Matthias Maisner[1], Ruth Bialucha[2], Kristiina Leismann[1], Thomas Merkel[2]

DETERMINATION OF GEOMETRIC PROPERTIES OF AGGREGATES

[1] Federal Waterways Engineering and Research Institute (BAW), Kussmaulstr. 17, 76187 Karlsruhe, Germany

[2] FEhS – Building Materials Institute, Bliersheimer Str. 62, 47229 Duisburg, Germany

Abstract

CEN/TC 351 „Construction products: Assessment of release of dangerous substances“ prepared Technical Specifications for horizontal test methods, which are necessary for the implementation of the Basic Requirement No 3 “Hygiene, Health and the Environment” of the Construction Products Regulation (CPR) into harmonized Product Standards. On account of European Commission (EC) mandate amendments, the Product Committee must integrate this basic requirement in the product standards for the European internal market as a further performance characteristic in future. With the publication of CEN/TS 16637-2 a “Dynamic Surface Leaching Test (DSLT)” was made available to the CEN Technical Committees. This relates to an index test method to evaluate surface-related release from construction products. For greater aggregates like EN 13383-1, armourstone and EN 13450 Aggregates for railway ballast, the DSLT is an appropriate test method, due to the surface-related release scenario. Till now there are no standards for the determination of the surface of aggregates available. In contrast to geometrically simple products such as paving stones it is not easy to calculate the surface area of aggregates with irregular side areas. The DSLT mentions the aluminium foil method for determination of the surface of products with irregular sides. Contactless 3D measurements by laser scanning or computed tomography system (CT) could be an alternative. This paper presents a comparison of these methods.

1 Introduction

The largest quantities of construction products on navigable waterways are aggregates. They can be used as concrete aggregate for solid structures or for revetments of navigable waterways. In the tidal area of rivers (see Figure 1) the intended use of aggregates can be as armourstone (top layer) and grain filter (bottom layer).

Figure 1: Construction of an embankment from aggregates; armourstone (top layer) and grain filters

Under structural aspects, the geometrical properties of the aggregates are important parameters to assess the functionality of these construction products for the revetment to be erected. Armourstone used in hydraulic structures and other civil engineering works can be in the sense of EN 13383-1 [1] natural, manufactured as slag material or recycled. For example [1] defined coarse gradings for armourstone with sieves, and the shape must be determined by the length-to-thickness ratio. The testing of the percentage of pieces of armourstone with a length-to-thickness ratio greater than 3 must be done by using straight laths and a carpenter's rule or a tape-measure, or by using a calliper. With the Construction Products Regulation (CPR), Regulation (EU) No 305/2011 [2] the basic requirement 3 (hygiene, health and environmental protection) must also be reflected in the harmonised construction product standards throughout Europe. In future, manufacturer must also indicate in their declarations of performance (DoP), whether dangerous substances can possibly be released. With the publication of the CEN/TS 16637-2 [3] of the CEN/TC 351 “Construction Products – Evaluation of the Release of Dangerous Substances”, the horizontal test method – the “surface leaching test (DSLT)” – was made available to the CEN Technical Committee for the implementation of basic requirement 3. This relates to an index test method to evaluate surface-related release from monolithic, plate- or sheet-like products. Armourstone [1] or railway ballast [4] can be considered as monolithic. In situ tests of single stones in water are carried out, in the case of which water samples are taken at fixed times and then analysed. A status report on leaching test methods developed by CEN/TC 351 was already presented at the 8th European Slag Conference in Linz 2015 [5]. The surface of the samples is needed two times for the DSLT [3]. First the liquid volume to surface area-ratio (L/A) must be calculated. For monolithic products the test is carried out at an L/A ratio of (80 ± 10) l/m^2, for sheet- or plate-like products lower L/A ratios ≥ 20 may be applied. Furthermore, the concentration of released substances after 64 days must be expressed in mg/m^2 to provide a surface-related specification of the release of dangerous substances. Till now no standard test methods for the determination of the surface or contactless measurements of irregular aggregates are available.

2 Test methods and measuring devices for geometric properties

Up to now the product standards for aggregates requires only contact measuring methods like the determination of the shape or size. For instance, armourstone in accordance with EN 13383-2 [6] requires for the determination of the length-to-thickness ratio labour-intensive manual measurements. Figure 2 shows the measuring with a carpenter’s rule on a revetment of a river.

Figure 2: Stone with a length to length-to-thickness ratio greater 3

Due to the new horizontal Dynamic Surface Leaching Test (DSLT) [3] the surface determination will be an important geometric property in the future. According to [3] the geometric area of very irregular test pieces has to be determined using the aluminium foil method. Figure 3 shows the steps of the procedure: A stone must be wrapped in aluminium foil and the foil which is in contact to the lateral surface must be torn down and weighed. With the mass per unit area of the foil the surface of the sample can be calculated.

