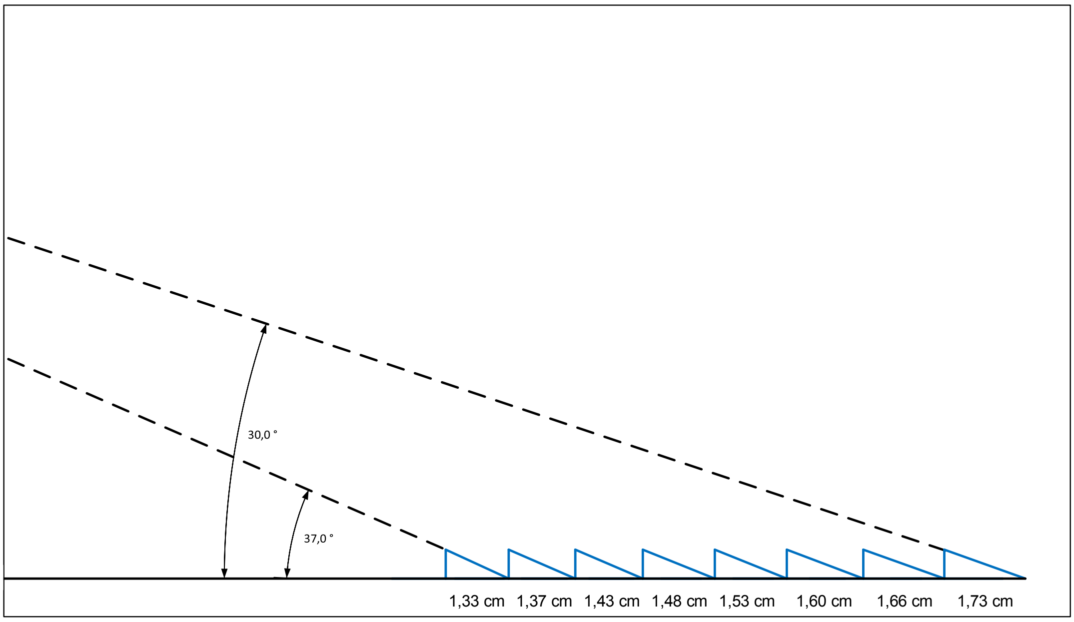

Figure 1: Template and visual axis of the camera, according to [2]

Greyish aggregate particle were placed on the red stencil to take the pictures and two green circles of known diameter were used as a scale. The recorded images of 8/11 mm grain size were divided into the L*a*b* colour spaces and the colour space a* was selected for further analysis based on the colours predominant in the images (cf. figure 2). The green and grey colour areas were each converted into a zero matrix, whereby the scale and the aggregates were separated. By eroding and dilating the images with the structural element "disc", small inaccuracies were eliminated. Finally, the function "regionprops" was used to determine the geometric properties, such as the length of the major and minor axis of the individual aggregates. With the help of these parameters the shape index could be calculated in a final step. This was determined from the area proportions of the aggregates with an L/E ratio > 3 related to the area of all particles.

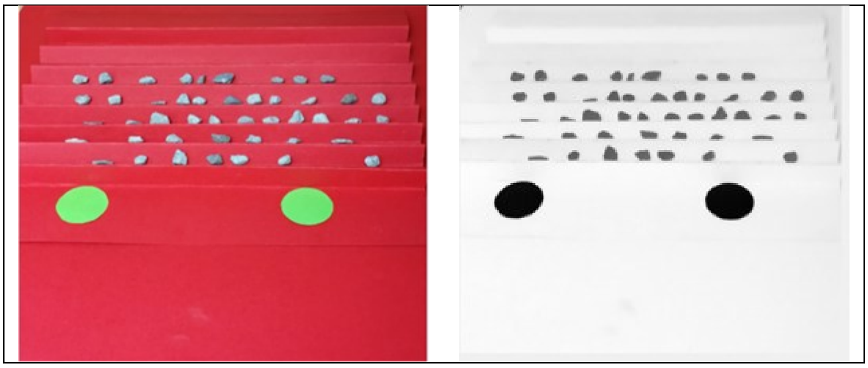

Figure 2: left: recorded image, right: the colour space a* [2]

