Evaluation of adhesion between bitumen and aggregate with the digital image processing method

A Riekstins$^{1,2}$, V Haritonovs$^1$ and A Balodis$^2$

$^1$Riga Technical University, Department of Roads and Bridges, Riga, Latvia
$^2$SJSC Latvian State Roads, Riga, Latvia

E-mail: riekstins.arturs@gmail.com

Abstract. Although adhesion in asphalt between bitumen and aggregates is one of the essential properties, it is still evaluated visually. European Standard EN 12697-11 provides 3 test methods for the preparation of samples for evaluation - rolling-bottle method, static method and boiling water stripping method. The method used in Latvia is different from EN 12697-11, but with similarities. Bitumen coverage is evaluated visually for all options. The result is the average value of two parallel operators. This principle of evaluation is much criticized as inaccurate and subjective. Today's technologies are evolving, and in many fields, they are more reliable than a human. This study aims to determine whether a visual assessment method can be replaced by a digital image processing method. To evaluate the accuracy of the image processing method, four different mineral materials - granite, dolomite, quartz diorite, gravel, were selected. Samples obtained during the test procedure were tested visually and using an image processing method. For image evaluation, a mini photo studio was created, where pictures were taken using a professional camera and a budget smartphone. The smartphone was used to determine if it is possible to get high-quality images and results using budget smartphones in our pockets.

1. Introduction
The basic property for quality asphalt concrete is strong adhesion between bitumen and aggregates. [1, 2, 3]. Adhesive properties are known to be affected by the chemical composition, surface tension and viscosity of bitumen, as well as oil used in the production of bitumen. [4, 5] Likewise, adhesion is influenced by the properties of the aggregates, such as chemical composition, surface roughness, shape, amount of cut surface and porosity. [4, 5] To improve the adhesion properties, the bitumen is modified by the addition of a variety of improving additives.[1]

To test the adhesion properties between bitumen and aggregates, European Standard EN 12697-11 provides three different methods: rolling-bottle method, static method and boiling water stripping method [6]. In Latvia, the method used to evaluate adhesion has been remained from GOST standard and is described in Road Specifications 2019. [7] All of the methods mentioned above of sample evaluation are done visually by two independent operators. Coverage is rated as a percentage with an accuracy of 5%. In figure 1 can see a visual example of the evaluation of bitumen coating. The method of visual assessment has caused many disputes.
Figure 1. A visual example of evaluation of bitumen coverage [6].

The main factors that influence the results of the visual assessment test are operator skills, lighting, colour of mineral material. The darker the mineral material, the more difficult it is to distinguish it from bitumen. [8] In practice, there are often cases where the difference between the results of operators are significant, which can affect the long-term quality of the road. It may also be a reason for imposing unjustified sanctions on the builder and just because everyone sees it differently.

The human eye can distinguish about 10 million colours. [9] However, colour perception is an extremely complex psychological process in which the subjective attribute of human colour vision has a huge impact. Light has a great effect on colour perception. Therefore it is necessary to improve the objectivity of the test.

To improve the accuracy of the test, it is necessary to reduce the impact of the human factor. One of the possible solutions is to use a digital image processing method instead of visual assessment. [8, 10, 11] The resulting images are processed in an image processing computer program, trying to highlight colour contrasts. In this way, it is possible to determine the ratio of covered areas to the total aggregates area. The main difficulty from previous studies to obtain accurate results was the colour of the aggregates, the falling shadows and the light reflection. [8, 10, 11]. If the colour of the mineral material in the sample is different, it is difficult to evaluate the exact coverage of the bitumen.

This study aimed to compare the visual assessment with the digital image processing method. Two different photo devices were used for the digital image processing method - a professional camera and a budget smartphone.

2. Experimental section

2.1. Raw materials

In Latvia, aggregates of different colours and shapes are used for the production of asphalt concrete. Therefore, four visually different mineral materials were selected to verify the accuracy of the image processing method: dolomite, granite, quartz crystal, gravel. Bitumen 70/100 was used as a binder.

