Analysis of morphology and composition with computed tomography exemplified at porous asphalt

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Abstract

X-ray computed tomography provides a powerful tool to analyse morphological information in porous materials like metallic foams. Additionally in some cases the composition can be quantified, which is performed exemplarily at porous asphalt pavement materials. In practice the dust infiltration is added to the 3-phase standard mixture of hot-rolled asphalt consisting of mineral, binder and air.

X-ray computed tomography measurements applied to open-pored noise reducing asphalt pavements will be presented. The results are completed with measurements of reproducibility and an estimation of uncertainty in the composition of the samples.

Keywords: Computed tomography, X-ray, morphology, bitumen, porous asphalt pavements

1. Introduction

The analysis of composition and morphology of multi component materials lays high demands on the applied method even if it is required that the evaluation is non-destructively. X-ray computed tomography (CT) could be such a method, but it has to be tested. As an example for a multi component material porous asphalt a special kind of hot-rolled asphalt for noise reducing pavements was selected. Hot-rolled asphalt for noise reducing pavements is an open graded mixture of coarse and fine aggregates, mineral filler and bitumen resp. polymer modified bitumen as binder. Background of the investigations are the use of porous asphalt as a material, which reduces traffic noise as well as aquaplaning. But under practical use this material can be infiltrated with dust, soil and other dirt-particles as additionally unrequested filler loosing its special noise-reducing performance. To evaluate the performance and durability of these porous asphalt pavements and to understand the procedures leading to loss of performance knowledge about morphology and composition is essential.

2. Experimental

2.1 Experimental set-up

The investigations are performed with a high-resolution tomograph developed at BAM. The differences to the recently described apparatus [1] are the replacement of the micro focus X-ray tube with a tube with enlarged maximum high voltage of 225 kV and an amorphous silicon based flat panel detector (PE XRD 1620 AM3) with 2048 x 2048 elements of (200 µm)^2. The scintillating material is Caesium Iodide. The detector is temperature stabilized to reduce the background noise. Fig. 1 shows the apparatus with the effective area of 40 x 40 cm^2, covered by a thermal insulating foil.

2.2 Samples

The samples are core samples with a diameter of 50 mm and a height of 40 mm, cut of porous asphalt plates of 60x130x40 mm^2 with jet cutting (Fig. 2). The open porous asphalt has a particle size fraction of 0/8 mm. One of the two plates was artificially infiltrated with dust. Additionally real samples after more than 10 years of practical use were analysed. An example is treated in section 3.2.

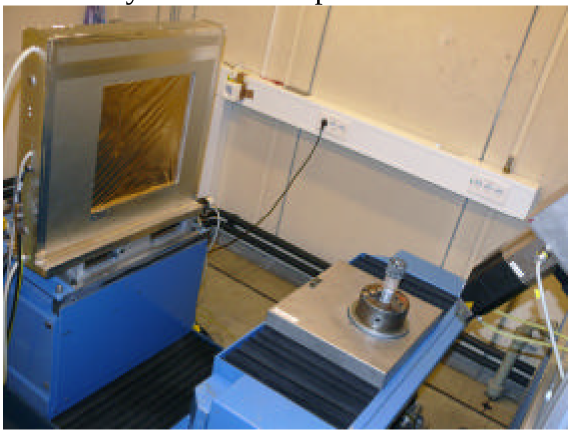

Fig. 1: High resolution tomograph with 225 kV micro focal X-ray tube and a temperature stabilized flat panel detector.

Fig. 2: Plate of open porous asphalt (160x130x40 mm^3) together with one of the five core samples (? =50 mm, height= 40 mm).

2.3 Parameters of measurement

Adapted to the sample diameter and the detector properties the investigations were performed with a high voltage of 140 kV and a current of 160 µA. The beam hardening was suppressed by prefiltering the radiation with 0.25 mm Cu and 0.5 mm Ag. The number of projections was 900 / 360°. The integration time per projection was 6 sec. The voxel resolution was (52 µm)^3.