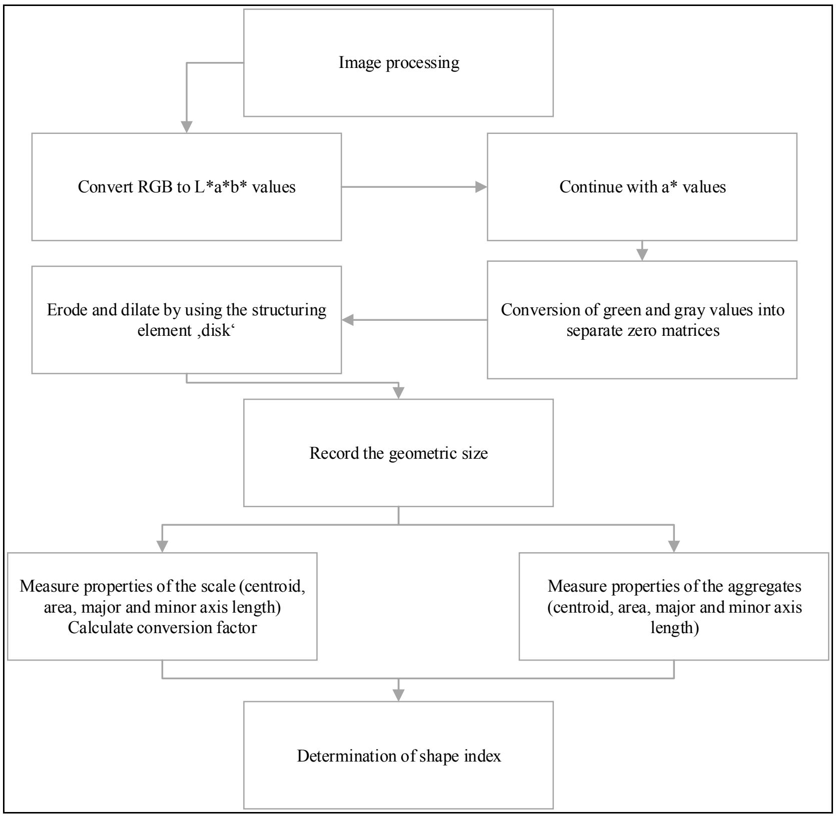

Figure 3: flowchart of the algorithm for determining the shape index of loose aggregates

2.2 Photo-optical determination of the shape index using sectional images

Photo-optical analyses of sectional images of asphalt specimens can be used to detect the aggregate's particle shape within. For this purpose, a method was also developed using MATLAB® to determine both shape index and L/E ratio of the individual aggregates in sectional images (cf. figure 4). In a first step, the contrast of the scanned images was increased so that they could be optimised using different filters. After the transformation into binary images, small holes were filled and then the objects too small and not clearly attributable to the aggregate were removed. In this way, the geometric properties of the aggregates could be recorded and the L/E ratios of individual aggregates and the shape index, analogous to the procedure in Section 2.1, could be determined.