2.2. Preparation of samples

According to the requirements of LVS EN 12697-11 [6], for each aggregate, a density was determined according to EN 1097-6 [12]. The amount of mineral material in all samples was constant 510 grams. The necessary amount of bitumen was calculated from the density of the mineral material. The results can be seen in table 1.

\[ \alpha = \frac{2650}{\rho_m} \times 16 \]  \hspace{1cm} (1)

| Material      | Density Mg/m3 | Bitumen amount, g |
|---------------|---------------|--------------------|
| Dolomite      | 2.789         | 15.20              |
| Granite       | 2.780         | 15.25              |
| Quartz diorite| 2.779         | 15.26              |
| Gravel        | 2.733         | 15.52              |
The materials were heated at 150 °C for at least 3 hours until the material is all over warmed up. All the steps for mixing and testing are described in Road Specifications 2019 [7]. In the next day operator from sample choose at least 30 particles which are fully covered by bitumen. These particles are placed on a metal mesh so that they do not interfere with each other. Next step is to place a metal mesh with particles in boiling water for 10 minutes. During the water boiling process, laboratory assistant must remove excess bitumen from the surface of the water. After boiling, the sample should be cooled down, and after that, it is possible to do the last step – visual assessment.

2.3. Obtaining of images
A photo studio was set up to get high-quality images. To create a studio, it is advisable to choose a dark room so that the surrounding lights do not create shadows on the sample. Necessary equipment for studio creation: two stands, petri dish, two adjustable light sources, a green paper sheet. In figure 2 a) and b) can see a drawing of the photo studio and the picture of the created studio.

![Figure 2. a) drawing of a photo studio; b) photo studio.](image)

When designing distances and angles, the aim was to minimise falling shadows and reflections of the light on the sample. The bitumen surface has a fine structure, so it reflects light. A petri dish filled with water was used to make a less reflection on bitumen. Water diffuse the light rays [13], so the reflection on the bitumen is limited.

Similarly, attention should be paid to the height of the petri dish from the ground, as shadows may be formed on the green background sheet. Adjustable table lamps with LED bulbs were used as light elements. It is advisable to use LED bulbs as other types of light bulbs can create light waves. The light sources were placed in front of each other. The height of the camera was not fixed to allow adjustment as needed. Considering the procedures which were described above, it was possible to start taking photos.

First, 30 stones were placed in a petri dish filled with water. The appropriate shooting height was found, and a picture was taken. Two devices were used to create photos. The first one was a professional photo camera - Canon EOS 600D with 18 megapixels APS-C CMOS sensor. The second one was a budget smartphone Huawei P9 lite with a camera specification of 13 MP, f / 2.0, 1/3 "", 1.12µm, AF. Then, manually, all the bituminous stones were inverted and photographed again. Then the sample was mixed again and repeated the steps described above two times. As a result, six different images with a camera and six different images with a smartphone were obtained for each type of mineral material.

2.4. Image processing
An important role in photo processing was to choose an image processing program. It was found that the ImageJ photo processing program was used to perform similar work [11]. This program is simple, and it is possible to process the image in a concise time. There is a good reasons to use this program because the key is to get accurate results in a short time. The use of the program is also free. Here are steps to process the image:
1. To draw the contour around the sample in the petri dish;
2. Delete background;
3. Do action: analyse – measure;
4. To open Image-Adjust-Colour threshold;
5. Take action with Hue, Saturation, Brightness adjustment. Get pictures from which is possible to measure the stone area and then the bitumen coverage area (see Figure 3).

