Research Concerning the Impact of Geometrical Characteristics of Natural Quarry Aggregates Used in the Composition of Asphalt Concrete

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Abstract. The paper presents studies and laboratory tests concerning the influence of the way the natural quarry aggregates are processed upon the composition of an asphaltic concrete with a maximum grain size of 16 mm (BA 16). The research included the realization of grading curves on certain aggregates, curves lately compared to the maximum density line. This approach aims at classifying certain aspects concerning some of the physical-mechanical characteristics of the asphalt concretes determined through static and dynamic laboratory tests. The research resulted from the fact that in Romania, the elementary gradings on granular fractions from the same source, entering the composition of a certain asphalt mix, differ most of the times depending on the manipulation and the processing manner, respectively. This finding is based on the experience of the laboratory testing, where different values concerning the volume weight, apparent volume weight, voids and rigidity module were obtained on the same asphalt mix dosage prepared according to the prescription in two separate samples. Thus, in order to emphasize the impact of the processing manner (crushing) of the natural aggregates, the authors determined the percentage distribution on intermediate granular fractions of the gradings entering the composition of an asphalt concrete. Since the Romanian Standard for asphalt mixtures stipulates a large grading envelope between the standard sizes corresponding to each grading, the authors considered that there is no uniform distribution ratio depending on the size of the grains entering its composition. The study started from different research methods found in the specialized literature dealing with the calibration of the optimal grading curve. The results of the laboratory tests performed on the asphalt mixture confirm the importance of the particle size analysis in obtaining high quality physical-mechanical characteristics.

1. Introduction

With the rapid growth of traffic flow and the combined effect of natural conditions, for instance, the global temperature increasing [1], asphalt pavement was damaged seriously. Rutting, cracks, potholes and other road distresses seriously affect the safety and comfort of driving. Many roads have not yet reached the designed service life and require extensive maintenance and renovation [2].

The existing researches mainly focus on the properties of asphalt [3–5], anti-stripping agent [6–9] and rejuvenator [10–13] to optimize the asphalt mixture. But researches on the aggregate characteristics are being left far behind. Aggregate is an account for >90% of the total mass in asphalt mixture and the study on improving the performance of asphalt mixture based on the characteristics of aggregate morphology is a significant research orientation. Asphalt mixtures are typically thought to
be heterogeneous materials consisting of aggregates, asphalt binder, and air voids. The majority of a dense-graded asphalt mixture is the aggregates (approximately 85% by volume) and as such, the load bearing capacity of an asphalt mixture is strongly related to its aggregate skeleton.

Besides the physical and mechanical properties of the asphalt binder, the aggregate related parameters such as shape, texture, chemical properties, and gradation affect the volumetric properties and subsequently, the performance of asphalt mixtures [determination of voids]. The effect of aggregate gradation on the asphalt mixture properties was also evaluated by Elliott et al. [14] who concluded that changing the gradation curve shape has a substantial effect on the mechanical and volumetric properties of asphalt mixtures. Haddock et al. [15] also evaluated the impact of aggregate gradation on asphalt mixture performance. They used two mixture types having nominal maximum aggregate sizes (NMAS) of 9.5 and 19.0 mm to evaluate the sensitivity of asphalt mixture performance to gradation changes. For each mixture type, three aggregate gradations (above, through, and below the Superpave restricted zone) were designed. Triaxial tests, accelerated pavement tests, and laboratory wheel tracking tests were used to gauge mixture response. Results of the study indicated that mixtures with gradations above the restricted zone (fine-graded) had the best rutting resistance in both the accelerated pavement tests and the laboratory wheel tests. Additionally, the fine-graded mixtures displayed higher strength, based on the triaxial compression testing results. In addition to experimental approaches, the effect of particle size distribution on the packing behavior of mixtures has been studied by two other approaches, numerical and analytical analyses [16, 17].

A conceptual and analytical approach to the effects of asphalt mixture gradation on asphalt mixture performance has also been studied by Roque et al. [18] who proposed an analytical model to evaluate the coarse aggregate structure of asphalt mixtures based on the basic principles of particle packing. Their work determined the main aggregate size range of the aggregate structure in an asphalt mixture and related the quality of this structure to asphalt mixture performance.

The researchers named the main aggregate size range the dominant aggregate size range (DASR) and suggested that to keep the DASR particles in contact with each other, the DASR porosity should not exceed 48%. Evaluation of their proposed model using an extensive range of asphalt mixtures indicated the model could identify asphalt mixture gradations that resulted in asphalt mixtures with poor rutting performance. Guarin et al. [19] used the concept of DASR to evaluate the effects of binder content changes, aggregate smaller than the DASR, and air voids content on asphalt mixture performance, both (rutting and cracking). In the study, aggregates smaller than the DASR were referred to as the interstitial component (IC) and a new parameter, the disruption factor, was introduced to measure the disruptive effect of the IC particles on the DASR particle structure. Additionally, in Lira et al. [20] presented a framework to recognize the range of aggregate sizes which form the load carrying structure in asphalt mixtures and determine its quality.