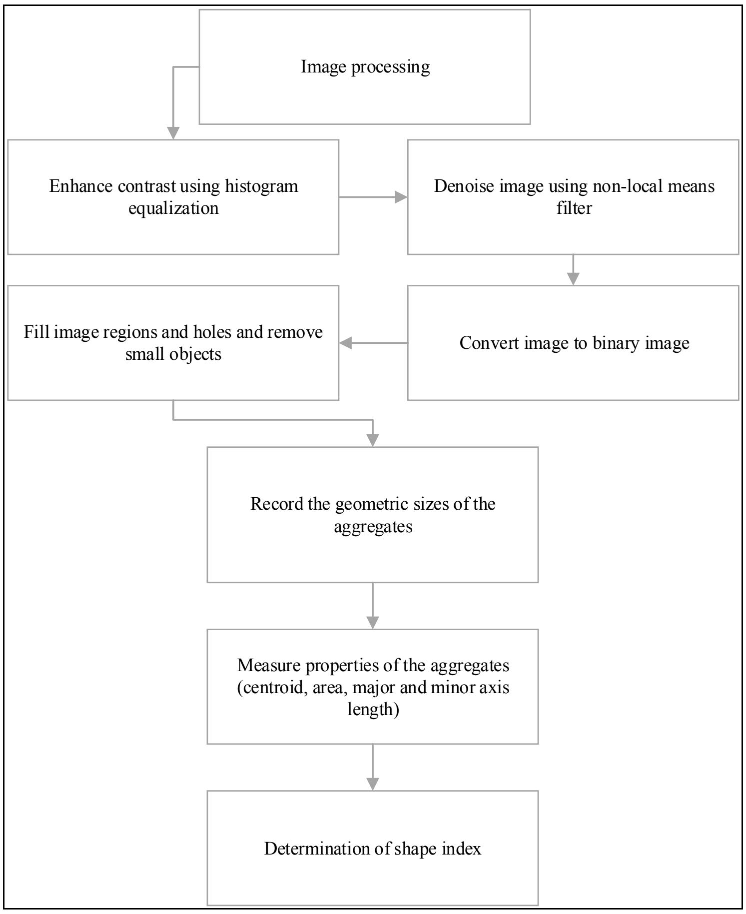

Figure 4: flowchart of the algorithm for determining the shape index from sectional images

2.3 Examinations of the influence of particle shape on durability

The influence of particle shape on the durability of porous asphalts was tested in laboratory tests. For this purpose, four mix designs were investigated for each maximum particle size (8 mm and 11 mm), each with three different particle shapes. The grain size distributions of the eight grading curve variants are shown in figure 5Figure . The grading curves were designed for investigations in the permissible grading curve range and partly beyond in order to present a large variance. In order to avoid further influencing components, all variants were manufactured with the same mastic.

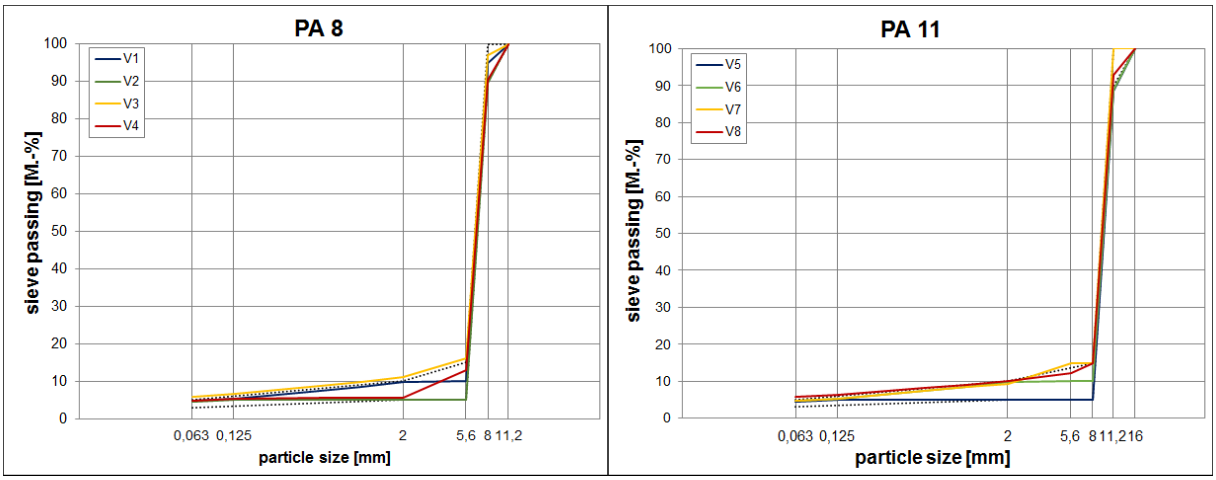

Figure 5: Grain size distributions of the PA 8 and PA 11 variants

Since not every aggregate particle could be analysed individually for the production of asphalt specimens, the flatness index FI according to [3] was used for the laboratory tests. Since the same requirements generally apply to both proceedings and the proceeding can be freely selected within the framework of the factory production control, a sufficient variation of the grain shape should also be ensured via the flatness index. The respective mixtures were produced with flatness indices FI of 0, 10 and 20. The influence of the particle shape on durability of porous mix compositions was examined on the basis of the particle loss PL of porous asphalt specimen according to [4]. Three Marshall Test specimens (MPK) per variant were individually placed in the Los Angeles device at a temperature of 22 °C ± 2 °C and removed again after 300 revolutions. Before and after the test the MPK were weighed and the particle loss was determined.