Bitumen coverage was calculated by using the following formulas:

- $A_1$ - Cropped image area;
- $A_2$ - Green background area;
- $A_3$ - Total area of green background and uncovered aggregate particle area;
- $A_{bit}$ - Calculated by the formula:

$$A_{bit} = A_1 - A_3$$  \hspace{1cm} (2)

- $A_{akm}$ - Calculated by the formula:

$$A_{akm} = A_1 - A_2$$  \hspace{1cm} (3)

Bitumen coverage is calculated according to the formula:

$$B_p = \frac{A_{bit}}{A_{akm}} \times 100\%$$  \hspace{1cm} (4)

where:

- $A_{bit}$ – Area with bitumen coverage;
- $A_{akm}$ – Total aggregate particle area;
- $B_p$ – Bitumen coverage on aggregates.

**Figure 3.** Processed images with highlighted bitumen coverage.

**Figure 4.** Reflection areas on aggregate surface.

2.5. *Inaccuracy caused by reflection*

After viewing the photos, it was found that a small reflection was formed on the sample (see Figure 4). A decision was made to evaluate the effect of reflections on the final result. It was assumed that the untested sample had a 100% bitumen coverage. Each sample was photographed four times, mixing the sample each time. A total of 16 images were obtained. Table 2 shows the results obtained after the photos were processed.
Table 2. Average reflection size.

| Material       | Dolomite | Bitumen coverage, % | Granite | Bitumen coverage, % | Quartz diorite | Bitumen coverage, % | Gravel | Bitumen coverage, % |
|----------------|----------|----------------------|---------|---------------------|----------------|---------------------|--------|---------------------|
| Photo no. 1    | 95       | 97                   | Photo no. 1 | 97               | Photo no. 1 | 97                   | Photo no. 1 | 94               |
| Photo no. 2    | 97       | 98                   | Photo no. 2 | 97               | Photo no. 2 | 97                   | Photo no. 2 | 96               |
| Photo no. 3    | 96       | 97                   | Photo no. 3 | 97               | Photo no. 3 | 97                   | Photo no. 3 | 95               |
| Photo no. 4    | 96       | Average              | Photo no. 4 | 96               | Average     | 97                   | Average     | 94               |
| Average        | 96       | Average              | Average  | 97               | Average     | Average              | Average     | 95               |

The effect of reflection on different materials is variable. The shape of the surface can explain it. It was assumed that an average reflection is 4% if the material is 100% covered. However, if the sample coverage is 75% after boiling, only 3/4 of the total sample area can produce a reflection. In this case, the reflection effect is only ~ 3%. The formula for calculating bitumen coverage was improved as follows:

\[ R = \frac{B}{100} \]  
\[ B_{gal} = B + (R \times 4) \]  

\( B \) - calculated bitumen coverage before correction, %;
\( R \) – reflection correction coefficient, %.

3. Results

3.1 Results from visual assessment

The Visual evaluation was carried out by five independent operators. The results showed significant differences (see Table 3). The biggest difference between evaluations was from the sample with the smallest bituminous coverage. The smallest difference between the results of the evaluation was given by a gravel sample.

Table 3. Test results from a visual assessment.

| Material       | Dolomite | Granite | Quartz diorite | Gravel |
|----------------|----------|---------|----------------|--------|
| Operator 1     | 43 %     | 84 %    | 72 %           | 81 %   |
| Operator 2     | 52 %     | 80 %    | 71 %           | 80 %   |
| Operator 3     | 56 %     | 80 %    | 72 %           | 85 %   |
| Operator 4     | 53 %     | 75 %    | 63 %           | 81 %   |
| Operator 5     | 46 %     | 77 %    | 69 %           | 78 %   |
| Average        | 50 %     | 79 %    | 70 %           | 81 %   |
| Amplitude between results | 13 % | 9 % | 9 % | 7 % |
3.2 Evaluation using a photo processing program

Dolomite is a monochrome and light material, but when images were processing, it was found that the difference between Canon EOS 600D and Huawei P9 lite was 8% and it is the most significant difference between all the samples.