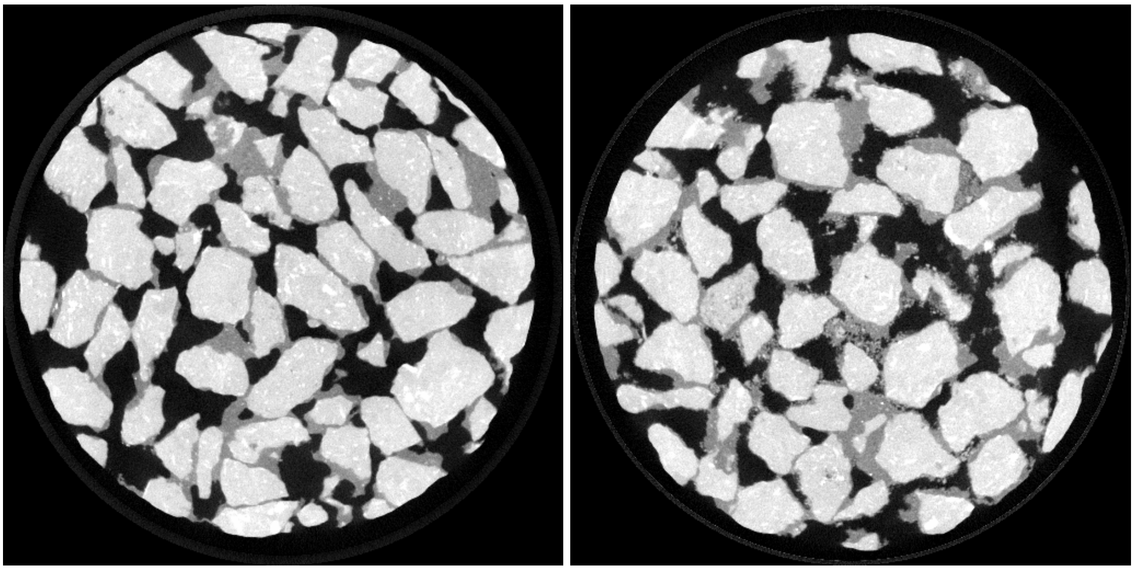

Fig. 3: Two slices of the 3D-data set of two core samples (? = 50 mm, height = 40 mm). The sample at right was contaminated with artificial dust.

The raw projection data were processed to correct the influence of the dark current and the distribution of the X-ray intensity only, no further image processing was applied.

2.4 Image analysis

Most of the image analysis was done with the software VG Studio Max [2]. Start point for the image analysis of the CT data and the separation of the three components aggregates, bitumen/mineral filler and porosity is the histogram of the CT image data set. An example is shown in fig. 4. The maxima of the three components in the histogram shows fig. 5. Table 1 summarizes the mean value and the standard deviation for all measurements. The small deviations are a measure, that the X-ray conditions (energy spectrum, detector properties and so on) are very stable over the period of measurement of six month. However, the histogram is not sensitive to changes of the geometrical properties of the equipment that means scale errors, which influence the absolute values of the content determined.

