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Evaluation of particle size distribution of aggregates in asphalt concrete by means of image analysis software

Pomiar rozkładu wielkości kruszyw w betonie asfaltowym przy zastosowaniu oprogramowania do analizy obrazu

Abstract

Analysis of (cylindrical) samples of asphalt concrete, in terms of weight and size distribution of different fractions of aggregates and by means of mechanical methods is a complicated and time consuming process. This article presents a proposal of a method for the same kind of analysis, but without the need for machining. The suggested method is based solely on a computer based analysis of photographs of the samples. The mechanism described in this paper is only a preliminary process, illustrating the potential use of an image analysis for this type of study.

Keywords: roads building, asphalt concrete, aggregate distribution, image analysis

Streszczenie

Analiza (walcowych) próbek betonu asfaltowego, pod kątem rozkładu wielkości/wagi różnych frakcji kruszywa, z użyciem metod mechanicznych jest procesem złożonym i długotrwałym. W artykule przedstawiono propozycję metody takiej analizy bez konieczności jakiejkolwiek obróbki mechanicznej. Zaproponowana metoda bazuje wyłącznie na komputerowej analizie zdjęć wykonanych próbkom. Przedstawiony w artykule mechanizm jest jedynie procesem wstępnym, przedstawiającym potencjał wykorzystania analizy obrazu do tego typu badań.

Słowa kluczowe: budowa dróg, beton asfaltowy, rozkład kruszywa, analiza obrazu

1. Introduction

The process of measurement of the size distribution of aggregates in asphalt concrete is used in approval procedures for the use of road objects such as roads, expressways and motorways. Such studies help to check whether the Contractor performed construction works in accordance with building regulations, and whether the actual state of the road corresponds with the documentation. Every planned road has its own set of required properties, depending on its location, planned traffic, tonnage limits, etc. However, most of these parameters are included in standards, describing road construction and maintenance, pavement technologies [3], or a type and kind of construction aggregate [2]. Apart from the approval process, the same procedure is used for a periodic examination or in case of events of natural disasters [5]. In this case, surface tests are performed to examine whether the road is suitable for further use or there is a need to perform a maintenance or repair procedure. For example, during major quakes, construction aggregate contained inside asphalt concrete may crack, turn into finer grain and thus lose its original stiffness parameters.

A full examination should be performed in accordance with relevant procedures [4], ie. cutting out a sample of asphalt concrete from the study area. The sample has the form of a cylinder with a diameter of 100, 150 or 200 mm, with a depth of about 400 mm (although in case of checkups it does not exceed 250 mm in depth). The sample consists of three layers: base, binder and a surface course. The deeper the layer, the more stiff and more coarse aggregate. For a change, the top layer contains more of fine aggregate. There is a justified purpose for each layer. Then, the tests are carried out, as described in the next chapters.

2. Preparation of test samples

For the purpose of the experiment, the samples were prepared according to the author's own procedure, instead of using samples cut out from a road. This was performed to have full knowledge of the sample contents.

The samples are compacted in the Marshall Compactor, and then flooded with asphalt. Aggregate that was used to test this is an assortment (type 1, according to PN-B-11112:1996 norm) of granulated, crushed aggregate, in the following fraction groups: 2/4; 5,6/8; 11,2/14. The X/Y range denotes that a mix of aggregate underwent the procedure a mechanical sieving by means of a sieve with a square mesh. The fraction was able to pass through a sieve which has a Y (and larger) mesh, but was unable to pass through a sieve with an X mesh. Thus, in this fraction there are particles of a diameter greater than X and smaller than Y. The experiment used the grain of all the above groups, in the article and graphs referred to as: „Small" (S), „Medium" (M) and „Large" (L), respectively. 7 samples were prepared, representing all possible combinations of the groups. In the mixed samples, the weight of each fraction group was identical. The contents of each aggregate in the samples formed from two groups was 50% by weight, and those formed from three groups was 33% by weight. As the aggregate used is derived from a single source, thus it has the same density. It can be assumed that if the weight of different fractions of aggregates are equal, their volume is the same. During the preparation of subsequent samples, the amount of asphalt was varying (and excessively high in relation to the requirements of PN-S-96025:2000 [3]). At this stage of the experiment, asphalt content in each sample is not essential.