2.4 Examinations of the influence of mastic on durability

DSR temperature sweeps were carried out in order to assess the influence of mastic on the durability of porous asphalt. Therefore eight different binders in fresh and short-term aged (RTFOT) condition were used pure as and mixed in fresh condition with two different fillers (highly stiffening limestone and mixed). Due to the test temperature range between -10 °C and +30 °C, an 8 mm plate and a 3 mm gap was chosen for testing the mastic.
The influence of the mastic composition on the durability of the porous asphalt was also examined on the basis of the particle loss PL of test specimens (MPK). For this purpose, a PA 8 mixed material composition with a total of 16 different mastic compositions and a PA 11 mixed material composition with four mastic compositions were prepared and investigated.
Five polymer modified bitumen (PmB) (B1 and B3 to B6), two rubber modified bitumen ready for use (RmB R) (B7 and B8) and one rubber modified bitumen with granulate (RmB G) (B9) were combined with the high stiffness limestone filler and the mixed filler each.

3 RESULTS

3.1 Results of the photo-optical determination of the shape index

The determination of the shape index SI by means of photo-optical analysis shows very good correlation with the determination of the shape index according to [1] (see Table 1). With a maximum deviation of 1.6, the developed analysis method is a fast and well-suited alternative to the conventional method.

Table 1: Results of the two analytical methods used to determine the shape index

sample	shape index photo-optical [%]	shape index DIN EN 933-4 [%]	difference Δ [%]
1	11,5	11,2	0,3
2	15,8	16,3	0,5
3	20,7	21,1	0,4
4	36,6	37,6	1,0
5	19,6	19,8	0,2
6	26,2	27,2	1,0
7	16,2	17,8	1,6
8	10,2	9,8	0,4

The determination of the shape index on the basis of sectional images works sufficiently for the individual aggregate particles according to the method presented in Chapter 2.2. When looking at the results, some details must be critically questioned. As the sectional images do not capture the maximum geometric characteristics of the entire particle, the geometric characteristics depicted are those of the sectional image only. Therefore, they are only partial results and can only be regarded as the overall result of a test specimen with sufficient accuracy by the analysis of several sectional images of a test specimen. The analysis of the sectional image shown in figure 6 shows L/E ratios between 1.0 and 9.0 and a grain shape index of 3.68 for the 64 aggregate particles recorded.
To verify the analysis method, it was also tested on a CT scan (see figure 7). L/E ratios between 1.0 and 6.0 were measured in this analysis. The grain shape index is 3.15 for a sample size of 49 captured aggregate particles in the CT scan. When looking at the last processed image, however, it is noticeable that some particles are not clearly separated from each other, which can lead to inaccuracies in the analysis of the grain shape index.

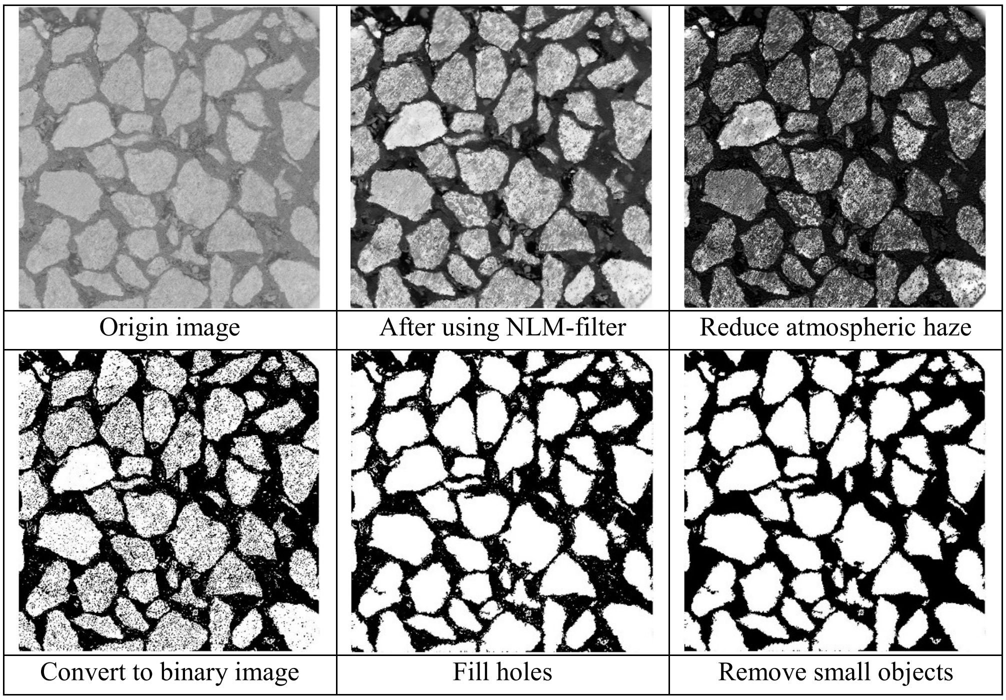

Figure 6: Process steps of image processing (sectional images)

Both in figure 6 and in figure 7 specimen with a maximum grain size of 11 mm were analysed, but not the same specimen. Therefore the results cannot be compared with each other. It should be shown however that with the presented analysis method the determination of the grain shape index is possible also on basis of different image capture.