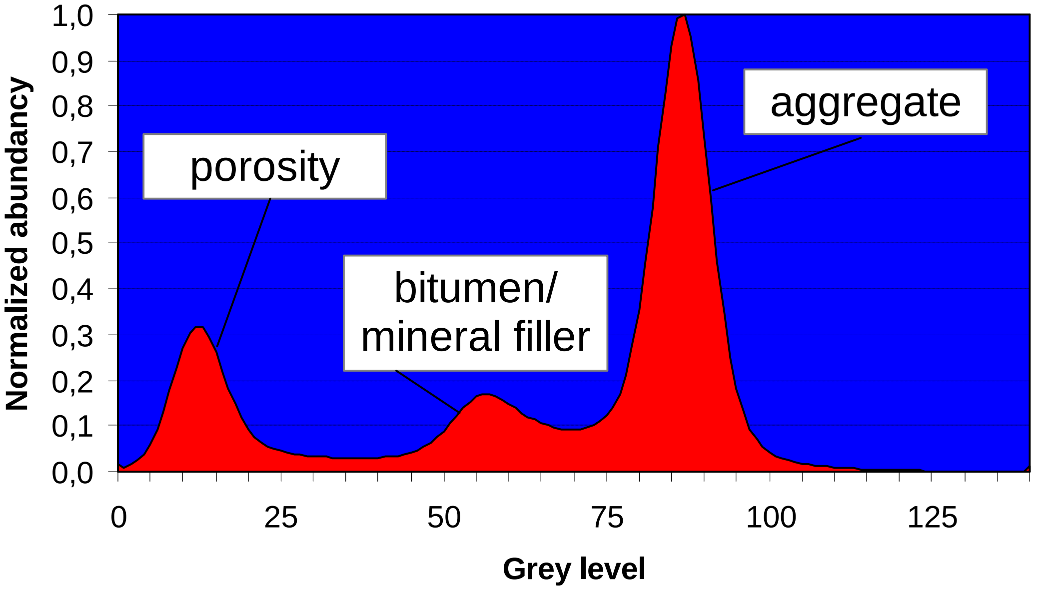

Fig. 4: Histogram of a core sample with the three components porosity, bitumen/mineral filler and aggregates.

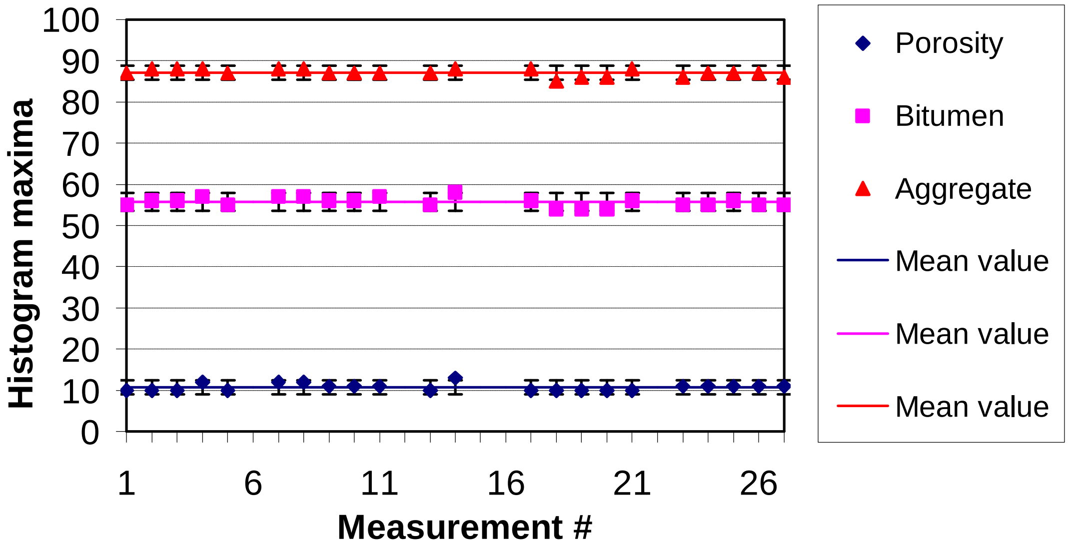

Fig. 5: Dependence of porosity from the elected sample volume.

	mean value [GW]	Standard deviation [GW]
Aggregates	87.09	0.87
Bitumen/mineral filler	55.68	1.09
Porosity	10.77	0.87

Table 1: Mean value and standard deviation of the maxima in the histogram of all measurements.

A further condition is a statistical representation of the selected sample volume that means that the sample volume should as large as possible and edge effects should be neglect able. To fulfil these conditions, the diameter of concentric cylinders was varied which are complete contained in the sample complete contained and the porosity as function of diameter of the cylinders was determined (fig. 6).