Figure 3: Aluminium foil method for surface determination, tear down of foil pieces

Already in 2012 [7] a comparison of several different methods for determining the surface – one of them being the Aluminium foil method – was published. As a result, the aluminium foil method showed the best results with regard to the statistical uncertainty, compared to a 3D laser scanning method. However, this comparison was presented only for small samples with a mass of less than 2 kg. It was described that this method was fast, inexpensive and reliable.

In the meantime, more accurate scanners have been developed, and the use of industrial computed tomography (CT) is more widespread and less expensive. Photogrammetric is the measuring system for the hand-held scanner (see Figure 4).

Figure 4: Measuring by a hand-held scanner

A portable laser scanner (see Figure 5) has a more modern measuring technique with greater range accuracy. In the non-contact 3D scanners used here, the light acts as a measuring medium based on reflection and absorption. Optical sensors are able to detect and evaluate visually accessible areas of an object.

Figure 5: Measuring by laser scanner

A greater point density is recorded, and the result can be timely compared with a reference model. Contact measurement technology is currently reaching its limits when it comes to measuring speeds or measuring surface structures in the millimetre range. An important component for non-contact measuring systems is a powerful evaluation software for the analysis of large amounts of data, e. g. for a complete 3D model. A hand-held portable scanner older design (Artec MHT 3D, works with photogrammetry) and the current model of a laser scanner (Leica P30) were used. Terrestrial laser scanners are working on reflectorless distance measurement with simultaneous determination of two solid angles. Local three-dimensional coordinates can be derived. Discrete points are not specifically observed with terrestrial laser scanners. Rather, the environment of the measuring object is recorded at high speed in defined steps. The measurement result of the laser scanner is a point cloud. In addition to the 3D coordinates, the user receives an intensity value per point that describes the reflectivity of the measured object. Essential characteristics of a scanner are the range, the resolution, the beam divergence and the measuring accuracy. The range of a laser scanner is determined by the manufacturer depending on the laser power and quality of the receiving optics. The resolution of the measurement depends on the selected step size for the two deflection angles. The smaller the step size, the finer the spatial resolution of the measurement object. With regard to beam divergence, the sampling rate should be tuned to one another. No sampling rate should be selected that is smaller than the spot size. The scan station P30 has a range accuracy of 1,2 mm + 10 ppm over the entire range. It also has a 3D position accuracy of 3 mm at 50 m. The beam divergence is > 0,23 rad and the laser spot size at the front window is less than 3,5 mm. In contrast to medical use for CT in non-destructive testing the sample is rotating. A 3D volume is reconstructed from series of 2D x-ray projection. High resolution CT can be performed for greater samples like armourstone by macro-focus technology (see Figure 4). An application for CT on construction products with irregular side areas is described in [9]. The resolution of the 3D CT data is described in voxel, and the size of this data directly depends on the sample size and the pixel size of the detector. A CT measuring of an armourstone can be done in 30 min (see Figure 6). Further details of the used measuring methods are described in [8].

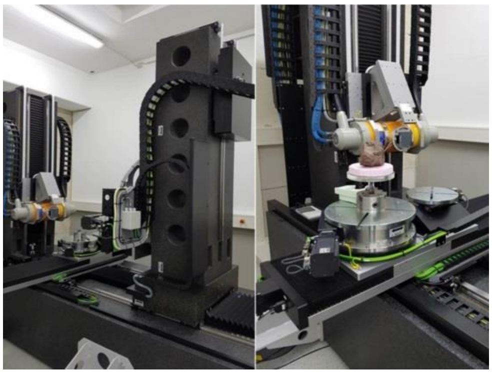


Figure 6: Measuring by CT, macro CT system (left) and armourstone sample (right)

3 Measurements and results

In order to being able to evaluate the accuracy of the methods by comparing with calculations, measurements were first carried out on geometrically simple test specimens of natural stone and concrete (see Table 1). The selection of specimens was made due to their different colours and pattern. In order to test resolution of the measuring systems, a cylinder with chamfer and a bore was chosen. The surface and volume of cubes and cylinders can be easily calculated. Contactless 3D measurements were carried out by laser scan and CT. The granite cube was calculated without bore and chamfer. At first it must be pointed out that the laser cannot detect the chamfer and the bore of the cube. The surface of the cube was calculated without core and therefore the CT result of the surface is slightly larger and the volume slightly lower. For the concrete cylinder the CT shows a slightly larger surface due to roughness of the lateral surface and the pores. In summary it can be stated that the CT shows a better match with the calculations than the laser scanner.

