Evaluation of Different Mineral Filler Aggregates for Asphalt Mixtures

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Abstract. Mineral filler aggregates play an important role in asphalt mixtures because they fill voids in paving mix and improve the cohesion of asphalt binder. Limestone powder containing over 90% of CaCO3 is the most frequently used type of filler. Waste material from the production of coarse aggregate can be successfully used as a mineral filler aggregate for hot asphalt concrete mixtures as the limestone powder replacement. This paper presents the experimental results of selected properties of filler aggregates which were obtained from rocks with different mineral composition and origin. Five types of rocks were used as a source of the mineral filler aggregate: granite, gabbro, trachybasalt, quartz sandstone and rocks from postglacial deposits. Limestone filler was used in this study as the reference material. The following tests were performed: grading (air jet sieving), quality of fines according to methylene blue test, water content by drying in a ventilated oven, particle density using pyknometer method, Delta ring and ball test, Bitumen Number, fineness determined as Blaine specific surface area. Mineral filler aggregates showed significant differences when they were mixed with bitumen and stiffening effect in Delta ring and ball test was evaluated. The highest values were achieved when gabbro and granite fillers were used. Additionally, Scanning Electron Microscopy (SEM) analysis of grain shape and size was carried out. Significant differences in grain size and shape were observed. The highest non-homogeneity in size was determined for quartz sandstone, gabbro and granite filler. Their Blaine specific surface area was lower than 2800 cm²/g, while for limestone and postglacial fillers with regular and round grains it exceeded 3000 cm²/g. All examined mineral filler aggregates met requirements of Polish National Specification WT-1: 2014 and could be used in asphalt mixtures.

1. Introduction

The durability of the road pavement is related to the appropriate choice of materials. The technology of a particular layer, its function in pavement construction and traffic categories should be taken into account on the stage of design. All the component materials which are used for upper layers of pavement made of asphalt mixture must be of the highest quality. Bituminous mixtures are basically composed of aggregates of different sizes, filler and bitumen. Fillers (filler aggregate) consists of mineral grains most of which pass 63µm sieve (EN 13043). This component represents 3–14% of the total aggregate by weight in the whole mixture regardless the type of asphalt mixtures (Stone Mastic Asphalt, Asphalt Concrete). In the case of Mastic Asphalt content of filler is in the range 26-36% [1].
Fillers may be of natural origin when derived from the crushing of rocks or can be manufactured as it is in the case of lime, cement, ash or slag. Their main functions are filling the voids in the aggregate skeleton to create a denser mixture and improving the cohesion of asphalt binder and the stability of the mixture. As a result, the asphalt mixture pavement should be resistant to water and frost, plastic deformations, fatigue cracks and low temperature cracks. Several studies have demonstrated that fillers perform also other important functions. Depending on their particle size and structure, they stiffen and/or extend the binder [2,3], which affects rutting and fatigue phenomena. Fillers also may modify the ageing processes [4,5] and their finest grains may prevent moisture damage [1]. Numerous studies have proven that the properties of mineral filler aggregate had a significant effect on the properties of the asphalt mixtures [4-7].

Most recent regulations on filler for bituminous mixtures (EN 13043, ASTM D242, AASHTO M17) established the limit values for several characteristics such as grading, water content, plasticity index and organic content. These characteristics are necessary for quality control, but are not sufficient to obtain information correlated with the expected performance of bituminous mixtures [7].

In the Polish regulations [1] only material which is intentionally manufactured as filler aggregate may be used for this purpose. This requirement limits application of fillers obtained as a by-product from production of fine and coarse crushed aggregate or hot asphalt mixture. As a consequence, only limestone powder containing over 70% by weight of CaCO₃ is used as a filler for asphalt mixtures. It should be noted that in Poland 95% of the aggregates used for road construction come from natural deposits [8]. Considering the rational management of natural resources and wastes the use of fillers other than limestone powder is worth to be investigated. Numerous investigations prove that such waste powders may have no negative influence on asphalt mixture and they may even improve its engineering characteristics to some degree [9,10,11].