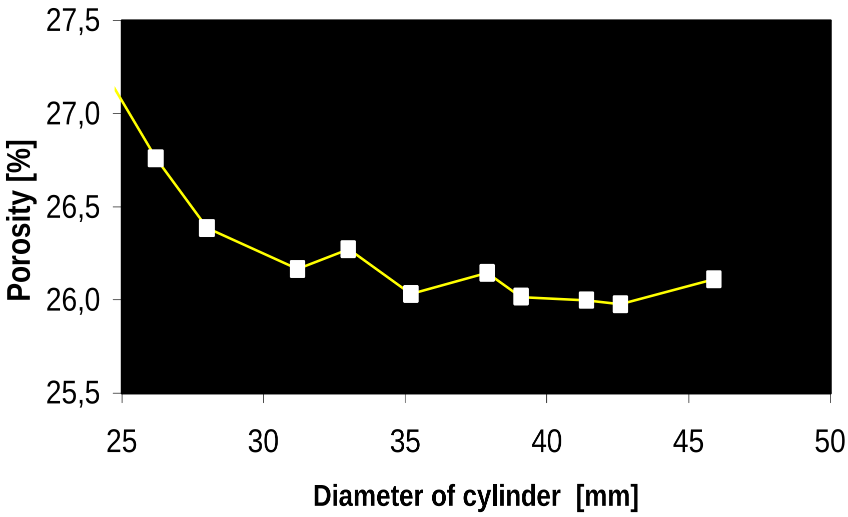

Fig. 6: Dependence of porosity from the elected sample volume.

3. Results

3.1 Analysis of composition

The porosity for each core sample of the untreated plate and the plate artificially infiltrated with dust is shown in fig. 7. The difference in the porosity of more than 5 % was the reason to study the influence of apparatus, of the image analysis procedure and of the operator in more details. One of the five sample was measured with identical parameters five times by two operators (A and B) during a period of six months, to evaluate the influence of apparatus (changes in X-ray spectrum, detector properties etc.). Table 2 contains the result of the selection of threshold. Additionally to the individual threshold found by the software VG Studio Max, the porosity was determined using fixed values for all samples. The uncertainty determined from the standard deviation was about 0.23 Vol.-%. The influence of the operator could be estimated between 0.23 and 0.53 Vol.-%. The repeatability is shown in table. 4, resulting in an uncertainty of about 0.3 Vol.-%. Summarising the different influences it can be concluded the following:

- ? The X-ray components are stable over a period of six months, resulting in a standard deviation for the porosity of about 0.3 Vol.-%.
- ? The selection of threshold influences the content of porosity only by a standard deviation of about 0.23 Vol.-%.
- ? The operator influence amounts to 0.23 or 0.53 Vol.-%.
- ? The standard deviation of the repeatability is about 0.30 Vol.-%

The summation of these contributions give an upper limit in the uncertainty determining the porosity of about 1.5 Vol.- %. The reason for the differences in the porosity of the five untreated samples and the five samples infiltrated artificially with dust results therefore from local inhomogenities in the asphalt plate.

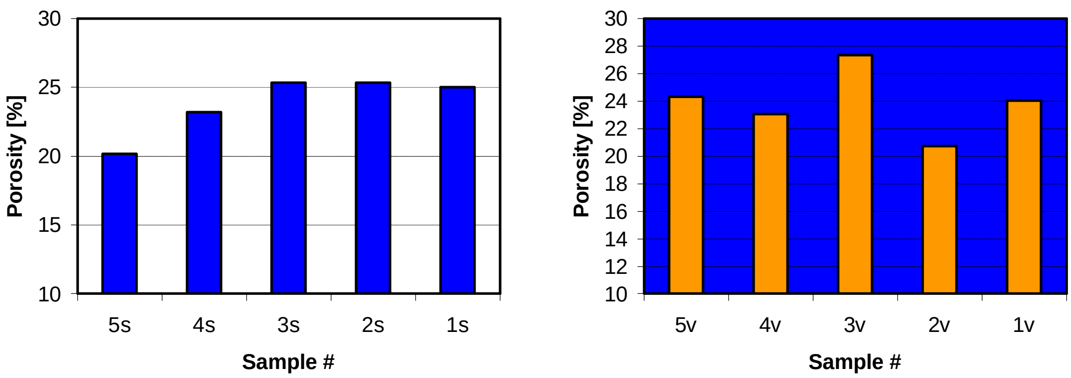

Fig. 7: Porosity of five core samples (Ø=50mm, height=40 mm), which are cut from two plates with water jet cutting. On of the plate (samples 'v') was artificially contaminated with dust.