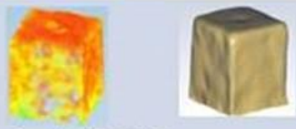
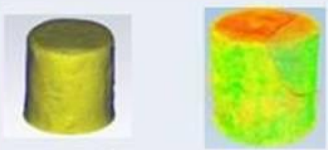
calculated	laser scanner	CT
sample 1: granite surface [cm^2] = 206,5 volume [cm^3] = 201,8 	 surface [cm^2] = 208,7 volume [cm^3] = 205,3	 surface [cm^2] =209,11 volume [cm^3] = 195,50
sample 2: concrete surface [cm^2] = 117,8 volume [cm^3] = 98,2 	 surface [cm^2] =116,3 volume [cm^3] = 96,2	 surface [cm^2] =151 volume [cm^3] =98,26
sample 3: rhyolithe surface [cm^2] = 72,4 volume [cm^3] = 40,9 	 surface [cm^2] =60,6 volume [cm^3] =33,7	 surface [cm^2] =70,85 volume [cm^3] =39,89

Table 1: Samples with regular dimensions, comparison of methods

In order to assess the applicability of the methods for irregularly shaped samples, a volume determination by immersion weighing according to Archimedes was performed as a reference method. The determination of particle density was carried out in accordance with [6] and the Archimedes volume was calculated by the density. To assess the application limits of the scanners, samples with different colours and textures were selected (see Figure 7). The copper slag is homogeneous, dark and partly metallic glossy. By contrast the dolomite is cream-coloured and bright. Table 2 shows the measuring results.

Figure 7: Copper slag (left) and dolomite (right)

The dolomite can be detected relatively well by the scanner systems due to the surface colour. Due to the accuracy of these measuring devices, smaller structures such as the fixing wire of the samples are not visible. When comparing the CT results of the copper slag sample with the other measuring methods, it can be seen that the non-contact scanners show the largest differences. This is probably due to the glossy areas, which are difficult to capture by the scanner due to the reflective beam reflection.

test method	**dolomite**		**copper slag**	
	surface [cm²]	**volume [cm³]**	**surface [cm²]**	**volume [cm³]**
aluminium-foil-method	546,4		315,3	
Archimedes volume		641,1		235,0
laser scanner Leica P30	559,1	601,5	239,2	239,8
hand-held scanner Artec MHT 3D	467,2	646,9	227,3	234,2
CT	668,0	641,5	535,5	243,7

Table 2: Comparison of results for dolomite and copper slag, respectively

Further measuring tasks were differently shaped and porous steel slag samples (see Figure 8). The specimens differed in surface texture and cavity.

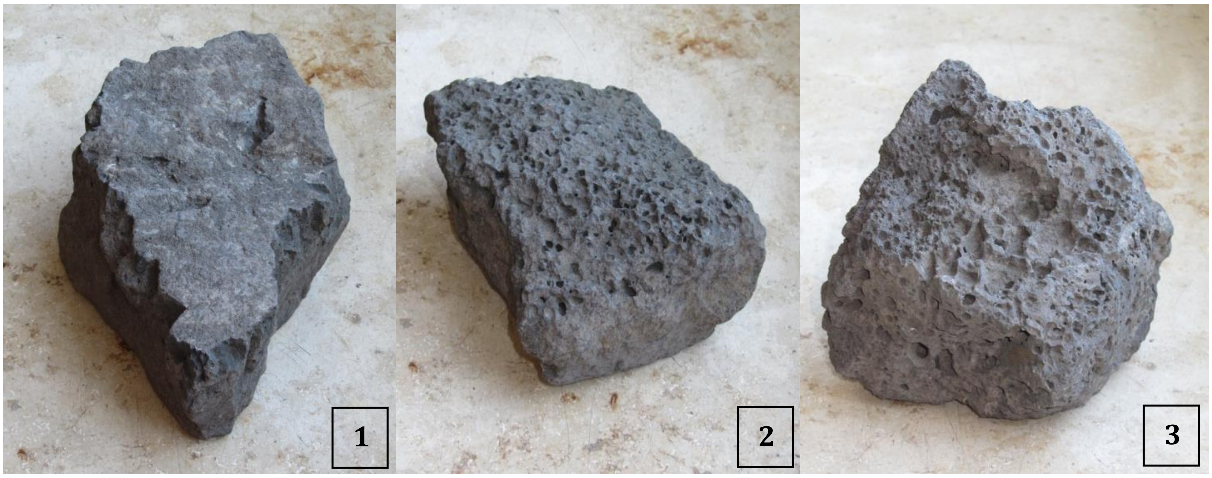


Figure 8: Steel slag samples, homogeneous (1), partly cavities (2) and cavities (3)

sample		**homogeneous 1**	**partly cavities 2**	**cavities 3**
weight	g	1605	1431	1147
aluminium-foil-method				
surface	cm²	400	360	400
Archimedes volume	cm³	482	419	401
	cm²/cm³	0,83	0,86	1,0
Laser scanner Leica P30				
surface	cm²	342	333	344
volume	cm³	443	436	439
	cm²/cm³	0,77	0,76	0,78
hand-held scanner Artec MHT 3D				
surface	cm²	346	359	407
volume	cm³	422	339	484
	cm²/cm³	0,82	1,06	0,84
CT				
surface	cm²	663	680	1233
volume	cm³	448	413	411
	cm²/cm³	1,48	1,65	3,0

