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Effect of aggregate petrology on the durability of asphalt pavements

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HIGHLIGHTS

- The petrographic analysis of rocks is not considered for their application.
- Asphalt performance depends on the rock quality.
- Hydrophilic minerals and micro-cracks are important information.

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ABSTRACT

A petrographic analysis of the aggregates, generally carried out in the quarry exploration phase, gives information about fundamental characteristics on which all the others, including mechanical resistance, depend. However, in the asphalt industry the interest is often limited to the mica and sometimes quartz content. This article aims to expose the limitation of the current asphalt concrete design method compared to the advantages given by a deeper analysis of the stone material properties through an analysis of the behavior of four asphalt mixtures subjected to durability tests. The findings support the importance of the evaluation of the geological parameters.

1. Introduction

Weathering, traffic and climatic conditions are among the several challenges that must be considered when designing an asphalt mixture. Whether the pavements will be able to sustain such conditions without any significant damage depends in large scale on the chosen materials. While great effort is put into improving the bond between binder and aggregates or into studying the long term properties of bitumen to assure a long lasting homogeneous surface, the selection of the aggregates for road construction is still mainly based on experience, reputation and mechanical properties, in many countries including Norway [1].

However, as the research on other mixture components and their compatibility advances, other properties of the aggregates such as surface charge and energy, polarity and adsorption sites of the aggregate surface become more and more relevant. Although relevant for research purposes, their use in the pavement industry is still limited. A different approach would include a preliminary analysis of the rock material in order to determine its adequacy to be included in asphalt mixtures. The mentioned properties, together with other characteristic such as mechanical resistance, roughness, shape and permeability are evaluable through a petrographic analysis of the rock already in the quarry [2–4].

Quantifiable parameters are the mineralogy, grain size (mineral grain size) and microcraks. The mineralogy of the aggregates has been known to affect the durability of the asphalt mixtures: the presence of mica affects the mechanical resistance of the mixture or elevated amounts of quartz and alkali feldspars decrease the adhesion between the binder and the aggregate [5–7]. Several investigations have also shown the importance of the grain size and grain size distribution on the mechanical properties of the rocks [8,9]. For example, a grain size smaller than 1 mm is indirectly proportional to the strength parameters: increased size provides more continues paths of weakness for growing cracks (micro-cracks) to propagate along promoting a rapid degradation of the material [1,10]. Additionally, micro-cracks can be access channels for water. However, at least in large scale, their presence does not seem to affect the result of mechanical processes such as the freeze-thaw cycles [11].

Although the quantitative investigation of those parameters (mineralogy, grain size and micro-cracks) can already give a large amount of information about the rock durability, a visual analysis of thin sections of the rock type can help evaluating the future performance of the material. Granite and schist are for example char-

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acterized by the similar mineralogy however, schist is a much weaker rock due to the laminar and oriented pattern of the contained mica [12].

However, it should be taken into account that the complexity of the rock material and large amount of factors, such as the quantity or type of alteration minerals could hinder the direct association of the petrographic variables with asphalt concrete mechanical properties [9]. While the petrographic analysis could be of great help in evaluating the long term durability of the aggregates, its use in design process is however still limited to few recommendations from the national road administrations [7].

This study tries to establish a preliminary relationship between geological parameters and asphalt performance. The petrographic properties of four local rocks, chosen depending on experience, reputation and mechanical characteristics, were quantified trough quantitative and qualitative parameters.

2. Methodology

Four asphalt mixtures, each characterized by one type of coarse aggregate, were designed and tested during this study. The testing procedure was divided in two sections: this first part consisted in the petrographic analysis of the aggregate material while the second focused on the testing of the whole asphalt mixtures.

Because of the small sample, a statistical analysis of the results was considered premature.