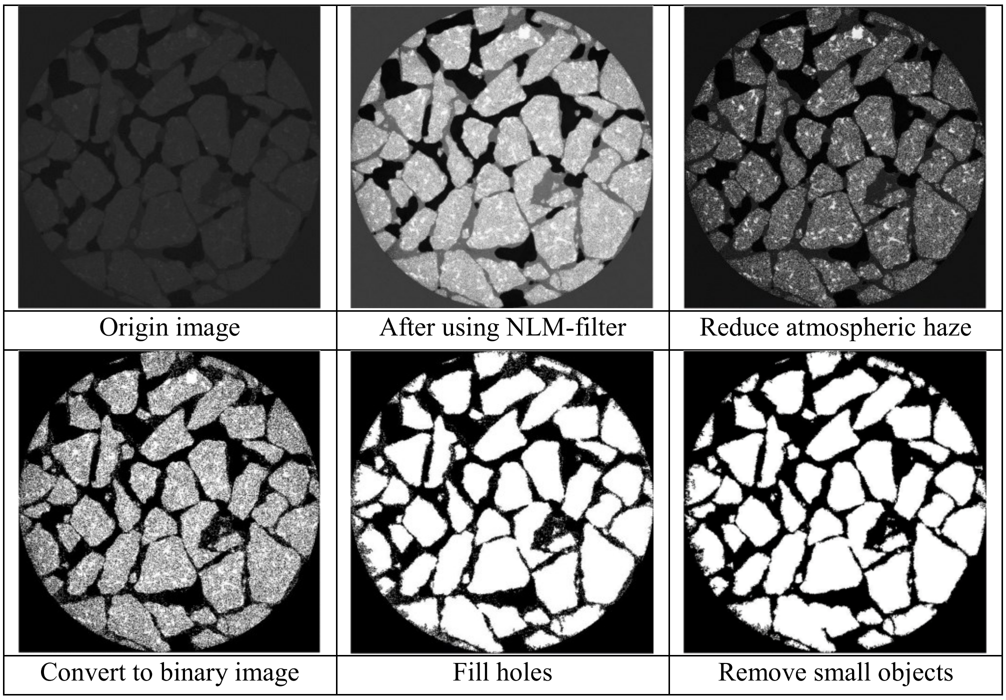

Figure 7: Process steps of image processing (CT scans)

3.2 Influence of grain shape on the durability of porous asphalts

Figure 8 shows the results of the investigations of the particle loss of porous asphalt test specimens. A direct relationship between flatness index and particle loss is not discernible in this series of investigations. Due to the different sieve curves of the individual variants, a comparison between the variants is not possible. However, even the order of the mass losses as a function of the flatness index within the individual variants does not allow the influence of the grain shape to be demonstrated.

