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Evaluation of the laboratory compaction method on the air voids and the mechanical behavior of hot mix asphalt

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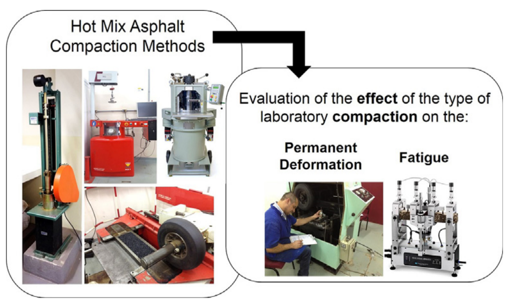
HIGHLIGHTS

- Superpave mix design with 150 mm mold leads to lower optimum asphalt content.
- Compaction in SGC causes higher densification of asphalt mixes in relation to PCG.
- The 100 mm Superpave optimum asphalt content proved to be more technically reliable.

GRAPHICAL ABSTRACT



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ABSTRACT

Marshall and Superpave mixture designs are based mainly on volumetric parameters. Despite this similarity, the definition of the optimum asphalt binder content is highly influenced by the laboratory compaction method. The main objective of this study is to evaluate the effect of the compaction method on the air void content and the mechanical properties of compacted asphalt mixtures. The experimental procedure included the Marshall and Superpave mixture design methods (the second one uses SGC – Superpave Gyratory Compactor, with two mold sizes), the French gyratory shear compactor (PCG), and also the LCPC French roller compactor. The effect of the compaction method, mold size and the number of gyrations on the air void content (and, consequently, on the optimum asphalt binder content), mechanical properties, permanent deformation, and fatigue behavior were evaluated. The main contribution of this study is the recommendation of the Superpave Gyratory Compactor with mold size of 100 mm diameter (Nominal Maximum Aggregate Size NMS ≤ 12.5 mm) for medium and high traffic. The use of 150 mm molds in the SGC is recommended only if the number of gyrations is smaller than the one used in this study (100 gyrations).

1. Introduction and background

Both the hot mix asphalt design and the structural design of pavements have the target to promote solutions that result in greater paving life performance within the available resources, providing safety, and comfort to the user. In order to meet these premises, one should mitigate the major types of distresses on asphalt pavements: fatigue cracking, and rutting.

The main purpose of the hot asphalt mixtures design methods is to determine the proportion of binder to a preset aggregate gradation that results in a satisfactory performance when applied in the field. These methods are usually derived from laboratory tests and procedures.

The laboratory compaction should produce specimens with internal structure similar to the ones in the field [1–3]. In the American mix design methods, the laboratory compaction proce-

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dure premise is that the specimens should be representative of the last compaction found in field. Such last compaction is defined as that one verified after constructive compaction of the asphalt layer, and subjected to densification by traffic, which is usually noticed after two years of operation [3]. The traditional Marshall compaction method has already been questioned by several studies for not resembling that one practiced in the field [1–7].

It is observed that different laboratory compaction procedures can also produce specimens with different volumetric characteristics for the same asphalt content, while the other conditions remained the same. Some authors mention that compaction by rolling is the one that best simulates road compaction [2,8], producing specimens with mechanical behavior similar to the ones obtained in the field [9].

Despite the differences among the laboratory compaction methods, volumetric evaluation of the specimens is an important step in all the mix design procedures. Specimens compacted differently, but with similar volumetric characteristics, may result in different mechanical behavior, once it is also a function of the internal material structure [3,10].

The French mix design method includes mechanical tests in order to simulate the road demands even during the mix design phase. The tests are eliminatory and divided into different levels. This is the result of years of field-laboratory research in that country [11,12]. The level 1 is based on the evaluation of the air voids (Va) and the moisture-induced damage of the asphalt mixtures compacted in the French gyratory shear compactor (PCG). Level 2 includes the tests of the previous level and the permanent deformation evaluation of slabs compacted by the roller compactor in laboratory. The French specification establishes permanent deformation limits depending on the type of asphalt mixture under evaluation. Level 3 encompasses both previous levels along with the complex modulus, and the fatigue test using trapezoidal specimens. At this level, the specimens are sawed from the slabs compacted in the French roller compactor [22].

The Superpave mix compaction method has the advantage of measuring the bulk specific gravity of the mixture for each applied gyration. However, it has been found that specimens produced in the Superpave Gyratory Compactor (SGC) do not reproduce the mechanical properties obtained from specimens extracted from the field. There are reports that mixes designed by this method have resulted in reduced binder content, and that asphalt layers have presented premature cracking [13–16].