The tested samples were prepared as follows:

1) Identical sample weight of each fraction was prepared.
2) Individual samples were made in such a way that individual fractions or mixtures of the same mass fractions was poured into the prepared containers, so that the entire sample was approx. 1200 grams. Aggregates were then mixed in a container. Asphalt (MODBIT 45/80-55) was heated to 180°C and poured with a significant overmeasure in order to completely fill all voids in the mineral mix. The mix was stirred to paste the asphalt all over the grain.
3) The mix was then poured into cylinders. After a slight cooling of the mixture, a Marshall Compactor was used to knead sample and integrate smaller grains in the open spaces. The sample prepared in this way was about 10 cm high.
4) The samples were left for 12 hours to fully cool down to ambient temperature (15~20°C).
5) Each sample was sliced several times using a stone cutting saw. This way, four subsamples and 6 uniform surfaces, with a visible distribution of aggregate on their both sides, were acquired as material for further studies.

3. The mechanical method of analysis of aggregate distribution

The mechanical method involves a preliminary, mechanical cleaning of a cylindrical sample with a wire brush, to clean it from free, loose parts. The sample is then placed in a laboratory dryer, preheated to 180°C, and after 30 minutes it is hand crushed.

The resulting mixture of asphalt and minerals (not asphalt concrete anymore) is a subject of processing in an automatic asphalt extractor, to get a mixture of powder and dust. The process takes approximately one and a half hour. The asphalt content of the sample is calculated based on a mass difference of the unprocessed sample and the resulting mixture. The combination of ingredients is then sifted to determine the percentage of each fractions, to compare its composition with the recipe.

Each layer of the sample is analysed individually. Therefore, before the main examination, each piece must be sliced in such a way so as to separate the layers (base, binder and a surface course).

4. The method of image analysis of distribution of aggregates

The proposed method of video analysis involves cutting each sample into slices which are then photographed to obtain high quality images. All image files have to be preprocessed. Methods of dealing with compacted group of elements, such as concrete aggregate, of various shapes and sizes in the photographs, are well known and documented [1]. Shortly, each procedure requires scaling of the photographs to a desired resolution. In the case where we are interested only in two areas of brightness, it is necessary to perform binarization to separate the elements from each other. The resulting image consists of bright, closed shapes, varying in size (intersections of concrete aggregates) on a dark background (asphalt, filling of voids between aggregates). The rest of the analysis and the methods of the conduct are up to the researcher.

To perform the procedure, it is necessary to scan the image both horizontally and vertically, with lines distant from each other by a fixed number of milimeters (or pixels), then compute distribution statistics of length of the „bright" lines (that is, those which pass through the aggregate) for each sample. Based on this principle, a simple database of distribution statistics was created, with the use of test samples made from single and mixed aggregate fractions. It can be assumed that after creating a large database with many uniform and mixed fractions, there will be a way to create a method of calculation, for unknown samples, to find the percentage of a fraction distribution.

The article describes the initial stage of the procedure, which is an analysis of the only samples containing fractions whose size and percentage of the content are known. Mixed samples are included only as a comparative element, because the method to account for their composition is not yet developed.

5. Software

A special software was created to perform preliminary operations of the photographs and to analyze the image. It was decided that for every intermediate stage of the process, a BMP image fil will be saved, not to lose any information of every phase of transformations.

First, the software resamples photographs to a desired size. Digital cameras make images of high resolutions. It is assumed that every image will be scaled to 10 pixels per milimeter resolution. At this stage, there is no mechanism to automatically scale the images, users are required to do it on their own. To ease scaling for the user, a photograph should be taken with a ruler in the background. This allows for simplifying the operation by letting the user select a known distance on the image and then type in the real distance.

Then the user selects a rectangular area of the image and cuts it with a cropping tool. In the future, a tool will be added to distinguish between the sample and the background to remove the need for the user to select the sample area.

In the next step, to separate the aggregate from its surroundings, namely the brighter area from the darker area, an image will be converted to a grayscale and then binarized. The grayscale conversion uses generic coefficients for every colour component. Due to the fact that each sample has a slightly different luminosity (it depends on technology of the sample), a fixed threshold for brightness of asphalt and aggregates cannot be used. In addition, the color of the aggregate and the asphalt slightly change even for a single sample. In the course of the experiment, it was determined that classical edge detection algorithms are not suitable for this.