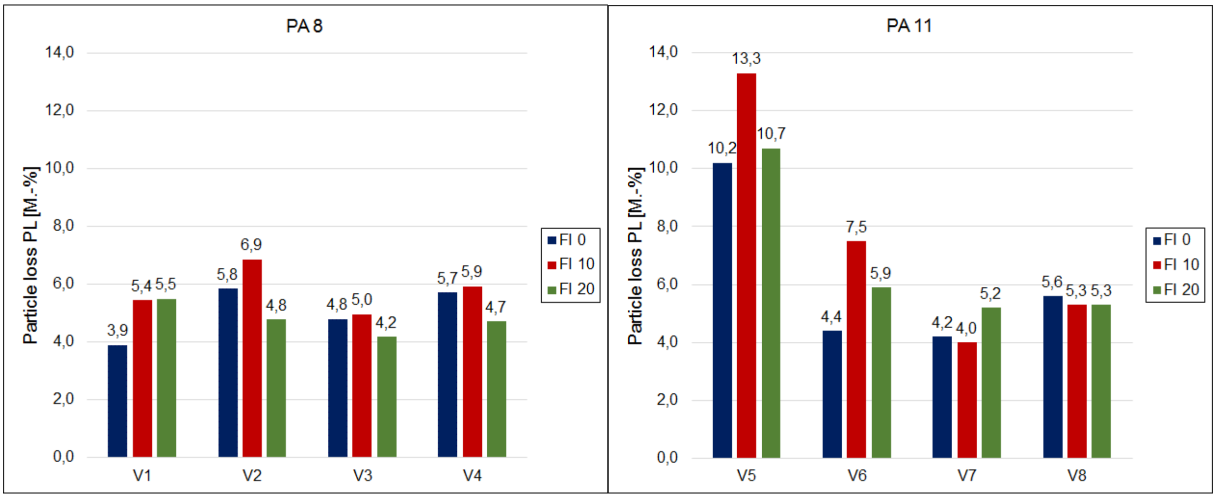

Figure 8: particle loss of PA 8 and PA 11 variants

3.3 Influence of mastic on the durability of porous asphalts

The composition of the mastic has a greater influence on particle loss than particle shape. The graphical representation (cf. figure 9) of particle losses shows clearer differences, especially between polymer modified bitumen (shown in blue) and rubber modified bitumen (shown in red/orange). Regardless of the maximum grain size, the particle losses of asphalt specimens with rubber-modified bitumen are significantly higher than those of variants with polymer-modified bitumen.

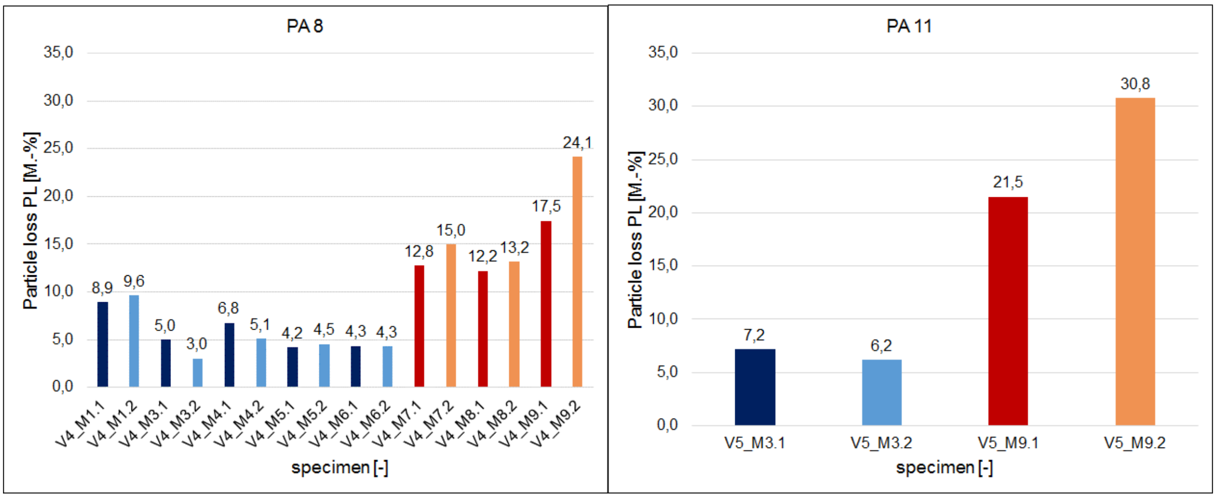

Figure 9: particle loss of PA 8 and PA 11 variants with different mastic

One reason for these differences lies in the different rheological properties of the bitumen and thus also of the mastic variants. At a phase angle of 45°, the elastic stiffness component (storage modulus) and the viscous stiffness component (loss modulus) are equal. At a phase angle higher than 45°, the loss modulus predominated, while lower than 45° the storage modulus is greater.

Figure 10 shows the particle losses of the PA 8 variants plotted against the shear moduli and against the phase angles of the mastic variants. The results of the DSR investigations on mastic in the fresh state show that the phase angles of the mastic variants lie between 40° and 62°. The variants with a phase angle of less than 45°, which additionally exhibit a particle loss of more than 10 M.-%, have been produced with RmB R. Two variants (one RmB R and one PmB variant) are located exactly in the limit range around 45° and cannot be evaluated solely with the aid of the phase angle. All other variants which have a phase angle greater than 45° and a grain loss of less than 10 M.-% at the same time are PmB variants. On the basis of the coefficient of determination of 0.70, the relationship between particle loss and phase angle of the mastic variants can be described as useful.