Specimen diameter and height influence the distribution of air voids into the specimens compacted by the SGC [17]. The increase in sample heights represents an increase in the vertical heterogeneity of air voids [18,19]. However, this effect was not considered statistically significant [18].

Another relevant aspect is the relationship between the number of gyrations and the densification of the mixes in the SGC. Barral et al. determined that 100 gyrations were equivalent to the densification obtained by the 75 blows of the Marshall compaction at 160 °C for dense asphalt mixtures type AC16 [20]. Watson et al. found that 66 gyrations in the SGC represent similar level of densification compared to which occurred in the field for dense asphalt mixtures with different nominal maximum aggregate size (NMS) [21]. Nascimento, in a comparison between the Superpave and the Marshall design procedure, argues that what defines the asphalt binder design content in each of these systems is the compaction energy applied [10]. In this study, 50–62 gyrations in the SGC were the equivalent to 75 blows of the Marshall method to achieve the same optimum asphalt content for 12.5 mm NMS mixtures [10]. Zamorano et al., however, does not recommend to establish the number of gyrations in the SGC in relation to the densification obtained by Marshall compaction because the number of cycles varies depending on the bitumen type and mixture [22]. In that work, one dense asphalt mixture type AC16S and one gap-graded (BBTM11B) were studied.

Finally, neither Marshall nor the Superpave design considers in their formulations tests that reproduce the field compaction efforts. Despite the level of technological development on materials characterization, and pavement design, these mix design methods still have volume of air voids as the main criterion for evaluating asphalt mixes and defining the design asphalt binder content.

The main objective of this study is to evaluate the effect of laboratory compaction on the air voids, and on the mechanical behavior of dense hot mix asphalt (HMA), considering the effects of different variables related to compaction in the SGC and to the binder type.

2. Materials and methods

The aggregates used in this study are from granitic origin [23]. The aggregate gradation has a nominal maximum size (NMS) of 12.5 mm for the Superpave (SPV 12.5 mm) and meets the criteria of the Bailey method [24], in order to ensure the interlocking of the stone structure, favoring resistance to permanent deformation. The asphalt binders used were (i) one modified by SBS (styrene–butadienestyrene), and (ii) a conventional binder classified by penetration as 50/70 (50/70 PEN). The experimental method was divided into three steps, as illustrated in Fig. 1.

The first step included the Marshall and Superpave mix design methods in addition to the study of different compaction methods, the Superpave mold size, and the number of gyrations on the SGC and their impact on the volume of air voids of the specimens. Traffic was considered equal to 3×10^6 ESALs, which demands 75 blows per side and 100 gyrations ($N_{project}$) for specimens compacted by impact (Marshall) and by (Superpave) gyratory shear, respectively [25]. The optimum asphalt content was chosen to meet the criterion of 4% volume of air voids, respecting, at the same time, the limits established by the Asphalt Institute for the VMA (voids in the mineral aggregate) and VFA (voids filled with asphalt) [25].

As for the Superpave mix design method, the effect of: (i) the specimen diameter (100 and 150 mm); (ii) the number of gyrations (50, 75, and 100 gyrations), and (iii) the process of coring and sawing (reduction of the Superpave specimens to the size of the Marshall specimens) in the volume of air voids were evaluated, as well as in the optimum asphalt binder content. Besides the comparison between Marshall and Superpave compactions, comparisons were also carried out on specimens molded on the French gyratory shear compactor (PCG: gyratory shear press), and on the French roller compactor. Fig. 2 schematically shows the size of each compaction systems, and the coring and/or sawing procedures evaluated.

The French procedure to the volumetric mix design is quite distinct from the Marshall and Superpave methods. It does not define a specific volume of air voids for the selection of the optimal asphalt binder content. Instead, it suggests a range of air void values that the mixture should present at a certain number of gyrations [11]. For the aggregate gradation selected in the present study, the limits are between 4% and 9% after 80 gyrations, since this gradation meets the aggregate size requirements of a BBSG 0/14 (*Béton Bitumineux Semi-Grenu*) [11].

In the second step of the experimental design, resilient modulus tests were performed on Marshall specimens, and on cored and/or sawed from of the SGC specimens, and also from the roller compacted slabs [31]. A new set of samples was compacted in the