The influence of mineral fillers from different rock deposits and a type of asphalt binder on the properties of asphalt mixture was investigated in the project [11]. The results indicate that even high content of SiO₂ in mineral filler does not disqualify the material and has not negative influence on the quality of asphalt mixture. Additionally, the finding was that it is the type of the binder and not the type of the filler that had the significant influence on the asphalt mixture performance. When modified or highly modified asphalt binders with high resistance to permanent deformations, fatigue and low temperature cracks are used, other fillers than limestone powder may be worth considering. This is economically important. In Poland all plants producing limestone powder are located in only two regions: Świętokrzyski and Kujawski. Limited number of producers and transportation costs affect costs of asphalt mixtures.

The study described in this paper presents the experimental results of selected properties of filler aggregates which were obtained from rocks with different mineral composition and origin.

2. Research program

2.1. Materials

Five types of rocks were used as a source of the mineral fillers: gabbro, granite, trachybasalt, quartz sandstone and rocks from postglacial deposits. Postglacial aggregate contained 60% of igneous and metamorphic rocks (granite, gneiss, granodiorite) and 40% of sedimentary rocks (sandstone, limestone and dolomite). Limestone filler was used in this study as the reference material. Aggregate characteristics is given in table 1.

Filler aggregate was obtained from fine aggregates by grinding for about 30 min. in the ball mill. Images of coarse grains and mineral fillers are presented in figure 1.
Table 1. Aggregate characteristics

| Rock type        | Genetic classification | Structure       |
|------------------|------------------------|-----------------|
| Granite          | Igneous                | Holocrystalline |
| Gabbro           | Igneous                | Holocrystalline |
| Trachybasalt     | Igneous                | Hypocrystalline |
| Quartz sandstone | Sedimentary            | Sandstorm       |
| Postlacial       | Sedimentary            |                 |

Figure 1. Images of coarse grains and fillers form different rocks: a) gabbro, b) granite; c) trachybasalt; d) quartz sandstone; e) postglacial

A standard 70/100 penetration paving grade asphalt was used for the laboratory production of filler–bitumen mastics. Softening point R&B for this asphalt was 50°C.

2.2. Methods
The experimental plan was design in order to assess the physical and chemical characteristics of the mineral filler aggregate according to the Polish regulations [1] and the results were compared with the
international standard on filler for bituminous mixtures EN 13043. Grading (investigated by jet sieve analysis - EN 933-10), water content (EN 1097-5), harmful fines (Methylene blue test EN 933-9), particle density (Pycnometer method EN 1097-7), variation in "Delta ring and ball" temperature (EN 13179-1) and Bitumen Number (EN 13179-2) were evaluated. Fineness was determined as Blaine specific surface area according to EN 196-6.

Additionally, the shape, size and texture of grains was examined. Images were made using FEI Quanta 250 FEG Scanning Electron Microscope.

3. Results and discussions
The experimental results of sieve analysis (table 2) show that all fillers met the requirements. It should be noted that the limit values given in table 2 are the same for asphalt mixtures for all layers of road pavement structure in Poland [1]. Other tested performance parameters of mineral fillers and the requirements (when given) are summarized in table 3. Graphical interpretations of Delta R&B temperature and Bitumen Number test results are shown in figures 2 and 3.

| Filler type      | Passing fraction [%] | 0.063 | 0.125 |
|------------------|----------------------|-------|-------|
| Granite          | 100 100 100          | 0.063 | 0.125 |
| Gabbro           | 100 100 100          | 0.063 | 0.125 |
| Trachybasalt     | 100 100 100          | 0.063 | 0.125 |
| Quartz sandstone | 100 100 100          | 0.063 | 0.125 |
| Postglacial      | 100 100 100          | 0.063 | 0.125 |
| Limestone powder | 87 99 100            | 0.063 | 0.125 |

Table 2. Results of sieve analysis.

| MBF [g/kg] | Water content [%] | Particle density ρf [Mg/m³] | BN [-] | ΔR&B [°C] |
|------------|-------------------|----------------------------|--------|-----------|
| Granite    | 6                 | 0                           | 2.45   | 32        | 14.0      |
| Gabbro     | 6                 | 0                           | 2.62   | 28        | 10.2      |
| Trachybasalt | 6               | 0                           | 2.49   | 28        | 11.2      |
| Quartz sandstone | 6        | 0                           | 2.58   | 30        | 12.0      |
| Postglacial | 6                | 0                           | 2.65   | 27        | 11.0      |
| Limestone powder | 6       | 0                           | 2.70   | 28        | 12.0      |

Table 3. Results of methylene blue, water content, particle density, Delta R&B temperature and Bitumen Number tests.