Threshold [Grey level]	Porosity [Vol.-%]
Function 'Calibration': 34 - 36	26.0 ± 0.23
Fixed: 34	25.8 ± 0.24
Fixed: 35	26.0 ± 0.20
Fixed: 36	26.2 ± 0.23

Table 2: Influence of selection of threshold on the porosity.

Operator	A	B
Bitumen/Filler/Dust	16.3 ± 0.2 Vol.-%	16.0 ± 0.3 Vol.-%
Aggregates	57.7 ± 0.3 Vol.-%	57.2 ± 0.3 Vol.-%
Porosity	26.0 ± 0.3 Vol.-%	26.5 ± 0.5 Vol.-%

Table 3: Content of sample ‚3v', measured and analysed five times by operator A and B.

Analysis	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8	# 9	# 10	Mean value ± Sigma
Threshold	40	37	34	39	37	37	35	35	36	39	36.9 ± 2.0
Porosity	21.0	20.7	20.2	20.8	20.7	20.7	20.2	20.2	20.3	20.8	20.6 ± 0.3

Table 4: Repeatability of the determination of porosity, exemplified on sample ‚5s'.

3.2 Analysis of Morphology

The second structural parameter is the morphology of such complex material samples like porous asphalt, which can be characterized by grain size distribution, open or closed porosity, pore size distribution and localization of dust.

Size distribution of aggregates

The distribution of the size of aggregates is shown in fig. 8. The maximum is in good accordance with the nominal values of grain size 0/8 mm.

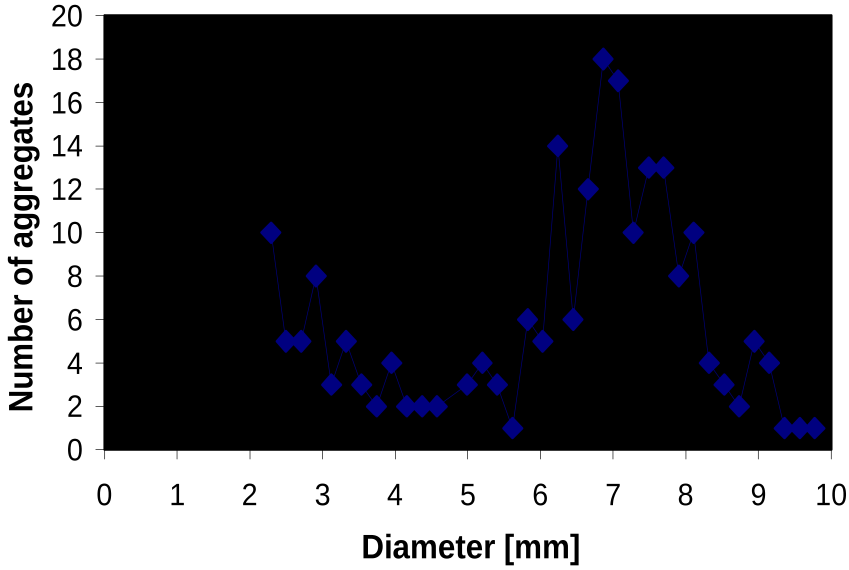

Fig. 8: Dependence of porosity from the elected sample volume.