The rubber modified bitumen with granules (RmB G) was produced on the basis of a road bitumen 70/100. In the fresh state there are hardly any differences between the storage moduli of the road bitumen and the RmB G at 1.59 Hz in the temperature range around 20 °C. It can therefore be assumed that the properties of the rubber modification in these temperature range are not yet sufficiently effective or that the production process did not open up the crumb rubber properly. Due to this assumption, in this analysis the results of the RmB G were not taken into account.

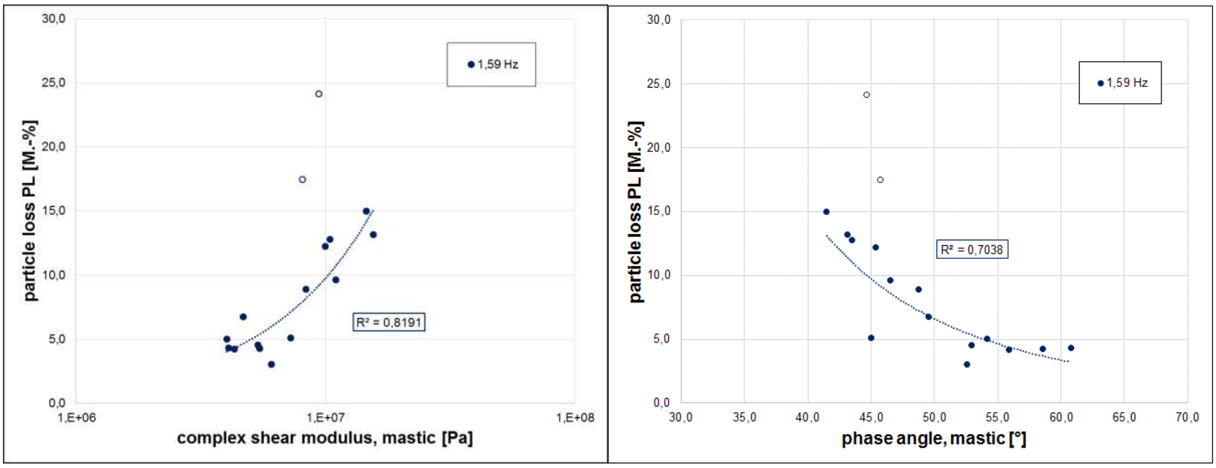

Figure 10: Correlation between particle loss (PA 8) and complex shear modulus (left) and phase angle (right) of mastic at T = 20 °C

With a coefficient of determination of 0.82, the relationship between particle loss and the complex shear modulus can also be described as good. For all mastic variants with a complex shear modulus below 10 MPa, a particle loss of less than 10 M.-% was measured when determining the grain loss. Four of the five variants with a complex shear modulus greater than 10 MPa were produced with RmB R.

Since the filler-to-bitumen ratio is less than 1.0, it could be concluded that the bitumen used has the greater influence on mastic stiffness as the filler. As shown in figure 11, higher stiffness's (complex shear moduli) are achieved by adding the highly stiffening filler, but there is a very good correlation between the bitumen and mastic stiffness. Therefore, in the next step a relationship between bitumen stiffness and particle loss was investigated.