The experimental results of grading, quality (MBF) and water content obtained for the considered fillers do not differ significantly from the limestone powder characteristics. The requirements regarding grading are easy to be satisfied by a producer. When there is a need for high content of fractions <0.063mm more intense milling should be applied, by increasing the number of balls in a ball mill for instance.

The methylene blue (MBF) test is used to quantify the amount of harmful clays of the smectite (montmorillonite) group, organic matter and iron hydroxides, which might be present in a filler. The principle of the test lies in adding quantities of a standard aqueous solution of the dye (methylene blue) to a sample until adsorption of the dye stops. Clay minerals are crystalline hydrated aluminum-silicates, which, due to their charged surface and ability to exchange cations, adsorb methylene blue from an aqueous solution. The quantity of methylene blue adsorbed during the test increases in
proportion to the content of clay. The presence of clay can have a detrimental effect on the water sensitivity of asphalt mix. For example, clay minerals present in aggregates can prevent asphalt binders from thoroughly bonding to the surface of aggregate particles, increasing the potential of water damage to the paving mixture. The test results prove that the tested fillers are free from contaminations.

The value of particle density is necessary to determine variations of softening point, voids content in dry compacted filler and for proportioning asphalt mixture content. Particle density and Bitumen Number (\(BN\)) have to be declared by a producer but there are no limit values in the regulations or standards. All tested mineral fillers are categorized as BN28/39 according to EN 13042.

![Figure 2. The mean values of BN with 95% confidence interval](image1)

![Figure 3. The mean values of \(\Delta R&B\) with 95% confidence interval](image2)

All tested mineral fillers met the requirements for the category \(\Delta R&B\) 8/25. The highest values were obtained for trachybasalt, postglacial filler and limestone powder which is related to the highest specific surface area of these fillers. All tested mineral fillers met the requirements for Blaine specific surface area (table 4). The microscopic morphology of the evaluated fillers is shown in figure 4 gained
from Scanning Electron Microscopy (SEM). SEM images allow to evaluate shape and size of the individual filler grains.

The imagines of gabro, granite and quartz sandstone show clearly that there is a significant variation in particles size. The individual grains are irregular and elongated. In the case of postglacial filler both spherical and regular grains (like in limestone powder) as well as irregular and elongated grains (like in gabro, granite and quartz sandstone) can be found. This is due to the varied lithological composition of postglacial aggregates.

| Table 4. Results of Blaine specific surface area |
|-----------------------------------------------|
| S \[ \text{cm}^2/\text{g} \]                  |
| Granite                                      | 2938 |
| Gabbro                                       | 2778 |
| Trachybasalt                                 | 3429 |
| Quartz sandstone                             | 2850 |
| Postglacial                                  | 3162 |
| Limestone powder                             | 3239 |
| Requirement                                  | 2500 - 4500 |

Trachybasalt filler most resembles limestone powder when size of grains is taken into account. These two materials have also the highest Blaine specific surface area. However, in the larger magnification (figure 5) there are visible differences in grain shape between them. The limestone filler has more spherical and very regular grains, while the trachybasalt grains are more irregular in shape.
4. Conclusions
All examined mineral filler aggregates met requirements of the Polish National Specification WT-1 and could be used in asphalt mixtures. Their properties are comparable with the features of limestone filler. The use of other powders than limestone based materials as the filler aggregate for asphalt mixtures is an economically justified solution, particularly in these regions where limestone powder is not produced. At the next stage of the study, the properties of asphalt mixtures with these fillers such as water sensitivity, permanent deformation, fatigue cracks and low temperature cracks should be evaluated. This could finally verify the suitability of non-limestone fillers for asphalt mixture production.

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