Table 3: Results for steel slag

Neither the aluminium-foil-method nor the scanners were able to detect the cavities and therefore the greatest deviation from the CT is found in the sample with the greatest porosity (see Table 3). A further comparison was made with copper slag samples. Here, too, the specimens differed in surface texture, metallic glossy areas and cavity. The results are shown in Table 4.

sample	CT volume [cm³]	CT surface [cm²]	Archimedes volume [cm³]	aluminium-foil-method [cm²]	Laser volume [cm³]	Laser surface [cm²]
copper slag 1	234,75	256,64	231,90	263,6	230,07	219,81
copper slag 2	160,86	518,56	164,30	278,2	190,12	218,64
copper slag 3	302,86	944,46	309,00	385,5	338,26	319,53
copper slag 4	1922,08	2921,68	1897,40	981,8	1880,61	834,21

Table 4: Copper slag, results of different surface determination methods

Only sample 1 shows an approximate match for the surface between CT and aluminium-foil-method. Sample 3 is a copper slag with large continuous cavities and therefore the greatest deviation from the CT is found in this sample. The cavities could not be found in the point clouds of the laser scanner and therefore the results differ also from CT. The largest deviation for the surface shows sample 4. Here the deviation is about three times.

4 Conclusion and discussion

Due to the European Products Regulation (CPR) [2] and basic requirement 3 (hygiene, health and environmental protection) the possible release of regulated dangerous substances must be considered for harmonised standards in the future. A horizontal test method for leaching [3] was developed and the expression of the results must be surface related. For products with irregular side areas like aggregates it is not possible to calculate the surface in an easy way. Therefore, standardized test methods are necessary. The paper shows the application of the test methods aluminium-foil-method, optical scanner and computed tomography (CT) in comparison. Today CT is less expensive and service providers can be found all over in Europe. Metallic glossy and or porous samples, e.g. aggregates made of slag, can be a problem for optical scanner systems. With CT it was easy to detect the real surface of these materials.

The error possibility measuring accuracy of the aluminium-foil-method depends on the size and kind of stone. This method is not purposeful for stones with cavities like slag materials or shell limestone and also material with coarse-grained mineral structure. Due to the size, railway ballast can be a problem for this method.

It must be considered that the surface for the DSLT [3] is needed two times and therefore an inaccuracy and errors in the measurement method can significantly manipulate the leaching result. In one sample, an almost threefold deviation was found between CT and the aluminium-foil-method. The comparison with the calculation of geometrically simple specimens and the volume determination by immersion weighing has shown that the CT is the appropriate method for the surface determination of aggregates.

5 References

[1] EN 13383-1, Armourstone - Part 1: Specification; 2002

[2] CPR Regulation (EU) No 305/2011

[3] CEN/TS 16637-2, Construction products - Assessment of release of dangerous substances - Part 2: Horizontal dynamic surface leaching test

[4] EN 13450, Aggregates for railway ballast; 2002

[5] Wiens, U., Ilvonen, O.: Release of dangerous substances from construction products into soil and water – A status report on test methods developed by CEN/TC 351/WG1, 8th European Slag Conference, Linz 2015, Euroslag Publication No. 7

[6] EN 13383-2, Armourstone - Part 2: Test methods; 2002

[7] Schmukat, A.; Duester, L.; Ecker, D.; Schmid, H.: Heil, C.; Heininger, P., Ternes, T. A. (2012): Leaching of metal(loid)s from a construction material: Influence of the particle size, specific surface area and ionic strength. In: Journal of Hazardous Materials, 227-228, pp. 257-264.

[8] Maisner, M., Leismann, K., Bestimmung der geometrischen Eigenschaften von Gesteinskörnungen, BAWBrief 02/2018,

https://henry.baw.de/bitstream/handle/20.500.11970/104582/BAWBrief_02_2018.pdf?sequence=1&isAllowed=y

[9] Maisner, M.; Retzlaff, J.; Dietrich, C. (2019): Geosynthetics in Traffic Infrastructure Construction in Contact with Groundwater and Surface Water –

Environmental Aspects. GeoResources Journal (2-2019), pp. 12–18. Online: https://www.georesources.net/download/GeoResources-Journal-2-2019.pdf