2.1. Petrographic analysis

Four aggregate types were considered in this study: a meta-sandstone, a meta-greywacke, a meta-gabbro and a greywacke. Thin sections of each rock type were examined under the microscope in order to determine the grain structure while their mineralogy was evaluated through the X-ray Diffraction method. The micro-cracks present on the aggregate surface were quantified through image analysis of thin sections of the rocks impregnated with a fluorescent agent, in which the intensity of the light transmitted was measured in fluorescent light by use of UV filters in the microscope [11]. The measurements represent an indirect quantification of the amount of micro-cracks and porosities in the aggregates.

The preliminary tests of the materials presented in Table 1, included an evaluation of the mechanical properties of the aggregates in terms of abrasion loss both with and without presence of water (Los Angeles test and Micro-Deval test respectively), necessary for a correct design of the mixtures.

2.2. Asphalt testing

The four asphalt mixtures were designed according to the Norwegian Public Roads Administration guidelines [7]. In Table 2 the main properties of the designed asphalt mixtures are presented. Each of the asphalt mixture, hereinafter mentioned depending of the characterizing aggregate type, was then subjected to three different test procedures: Indirect Tensile Strength (ITS) test, Cantabro test and Prall test. The tests were selected based on their ability to characterize the long-term durability of the mixture in the Norwegian traffic and climatic conditions, but also based on their strong relationship with the characteristics of the aggregate type.

Table 2
Asphalt mixtures characteristics.

Aggregate type	Binder content [%]	Air voids [%]	Maximum aggregate size [mm]
Meta-sandstone	5.9	2	11.2
Meta-greywacke	5.8	3.5	11.2
Meta-gabbro	5.1	2.5	11.2
Greywacke	6	4	11.2

The ITS test was carried out according to the European Standard after both dry and wet conditioning [13]. The test evaluates the water sensitivity of asphalt mixtures through the Indirect Tensile Strength Ratio (ITSR) evaluated as the ratio between the indirect tensile strength (ITS) of samples conditioned in water, 72 h at 40 °C, and those in air, 72 h at room temperature.

The difference in weight of an asphalt sample after 300 rotation in the Los Angeles drum define the Cantabro abrasion value [14]. This method, generally used to evaluate the durability of porous mixtures, was selected because of the morphology of the test that strongly challenges the cohesion of the mixture and the integrity of the aggregates. The Cantabro test was carried out after dry conditioning and after eight freeze-thaw cycles.

The Prall test, used in the Nordic countries to evaluate the abrasion due to studded tires was carried out according to the standard [15]. The test measures the loss in mass of an asphalt concrete sample is measured after the being worn by the abrasive action of 40 steel spheres for 15 min.

All samples subjected to water/ice conditioning were water saturated.

Three to five repetition were performed per each test.

3. Results

The results of the petrographic analysis are summarized in Fig. 1, Table 3, Fig. 2 and Table 4.

From the thin sections, the meta-sandstone aggregate shows a grano-blastic texture (Fig. 1a and b) with grain size ranges from medium to fine (Table 4). Quartz and feldspar are the main components of the rock type. Alteration minerals such sericite, epidote and carbonate are also present (Table 3). Although the mineralogy of the rock is dominated by quartz, a particularly strong mineral, the mechanical resistance of the aggregates is significantly diminished by the presence of mica minerals from matrix recrystallization during metamorphic episodes in between the grains. The reduced contact area between the grains translates into poor grain bonding and mediocre durability (see also the micro-cracks content in Table 1). Micro-cracks are found in matrix, around the grains, since mica minerals are weaker than quartz and feldspar. The micro-cracks found inside feldspar are caused by the chemical degradation of this mineral, a fast process that can induce a rapid disintegration of the rock.

Table 1
Aggregates' mechanical properties and micro-cracks measurement.

Aggregate type	Stone density g/cm^3	Los Angeles test %	Micro-Deval %	Water absorption %
Meta-sandstone	2.71	20.9	6.0	0.19
Meta-greywacke	2.75	14.4	8.4	0.14
Meta-gabbro	3.06	15.9	5.7	0.19
Greywacke	2.7	19.2	24.0	0.22