The method of dynamic image analysis was applied in terms of brightness. The image was scanned pixel by pixel, and bright pixel occurrence statistics were calculated. Because

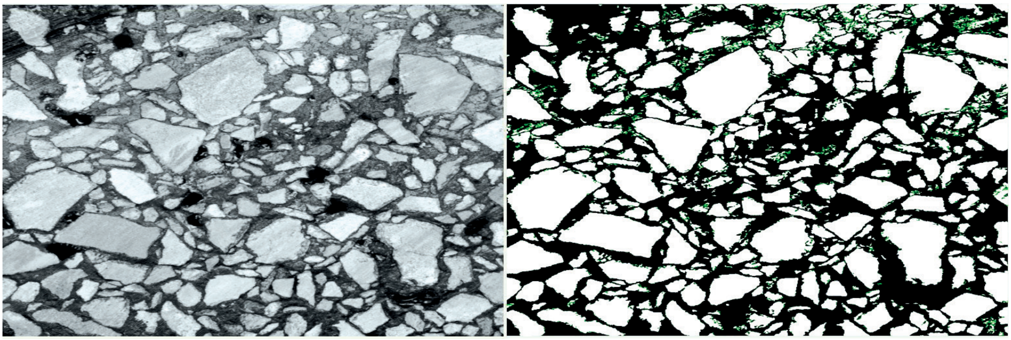

Fig. 1. Example photographs of a sampled mixed fraction and the image after binarization

a significant portion of the image is an aggregate's slice, it was assumed that in the distribution there must be a relatively large „bright" range. However, in the „dark side" there must be a corresponding range for the asphalt. The problem arises in the analysis of brightness that lies between these maxima. It was assumed that in this area, there is a point of minimum for the statistical occurrence of brightness. Therefore, the areas darker than on this point are the assumed to be asphalt, and similarly brighter areas belong to aggregate. All pixels which belong to this area were additionally treated with an alorithm, to bring them closer to the brighter or darker range. Additionally, all orphaned pixels, i.e. every lone pixel of an undetermined belonging. Also, all small dark areas contained inside the bright sections were eliminated – it could mean there is a void inside the aggregate, which in practice never occurs. The described algorithm of binarization helped get a fairly accurate reflection of the sample, which can be seen in the picture below.

6. Distribution of the aggregate size for the test samples

The software, as described in chapter 4, was used to perform a scan of binarized samples. The length of a line through the white area (hereinafter „Section") is an indicator of the area size. All the Sections directly adjacent to the edge of the image were rejected due to the fact

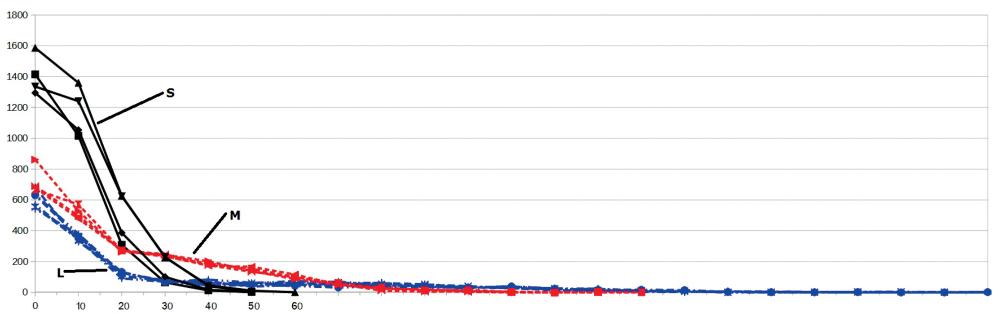

Fig. 2. Distribution of Sections for uniform samples

they may be unreliable. As only a fraction of aggregate might be scanned, it is not known where the Section begins or ends. All the Sections were grouped in ranges named 0, 10, 20 and forth. The size of each Section was mathematically approximated to the nearest range. Since the pictures were scaled to 10 pixels per millimeter, the resulting areas provide a resolution of one millimeter distribution of Sections. Individual distributions were denoted as letters, abbreviations of the sample size: „Small" (S), „Medium" (M) and „Large" (L).