2. Materials

2.1. Aggregates
The crushed aggregates used in this study come from a diorite quarry (3.00 g/cm³ bulk density, minimum 98% level of compaction and 0.22% water absorption). Diorite is an intrusive igneous rock composed principally of the silicate minerals plagioclase feldspar (typically andesine), biotite, hornblende, and/or pyroxene. Diorite is usually grey to dark grey in color, but it can also be black or bluish-grey and frequently has a greenish cast. Diorites have the qualities needed to be used as natural stone for roads, railways and constructions. For the study, a 0-16 mm aggregate skeleton was used. The basic performance indicators of the used aggregates are shown in table 1.
Table 1. Aggregate basic performance indicators.

| Properties                  | Unit    | Tested value |
|-----------------------------|---------|--------------|
| Resistance to wear Micro-Deval | Mde  | 19           |
| Bulk density                | g/cm³   | 3.00         |
| Water absorbtion            | %       | 0.22         |
| Adhesiveness                | %       | 86.21        |
| Affinity                    | %       | 89.84        |

2.2. Asphalt binder
Asphalt binder plays a role of cementing throughout the concrete system, making loose particles connected into a whole and directly affects the road performance of asphalt mixture [21]. 50/70 asphalt binder was used in this study. Characteristics of the 50/70 asphalt binder are presented in table 2.

Table 2. Characteristics of the used bitumen.

| Characteristic                              | Unit     | Tested value |
|---------------------------------------------|----------|--------------|
| Penetration at 25°C                         | 0.1 mm   | 54           |
| Softening point                             | °C       | 48.6         |
| Ductility                                   | cm       | >150         |
| Mass variation                              | %        | 0.04         |
| Increase of softening point after RTFOT     | °C       | 6.78         |
| Residual penetration                        | %        | 5.5          |
| Ductility after RTFOT                       | cm       | >150         |

2.3. Asphalt mixture
Thus, in order to emphasize the impact of the processing manner (crushing) of the natural aggregates, it was determined the percentage distribution on intermediate granular fractions of the gradings entering the composition of an asphalt concrete. Regarding this, four asphalt concrete BA 16 dosages have been designed (maximum aggregate size of 22.4 mm and nominal maximum aggregate size of 16 mm) with the same binder content 4.7% and:

-   four different percentages of aggregate participation, figure 1-4;
-   two options of percentage distributions on intermediate granular fractions of the gradings entering the composition of BA16, figure 5-10.
Figure 1. Grading curve – dosage 1

Figure 2. Grading curve – dosage 2

Figure 3. Grading curve – dosage 3

Figure 4. Grading curve – dosage 4

Figure 5. Chippings 8-16 option I

Figure 6. Chippings 8-16 option II
3. Results and methodology
The main purpose of this study is to highlight the influence of the percentage distribution on intermediate granular fractions of the gradings entering the composition of an asphalt concrete (BA16) on the values of the theoretical maximum density of the asphalt mixture (Gmm), the bulk density of the asphalt mix (Gmb), the air voids (Va) and the stiffness modulus values for all the four dosages of BA16 presented above. The BA16 testing samples were prepared with the gyratory compactor at 80 gyrations and a compaction temperature of 140 ºC. In order to determine the Gmb, there were used two different methods, to emphasize the differences between the two values of Gmb obtained, resulting in this way two other different values of air voids (Va) for each of the two Gmb values. The Gmb was determined according to the procedure described in [22] and the Gmm was determined in accordance with [23].

The Gmm, Gmb, Va and the stiffness modulus values were calculated and the results are presented in figures 11-14.
Figure 11. $G_{mm}$ values

Figure 12. $G_{mb}$ values

Figure 13. $V_a$ values

Figure 14. Stiffness modulus values

The results lead to the following conclusions:

Regarding $G_{mm}$, it can be mentioned that it has a linear tendency with an $R^2$ value of 0.89, which can be fixed around 2.550 g/cm$^3$ for all the four dosages. The highest $G_{mm}$ value was obtained in the fourth case, where the percentage of coarse aggregate was the highest, which helped to an easier removal of the included air among the coated aggregates in the moment of the determination;

The $G_{mb}$’s values are higher (that led to a lower $V_a$) in the case of using procedure B: bulk density-saturated surface dry. On the order way, using procedure C: bulk density-sealed specimen, led to lower $G_{mb}$ values (increasing the $V_a$) due to the fact that the internal and external voids were not filled with water anymore.

As regards $V_a$, this was calculated for all the four dosages taking into consideration both sets of $G_{mb}$ values. Thus, it can be mentioned that $V_a$ has an increasing tendency when the coarse aggregate percentage is higher (dosage number 4) and a decreasing when the percentage of fines increases;

The stiffness modulus value seems to be influenced by the quantity of coarse aggregate. Increasing the percentage of coarse aggregate led to a significant decrease of stiffness modulus value. For the first two dosages, where a high coarse aggregate percentage is not present, stiffness modulus value exceeds 4000 Mpa. Another factor that has a high proportion in decreasing the value of the stiffness modulus in the third and fourth dosage, it would be the binder content (4.7%), given the fact that the percentage
of fines is low and cannot be included in the mass of the asphalt mixture, remaining on the surface of the coarse aggregate.

4. Conclusions
The results emphasize that the natural quarry aggregates’ processing manner (crushing) is very important. The percentage distribution on intermediate granular fractions of the gradings entering the composition of an asphalt concrete led to the proper values for Gmm, Gmb and Va in the case of using a high percentage of coarse aggregate and a low percentage of fines and to inappropriate values for stiffness modulus beginning with dosage number 3 and 4. The geometrical characteristics of quarry aggregates may influence the performance of asphalt mixtures. Accurately understanding the geometrical characteristics of aggregates is of great significance to the initial design stage of the asphalt mixtures and extending the service life of the road. That is why it is intended to continue the research in this field in order to establish a dosage of asphalt mixture realized with percentage distribution on intermediate granular fractions of the gradings entering the composition of an asphalt mixture and an optimum binder content, which will lead to higher values of the physical characteristics of asphalt mixtures.

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