Table 4. Test results with dolomite when photo processing method was used.

| Dolomite     | Canon EOS 600D Side 1 | Side 2 | Huawei P9 lite Side 1 | Side 2 |
|--------------|------------------------|--------|-----------------------|--------|
| Photo eval. 1| 49 %                   | 43 %   | 54 %                  | 58 %   |
| Photo eval. 2| 45 %                   | 45 %   | 52 %                  | 53 %   |
| Photo eval. 3| 46 %                   | 47 %   | 52 %                  | 56 %   |
| Average      | 46 %                   | 54 %   |

The granite selected was various colours and gave the impression that it will be difficult to process it using a computer program. In the end photo processing for granite took more time. Result difference between Canon EOS 600D and Huawei P9 lite was the smallest 5%.

Table 5. Test results with granite when photo processing method was used.

| Granite      | Canon EOS 600D Side 1 | Side 2 | Huawei P9 lite Side 1 | Side 2 |
|--------------|------------------------|--------|-----------------------|--------|
| Photo eval. 1| 85 %                   | 86 %   | 81 %                  | 81 %   |
| Photo eval. 2| 82 %                   | 85 %   | 75 %                  | 82 %   |
| Photo eval. 3| 88 %                   | 82 %   | 76 %                  | 83 %   |
| Average      | 85 %                   | 80 %   |

Gravel material typically consists of different types of mineral materials. Their colour may vary. In this sample, it was hard to make good repeatability. Every time the sample was mixed the different result was possible to get. Therefore, image processing may be problematic with gravel type material. The difference in results between Canon EOS 600D and Huawei P9 lite was 7%.

Table 6. Test results with gravel when photo processing method was used.

| Gravel       | Canon EOS 600D Side 1 | Side 2 | Huawei P9 lite Side 1 | Side 2 |
|--------------|------------------------|--------|-----------------------|--------|
| Photo eval. 1| 80 %                   | 85 %   | 81 %                  | 74 %   |
| Photo eval. 2| 83 %                   | 73 %   | 72 %                  | 82 %   |
| Photo eval. 3| 83 %                   | 81 %   | 68 %                  | 67 %   |
| Average      | 81 %                   | 74 %   |
The chosen quartz diorite surface was with a homogeneous colour. The difference in results between Canon EOS 600D and P9 lite was 4%.

Table 7. Test results with quartz diorite when photo processing method was used.

| Quartz diorite | Canon EOS 600D | Huawei P9 lite |
|---------------|----------------|---------------|
|               | Side 1 | Side 2 | Side 1 | Side 2 |
| Photo evaluation no. 1 | Mixed 63 % | 63 % | 64 % | 68 % |
| Photo evaluation no. 2 | Mixed 60 % | 56 % | 61 % | 65 % |
| Photo evaluation no. 3 | Mixed 63 % | 66 % | 71 % | 66 % |
| Average        | 62 %  | 66 %  | 66 %  | 66 %  |

Figure 5. Comparison of the results of visual and image processing method.

Conclusions
1. Images taken with a high resolution professional camera are easier to process, the more precise the contours of the bitumen coverage. Images taken with the smartphone were more difficult and inaccurate to process. The difference between the two electronic devices averaged 4-8%.
2. Reflection error evaluation improved the accuracy of the results.
3. The smaller the bitumen coverage, the more inaccurately results are evaluated by the human.
4. The image processing method shows the smallest scattering when is used a professional camera to capture images.
5. For dark mineral materials, it is significantly more difficult to distinguish the bituminous coverage from the surface of the material.
6. If the mineral material contains stones of different colours (gravel), then it is not recommended to use the image processing method.

Further work
As a future option, we see the use of computer learning to estimate bitumen coverage. It could improve accuracy because the material could be heterogeneous in colour. However, to do this, it would be necessary to improve the accuracy of the image processing method. It is possible to do it by using a higher resolution camera and developing the photo studio lighting.
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