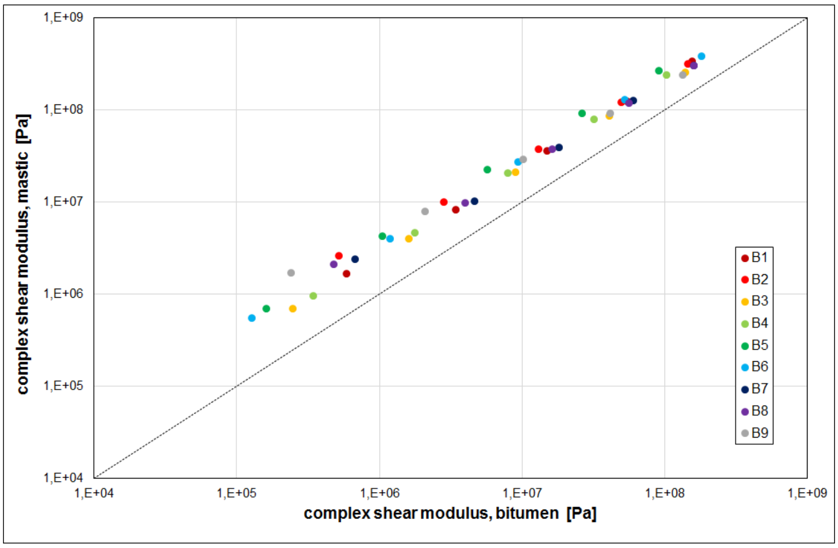

Figure 11: Correlation between complex shear modulus of bitumen and mastic

Figure 12 shows the correlation between particle losses of the MPK and the complex shear moduli (left) and phase angles (right) of the bitumen. For the production of the MPK only unaged not short-term aged bitumen were used. As RTFOT ageing is intended to simulate the condition of the bitumen after asphalt production, higher correlations were expected in this comparison. The correlation between particle loss and complex shear modulus of fresh bitumen is better in this comparison with a coefficient of determination of 0.93, but the comparison with complex shear modulus of short-term aged bitumen shows an even better correlation ($R^2 = 0.96$).

The limit of the complex shear modulus of the mastic of less than 10 MPa to achieve a particle loss of less than 10 M.-% must be corrected downwards in view of the correlations for pure bitumen shown in figure 11. For an unaged bitumen, the limit is approx. 3.4 MPa; after RTFOT aging of the bitumen, a maximum complex shear modulus of 4.3 MPa or less can achieve particle loss of less than 10 M.-%.

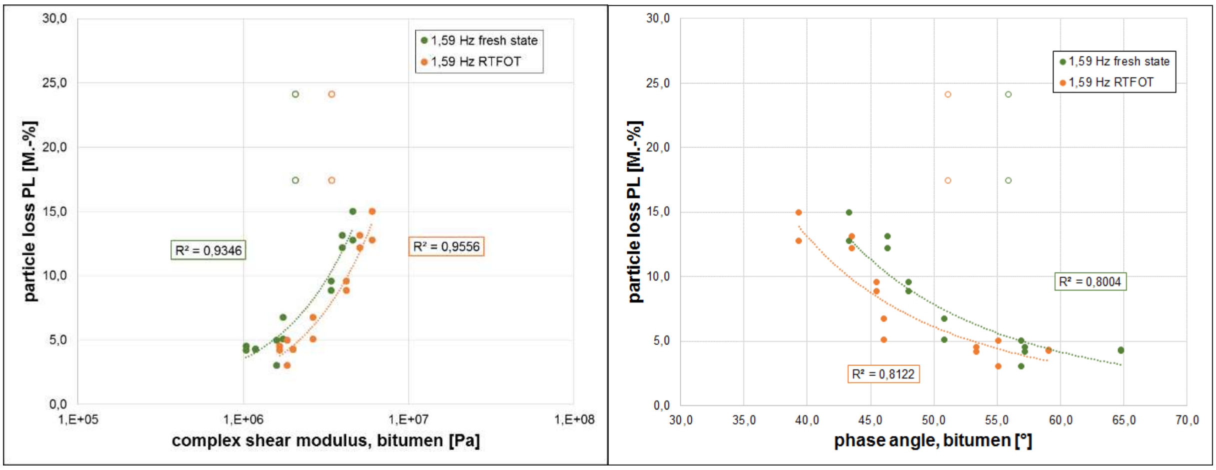

Figure 12: Correlation between particle loss (PA 8) and complex shear modulus (left) and phase angle (right) of bitumen at T = 20 °C

The correlations between particle loss and phase angle also improve when considering pure bitumen compared to the mastic results. The correlations between particle loss and phase angle also improve when considering pure bitumen compared to results for mastic (0.80 with unaged bitumen; 0.81 after RTFOT ageing compared to 0.70 with mastic). The criterion that the phase angle at a temperature of 20 °C should be greater than 45° in order to achieve a grain loss of less than 10 M.-% can be adopted for bitumen after RTFOT ageing.
Thus, the phase angle could be a criterion for determining the particle losses of the MPK on the basis of the rheological properties of the bitumen after RTFOT ageing. Further investigation is required for a final evaluation.
The investigation presented here shows that bitumen and therefore also mastic has a great influence on the durability of porous asphalt, while the particle shape has no obvious influence.

4 ACKNOWLEDGEMENTS

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The author is solely responsible for the content.

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