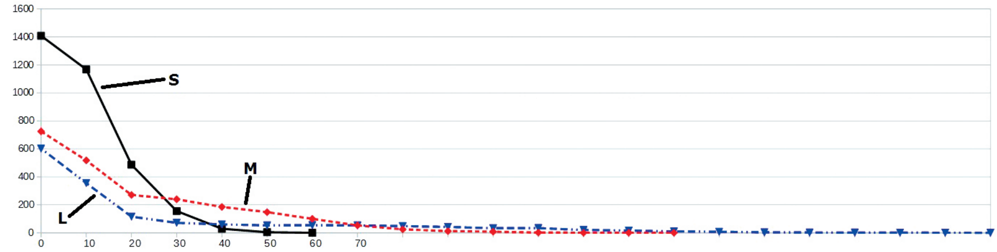

Fig. 3. Distribution of Sections for uniform samples (averaged values for the types of samples)

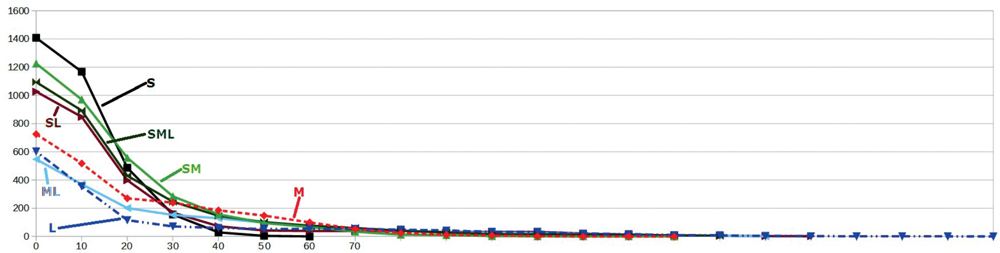

Fig. 4. Distribution of Sections for all samples (averaged values)

When slicing at random a three-dimensional object and then making its two-dimensional representation, small areas tend to occur more often than large areas. This is clearly visible on the example of a significant spread of the Sections distribution of samples 2/4 which contain aggregates of diameters ranging from 2 to 4 mm. In that example, there is an occurence of Sections larger than 4, which do not exist in a physical sample. However, these are only isolated incidents and are associated with the inaccuracy of the binarization algorithm. The algorithm indentified two adjacent small areas as a single larger area.

It can be spotted on the diagrams that there is a substantial representation of the „0" measurement for each sample. The method gives inaccurate results for image areas of intermediate, unsettled brightness. By averaging the distribution Sections of samples, the differences between them can be distinguished. Due to the scale of the graph it is not visible, but after enlarging the areas of M and L Sections, differences between individual samples can be seen.

Samples ML are very interesting, there is a clear distinction of distribution in the „measures". It would seem that small Sections should fall somewhere between samples M and L, but it turned out that they fell below the L section. Samples SL also look interesting: in the initial distribution the Sections are similar to S, but for larger Sections the chart „flattens" like for L samples.

7. Conclusion

The first objective of the experiment was to develop a software for the pretreatment of photographs of samples, the binarization, scanning and creation of distribution statistics of Sections. The first phase was a success, although some things will be improved (eg. the binarization algorithm) and additional features will be added (eg. generating full reports of the scans, not only tables).

The second objective was to scan the prepared samples and demonstrate the distribution occurring in the fractions. The graph shows that uniform samples differ considerably. Also, distributions for the samples of mixed fractions are distinct enough to easily classify the mixed samples only with the knowledge of the distribution of homogeneous fractions. However, this would be possible only to distinguish between S, M and L fractions, because the determination of the exact size of fractions is not possible at this stage.

Based on these results, it was found that it would probably be possible to accurately (within a certain error in estimation) determine the percentages of fractions of unknown size and their sizes in the scanned samples. To do this, it is neccessary to create a database containing all the possible combinations of distributions for samples of homogeneous and mixed fractions. There are not too many combinations, as fractions are prepared in groups of size ranges, described as size „from-to". With the database, one could scan a sample, and using a kind of an inference algorithm, perform an „approximation" of the distribution, interpret the deviation points and on this basis determine the actual percentage distribution of aggregate and its size. At this point, it has not yet been found what algorithm should be used. Further studies will be presented to build the database and to create the inference algorithm.

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