Open or closed porosity

An essential question is the analysis of open or closed porosity. The core samples cut of the two plates show mostly open porosity, but the infiltration with dust was artificially. Therefore a core sample (Ø 145 mm) of a real road surface made of porous asphalt with a granular size 0/11 mm, taken from the national highway B10 in the city region of Neu-Ulm was analysed. The road was produced in 1994. Fig. 9 shows a photography of the sample in the left image. The closed porosity is visualised in the right image of fig. 9, represented by the yellow marked volumes. The upper red part marks the surface of the sample witch consists of open porosity, separated for the visualisation of closed porosity. A more sophisticated and also time consuming procedure are search algorithms, which are also contained in the software 'VG Studio Max' or are available with self developed image processing modules on the basis of the software 'AVS' (Advanced Visualisation System).

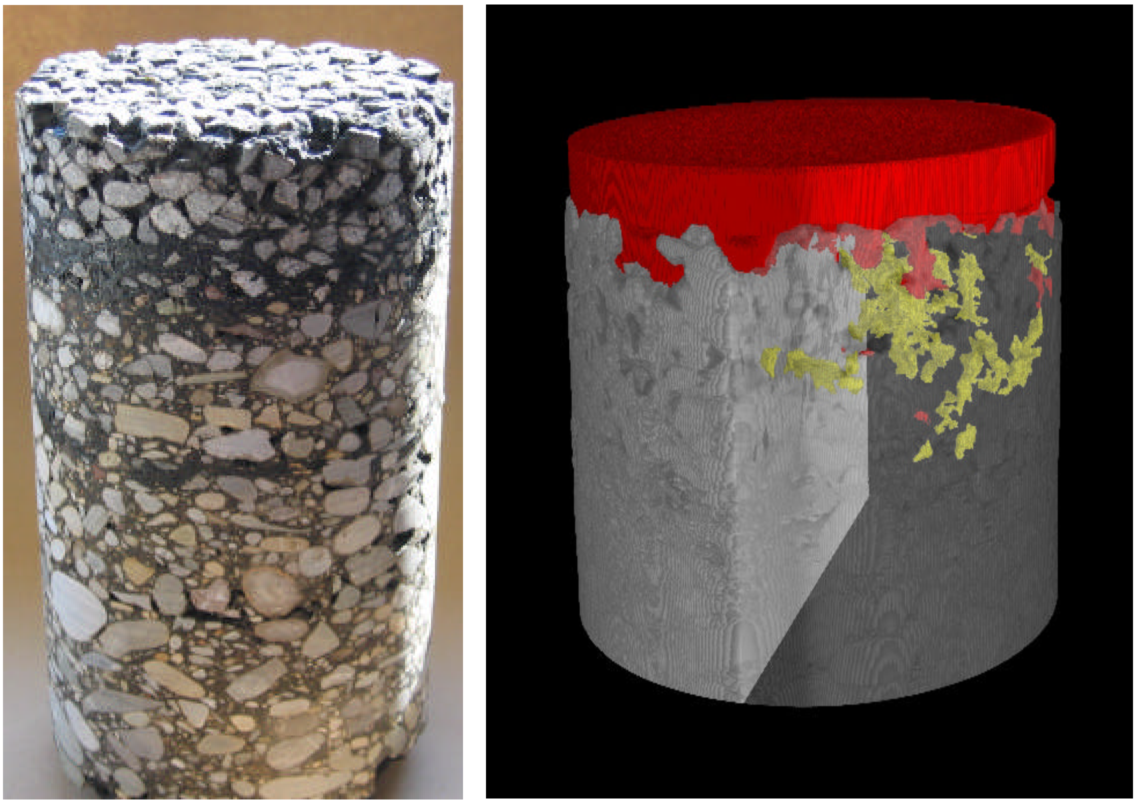

Fig. 9: Core sample (left image) and visualisation of closed porosity (right image).

