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Stochastic simulation of the influence of variation of mineral material grading and dose weight on the homogeneity of hot-mix asphalt

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Abstract

The aim of the study is to evaluate the influence of random errors of the stochastic technological process occurring in a batch type plant on the homogeneity of the hot-mix asphalt (HMA). The article presents the algorithm of prognosing mineral part composition of HMA, which takes into consideration a variation of mineral material cumulative percent passing through control sieves as well as errors of mineral material dose weight in the finite dosing. It is considered that percent passing and dose weight errors are independent random quantities, distributing according to the normal law. The original algorithm for the simulation of values of these two quantities is used. The mineral material grading and dose weight of the batches of HMA are selected through the use of the random number generator. To evaluate the homogeneity of the simulated lot of HMA batches, reference was made to Lithuanian Construction Recommendations R35-01, limiting the admissible deviations of components quantities of HMA in comparison with the job-mix formula. The example of simulation discussed above is presented, and the results are analysed.

Keywords: Asphalt plant; Technological process; Hot-mix asphalt; Homogeneity; Stochastic simulation

1. Introduction

The composition and properties of hot-mix asphalt (HMA) used in the road pavement depend on the physical and mechanical properties of the used materials, its composition project and production technology. One of the most important quality characteristics of HMA is homogeneity, which, besides composition project, production technology scheme and the quality of mixing, is also influenced by the variation of mineral material grading as well as its weight errors in the finite dosing. These two factors are stochastic. Therefore, during the production of HMA the grading and dose weight of mineral materials as well as its composition and properties vary, i.e. HMA becomes heterogeneous [1].

HMA may be produced in three types of asphalt concrete plants: batch plant, continuous mix plant and drum-mix plant [2]. In Lithuania as well as in other European countries, HMA is mostly produced in batch plant, in which a mixture of dried and heated initial mineral materials is screened into 3–6 hot fractions, weighed in the common dosing bin according to the principle of summing their weights up. Therefore, HMA batches investigated in the article are composed not of initial (cold) mineral materials, but of hot fractions screened in the finite dosing.

The theoretical background [3–5] of composing the appropriate structure of asphalt concrete and guaranteeing its properties show that HMA used for it must be not only of optimal composition but homogeneous as well. The homogeneity of HMA mostly decreases due to the segregation processes during storage, transportation, laying and compacting [6–9]. The study of the variation of the composition of HMA [10,11] identified the factual values of standard

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deviations of component quantity, which differ in each type of mixing plants. The influence of separate technological factors on the scattering of the component quantity in the lot during HMA production has not been studied thoroughly yet.

Let us discuss the influence of composition project quality, variation of mineral material grading and mineral materials dosing errors on HMA mineral part composition.

1.1. HMA composition project

HMA composition project is designed taking HMA functionality and required mark into account. Grading averages of mineral materials are used in the production of HMA as well as the production technology in the mixing plant is taken into account. Target HMA properties and its homogeneity are guaranteed by properly designed composition project, where the ratio of basic cold mineral materials weights is determined. The principles and methods of designing the optimal HMA composition project, when averages of material properties characteristics are used (determination task is solved), are presented in research works [12–14]. Calculation of HMA grading, and its optimization in particular, is a very complicated problem. It is usually solved by the way of mathematical approximation; although some authors [15,16] recommend to solve this problem through the use of mathematical programming methods. When applying mathematical programming [17–19], the main problem of calculating the optimal HMA grading is not the scope of calculations, but the optimal criteria.

1.2. Variation of mineral material grading

The grading of mineral materials used in the production of HMA varies within a certain interval, which depends on their storage, transportation and loading technologies [20,21]. HMA designed of initial cold mineral materials is produced in batches, the composition of which must not deviate from design coarse aggregate, fine aggregate, filler and bitumen more than statistical tolerances allow. In some countries (USA [22] and Great Britain [23]) statistical tolerances do not depend on the number of samples; in other countries (Germany [24] and Lithuania [25]) they are differentiated according to the number of samples: they are lower of the sample lot and higher of a separate sample.

When is producing HMA in a batch plant, its batches are composed not of initial cold mineral materials, but of finally dosed 3–6 hot fractions and reclaimed dust. The grading of these finally dosed mineral materials and its variation are mostly unknown if it had not been identified through experimental studies.

Percent passing through control sieves of hot fractions used in HMA producing vary due to the following three main reasons [1,26]: (a) changing of the flow intensity (debit) of hot mineral mix continuously running on the sieving equipment of a mixing plant; (b) variation of the grading of hot mineral mix continuously running on the screening equipment of a mixing plant; (c) segregation of hot fractions running into the bin sections under the screening equipment and their segregation when running into a batcher. All these technological stochastic factors impact on the variability of the grading of the hot fraction intermittent flow, which runs from each section of the hot mineral material bin into a batcher. So, even extremely accurate dosing of hot fractions does not guarantee the homogeneity of HMA separate batches. The percent passing through control sieves of such batches distribute according to the normal law.

1.3. Dosing errors of mineral materials

When weighing finally dosed mineral materials with computerized automatic proportioning systems, the weight of hot fractions, fillers and reclaimed dust doses is not constant and fluctuates around the mean, which may be moved from the job-mix formula dose additionally. Average weight of each mineral material dose must comply with the job-mix formula weight, and its variation depending on the structure and technical condition of the dosing equipment, succession of weighing according to the principle of 'summing up weights', weight tolerances set in the program and operator's actions (human factor) must be minimal.

Therefore, even if the project is very well-prepared, good results cannot be expected if improper mixing plant is used and if the HMA production technological process is not properly controlled and managed. Modern computerized asphalt concrete plants ensure rather stable dosing of materials. However, HMA produced in them is not homogeneous due to the variation of grading of mineral materials used. It was identified [1] that a 42% standard deviation of the coarse aggregate's (particles larger than 5 mm) quantity in the produced HMA depends on the variation of the used mineral material grading and 58% on their dosing errors, fine aggregate (5–0.071 mm particles) 70% and 30%, respectively, fillers (particles smaller than 0.071 mm) 60% and 40%, respectively. These data show that the factual variation of mineral material grading and their dosing errors have the same influence on the reduction of the homogeneity of HMA composition. Therefore, it is likely that HMA complying with the standard requirements will be produced so that some of its batches will not meet these requirements; quantities of its components will not fall between the lower and upper limits of technical tolerances and deviations from the job-mix formula will exceed the limits of tolerances. In the article this hypothesis is confirmed through the use of mathematical simulation methods.

The aim of the study is to present the algorithm of prognosing the grading during HMA production, i.e. to show how the influence of mineral material percent passing through control sieves and dose weights' variation on the homogeneity of the produced HMA may be evaluated.