Evaluation of dust content
A challenge is the evaluation of dust content for several reasons:

? Low fraction at the whole composition
? Generally small thickness of dust, resulting in partial volume artefact
? Overlapping attenuation coefficient with the bitumen/mineral filler component

Therefore a separation due to a histogram analysis is not very helpful. A very sensitive method is the performance of difference measurements, which requires a registration of the image data sets before and after infiltration with dust, shown in fig. 10. For real samples in many cases only the state after infiltration is available for an analysis. Different methodological approaches have been tested, e.g. determining the variance of components and the surface of the pores. The first method shows clearly the enlarged variance of the dust but a quantitative analysis is hindered by the fact that the transition of aggregates to air shows the same feature. A more promising procedure is the calculation of the surface of the pores, shown in fig. 11. There is clear difference in the surface between the untreated samples and the samples infiltrated with dust.

4. Conclusion

CT can be used as a accurate non-destructive tool to analyse the composition and morphology of the multi component system porous asphalt. The quality of the inner structure can be visualized, digital reconstructed and specimen composition as well as pore structure features can be determined. First results to detect the infiltrated dust with a structural property seem to be hopefully.

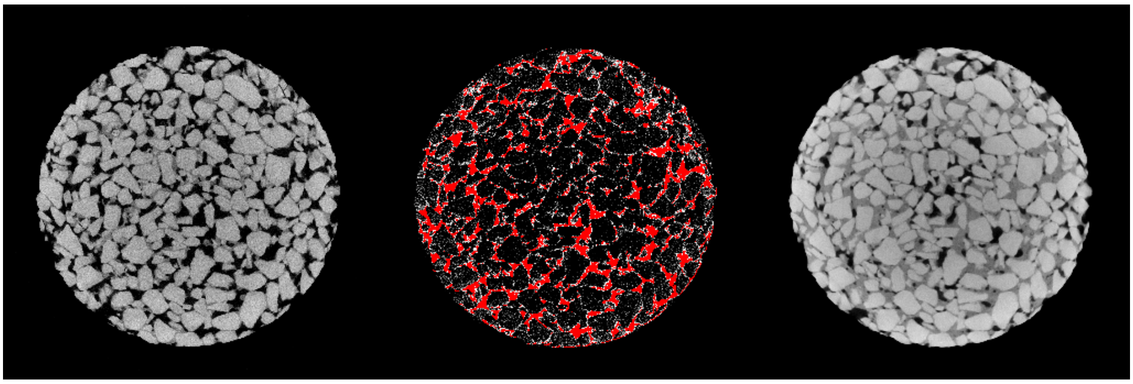

Fig. 10: Difference image (middle image) of an untreated sample (left image) and subsequent artificially infiltrated with dust (right image).

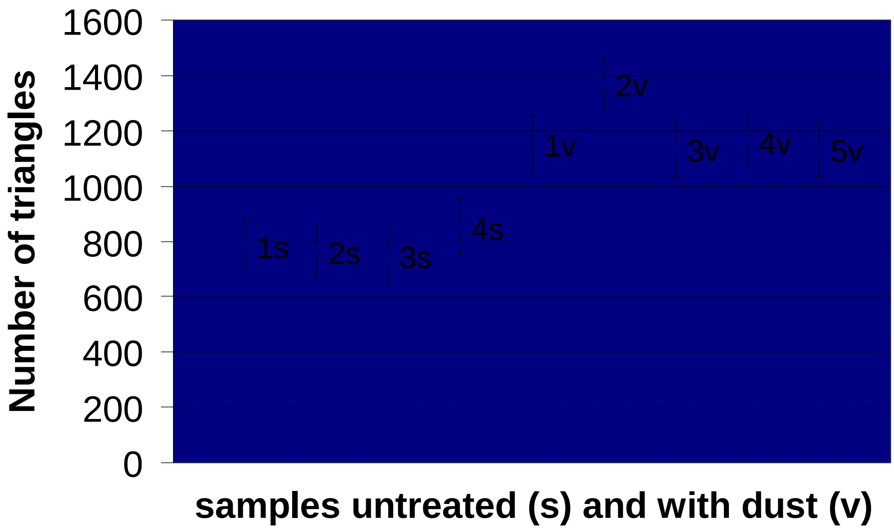

Fig. 11: Surface of the untreated and artificially with dust infiltrated samples.

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